UNIVERSITI TEKNOLOGI MARA

EXPERIMENTAL STUDY ON THE RECYCLABILITY AND REUSABILITY OF PLASTER OF PARIS (POP) MOULD IN CERAMICS MANUFACTURING

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CONFIRMATION BY PANEL OF EXAMINERS

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ABSTRACT

In this research, the recycling process of used Plaster of Paris (POP) has been studied by involving the drying of POP powder to restore the original properties of Plaster of Paris that can be reuse in mould casting. This research was done by collecting used POP powder samples and drying them at different temperatures: 37°C, 150°C, 160°C, 170°C, 180°C and 190°C. This drying process aims to remove crystal water from the hydrated powder and return it to the hemihydrate form. Hence, this used POP is denoted as Recycle Plaster of Paris (RPOP). The results of the study show that temperature plays an important role in the recycling process. At the first stage, a drying temperature of 37°C, the dehydration process is incomplete producing used RPOP that cannot be reused, and the slurry does not freeze with low mechanical strength. At 150°C, a better partial dehydration occurs, but there is still moisture in the material. At 160°C, results are obtained with almost perfect dehydration, producing RPOP that is almost equivalent to New Plaster of Paris (NPOP) in chemical and physical properties that have been tested. The drying temperatures of 170°C, 180°C and 190°C cause some material degradation, although complete dehydration is achieved. Based on the results obtained, the optimal RPOP recycling process was found at a temperature of around 160°C, where RPOP can be converted back into hemihydrate with almost the same quality as NPOP. This process also indicates that increasing the temperature above 170°C does not provide significant additional benefits and can even damage the material. In the second stage, this study continues by testing the chemical and physical properties of RPOP through drying at a temperature of 160°C and adding the activator Silubit G80 to find out the reaction of RPOP with Silubit G80 whether the chemical and physical properties of RPOP + Silubit G80 are better or vice versa. This ensures that the final product has acceptable performance for casting use. The third stage, after all the tests were completed and the most optimal results were obtained, the mould making process using NPOP, RPOP 160℃ and RPOP 160℃ + Silubit G80 0.5% was tested again to estimate its casting capability. At this stage, the casting time and performing consistence were precisely analyzed to ensure that each mould could function properly. As a control reference, NPOP was used as a control in this evaluation. The testing was carried out using a simple form so that the comparison between NPOP, RPOP 160℃ and RPOP 160℃ + Silubit G80 0.5% could be evaluated objectively and directly before the intrate form was used. This study shows that used moulds can be reused by undergoing a recycling process. Furthermore, RPOP can produce an intracate mould shape without damage to the mould wall, especially in the geometrically angled part. Even so, the RPOP + Silubit G80 0.5% mould can still be used as a casting mould. This study contributes to the development of sustainable mould materials in the ceramics industry and helps reduce material waste.

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LIST OF SYMBOLS

Symbols

°C	Degree Celsius
%	Percentage
μm	Micrometres / Microns
cm	Centimeters
mm	Millimeter
kN	Kilonewton

LIST OF ABBREVIATIONS

Abbreviations

$B_4O_7^{2-}$	Borate Ions
$CaSO_4 \cdot 0.5H_2O$	Bassanite
$CaSO_4 \cdot 2H_2O$	Calcium Sulphate Dihydrate
CaO	Calcium Oxide
$Ca\,(OH)_2$	Calcium Hydroxide
$CaCO_3$	Calcium Carbonate
Ca^{2+}	Calcium Ions
SO_4^{2-}	Sulphate Ions
Na^+	Sodium Ions
K_2SO_4	Potassium Sulphate
$Na_2B_4O_7 \cdot 10H_2O$	Sodium Borate
pH	Potential of Hydrogen

LIST OF NOMENCLATURES

Nomenclatures

ASTM	American Society for Testing and Materials
POP	Plaster of Paris
NCEC	National Circular Economy Council
NPOP	New Plaster of Paris
RPOP	Recycle Plaster of Paris
SEM-EDS	Energy Dispersive X-ray Spectroscopy
SEM	Scanning Electron Microscopy Analysis
WPOP	Waste Plaster of Paris
XRD	X-ray diffraction

CHAPTER 1
INTRODUCTION

1.1 Research Background

Plaster of Paris (POP), chemically known as calcium sulphate hemihydrate ($CaSO_4 \cdot 0.5H_2O$), is a material widely used in various industries, especially in construction, ceramics and orthopaedics. Despite its widespread application, POP is often seen as a non-recyclable material due to its hardening properties when hydrated, turning into calcium sulphate dihydrate ($CaSO_4 \cdot {}_2H_2O$). This transformation usually renders it useless for further applications. However, recent advances in recycling technology and growing environmental concerns have spurred interest in developing methods to recycle Plaster of Paris (POP), thereby reducing waste and promoting sustainability.

The main challenge in recycling RPOP lies in reversing the hydration process. When POP is mixed with water, it undergoes an exothermic reaction, forming gypsum. This gypsum is then disposed of, contributing to environmental pollution. POP recycling involves converting hardened gypsum back into usable POP. This process requires a heat treatment to remove the water of hydration, effectively returning the gypsum to its hemihydrate form. However, this thermal process must be carefully controlled to avoid decomposition into calcium oxide, which would result in a loss of material properties and potential usability.

Several experimental methods have been proposed to effectively recycling the RPOP. A notable approach involves heating the hardened gypsum to a temperature between 37°C,150°C,160°C,170°C,180°C and 190°C. This controlled heating process, known as calcination, drives water molecules, converting the gypsum back into its hemihydrate form. The resulting POP can then be reused in various applications, retaining its original properties. Another method involves the use of chemical additives that facilitate the dehydration process at lower temperatures, making the recycling process more energy efficient and economically viable.

In addition to thermal methods, mechanical and chemical tests have also been explored. The mechanical process involves grinding hardened gypsum into a fine powder before being subjected to heat treatment. This increases the surface area, allowing for more efficient dehydration. The chemical process involves the use of an activator to break down the gypsum matrix, followed by dehydration. This method has shown promise in laboratory settings but requires further refinement for large-scale applications.

The benefits of POP recycling go beyond environmental sustainability. Economically, it reduces demand for raw gypsum, conserves natural resources and lowers production costs for POP dependent industries. Furthermore, it reduces the environmental impact associated with gypsum mining, which often results in habitat destruction and soil degradation. By closing the loop in POP production, the industry can move towards a more circular economy, where materials are constantly reused and recycled. Despite encouraging developments, large-scale implementation of POP recycling faces several obstacles. The main challenge is the development of cost-effective and energy-efficient recycling processes that can be easily integrated into existing industrial frameworks. Additionally, ensuring the quality and consistency of recycled POP is important, as any variation in material properties can impact its usability in precision applications such as medical castings and ceramic moulds.

Recycling the POP recycling provides a viable solution to the environmental and economic challenges associated with widespread use and disposal. Through innovative thermal, mechanical and chemical processes, it is possible to convert hardened gypsum back into reusable POP. Although significant progress has been made in developing these recycling methods, further research and investment are necessary to overcome the technical and economic barriers to large-scale implementation. By embracing POP recycling, industry can contribute to a more sustainable future, reduce waste and conserve natural resources.

Art is a broad and complex concept that includes various human activities, creations, and expressions. Its meaning can be interpreted in various ways depending on the cultural, social, and personal context. Art serves as a medium to express emotions, thoughts, and ideas. Artists use different forms and techniques to convey their feelings and intellectual concepts, often resonating with the audience on a deep emotional level. Art is also often valued for its beauty and ability to provide an aesthetic experience. This can include the visual appeal of a painting, the harmony of a piece of music or the grace of a dance performance. Moreover, art reflects the culture and society from which it originates. It can provide insight into the values, beliefs and historical context of different societies and eras. Through art, we can understand and appreciate various cultures and historical periods.

Art can convey messages and foster relationships between people. It overcomes language barriers and allows individuals to share experiences and ideas. Art can bring people together, evoke empathy, and encourage dialogue. Art is a manifestation of human creativity and innovation. It pushes boundaries, explores new possibilities, and challenges conventional thinking. Artists often experiment with new materials, techniques, and ideas to create unique works. The definition of art is very subjective and can vary from person to person. Everyone may interpret a work differently based on their own experiences, emotions, and perspectives. Art can serve a variety of functions, including ritual, decorative, therapeutic, educational, or political purposes. It can be used to inspire, provoke, heal, or simply entertain. At its core, art is a multifaceted phenomenon that plays an important role in human life by enriching our experience, fostering understanding, and allowing us to explore the depths of human creativity and emotion. Art is a diversified and expressive form of human creativity that includes an extensive variety of mediums such as painting, sculpture, music, and literature. The primary purpose of art is to evoke emotions, provoke thought, or convey a message. It may not always have a specific function or utility beyond this. Individualism and self-expression are encouraged by art, which is highly subjective. It allows artists to explore personal and emotional issues, and its interpretation can differ from one individual to the next, making it a vast and multifaceted realm of human expression.

Ceramic art is the creation of artistic items created from ceramic materials, typically clay, that are fired at high temperatures to ensure durability and permanence. This art style comprises a wide range of things, including both useful items like ceramics and plates and merely decorative pieces like sculptures and installations. The process of creating ceramic art consists of numerous steps, including design and formation. Among the processes used to conceptualize and shape the clay are hand building, wheel throwing, and slip casting. The greenware product will then be fired in bisque. The dry clay product is burnt in a kiln at a lower temperature, transforming it into bisque ware, which is porous and semi-hard. This is the stage at which glaze is applied to prepare for the final firing. Work can be dipped in glaze or poured over the bisque pot. Water is absorbed into the clay, causing the glaze to cling to the pot's surface. A bisque-fired object is finished with a glaze, a glassy material that gives color, texture, and a weatherproof finish. A piece of glaze is re-fired at a higher temperature, causing it to vitrify and form a smooth, completed surface.

Furthermore, ceramic art can be both utilitarian and nonfunctional, frequently blurring the distinction between craft and high art. Some of the most common types of pottery are useful pieces like bowls, plates, and vases. A three-dimensional creative ceramic sculpture, which can be abstract or realistic. In addition, jubin's work is classified as ceramic art. Decorative and practical tiles used in architectural settings. Ceramics have been used for thousands of years by cultures all over the world, including well-known traditions in China, Japan, the Middle East, Europe, and the Americas. Contemporary art ceramics is evolving, with artists experimenting with new techniques, materials, and themes to push the frontiers of the medium.

Ceramics is desirable properties such as high strength and hardness, high melting temperature, and chemical humidity. Ceramics are often created by applying heat to processed clays and other natural raw materials to create a hard product. These attributes play a big role in the final properties of the finished ceramic. Some ceramic products also use chemically produced powders as starting materials. The chemical composition and particle size of powders made from these synthetic materials may be precisely regulated. To make a ceramic product it is necessary to go through shaping the ceramic particles into the desired shape through several processes after forming using hand build or machine using clay. This is accomplished by the addition of water or additives such as binders, followed by a shape forming process. Some of the most common forming methods for ceramics include extrusion, slip casting, pressing, tape casting and injection moulding using POP by Roux, (2016). The clay form will leather hard for 1-2 days and greenware before firing. After firing the product during reaching up to 800°C - 900°C is called bisque fire. At the time of bisque ware, the product will be glazed and firing at a temperature of 1200°C to get the finished product. Some ceramic products such as electrical insulators, dinnerware and tile may then undergo a glazing process.

Plaster of Paris, a versatile material known for its various applications in construction, art and medicine, is mainly composed of calcium sulphate hemihydrate ($CaSO_4 \cdot 0.5H_2O$). Previous studies have been reported by Hemant Sharma & Dhanasekara Prabu, (2023) mentioned the large deposits name of gypsum (calcium sulphate dihydrate, $CaSO_4 \cdot 2H_2O$) found near Paris, which is the raw material used to produce it. Understanding the chemical and physical properties of Plaster of Paris is essential to appreciate its functions and applications in various domains. POP is chemically known as calcium sulphate hemihydrate. Its formula, $CaSO_4 \cdot 0.5H_2O$, indicates that it contains half a molecule of water for every molecule of calcium sulphate. This hemihydrate form is achieved by heating gypsum to about 150°C, driving off some of the water of crystallization. One of the most notable chemical properties of POP is its reaction with water. When mixed with water, it undergoes an exothermic reaction, rehydrating to form gypsum ($CaSO_4 \cdot 2H_2O$). The reaction can be represented as this rehydration process leading to the setting and hardening of plaster, making it useful for creating moulds, castings and sculptures.

Calcium sulphate, the main component of POP, has a low solubility in water. This property is important because it allows the plaster to maintain its integrity and structure when exposed to moisture, although prolonged exposure to water can cause gradual dissolution. POP is relatively stable in neutral and slightly acidic environments. However, in the presence of strong acids, it decomposes, releasing calcium ions and sulphate ions into the solution. On the other hand, in a very basic environment, it can form calcium hydroxide and sulphate ions.

POP is a fine white powder that is smooth to the touch. Its whiteness makes it ideal for artistic applications, as it provides a neutral background that can be easily painted or finished. When dry, POP has a relatively low density of about 2.32 grams per cubic centimetre. When set, it forms a porous structure, which is beneficial for certain applications, such as creating lightweight casts in medical settings. Porosity also allows some degree of air and moisture permeability. POP setting time is an important physical property, especially in construction and medical applications. Typically, it begins to set within minutes of mixing with water and hardens completely in about 30 minutes. Setting time can be adjusted by adding accelerators or retarders to the mix, providing flexibility in a variety of applications. Once set, POP exhibits moderate mechanical strength. It is strong enough to hold its shape and bear some weight but is quite fragile compared to other building materials. This fragility can be advantageous in applications that require easy breakability, such as in orthopaedic casts that need to be removed without damaging the underlying skin. POP has good thermal insulation properties due to its porous structure. However, it is not suitable for use in high temperature environments because it can dehydrate again when exposed to temperatures above 150°C, returning to the hemihydrate form and losing its structural integrity. One of the beneficial properties of POP is its fire resistance. When exposed to fire, it releases water vapor, which helps slow the spread of fire. This property makes it useful in fireproof applications and in the construction of fireproof walls and ceilings.

The unique combination of chemical and physical properties of POP makes it suitable for various applications in construction, POP is used to make decorative elements such as cornices, mouldings and false ceilings. Ease of forming and smooth finish make it ideal for intricate designs. In medicine, it is used to make orthopaedic casts to immobilize broken bones. Its quick setting time and moderate strength provide the necessary support while being relatively easy to remove. Artists and sculptors use POP to create detailed sculptures and moulds. fine texture and smooth finish are ideal for capturing intricate details. n industrial applications, it is used to make moulds and casts for metal casting, pottery, and ceramics. Its ability to reproduce fine details makes it invaluable in these processes.

POP with its unique chemical and physical properties, remains a material of immense utility across various domains. Its ability to transform from a powder to a solid form through a simple reaction with water, coupled with its ease of shaping, moderate strength, and fire resistance, make it indispensable. From ancient civilizations to modern times, POP continues to be a vital material, proving that sometimes the simplest compounds can have the most profound impacts. Understanding these properties allows for better application and innovation, ensuring that this material remains relevant for future generations.

The use of POP in art requires proper technique to ensure satisfactory results. Artists need to master how to mix, pour, and shape POP to produce high quality artwork. Creativity in its use is also unlimited, from creating surface textures to carving fine details. POP is a versatile and important material in the world of arts and crafts. With its malleable and quick-hardening properties, it gives artists the opportunity to create beautiful and long-lasting works. Its widespread use in various fields of art, from sculpture to restoration, shows how important POP is in the production and preservation of art. It is clearly proven that POP is one of the important materials in the production of art. Without this material, there will be no sculpture, cast material and so on.

Moulds are used in ceramic as a means of supporting and forming clay. It made from porous material to draw moisture from the clay. This is commonly plaster, although simple press-moulded forms can be made from low-fired bisque. There are two types of mould. First, press mould use in conjunction with hand-building techniques for make the pieces such as functional dishes and bowl, architectural details, large shape, and sculptures. Through Stan, (2018) press mould allows the maker greater control during construction and suit forms that would be difficult to throw or slip cast and the last is slip casting involved pouring liquid slip into a plaster mould. The water content of the slip is to absorption into the plaster, leaving behind a unified skin of clay. Making mould for slip casting requires a certain degree of accuracy, which some makers find very appealing. It is excellent for producing crisp forms and multiples of an object, each one being identical to the next.

Design is a purpose-driven, controlled creative process that focuses on solving real problems or meeting specific demands. Graphic design, industrial design, web design, and other fields are included. The basic purpose of design is to strike a balance between aesthetics and usefulness, resulting in solutions that are both visually appealing and functional. Design follows principles and norms, aiming for usability and efficiency. It is a practical and problem-solving-oriented field that frequently involves the application of design principles to produce goods, environments, or visuals that serve well-defined functions. The intends to go deeper into this field of art in this study by touching the materials used in the field of design to create an art product. The material used in the field of ceramics as the subject of the study with caution.

Human creativity and innovation are fundamental aspects of human nature that drive progress and cultural development. They often involve experimenting with new materials, techniques and ideas to produce unique and original works. This process can be seen in many fields, including art, science and technology. Art always has new ways to express one's vision and emotions. Therefore, experiment with different materials (such as digital media, recycled objects and non-conventional materials such as coffee or blood) and techniques (such as mixed media, augmented reality and generative art) to create a distinctive work of art. These experiments helped push the boundaries of traditional art forms and led to new genres and movements. In addition, scientific innovation thrives on experimentation and the use of new materials and methodologies. By develop a new technology, such as advanced materials (graphene, biodegradable plastics) and advanced techniques (CRISPR for gene editing, quantum computing). These innovations often lead to important discoveries that change our understanding of the world and improve our quality of life. In the technology industry, innovation is key to staying ahead. Engineers and developers are experimenting with new hardware (such as flexible displays, wearable technology) and software (AI algorithms, blockchain). Educators and institutions experiment with new teaching methods and tools to enhance the learning experience. This includes integrating technology in the classroom (interactive whiteboards, online learning platforms), adopting innovative curricula (project-based learning, gamification), and focusing on skill development (critical thinking, creativity).

In essence, human creativity and innovation involve a continuous process of exploring unknown paradigms, challenging existing paradigms, and integrating multiple perspectives. This willingness to experiment and take risks leads to the creation of unique and effective works that shape and redefine various aspects of society.

Recycling waste is the process of gathering, sorting, processing, and transforming discarded materials into new goods or raw resources that can be reused. This procedure diverts waste from landfills or incineration plants, conserves natural resources, lowers pollution, and saves energy. In this research, use recycling waste art as the main study, also known as "upcycled art" or "found object art," involves creating artwork using discarded materials or objects that would typically be considered waste. This form of art not only showcases creativity and innovation but also promotes environmental awareness and sustainability by giving new life to materials that might otherwise end up in landfills or pollute the environment. Mould Plaster of Paris as the main material used in this study. Mould that has been disposed of and discarded is re-treated to make plaster powder again. The mould Plaster of Paris is one of the art materials used in the field of mould ceramics. The use of this mould has its level of use in producing a casting product. If this mould has been used many times or has a defective body mould, the user will not use it again and will throw away the old mould. Until now, there is no information that states how Plaster of Paris mould is disposed of or disposed of with the correct method according to the correct specifications like other garbage.

The aim of this study is to identify that Plaster of Paris (POP) can be recycled and reusability able to be function like the new plaster without changing the properties. This method of Recycle Plaster of Paris (RPOP) is eco- friendly when reused. The resulting recycling process begins by finely grinding the used Plaster of Paris and dry the fine powder in oven at a temperature of 180°C for 3/hour as reported Bardella and Camarini, (2012).

The use of activator mixtures was controlled to know an appropriate response to Recycle Plaster of Paris (RPOP) to preserve plaster properties. When RPOP is ready to be used for the mould making process, slip durability and absorption test are studied to ensure that the mould RPOP can absorb the water content in the slip just like a new mould. The outcome this study will show that RPOP has the same characteristics as commercial plaster that works well for industrial use and can reduce the production of solid waste in landfills.

1.2 Problem Statement

In Malaysia, there are landfills, but not all of them can manage solid waste perfectly. As a result, many waste disposal contractors look down on solid waste management such as POP. This is even more complicated when there are a handful of them who take the easy way out by disposing of this POP waste by planting or dumping it into rivers and seas. This causes various problems that arise to the environment and health. The materials used are prohibited substances are very dangerous in their natural state. Dumping of wastes in open fields and rivers are common even until today and a study of waste disposal behaviours in Kuala Lumpur indicated that 31.9% of waste were disposed by open burning, while 6.5% were dumped into the river system Murad and Siwar, (2007). Hence the environmental safety concern in Malaysia was secondary and most municipalities had a tough time in finding new dispos al sites as, the existing disposal sites were nearly exhausted. The problem of solid waste in Malaysia is increasingly worrying many parties, especially in the Ministry of Housing and Local Government. A total of 1552,238 tons of solid waste was disposed from January to June 2019. The Government has implemented various efforts to reduce the delivery and disposal of this solid waste to landfills to prevent environmental pollution. Plaster of Paris (POP) is commonly used in ceramic mould manufacture due to its ease of preparation, good surface polish, and low cost. However, typical POP moulds have a limited lifespan, especially when applied to many slip casting cycles, since it eventually lose strength, dimensional stability, and absorbent properties. This issue contributes to excessive waste generation, raising economic and environmental concerns in the ceramic industry.

Recycling POP (RPOP) through thermal reactivation is a sustainable solution, but current research provides little insight into its long-term usability and material performance. While several studies have studied the physical and chemical aspects of RPOP, there is still a lack of comprehensive research on its usefulness in intrace form geometric mould designs. Furthermore, the role of chemical activators like Silubit G80, which have the potential to improve the efficacy of RPOP, has not been thoroughly explored or optimised for industrial applications.

Thus, the lack of a thorough, scientific framework that determines the recyclability and reusability of POP moulds is the issue this study attempts to solve. In particular, no information is known about (i) how well RPOP performs in comparison to new POP (NPOP), (ii) how much Silubit G80 is needed to strengthen RPOP, (iii) how long RPOP moulds last and how durable they are during repeated slip casting cycles, and (iv) whether RPOP can be applied to complex geometries. To ensure industrial applicability and material efficiency while supporting sustainable practices in ceramic mould production, these gaps must be filled. Because of its affordability, excellent surface polish, and ease of preparation, plaster of Paris (POP) is frequently used in the production of ceramic moulds. However, conventional POP moulds have a limited lifespan, particularly when exposed to repeated slip casting cycles, as they gradually lose strength, dimensional stability, and absorption capacity. This issue contributes to excessive waste generation, which poses economic and environmental concerns in ceramic industries.

In this study, the problem has been identified as follow;

a) The chemical properties of used RPOP needed to be identified. Through a study made by M. M. Pinheiro and Camarini, (2015)*,* the recycled gypsum plaster was produced by grinding and burning the waste along three successive recycling cycle. The recycled material was evaluated by chemical and physical properties. In this way, that the same purpose that the original binder. Recycled plaster of Paris often requires energy-intensive processes such as heating to remove moisture or contaminants. This energy consumption can be a limitation, especially if the recycling process is not energy efficient. Recycling depending on the recycling method used, there may be significant costs associated with equipment, labour, and maintenance. These costs can sometimes outweigh the benefits of recycling, especially for small-scale operations. Despite these limitations, Recycled Plaster of Paris can still be a viable option in many cases, especially when considering the environmental benefits of reducing waste and conserving resources. However, it is important to carefully evaluate the cost, quality and feasibility of recycling based on specific circumstances and needs.

b) However, this problem has used an activator that needs to identify its concentration. using recycled plaster in combination with fresh plaster or other additives can help improve its performance and extend its lifespan. However, loss of mechanical strength, changes in setting time, and decreased workability often restrict its applicability. According to Li, et al. (2019) study the mechanical and hydration properties of recycled plaster materials mixed with quicklime were examined, and a comparison of the quality of plaster of Paris after quicklime was added was also carried out. Activators are often added to improve the quality of the casting, although the best concentration to achieve superior results is still unknown. Finding the right concentration of activator is essential to improving the quality and usability of RPOP in various fields. Although thermal reactivation recycling of POP (RPOP) is a sustainable alternative, no information is known about its long-term material performance and usability. Although RPOP's physical and chemical characteristics have been the subject of significant research, a thorough assessment of its performance in intricate geometric mould designs is still lacking. Furthermore, the function of chemical activators like Silubit G80, which may improve RPOP performance, has not been thoroughly investigated or optimised for use in industrial settings.

c) Another problem with this approach is the lifecycle of used mould during casting process. The problem statement for RPOP typically revolves around reducing waste and environmental impact associated with its disposal. POP commonly used in various applications such as moulds, casts, and sculptures, poses a challenge due to its non-biodegradable nature and potential for pollution if improperly disposed of. The aim of RPOP is to find efficient methods to reclaim, process, and reuse the material, thereby minimizing waste, conserving resources, and mitigating environmental harm. This study are developing techniques for collecting used plaster, devising processes to remove contaminants, and identifying suitable applications for RPOP to close the loop in its lifecycle. The aims to close this research gap by methodically evaluating the performance, evaluating the durability and casting life cycle of RPOP moulds over several casting cycles, and offering guidance on how to increase functional life and enhance sustainability in the ceramic production process.

d) However, difficulties in producing the intricate shapes designed arise when RPOP is used as a mould. One potential problem with using Plaster of Paris for ceramic art moulds is its tendency to absorb moisture from the clay. This can lead to problems such as Plaster of Paris moulds can warp or change shape over time due to moisture absorption, leading to inaccuracies in the reproduced ceramic pieces. Additionally, excessive moisture absorption can cause the clay to stick to the mould, making it difficult to remove the finished piece without damaging either the mould or the ceramic. Frequent and repeated use of Plaster of Paris moulds causes a short lifespan. Plaster of Paris moulds may deteriorate more rapidly with repeated use due to exposure to moisture, resulting in the need for frequent replacement and increased production costs. Through the study by Randazzo et al., (2016), moisture absorption can also cause surface imperfections on finished ceramic pieces, such as rough texture or uneven drying, affecting the overall quality of the artwork. With the occurrence of the above problem, the frequency of mould disposal is increasing, and the dumping of solid waste materials is increasing.

Therefore, the problem addressed in this study is the absence of a comprehensive, scientific framework that evaluates the recyclability and reusability of POP moulds. Specifically, there is insufficient knowledge on (a) the comparative performance of RPOP versus new POP (NPOP), (b) the optimum concentration of Silubit G80 to strengthen RPOP, (c) the lifecycle and durability of RPOP moulds during repeated slip casting cycles, and (d) the feasibility of applying RPOP to complex geometries. Addressing these gaps is essential to support sustainable practices in ceramic mould production while ensuring industrial applicability and material efficiency.Despite many studies on plaster of Paris (POP) and its recycling potential, there is currently no thorough evaluation of recycled POP (RPOP) moulds, particularly when used in complex geometric patterns. Furthermore, the optimum amount of chemical activators like Silubit G80 for industrial moulding applications has yet to be experimentally determined. Previous study has also provided limited insight into the long-term durability and absorption behaviour of RPOP moulds following several slip casting cycles. These gaps underline the importance of this study, which aims to address the material, mechanical, and practical constraints of reusing POP in ceramic mould fabrication.

1.3 Research Objectives

The aim of this work is to identify the Recycle Plaster of Paris, with the objectives for this research as follows.

a) To study the chemical and physical properties of Recycled Plaster of Paris (RPOP) compared with New Plaster of Paris (NPOP) through laboratory testing.

   The initial objective was to determine the chemical and physical equivalents of NPOP and RPOP. Several tests have been used to determine the similarities between these two materials, including particle size analysis, SEM, XRD, compressive strength, porosity, and absorption testing. However, before this test was carried out, RPOP underwent an important process which is recycling. At this stage, several RPOP drying temperatures were tested between 37˚C (room temperature), 150˚C, 160˚C , 170˚C, 180˚C and 190˚C. Then, all these samples will be evaluated using the testing stated above. The next investigation will focus on samples with similar chemical and physical features to NPOP. By carrying out these tests and analyses, it is possible to draw comprehensive conclusions about the differences in chemical and physical properties between new and used Plaster of Paris, providing insight into its performance and durability over time.

b) To determine the optimum concentration of the chemical activator (Silubit G80) for enhancing the mechanical performance and absorption capacity of RPOP.

For objective 2, carry on employing the activator in RPOP that was decided on in Objective 1. At this stage, the RPOP has been mixed with Silubit G80 activator at the percentages recommended by the supplier, which range from 0.5%,1.0%,1.5% and 2.0%. This activator is dissolved in water before RPOP is mixed. Also at this stage, the RPOP + Silubit G80 is tested as well using many tests, including compressive strength, porosity, and absorption. The purpose of utilising this activator is to improve the properties of the RPOP.

c) To evaluate the lifecycle and performance of RPOP moulds under repeated ceramic slip casting processes.

At this stage, 3 types of moulds have been made using NPOP, RPOP 160 ˚C and RPOP 160˚C + Silubit G80. Next, the casting process is carried out to see the casting ability of RPOP 160˚C and RPOP 160˚C + Silubit G80. NPOP is a reference during the casting process. At this stage as well, the casting time and the thickness of the casting product are recorded to see the difference between the RPOP 160˚C and RPOP 160˚C + Silubit G80 samples.

d) To assess the effectiveness of RPOP in producing moulds for complex geometries and its durability during the casting process.

At the last stage, the sample will be tested by making several mould with various types of intricate designs. Elements of art are used in the manufacture of this product. The form tested uses a complicated design produced through a cup product. The cup product is produced with a geometry form to test the feasibility of RPOP as a mould that uses an intricate model. In one cup design, there are two curved parts on the cup, the first part of the cup surface is flat, and the second surface of the cup surface is formed using a geometry design. Then the mould is produced using RPOP and finally the casting process will be tested whether the mould can be used repeatedly without affecting the form or surface of the mould that uses this RPOP.

1.4 Research Question

Based on the proposed research objectives stated above, the are several requestion questions that have been raised. The research question of this study are.

a) What are the differences in chemical and physical properties between RPOP and NPOP based on laboratory analysis?

   The physical NPOP will be a control to the physical RPOP to see the difference between these two materials when the Plaster of Paris mould is recycled, is there an increase in the physical RPOP or is there a lack of physical RPOP after going through the recycling process.

b) What is the optimum concentration of Silubit G80 that improves the mechanical strength and absorption properties of RPOP?

   The use of activator serves as an improvement to RPOP so that it can function properly during the process of mixing RPOP powder. RPOP usually involves mixing a powder with a liquid to initiate a rapid polymerization reaction. To make RPOP reusable, requires an activator that can effectively trigger the polymerization reaction each time the RPOP is mixed. The choice of activator and its concentration depends on the polymer and the specific conditions used in the RPOP system. To determine the appropriate activator and concentration for the RPOP system, it is necessary to conduct experiments to evaluate the effectiveness of different options. Factors to consider include the speed and completeness of polymerization, the stability of the activated RPOP mixture, and any possible side reactions or adverse effects.

c) How do RPOP moulds perform in terms of durability, absorption, and reusability under repeated slip casting cycles?

The RPOP mould casting process needs to be tested together with the NPOP mould to see the difference between the mould surface, product casting and product thickness. In ceramic casting, measuring a used mould's life cycle entails assessing the several elements that influence its integrity and performance over time. Below is an outline of the most important factors. By counting the quantity of castings, the mould produces before it begins to deteriorate or wear out. This may provide a general notion of its longevity. Regularly check the mould for any obvious wear indicators, including chips, cracks, or deformation. This may point to weak points that compromise its functionality. Analyses the cast sheet's surface quality. Rougher surfaces or flaws may appear in the casting as the mould ages. Analyses the casting process's consistency throughout time. Damaged molds can result in less consistent castings. Monitor any changes in production rates. As the mold wears, it may become less efficient, leading to slower production times. Run periodic tests to evaluate mould performance under controlled conditions. This can include testing for dimensional accuracy, surface quality and material integrity. Establish criteria for determining when a mould reaches the end of its useful life. This may be based on a combination of factors such as the number of castings, level of wear and effect on production quality. By monitoring these aspects over time, it can develop a comprehensive understanding of the life cycle of used moulds in ceramic casting and determine the most appropriate time for replacement or repair.

d) Can RPOP moulds effectively reproduce complex geometries while maintaining strength and durability during the casting process?

The selection of the mould form begins with the manufacture of the complicated model. The researcher has decided to design a cup that has a square surface to test the mixing ability of RPOP to form a mould that has small square spaces. It is because a square design for the surface of a cup could offer a clean and geometric aesthetic. It might involve the cup having a square-shaped base or perhaps a square pattern etched or embossed onto the surface of the cup itself. This design choice could appeal to those who appreciate modern or minimalist aesthetics, as well as those who enjoy the symmetry and simplicity of geometric shapes. Additionally, the square surface could provide practical benefits, such as easier stacking or gripping.

1.5 Significance of Study

Plaster of Paris waste can be a significant environmental concern if not properly managed. Plaster of Paris waste typically refers to the waste generated from the use or production of POP, a type of gypsum plaster composed of calcium sulphate hemihydrate. This waste can include unused or excess plaster material, as well as materials contaminated with plaster residue, such as mixing containers, moulds, and tools. POP waste can be a concern for environmental reasons due to its non-biodegradable nature and potential for containing contaminants. Proper disposal methods should be followed to minimize environmental impact, such as recycling when possible or disposing of it in accordance with local regulations. Additionally, efforts should be made to reduce waste generation through careful planning and efficient use of materials. Recycling helps divert waste from landfills, reducing the overall environmental impact associated with disposal. The findings of this study will benefit the industry sector. Recycling POP waste may help industries ceramic comply with environmental regulations and sustainability standards, contributing to a positive corporate image and meeting legal requirements. This study will provide a good POP mould solid waste management application by providing an opportunity to the community, especially to students and small ceramic entrepreneurs to conduct field studies such as how to manage solid waste well.

This is because this study will help the industrial ceramic sector to produce using RPOP as raw material and for small/medium enterprises for the production process using RPOP as raw material. Next, this study will also be studied and facilitated for potters and students to find out how RPOP works especially in the preparation of the process. For researchers, this study will help them to reveal critical areas of the RPOP process and reference information for the future. this study will provide to save the cost of ceramic industry and university from buying new plaster through supply. Investing in recycling technology for plaster of Paris can lead to innovation in waste management and recycling processes. Research and development in this area may result in more efficient and environmentally friendly methods.

Using RPOP as a raw material for industrial ceramic production indeed has great potential for innovation and research. Not only does it address environmental concerns by reducing waste, but it also opens opportunities for cost-effective production methods, particularly beneficial for small and medium-sized enterprises (SMEs). Research in this field can explore various aspects such as the quality and properties of ceramics produced using RPOP compared to traditional raw materials. Understanding how to optimize production processes to efficiently incorporate recycled materials while maintaining product quality is essential.

Additionally, innovations in materials science and engineering may be required to overcome any challenges associated with the use of recycled materials, such as variations in composition or impurities. Developing techniques to purify and refine RPOP could improve its suitability for ceramic production. There is potential to explore the economic viability of such transitions for industrial ceramic manufacturers and SMEs. Analysing cost savings and environmental benefits can encourage widespread adoption of this innovative approach. Collaboration between academia, industry and government entities can further drive research and development efforts in this area, leading to a more sustainable and economically viable ceramic production industry.

Recycling waste offers many benefits to people and the environment. among them recycling helps conserve natural resources such as wood, water, and minerals by reducing the need for raw materials. For example, recycled paper saves trees and reduces the energy and water needed for paper production. then, recycling often requires less energy than producing goods from raw materials. For example, recycling aluminium saves up to 95% of the energy required to produce aluminium from bauxite ore. Recycling reduces the amount of waste sent to landfills, which helps reduce landfill congestion and reduces the release of harmful chemicals and greenhouse gases from decomposing waste. By reducing demand for raw materials, recycling helps protect habitats and ecosystems from the destruction and pollution associated with resource extraction and manufacturing processes. In addition to that, job opportunities and economic benefits. The recycling industry creates jobs in collection, separation, processing, and manufacturing, contributing to economic growth and stability. Most importantly, recycling can reduce pollution by reducing the need for waste incineration, which releases harmful pollutants into the air, soil, and waterways. It also reduces pollution from extracting, refining, and transporting raw materials. Besides being able to encourage involvement and education to the community. Recycling initiatives often encourage community involvement and awareness of waste management, environmental conservation, and sustainable living practices. Recycling certain materials such as plastic and glass can save a significant amount of water compared to producing new products from raw materials. Recycling reduces greenhouse gas emissions associated with resource extraction, manufacturing, and waste disposal, contributing to efforts to mitigate climate change. Recycling helps reduce dependence on imported raw materials, increase resource security, and reduce vulnerability to supply chain disruptions. Overall, waste recycling benefits society by conserving resources, protecting the environment, fostering sustainable development, and promoting a circular economy where materials are reused and recycled rather than being disposed of after single use.

Disposing of solid waste such as plaster of Paris (POP) requires careful consideration due to its unique properties and environmental impact. Plaster of Paris, chemically known as calcium sulfate hemihydrate, is widely used in construction, medical casting and art. However, once it has been set, it becomes non-biodegradable solid waste, posing disposal challenges. Correct disposal methods are important to minimize environmental hazards and ensure compliance with waste management regulations.

First, reuse and recycling of POPs should be prioritized. During the construction and manufacturing process, efforts should be made to minimize waste by accurately estimating the amount of POP needed. When reuse and recycling are not feasible, proper disposal methods must be used. Plaster of Paris should not be thrown into regular household waste bins or landfills, as it can cause environmental issues. When exposed to moisture, POPs can expand and harden, potentially damaging landfill liners and causing stability problems. Therefore, specialized waste management facilities that handle construction and demolition (C&D) waste are more suitable for disposing of POP. The facility has the equipment and expertise to manage the material safely and effectively.

One effective method to dispose of POP waste is through heat treatment. Combustion at high temperatures can break down materials into their basic components, mainly calcium sulphate and water vapor. This process significantly reduces the amount of waste and prevents the material from causing harm in landfills. However, it is important to ensure that the combustion process is carried out in facilities equipped with appropriate emission control systems to avoid the release of harmful pollutants into the atmosphere.

Alternatively, POP waste can be chemically stabilized and used in a variety of applications. For example, waste can be mixed with other materials to produce construction aggregates, which can then be used in road construction and other infrastructure projects. This method not only diverts POP waste from landfills but also provides valuable resources for construction projects, promoting a circular economy. The disposal of solid waste plaster of Paris requires a multifaceted approach that prioritizes reuse and recycling, uses safe disposal methods, and promotes education and awareness. By adopting this strategy, we can minimize the environmental impact of POP waste and contribute to sustainable waste management practices. It is important for individuals, industry and waste management authorities to work together and ensure that POP waste is handled responsibly to protect the environment and public health.

This study will also benefit industry ceramic and students to become more eco-system and green technology by replacing POP waste. POP waste can be a significant environmental concern if not properly managed. Recycling helps divert waste from landfills, reducing the overall environmental impact associated with disposal. Environmental problems due to solid waste will be reduced by other methods to eliminate POP waste. Therefore, the combination of RPOP and activator gives innovation and good effect for industrial ceramics.

The recycling of POP waste provides several benefits for various industries, especially ceramics and education. with improper disposal of POP waste can pose significant environmental concerns due to its non-biodegradable nature. POP recycling can reduce this by diverting waste from landfill and reducing the need for virgin materials. In addition, introducing recycling practices to students can foster a culture of environmental responsibility and sustainability from an early age. By incorporating recycled POP into educational projects, students learn about the importance of waste management and resource conservation and explore how recycling POP waste can drive innovation in green technology. Finding efficient methods to recycle and reuse POP can lead to the development of new environmentally friendly materials or processes.

To effectively implement POP recycling, collaboration between industry, educational institutions and environmental agencies is essential. This can involve research and development efforts to improve recycling techniques, educational programs to raise awareness, and policy initiatives to incentivize recycling practices.

Overall, POP waste recycling not only addresses environmental concerns but also promotes sustainability and innovation across various sectors.

1.6 Limitations of Research

Every research study has various restrictions that could affect how it is conducted, how its results are interpreted, and how much it can cover. There were a number of limitations in this study that had an impact on the theoretical and practical components of the investigation. These restrictions include things like the availability of laboratory equipment, the quality and performance of the materials, and creative and financial issues when it comes to recycling Plaster of Paris (POP). These problems show the difficulties in guaranteeing uniformity, effectiveness, and wider use of recycled plaster of Paris (RPOP), but they do not invalidate the results. Recognising these limitations is crucial because it puts the findings in context and directs future research efforts to address these issues.

1.6.1 Laboratory Equipment Accessibility

In conducting this study, several limitations have been identified related to the objectives of this study. The limitation is the availability of the machines used to process and test the waste at UiTM. The grinding machine used had to be shared with diploma students. This is because the machine is used to grind dry clay. Besides that, it needs to clean the grinding machine first before using it, so as not to mix it with other materials other than Plaster of Paris.

1.6.2 External Lab Dependency

This stage needs two days to make sure the machine is completely clean and dry before operating. The machine for testing particle size analysis, SEM, XRD and compressive strength, needs to send to IOS UiTM Shah Alam because the UiTM Cawangan Perak, Seri Iskandar does not have the equipment. Here it took a long time to conduct the test because researcher had to wait for the turn of the equipment user in addition to having to share with other students. As is well known, when Plaster of Paris is recycled, it undergoes several chemical changes that can affect its properties. Plaster of Paris (calcium sulphate hemihydrate, usually produced by heating gypsum (calcium sulphate dihydrate) to remove water molecules. After rehydration, POP returns to its gypsum form. However, gypsum that is dried again to produce RPOP, it may not retain all the original properties due to several factors such as the conversion back to POP may not be complete, leaving some gypsum, which has different properties compared to POP. In addition, during the recycling process, the material may pick up impurities or contaminants can affect its properties. This can come from the original POP microstructure. The POP may form an interlocking crystal network. The recycled material may not form the same microstructure, which leads to differences in mechanical properties. The conditions under which recycled materials are re-dehydrated (temperature, humidity, heating rate) can affect the properties of the final product. Improper dehydration can cause incomplete conversion or changes in crystal structure. Another limitation of this study was the dependency on external laboratories for advanced testing. Key equipment such as particle size analysis, Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), and compressive strength testing was not available at UiTM Perak, Seri Iskandar, and therefore samples had to be sent to IOS UiTM Shah Alam. This process required considerable time due to scheduling conflicts, machine availability, and the need to share facilities with other students. In addition, ensuring that the equipment was properly prepared and cleaned before use added to the delay. These factors collectively extended the experimental timeline and reduced direct control over the testing process.

1.6.3 Scale-Up Constraints

Although laboratory-scale recycling technologies show commitment, the transition to an industrial scale faces several problems. The shift from bench-scale experiments to full-scale production necessitates careful consideration of equipment design, process consistency, and quality control procedures. Equipment scalability is a big challenge, as laboratory-scale performance may translate poorly to industrial settings. Throughput, reaction kinetics, and material handling needs must all be reevaluated and optimized for large-scale operations. Furthermore, adequate industrial-scale equipment and technologies may provide constraints, necessitating specialized solutions or adaptations.

Maintaining process consistency across scales is another significant difficulty. Raw material qualities, environmental circumstances, and operating factors can all affect product quality and performance. A strong process control strategy, real-time monitoring system, and quality assurance protocol are required to reduce variability and ensure repeatability. Quality management is critical in bringing the recycling process to an industrial scale. Comprehensive testing processes, quality standards, and product certification procedures are required to ensure recycled materials' integrity and appropriateness for end-use applications. Furthermore, continuous improvement programmers and feedback mechanisms allow for incremental refinement of processes to satisfy performance needs and changing regulatory standards.

1.6.4 Quality and Process Monitoring

Additionally, the strength of RPOP may be reduced due to incomplete crystallization or the presence of impurities and unconverted gypsum. This will also cause changes in the microstructure to affect porosity, potentially leading to higher porosity and lower density, which can weaken the material. Overall structural integrity may be compromised, affecting material performance in applications where mechanical strength is critical. Although recycling Plaster of Paris is possible, the recycled material may not perform as well as the original. Properties such as strength, porosity, and structural integrity can be significantly affected due to the reasons mentioned above. To reduce this issue, a careful study of the recycling process is essential, and additives or treatments may be required to restore it.

Although the study's primary focus was on the mechanical, chemical, and physical properties of recycled plaster of Paris (RPOP), it was unable to capture the more expansive creative aspects that are essential to the process of art and design. Although laboratory testing provided reliable strength, absorbency, and durability data, studio-based ceramic production, where the creative process often involves experimentation, unpredictability, and the use of non-traditional slip or casting procedures, differs from these controlled settings. The findings may not accurately reflect these realities because materials are regularly pushed beyond their typical practical limit in creative activity.

Recycling RPOP presents several challenges related to quality and consistency. Variations in composition can result in unpredictable performance, making it difficult to ensure reliable outcomes in applications. The process of producing RPOP powder is also time-consuming and requires careful handling, which increases complexity. Additionally, the cost of RPOP may be higher than virgin POP due to the need for extra processing to remove contaminants and restore its properties.

Another limitation is the quick setting time of POP once mixed with water. This issue was observed during the experiment when RPOP exhibited a viscous flow, making it difficult to stir and blend effectively. Degradation is also a major concern, as exposure to moisture or environmental factors can reduce its quality and suitability for reuse. Furthermore, repeated recycling cycles often cause quality loss, leading to changes in strength and setting time, which may restrict its application. Despite these challenges, existing recycling methods such as grinding and rehydration can still be applied, though they may not always meet the same standards as fresh plaster.

1.6.5 Regulatory and Environmental Compliance

The use of chemicals in the cleaning and processing of recycled Plaster of Paris (RPOP) is essential to improve its quality and usability. However, this introduces significant limitations that must be carefully managed to ensure safety and environmental protection. According to Ali Abdul Hussein S. Al-Janabi (2017), exposure to POP chemicals and fine dust can cause skin irritation, respiratory problems, and potentially long-term illnesses such as cancer. Without proper training and protective measures, workers are highly exposed to these risks. The handling and disposal of chemicals are also subject to strict regulatory frameworks. Compliance requires considerable investment in safety equipment, waste management infrastructure, and adherence to operational protocols. Non-compliance may result in legal penalties, fines, or environmental damage. Moreover, the effectiveness of chemical treatments depends on the composition of RPOP, requiring ongoing optimization of recycling processes. Another challenge lies in contamination and degradation. POP can easily pick up dust, paint, or debris during use, which reduces the quality of recycled material. Each recycling cycle may further weaken its strength and performance. To minimize contamination, mould waste must be carefully collected, stored, and processed. In this study, broken moulds were placed in sacks to avoid exposure to dust and debris. Additionally, before grinding, the machine was thoroughly cleaned and dried to ensure no foreign materials remained in its components. While chemical treatment and strict handling protocols can enhance the quality of RPOP, these processes involve substantial costs, health risks, and environmental considerations. Continuous refinement of recycling techniques is required to ensure compliance with regulations and to maintain material quality.

1.6.6 Challenges in Data Collection and Materials

1.6.7 Several challenges were faced during data collection and material preparation for this study:

a) Activator Availability and Use

The activator used in this study was difficult to obtain due to limited stock and supplier restrictions. Careful planning was required to avoid wastage. Incorrect dosage or lack of supplier guidance could affect the properties of RPOP, making it unstable when mixed.

b) Limited Access to Industrial Data

Information regarding POP waste management in ceramic factories was difficult to obtain due to data confidentiality. In Kuala Kangsar, most artisans focused on *Labu Sayong* production and relied on moulds supplied by Perbadanan Kemajuan Kraftangan. This limited access to detailed information on mould-making and waste handling practices.

c) Material Handling and Processing

Unlike new POP, RPOP requires precise control of drying temperature to ensure proper rehydration and solidification. Handling the material was challenging, as contamination with paint, dust, or debris during collection could reduce quality. To minimize this, waste moulds were stored in sacks, and the grinding machine was thoroughly cleaned before use. Despite these precautions, the risk of contamination and degradation remained a limitation.

1.6.8 Material in Mould Recycle Plaster of Paris

The selection of the appropriate type of mould for reprocessing is important and requires proper care in the recycling industry, especially for materials such as POP. Moulds made of uniform material are easier to see again. This is because mixed materials can cause problems in the process of breaking and re-mixing. Materials such as homogeneous POP are more suitable because they facilitate the crushing and reprocessing process. Materials such as homogeneous POP are preferred for making moulds that need to be reused or recycled. Homogeneous materials have uniform properties throughout, such as density, hardness and texture. This consistency makes them predictable in terms of how they behave during the moulding process and subsequent reuse. When moulds made of homogeneous materials such as POP need to be recycled or reused, they can be broken more easily and uniformly. This facilitates the process of reprocessing and reshaping without introducing variability from the mixed material. Mixed materials can cause complications during the recycling process.

Therefore, this study recognises that access to homogeneous POP moulds is a crucial factor in ensuring the effectiveness and reproducibility of recycling outcomes. Mixed-material moulds remain a limitation as they compromise both the efficiency of recycling and the reliability of the final RPOP properties.

1.6.9 Ease of Cleaning in Mould Reprocessing

Moulds that can be easily cleaned before reprocessing are better. Waste material or dirt left on the mould can affect the recycling process and the quality of the resulting product. The selection of moulds that are easy to clean before reprocessing is important because dirty or contaminated moulds can mix waste material with new material during the recycling process. This can cause cross-contamination or poor product quality. Waste material stuck to hard-to-clean mould may be difficult to remove completely. This can cause non-uniform mixing or reduce the performance of the recycled product. By using moulds that are easy to clean, the recycling process can be done more quickly and efficiently. A quick cleanup means less time and resources are spent on mould re-use preparation. Materials such as POP or other recycled materials may require good stability for optimal performance. A dirty mould can affect the chemical or physical properties of the material during the re-mixing process.

1.6.10 Mould Size and Shape Constraints

Plaster of Paris recycling further limited by the mould's dimensions and shape. Oversized or intricately shaped moulds frequently call for specialised crushing or processing machinery, which increase expenses and processing times. Such moulds' irregularity further decreases the efficiency of handling and reprocessing because it may take extra steps to break it up into manageable pieces. On the other hand, because to its consistency, which enables faster crushing, grinding, and rehydration, smaller or standardised moulds are typically simpler to process. As a result, moulds with unusual sizes or complex patterns provide a serious challenge to guaranteeing consistent and affordable recycling results.

1.6.11 Resistance of Moulds to Recycling Processes

Moulds that are resistant to recycling processes, such as heating or cracking, are a better choice. Materials that can withstand high temperatures or pressures during the recovery process will reduce damage and increase efficient recycling. This is because materials that are resistant to recycling processes, such as heating or high pressure, will be more resistant to physical changes during the recovery process. When materials are not easily broken or compromised during reprocessing, it reduces material loss and allows more materials to be reused efficiently. For example, in the context of POP or recycled plaster, the ability to withstand high temperatures during the drying or water extraction process is important because it allows the plaster to be restored without suffering a loss of structure or material capacity. With this, it contributes to the efficiency of the overall recycling process.

1.6.12 Material and Additive Incompatibility

The incompatibility of materials in the recycling process can be a serious problem because it can cause some issues of incompatible additives can cause unexpected chemical reactions interacting with other materials in the process. This can produce unwanted or harmful byproducts. Incompatible materials can affect the physical or mechanical properties of the final product. For example, the strength, durability, or visibility of a product can be affected if incompatible materials are used.

Incompatible additives can reduce product stability, either in terms of shelf life or performance in the intended application. Incompatible additives may have different chemical reactivity to POP, causing unwanted chemical reactions.

1.6.13 Limited Exploration of Artistic and Design Implications

This study's limited investigation of the aesthetic and design aspects of recycled plaster of Paris (RPOP) is a further limitation. The study looked at how additives like Silubit G80 can improve mechanical qualities, but it didn't assess how these changes would affect artistic expression, design flexibility, or creative form-making. In the larger realm of art and design, materials are prized for their ability to stimulate fresh creative directions and aesthetic possibilities in addition to their technical performance. Future research can evaluate how recycled POP may enhance creative practices, artistic innovation, and design applications because this study primarily focusses on functional and mechanical factors.

1.6.14 Economic Constraints in Recycling Compared to NPOP Production

The next challenge is the cost difference between recycling and producing NPOP. The expense incurred in collecting used plaster, cleaning the contaminants, and processing it into a reusable form often exceeds the cost of making fresh plaster. This economic mismatch discourages investment in recycling infrastructure. RPOP involves complicated processes such as cleaning, drying and filtering to meet quality standards. These processes require specialized equipment and add to operating costs. Additionally, variations in the composition of used plaster from different sources complicate the recycling process.

1.6.15 Aesthetic and Artistic Considerations

In addition, the study primarily evaluated functional performance and did not address aesthetic qualities that are highly significant in Art and Design contexts. Factors such as surface texture, tactile qualities, finish, and the ability of RPOP moulds to support fine artistic details were not systematically studied. These aspects are important because they influence not only the technical success of a ceramic piece but also its artistic value and expressive potential.

While the study focused on the mechanical, chemical, and physical characteristics of RPOP in laboratory settings, these findings may not fully capture the realities of art and design practices. In ceramic studios, materials are often used in experimental and non-traditional ways, frequently pushing beyond their typical practical limits. As a result, laboratory data on strength, absorbency, and durability may not always reflect the actual performance of RPOP in creative applications.

Finally, although sustainability and waste reduction are central to this research, the social and cultural implications of using recycled materials in ceramic practice were not empirically examined. The study did not investigate how ceramic artists, designers, or audiences might perceive or respond to the use of RPOP in creative production. Such perspectives are essential in understanding the role of recycled materials in shaping future practices in Art and Design, but they remain an area for future research

1.7 Scope of Thesis

Through the scope of the study, the study was conducted on the ceramic industry sector in Kuala Kangsar, Perak, Malaysia. The target locations to be obtained are several places of Sayong operators in Kuala Kangsar, Perak that have been selected to study the Waste Plater of Paris. In addition, the experimental process was carried out in the ceramic laboratory of UiTM Seri Iskandar, Perak. This is because at UiTM Perak Branch. Raw materials are easy to find because the Kuala Kangsar area is close to UiTM Perak Branch, making it easy for researchers to move around to find data.

POP recycling is an interdisciplinary exploration that spans materials science, environmental engineering and sustainability practices. This study aims to address the growing environmental concerns posed by the disposal of POP waste, which is commonly used in the manufacture of plaster moulds. Traditionally, POPs are non-biodegradable, leading to significant landfill contributions. POP Recycling not only reduces waste management issues but also conserves natural resources by reducing the need for raw gypsum extraction.

The initial phase of the study involved an in-depth analysis of the chemical properties of RPOP. This includes understanding its composition, setting mechanisms and factors affecting its recyclability. RPOP, mainly composed of calcium sulphate hemihydrate, undergoes an exothermic reaction with water to form a hard and durable material. Reversing this reaction or developing methods to reprocess RPOP without significant loss of material integrity, is a major focus. It will investigate various chemical and physical methods to dehydrate the RPOP set back to its hemihydrate form, making it reusable.

Next, the study examines the mechanical properties of recycled RPOP to ensure it meets industry standards for strength and durability. This involved conducting a comparative analysis between recycled NPOP and RPOP in terms of compressive strength, setting time and overall performance in real-world applications. Potential additives or modifications to the recycling process will be explored to improve the quality of recycled RPOP. This phase is important because it determines the feasibility of using recycled RPOP in practical applications, ensuring that it can withstand the same conditions as new materials.

Economic analysis also forms a supplementary component of this study by highlighting the potential cost-effectiveness of recycling RPOP compared to producing new POP materials. While this research does not conduct an empirical market survey, the findings are discussed in relation to potential industrial benefits such as reduced raw material costs and minimisation of waste disposal expenses. The broader implications of this study therefore extend to sustainability and the promotion of circular economy practices in the ceramics industry.

In addition, the study considers regulatory and policy dimensions relevant to RPOP implementation. Existing frameworks in waste management, recycling, and material standards are reviewed to identify opportunities that may facilitate industrial adoption. While public perception and market acceptance are beyond the empirical scope of this research, these factors are acknowledged as important future considerations that may influence the widespread application of RPOP. Recommendations are therefore positioned to guide policymakers and industry stakeholders in supporting recycling practices through incentives, regulatory measures, and awareness campaigns.

The social implications of RPOP are considered. This involves assessing public perceptions, potential health and safety concerns, and overall societal benefits in reducing RPOP waste. Community engagement and education is an important component, aiming to foster a culture of sustainability and responsible use of materials.

The experiment will be divided into 4 phases, the first phase is to study the properties of RPOP and NPOP. The main material in this study is the re-pounded waste mould and needs to be dried in several temperatures to remove the water content before testing the RPOP properties. The second phase is to identify suitable activators to be used in RPOP to obtain better properties when activators exist. This activator is used to improve the durability properties of RPOP. The third phase is to determine the life cycle of reusable moulds as working moulds for the ceramic industry. At this stage, RPOP powder is used as a mould to test the casting ability of the product, at the same time, the final stage is also tested by producing an aesthetic and intricate cup design. Finally, RPOP is tested with various types of tricategory product forms, aiming to ensure that RPOP can be used to make various types and forms of moulds without problems.

In conclusion, the study on Plaster of Paris recycling is comprehensive, addressing technical, environmental, economic, regulatory and social dimensions. By developing efficient recycling methods and promoting sustainable practices, this research aims to reduce the environmental impact of RPOP, conserve natural resources and pave the way for a more sustainable future in material use.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The recycling and reusability of waste mould has an impact on the ceramic industry and the environment, especially in the Kuala Kangsar, Perak. This is because Kuala Kangsar is one of the places where ceramic products are produced, especially Labu Sayong, produced by casting techniques. The ceramic industry with the use of Plaster of Paris (POP) will be focused on in this study. Innovations regarding waste mould recycling and reusability will be comprehensively reviewed including recycling methods and Recycle Plaster of Paris (RPOP) application techniques and existing practices by the ceramic industry. outlines a comprehensive review of innovations in waste mould recycling and reusability, particularly focusing on recycling methods, RPOP application techniques, and existing practices in the ceramic industry. This review will likely delve into the various methods used by ceramic manufacturers to recycle and reuse moulds, including techniques for processing plaster waste, as well as explore how RPOP can be used effectively in this context.

In this chapter, a review was related to the research done. By conducting this review, the study aims to identify novelty aspects and gaps in the current knowledge. The methods used for recycling Plaster of Paris are examined in detail, including the various testing procedures that have been employed to evaluate the effectiveness and viability of these methods.

2.2 Process of Recycling

Malaysia is making significant strides in improving its solid waste management system. One of the key initiatives is the forth coming launch of the Blueprint for Solid Waste, set of November 2023, which will emphasize the principles of a circular economy. This approach aims to reduce waste and carbon emissions through the 9Rs strategy: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover. The goal is to achieve net-zero carbon emissions by 2050 through Dutch Prime Minister Rutte, (2023). Fatimah, (2024), reported Malaysia generates about 39,000 tonnes of solid waste daily, with efforts underway to enforce waste separation at the source. This regulation, part of Act 672, requires households in several states to separate their waste into recyclables and non-recyclables. The government plans to expand this enforcement nationwide to enhance recycling activities and reduce landfill waste.

Furthermore, community initiatives like centralised bulk waste collection centres have been proposed to manage large waste items more effectively, especially during festive seasons or house moves. These centres would provide a convenient way for residents to dispose of bulk waste, reducing illegal dumping and associated cleanup costs, (Tsai, 2024). The Housing and Local Government Ministry suggests that the Solid Waste and Public Cleansing Management Act, currently only applicable in Pahang, Johor, Melaka, Negri Sembilan, Perlis, Kedah, Kuala Lumpur, and Putrajaya, is open for further adoption. Malaysia lost an estimated RM291 million this year because recyclable products were not recycled and instead went to waste. Solid Waste Management and Public Cleansing Corporation (SWCorp), CEO Datuk Ahmad Husaini Abdul Rahman (pictured) stated that, based on the national recycling rate of 35.38% in 2023, the number of recyclable materials that were not recycled is estimated to be 6.96%, or nearly one million tons. According to the National Solid Waste Management Department's 2012 survey on solid waste composition, characteristics, and existing recycling practices in Malaysia, 42.34% of recyclable garbage has the potential to be recycled.

KPKT Minister Nga Kor Ming has launched the National Circular Economy Council (NCEC) to manage solid waste, aiming to unite stakeholders and accelerate the transition from a linear to a holistic cyclical economy. NCEC will focus on policies, laws, strategies, and collaboration between government and private sectors. In today's world, where environmental concerns are at the forefront of global discourse, recycling has emerged as a critical practice for sustainability. The recycling cycle represents the journey of materials, turning waste into a valuable resource. Recycle is the collection of waste or rubbish to be reused as a new product through several processes. The first recycling process is collection and processing. Collection of this material through curb side collection, drop-off canters and refund programs. There are many products are being manufactured with recycled content. For examples through household item, industry sector, agriculture sector and others are reported by Yang, (2011). Using new products made from recycled materials can significantly reduce waste in landfills. For example, when buying products made from recycled materials, it helps divert waste from landfills and reduces the need for new raw materials.

This minimizes the amount of waste produced and sent to disposal areas. Also, resource conservation by recycling things like paper, plastic, glass and metal means fewer natural resources are needed to produce new products. This helps preserve raw materials and reduce the environmental impact of extracting and processing these resources. Recycling can save energy producing products from recycled materials usually uses less energy than producing them from virgin materials. This can lead to lower greenhouse gas emissions and a smaller carbon footprint. The recycling industry creates jobs and stimulates the economy. By buying recycled products, its support the industry and contribute to a circular economy where materials are reused instead of thrown away. With the production of recycled materials can encourage innovation in the manufacturing industry, design and materials. The demand for recycled products drives innovation in product design and manufacturing. The company invests in better recycling technology and more efficient production processes, which lead to better quality recycled products.

Reported by Change _ Mount Holyoke College, (2021), the types of waste materials that can be recycled, including paper, bottles, plastic, cans, ceramic items, batteries, electrical items, and clothing. Recycling is an important practice to reduce waste and conserve resources. Here is a breakdown of the different types of waste that can be recycled. Paper includes newspapers, magazines, office paper, cardboard, packaging paper and books. This material is recycled in a way that collected paper is sorted, cleaned and processed into new paper products. Paper fibres are broken down, mixed with water, and then formed into new sheets. Glass bottles (beverage bottles, jars) are processed with glass bottles sorted by colour, cleaned, crushed into bullets, and melted to form new glass products. This process can be repeated indefinitely without loss of quality. PET bottles (water bottles), HDPE containers (milk jugs), plastic bags, packaging and various household plastic items. Plastics are sorted by type and colour, shredded, melted and formed into pellets. These pellets are then used to create new plastic products.

Recycling aluminium saves significant energy compared to producing new aluminium from raw materials such as lead-acid batteries (car batteries), lithium-ion batteries (telephone batteries), alkaline batteries are processed in such a way that the battery is opened, and its components (metals, plastics, chemicals) are recovered and processed for reuse. This helps prevent harmful substances from polluting the environment. Electrical goods will be recycled with electronic goods collected, opened and their components (metal, plastic, glass) were separated. Precious metals and other materials are extracted and reused in new products. Clothing includes textile materials (cotton, polyester, wool), shoes, accessories. Clothes are collected, sorted and either reused (through donation and resale) or processed into fibres for new textiles or other products (insulation materials, industrial fabrics). If this waste material is recycled, it will benefit humans and the environment. therefore, Mount Holyoke is committed to recycling and reducing and recycling waste and has a long-standing recycling program.

The recycling process begins with the collection and separation of recyclable materials. This stage involves a variety of methods, from curb side collection programs to recycling centres where individuals and businesses deposit their recyclables. The sorting process is important to ensure materials are properly separated by specific types, such as paper, plastic, glass, and metal. Efficient sorting streamlines the recycling process and improves the quality of recycled materials. Once collected and sorted, the recycled material undergoes processing and transformation. This stage involves cleaning, shredding, and melting the material to prepare it for reuse. For example, plastic bottles are washed, chopped into small pieces, melted, and formed into new products. Similarly, paper is returned and modified into recycled paper products. Through innovative technologies and processes, recycling facilities transform waste into valuable raw materials, saving energy and reducing demand for virgin resources. Recycled materials are then used in the manufacture and production of new products. Industry incorporates recycled content into a variety of goods, from packaging materials to construction products. By replacing virgin materials with recycled alternatives, manufacturers minimize the environmental footprint of their operations and support a circular economy. This stage promotes resource efficiency and reduces greenhouse gas emissions associated with the extraction and processing of raw materials.

Through Demirbas, (2011), the recycling cycle culminates in consumer use and disposal. Individuals buy products made from recycled materials and integrate them into their daily lives. When these products reach the end of their useful life, consumers play an important role in proper disposal. Recycling bins, designated drop-off locations, and waste management systems facilitate the return of materials to the recycling loop. Responsible disposal ensures that recyclables enter the cycle again, closing the sustainability loop. When recycled materials are incorporated back into the manufacturing process, the recycling cycle continues. This iterative process embodies the principles of sustainability, promoting resource conservation and waste reduction. Through continuous repetition, the recycling cycle minimizes the extraction of finite resources, reduces pollution, and preserves the ecosystem. In addition, public awareness, education, and government policy play an important role in fostering a recycling culture and ensuring cycle longevity.

Central bins for recycling, trash and composting are located on each floor of the residence hall, usually in the kitchenette. There are many benefits of recycling process which is to reduce the amount of waste sent to landfills, lowering greenhouse gas emission compared to plastic production, recycling can help protect the environment from mining, logging, open burning, and processing of raw materials from factories will pollute the air and water. However, product reusability should also undergo a special salvage, treatment, and processing process so that recyclable products can be reused for a long time and be safe to use Merriam-Webster, (2021) especially after salvaging or special treatment or processing. In 2008, Banar, Cokaygil, and Ozkan reported that Life cycle assessment (LCA) methodology was used to determine the optimum municipal solid waste (MSW) management strategy for Eskisehir city. Recycling one of the processes from reusable waste through several manufacturing processes to make new products.

However, in this study, it is more emphasized how to recycle the material of making ceramics into a new material that can be reused. Recycling materials including glass, ceramics, and Plaster of Paris necessitates special attention to environmental and safety concerns. Specific measures can be implemented to improve the efficiency, safety, and environmental friendliness of the recycling process. Large amounts of dust can be produced during the recycling, crushing and grinding process, putting workers' health at risk and contributing to air pollution. To reduce the risk, a dust extraction device is required. This technology may collect dust particles at their source, stopping them from spreading throughout the environment. Additionally, supplying workers with protective equipment such as masks and respirators can help decrease their exposure to dangerous dust. Regular maintenance and monitoring of this system assured its performance, makes the workplace safer, and decreases environmental pollution.

To reduce environmental impact, recycling enterprises must employ appropriate waste management practices. Not all recycled materials can be reused, and some residual waste is unavoidable. Proper disposal of these products is critical to preventing environmental damage. This includes segregating recyclable and non-recyclable garbage and ensuring that hazardous materials are handled and disposed of in accordance with safety regulations. Recycling facilities should have defined waste segregation and disposal standards in place, as well as relationships with waste management businesses that specialize in non-recyclable and hazardous trash. The recycling process's heating and melting steps require a lot of energy, which contributes to carbon emissions and environmental degradation. Implementing energy-efficient procedures can help to lessen the environmental impact of recycling processes. This can be achieved by using advanced technology that uses less energy, optimizes the heating process and recovers waste heat for reuse. Additionally, investment in renewable energy sources such as solar or wind power can further increase the sustainability of recycling facilities. Continuous monitoring and improvement of energy use helps maintain efficiency and reduce costs.

Complying with local and international regulations is important to ensure that the recycling process is safe and environmentally responsible. These regulations cover many aspects, including emissions, waste disposal, and worker safety. Compliance not only helps avoid legal penalties but also promotes trust and credibility among stakeholders. Recycling facilities should keep up to date with regulatory changes and implement necessary adjustments to meet compliance requirements. Regular audits and certifications can help maintain compliance with standards and demonstrate commitment to environmental stewardship

Engaging with community and industry stakeholders is crucial for promoting recycling and increasing sustainability. Furthermore, educating the community and industry on the benefits and significance of recycling glass, ceramics, and POP materials can increase participation rates. Awareness campaigns can emphasis the environmental and economic benefits of recycling, encouraging more people and businesses to participate in recycling activities. Workshops, seminars, and information campaigns can help people learn about proper recycling methods and the benefits of trash reduction. Collaboration with recycling companies, local governments, and non-governmental organizations (NGOs) can boost recycling activities. This collaboration can help with resource pooling, infrastructure development, and wider outreach. Local governments can help recycling programs by providing policy incentives and public awareness efforts. NGOs can contribute to the community. NGOs can play a role in community mobilization and advocacy, promoting sustainable practices at the grassroots level. By working together, these entities can create a robust recycling infrastructure that maximizes resource recovery and minimizes environmental impact

Recycling is the collection and processing of waste materials into new materials or products, which helps to reduce the consumption of fresh raw materials, minimize waste sent to landfills, and conserve natural resources. It can be applied to a variety of materials, including paper and glass.

2.3 Waste Material

Waste materials can be classified into various categories based on the source, composition, and potential impact on the environment. Here are some types of waste according by Abdel-Shafy and Mansour, (2018), among which is municipal solid waste (MSW). This includes everyday items that are used and then thrown away, such as food waste, packaging, clothing, appliances, and furniture. Biodegradable waste is organic waste that can be decomposed naturally, such as food waste, yard waste and paper products. While hazardous waste materials that pose a threat to human health or the environment if handled incorrectly, such as batteries, chemicals, pesticides, and certain electronics. Electronic Waste (E-Waste) is discarded electronic devices such as computers, TVs, mobile phones, and appliances, which contain hazardous substances such as lead, mercury, and cadmium.

Construction and demolition waste, debris produced during construction, renovation, or demolition activities, including concrete, wood, metal, and insulation materials. Industrial waste, waste generated by factories, manufacturing plants and industrial processes, which can include chemicals, metals, and various by-products. Medical waste is waste generated by healthcare facilities, including infectious materials such as syringes, bandages, and expired drugs. Agricultural waste, waste produced during agricultural activities, such as crop residues, animal waste, and pesticides. Radioactive waste is material containing radioactive material produced by nuclear power plants, research facilities and medical institutions. Plastic waste is a non-biodegradable synthetic polymer used in various products such as packaging, bottles, and containers, which can remain in the environment for hundreds of years. Glass waste is waste produced from glass products such as bottles, jars, and windows, which can be recycled but often end up in landfills. Textile waste, garments, fabrics, and textiles discarded from households, manufacturing processes and the fashion industry. Each type of waste requires a specific management strategy to minimize environmental impact, such as recycling, composting, treatment, or proper disposal in designated facilities.

Efforts to minimize construction waste include better planning and design to reduce material excess, implementing recycling and reuse practices on-site, and promoting the use of sustainable materials. These approaches not only reduce waste but also contribute to more environmentally friendly construction practices.

2.3.1 Type of Waste

2.3.1.1 Liquid

Liquid waste includes any waste substance that occurs in liquid form. It might originate from domestic, industrial, agricultural, or commercial sources. Saha, B., & Azam, F. A. B., (2021), explained the significance of dealing with liquid waste is to avoid the environmental and health concerns associated with incorrect disposal, such as contamination of water resources and ecosystems. This water pollution is caused by residential sources such as household wastewater, including sewage, grey water (from sinks and showers), and cleaning fluids. In addition, industrial sources include effluents from manufacturing processes, mining operations, and the chemical sector. These may contain hazardous materials such as heavy metals, chemicals, and oils. Pesticides, fertilizers, and animals are used to remediate farm runoff.

Maintaining a clean environment is critical to living a healthy and comfortable life. People, factories, processes, and animals generate trash daily, making it an unavoidable aspect of society. Waste is classified into five types, which include lliquid waste refers to all grease, oil, sludges, wash water, waste detergents and dirty water that have been thrown away. The hazardous and poisonous to environment and are found in industries as well as households. Wastewater, as it is often called, is any waste that exists in liquid form. There are two categories of liquid waste: non-point and point source waste. As stated by Wang et.al., (2023), manufactured liquid wastes are called point source, and non-point source wastes occur naturally in our environment. Three methods can remove liquid waste from wherever it is including containment involves storing liquid waste in barrels or tanks until it can be removed from the environment. The container prevents liquid waste from entering the environment. It is not necessary to dump any liquid waste.

Untreated or improperly handled liquid waste can contaminate freshwater systems, resulting in eutrophication, algal blooms, and the extinction of aquatic life. When liquid waste penetrates the soil, it can deteriorate its quality, hurting both agriculture and natural vegetation. Furthermore, contaminated water sources can transmit diseases to humans and animals, including cholera, typhoid, and dysentery. While the influence on marine species tainted with chemicals, oil, and plastic microbeads in liquid waste can be harmful to the marine ecosystem.

Liquid waste, especially gaseous waste, poses considerable environmental challenges. While gaseous waste has an impact on air quality, liquid waste mostly impacts bodies of water; yet both require proper treatment solutions. Liquid waste can emit gases during decomposition, adding to air pollution. Certain liquid waste, when evaporated, can produce gaseous emissions, uniting the two forms of pollution.

2.3.1.2 Gas

Waste gases are undesirable gas emissions that are emitted into the atmosphere because of numerous human and natural processes. These gases, including CO_2, CH_4, and NO_x, contribute to air pollution and global warming. Waste gas sources include industrial processes, agriculture, and burning fossil fuels in vehicles and power plants, releasing CO_2 and NO_x into the atmosphere through methane emissions. Yaashikaa, (2022), waste gas significantly impacts the environment, trapping greenhouse gases like CO_2 and methane, leading to global warming, climate change, and increased extreme weather events. It also poses health risks and economic costs, affecting resources and productivity.

When solid waste is dumped in a landfill, it will decompose over time, especially organic matter such as food waste. This decomposition produces landfill gas, which consists mainly of methane (CH_4) and carbon dioxide (CO_2). Landfill gases are a significant contributor to greenhouse gas emissions if not managed properly

2.3.1.3 Solid

Reported by Hossain and Roy, (2020) waste from manufacturing processes and energy generation contributes to ecological and health issues. Recycling or reuse of waste can transform it into value-added products. Ceramics are gaining attention due to their eco-friendly nature. Studies show the potential to use alternative ingredients like fly ash, rice husk ash, blast furnace slag, sludge, glass waste, and eggshell for ceramic fabrication. This approach not only solves disposal problems but also conserves natural resources. Solid waste refers to any rubbish, sludge, or refuse found in industrial and commercial facilities.

The five main categories of solid waste are glass and ceramics. Many firms readily recycle ceramics and glass. The catch here is that must be disposed of correctly. Plastic garbage encompasses any container, jar, bottle, or bag found in businesses and homes. Plastics are not biodegradable, and most of them cannot be recycled. Do not mix plastic waste with ordinary waste. Instead, sort them before throwing them out. Paper trash includes all newspapers, packing materials, cardboard boxes, and other paper items. Paper is recyclable. Tins and metals are commonly found in homes due to their use in food containers and household product. Organic waste includes meat, garden trash, and food that has rotted. This form of garbage is typically encountered in the home. They degrade over time and are converted into fertiliser by microbes. However, organic trash releases methane when it decomposes, thus it should not be disposed of with regular waste. Instead, use a green bin to properly dispose of this type of trash. Recycled waste includes any wasted goods, such as metal, furniture, and organic garbage, that can be recycled. When placing goods in recycling bins, keep in mind that not all products may be recycled. Additionally, hazardous garbage, such as flammable, corrosive, toxic, or reactive compounds, should be avoided. In a nutshell, they are waste items that constitute a significant or prospective risk to the environment.

Through Erna, (2020) domestic waste is classified into two categories: solid waste and liquid waste comp sed of organic and inorganic waste components. Animals and plants produce material that is organic, which can be degraded and disposed of. Inorganic materials are difficult-to-dispose waste produced by mineral sources, such as plastic, metal, glass, and building materials. Waste is an unavoidable by-product for most people human activity and refers to items or materials that have been abandoned, are no longer required, or have served their purpose and are no longer functional. Waste can take numerous forms, including solids, liquids, and gas. It is a byproduct of both human and natural processes.

Concrete, for instance, is one of the most abundant construction materials. While durable and strong, its disposal poses challenges because of its weight and volume. However, recycled concrete can be used as aggregate in new concrete mixes, reducing the demand for virgin materials and lessening environmental impact. Glass and plastic are also prevalent in construction waste. While glass is recyclable, plastic poses a more significant challenge due to its diverse types and recycling complexities. However, innovative solutions such as using recycled plastic in construction materials are emerging, helping to divert plastic waste from landfills and reduce environmental harm.

2.3.1.4 Solid Waste

According to RCRA, (2023), "solid waste" includes garbage or refuse, sludge from wastewater treatment plants, water supply treatment plants, or air pollution control facilities, and other waste products generated by industrial, commercial, mining, and agricultural operations, as well as the activity community. Almost everything that happens in this environment generates some sort of garbage. It is vital to remember that the term "solid waste" refers to more than just physical garbage. Many solid wastes consist of liquid, semi-solid, or gaseous components. Solid waste refers to any material that has been discarded, as the term discarded means thrown away. Abandoned materials include those that have been disposed of, burnt, or repurposed incorrectly. While inherent like trash poses a harm to human health and the environment, it is always classified as solid trash; these products are always deemed rubbish. Waste materials that include dioxins are one example of waste material. Kumar, (2022), there are 3 classification types of solid waste, mainly domestic, industrial, and commercial. To classify items, consider origin (household, industrial, commercial, manufacturing, or institutional), the material (organic, glass, metal, plastic, paper), and the potential hazard (toxic, non-toxic, combustible, radioactive, contagious). All type of solid waste is a waste that leads to negative effects on the ecosystem. Furthermore, there are a handful of irresponsible parties who do not manage this solid waste systematically and it leads to various pollutions such as water, air, soil pollution, and health problems. A good management of this solid waste are very important to protecting our earth and health.

Through a study made by Batayneh, (2007) waste consists of the field of construction, such as demolished concrete, glass, and plastic. Construction waste, indeed, encompasses a variety of materials like demolished concrete, glass, and plastic. This waste stream is significant due to both its volume and its potential environmental impact. When not properly managed, construction waste can contribute to pollution, habitat destruction, and resource depletion.

In Malaysia, the National Solid Waste Management Department has collaborated with several NGOs to reduce solid waste in Malaysia. The origin of waste milling, Argo culture forestry, industry, wastewater treatment, construction demolition and household. According to Jabatan Pengurusan Sisa Pepejal Negara, (2016), solid waste management policy has been implemented for more systematic improvement to achieve developed country status and compact solid waste management. In addition to population growth, technological advances, and socio -economic changes in Malaysia. Therefore, the solid waste management department has implemented solid waste management well based on the waste management hierarchy which gives priority to reducing solid waste through 3R Reduce, Reuse, Recycle. Implementing a solid waste management policy is indeed important to achieve systematic improvement and eventually move to the status of a developed country. Such policies usually involve a combination of strategies aimed at reducing, reusing and recycling waste, as well as proper disposal methods for non-reusable waste.

Here are some of the main components that are often found in an effective solid waste management policy implement waste reduction initiatives encouraging individuals, businesses and industries to reduce waste generation through measures such as product redesign, packaging reduction and encouraging the use of reusable products. Then, the Recycling Program. By establishing a comprehensive recycling program for materials such as paper, glass, plastic and metal. This includes setting up collection centres, implementing curbside collection services and creating awareness campaigns to educate the public about recycling practices. Composting programs can encourage composting of organic waste such as food waste and yard waste to divert it from landfills and create nutrient-rich soil amendments for agriculture and landscaping. The community can also practice waste segregation. efforts Promote proper segregation of waste at source to facilitate recycling and ensure hazardous materials are handled separately and safely. In addition, public awareness and education is also important. Conduct outreach programs and educational campaigns to inform the public about the importance of proper waste management practices and encourage behavioural change. Invest in research and development of new technologies and innovative solutions for waste management, such as advanced recycling techniques, waste-to-energy technologies, and sustainable packaging materials.

Solid waste management hierarchy has six levels. Through Jabatan Pengurusan Sisa Pepejal Negara, (2012), each stage plays an important role in the success of solid waste management as shown in Figure 2.1.

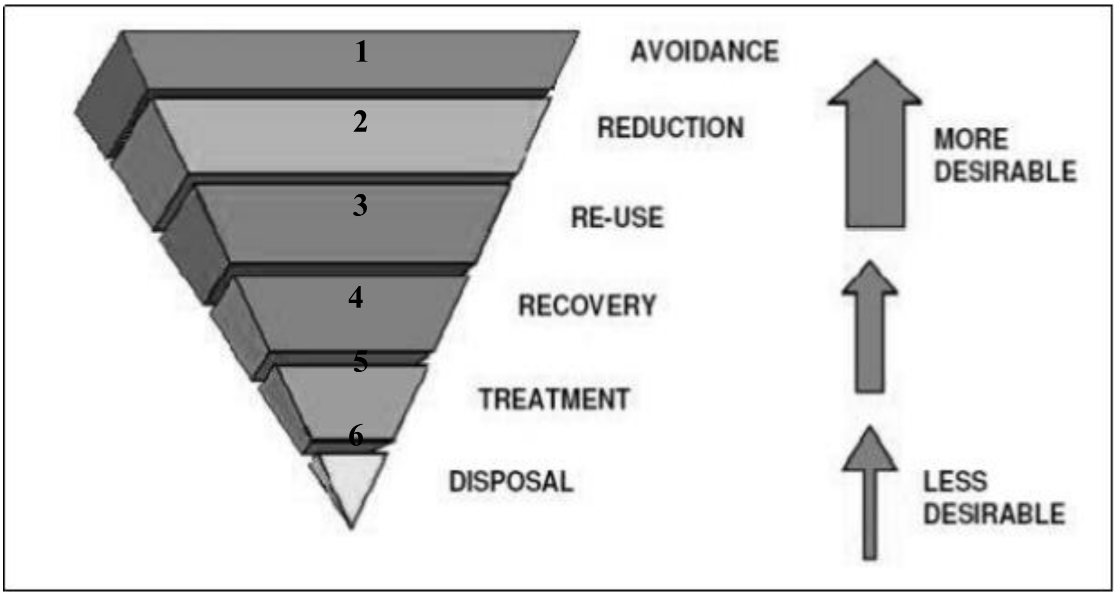


Figure 2.1 Solid Waste Management Hierarchy

Through Figure 2.1 shows the stages 2-4 the 3R process, while stage 5-6 is the treatment recovery process which is the framework for technology selection. Solid waste management usually follows a hierarchy known as the "3R" hierarchy: Reduce, Reuse and Recycle. This hierarchy prioritizes waste management strategies in an order such as, reduce is the first and most preferred approach is to reduce the amount of waste generated in the first place. This involves minimizing waste production through practices such as product redesign, using less packaging, implementing efficient manufacturing processes, and encouraging sustainable consumption habits.

The stage 2 is to encourage the reuse of products and materials whenever possible. This involves finding new uses for items that would otherwise be discarded, such as repairing, refurbishing, or reusing the item. By extending the lifespan of products and materials, the amount of waste sent to landfills or incinerators can be significantly reduced. Recycling involves the collection, processing, and conversion of waste materials into new products or raw materials that can be used to manufacture new goods. Common recyclable materials include paper, glass, metal, and certain types of plastic. Recycling helps conserve natural resources, reduce energy consumption, and reduce pollution associated with the extraction and processing of raw materials.

The hierarchy of solid waste management prioritizes waste prevention through reduction, followed by reuse and recycling, as the most sustainable and environmentally preferable approach to managing waste. Meanwhile, the last stage is disposal to control the entry of solid waste into the landfill.

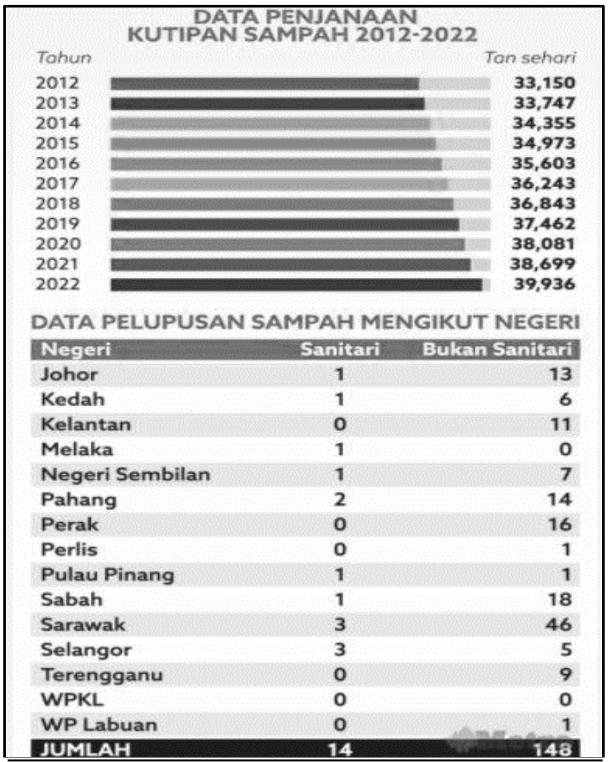
Waste Collection Statistics by Category January-June 2019, there are 7 categories of waste collected for recycling. Total Collected Volume refers to the number of recyclables collected in a certain period, usually measured in tons or kilograms. The highest waste in January-June 2019 was paper waste of 458 tons (43.1%) while the lowest waste was aluminium waste 3 tons (0.3%). Therefore, the total waste in January-June 2019 is 1063 tons (100.0%) through PERANGKAAN TERPILIH KPKT SEHINGGA 30 JUN 2019, (2019). The lack of solid waste landfill will lead to an increase in solid waste. This is because this solid waste cannot be managed systematically, moreover, this solid waste material is difficult to dispose. These types of Collected Materials include paper, cardboard, plastic, glass, metal, and sometimes electronic waste (e-waste). Each material may have its own collection statistics. These statistics are often collected and reported by municipal or government waste management agencies, environmental organizations, or research institutions.

Table 2.1

Statistics On Recyclable Waste Collection By Category January-June 2019

Type of Waste	Weight (Ton)	Percentage (%)
Plastic	314	29.5%
Paper	458	43.1%
Metal	134	12.6%
Aluminum	3	0.3%
Glass	103	9.7%
e-Waste	24	2.3%
Others	27	2.5%
Total	1063	100.0%

Table 2.1 contains waste generation and disposal data in Malaysia from 2012 to 2022. This table is divided into two main parts: "Waste Collection Generation Data 2012-2022" (Waste Collection Generation Data 2012-2022) and "Waste Disposal Data by State" (Waste Disposal Data by State).



Negeri	Sanitari	Bukan Sanitari
Johor	1	13
Kedah	1	6
Kelantan	0	11
Melaka	1	0
Negeri Sembilan	1	7
Pahang	2	14
Perak	0	16
Perlis	0	1
Pulau Pinang	1	1
Sabah	1	18
Sarawak	3	46
Selangor	3	5
Terengganu	0	9
WPKL	0	0
WP Labuan	0	1
JUMLAH	14	148

Figure 2.2 Data Penjanaan Kutipan Sampah 2012-2022 And Waste Disposal Data By State

This data reveals form Figure 2.2, the consistent increase in daily waste generation over the years. Starting from 33,150 tons per day in 2012, it continues to increase every year, reaching almost 40,000 tons per day by 2022. This upward trend indicates an increasing waste production, which can be attributed to population growth, urbanization and changes in consumption patterns. This shows that the waste management system in Malaysia is very weak. Malaysia has faced challenges with its waste management system, including issues related to inadequate infrastructure, inadequate recycling facilities, improper waste disposal practices and ineffective enforcement of regulations. These factors have contributed to environmental pollution, public health concerns, and natural habitat degradation. Some specific problems in Malaysia's waste management system include Limited Recycling Infrastructure.

Figure 2.2 also shows the data from 2012 to 2022 highlights a significant and consistent increase in daily waste generation. This growth can be attributed to several factors. As Malaysia's population increases, so does the amount of waste produce. Urban areas tend to generate more waste due to higher consumption rates and denser populations. With economic growth, consumption of goods and services increases, leading to more waste. Changes in lifestyle and consumer behaviours, such as increased use of disposable goods, contribute to higher waste generation.

This trend emphasizes the need to improve waste management strategies to cope with the increasing amount of waste. Effective waste management is essential to prevent environmental degradation, health hazards, and to promote sustainable development. Although efforts have been made to promote recycling, the infrastructure for the collection and processing of recyclables is still insufficient in many areas. Then illegal dumping contributes to this problem. Illegal dumping of waste, including hazardous materials, is a significant problem in Malaysia. This practice is not only harmful to the environment but also poses a health risk to nearby communities. Lack of public awareness, many Malaysians may not be fully aware of the importance of proper waste management practices, leading to littering and improper waste disposal. Waste collection is inefficient in some areas, waste collection services may be irregular or insufficient, leading to the accumulation of rubbish in public spaces.

Data on waste disposal by state in Figure 2.2 shows a significant reliance on non-sanitary landfills throughout Malaysia. Out of a total of 162 landfills, only 14 are sanitary, while the remaining 148 landfills are not sanitary. This distinction has several implications. Among them unclean landfills often lack appropriate containment measures, leading to potential leachate contamination of land and water resources, air pollution from uncontrolled discharges and general environmental degradation. Improperly managed waste disposal sites can pose serious health risks to nearby communities, including the spread of disease, unpleasant odor and the attraction of pests. Regulatory and Infrastructure Needs: The large number of non-sanitary sites indicates the need for a stronger regulatory framework and investment in waste management infrastructure to shift to cleaner and more environmentally friendly disposal methods.

States with High Unsanitary Sites: States such as Sarawak (46 unsanitary), Sabah (18 unsanitary), and Perak (16 unsanitary) have the highest number of unsanitary landfills. This may be due to the larger geographical area and possibly less stringent enforcement of waste management regulations. Concentration of Sanitary Sites: States such as Selangor (3 sanitary, 9 sanitary) and Sarawak (3 sanitary, 46 sanitary) show some efforts towards creating sanitary sites but still rely heavily on non-sanitary methods. Total Absence of Sanitary Sites: States such as Kelantan, Perak, Terengganu, WPKL and WP Labuan do not have sanitary landfills, highlighting the critical need for infrastructure development in these areas. Data on waste generation and disposal in Malaysia from 2012 to 2022 highlights the critical challenges faced in managing the increasing amount of waste and reliance on unsanitary landfills. Addressing this issue requires a multifaceted approach involving infrastructure development, regulatory enforcement, public participation and the use of innovative waste management solutions. By taking concerted action, Malaysia can improve its waste management practices, reduce its environmental impact and promote a sustainable future.

A field study was conducted by Ana López & Amaya Lobo, (2014) at a small landfill in Europe for waste from a construction and demolition (C&D) material recovery plant to assess liquid and gaseous emissions. The study involved characterizing materials, monitoring the quantity and composition of leachate and gas, and placing thermometers, piezometers, and sampling ports at waste points. Materials disposed of are mostly wood and concrete, with gypsum drywall less than 20% of the waste. Leachate contains common C&D contaminants, including ions and inorganic metals, which exceed previous literature values. Little net precipitation and recirculation of leachate to the landfill surface contribute to these higher concentrations. Unlike previous studies, no significant odor or landfill gas disturbances were detected. However, gas samples from the landfill inside revealed sulphate-reducing and methanogenic activities.

2.4 Physical and Chemical Properties of Plaster of Paris (POP)

According to J Tribillon , (2024) studies that the history name of Plaster of Paris (POP) had its origins from the fact that it was extensively mined from Montmartre in Paris district. However, its use before the industrial revolution have been found on the insides of pyramids. POP was beginning to be used in construction and by sculptors, surgeons observing its properties hit upon the idea of using it in orthopaedics. POP was early used in the medical field, where it was used to treat broken bones and malformations in the human spine using casting methods. However, the use of (POP) is growing with the progress of the world, where POP is also used in the manufacturing industry and construction. Because POP does not shrink or crack when dry, it is ideal for use as a casting mould in the production of artificial ceiling plaster and artwork. This is because POP has the advantage of being able to print a work in large quantities in a short period of time.

Plaster of Paris (POP) or Calcium Sulphate Hemihydrate is a white powder that will harden when reacted with water. The name POP comes from Montmartre in the Paris District where this material was first discovered and mined on a large scale through Britannica, (2019). POP is a white powder consisting of gypsum hemihydrate, which is derived from gypsum rock. POP exhibits excellent fire resistance, moldability and adhesion, making it suitable for casting moulds, building materials and medical castings. Gypsum, a versatile mineral with many types and uses, plays an important role in industries from construction to agriculture. The term "gypsum" includes several forms, each of which is distinguished by its chemical composition and specific characteristics. Natural gypsum comes from sedimentary deposits formed millions of years ago through the evaporation of seawater. It usually contains hydrated calcium sulfate, often seen in its crystalline form as selenite or satin spar. Natural gypsum serves as the main source for producing plaster and gypsum board, an important material in construction for its fire-resistant and insulating properties. the second is synthetic gypsum, produced as a byproduct of industrial processes such as flue gas desulfurization, offering an environmentally friendly alternative to natural gypsum. Its chemical composition is almost identical to natural gypsum, making it suitable for similar applications in construction and agriculture. Controlled production of synthetic gypsum ensures consistency in quality and purity.

The last is Plaster of Paris, a specialized form of gypsum POP, deriving its name from its historic use in the Paris region. This type of gypsum undergoes heating to remove the water content, creating a fine powder that, when mixed with water, forms a mouldable paste. POP finds applications in art, medicine and construction, where its ability to set quickly and retain shape makes it invaluable for creating casts, sculptures and architectural details.

In agriculture, gypsum works as a soil amendment to improve soil structure and fertility. By loosening heavy clay soils and increasing water infiltration, gypsum promotes root growth and nutrient uptake in plants. Its ability to reduce soil compaction and prevent crusting benefits crop yields, especially in arid regions where soil salinity poses a challenge to agriculture.

Additionally, recycled gypsum represents a sustainable approach to using waste materials from construction and demolition activities. Through processing and purification, recycled gypsum retains its essential properties, making it suitable for manufacturing new gypsum products while reducing landfill waste and conserving natural resources. The variety of forms and applications of gypsum emphasizes its importance in various industries. Whether as a basic material in construction, a soil conditioner in agriculture, or a sustainable resource through recycling, gypsum continues to contribute significantly to global development and sustainability efforts. Its versatility and beneficial properties ensure its enduring relevance in modern industrial and environmental practices.

Risdonne et.al., (2022) notice that mineral is quite pure, its colour is white. POP when properly prepared and in its purest form, usually exhibits a white colour. This characteristic colour stems from the mineral composition and manufacturing process used in its creation. POP chemically known as calcium sulphate hemihydrate, derives its colour primarily from the mineral calcium sulphate itself, which is naturally white or off-white in its pure state. During the production of POP, gypsum, a soft sulphate mineral composed of calcium sulphate dihydrate, undergoes heating to remove water molecules, turning it into calcium sulphate hemihydrate. This process is important because it changes the crystal structure of gypsum, creating a powdery substance that, when mixed with water and allowed to harden, hardens into plaster. The removal of water molecules and the subsequent hydration process affect the final colour of the plaster. The white colour characteristic of POP is important in various applications, especially in the art, medical and construction sectors. In art and sculpture, its white hue serves as an ideal canvas for paint and other artistic finishes, allowing artists to achieve vivid colours and intricate detail. Physicians use POP to cast broken bones because of its ability to harden quickly and form a strong yet lightweight protective layer around the injured limb. In construction, POP is used to create moulds, sculpt architectural details, and as a base for decorative finishes, benefiting from its smooth texture and ease of use. Furthermore, the white colour of POP increases its flexibility and compatibility with different additives and pigments. This feature allows customization in various industries, adapting to specific aesthetic and functional needs. For example, pigments can be added during the mixing process to create coloured plaster, which finds application in artistic endeavours and architectural design where a coloured finish is desired. Despite these variations, the white colour attached to POP remains the basic palette upon which such modifications and improvements are built.

The white colour of POP is the result of the mineral composition and the manufacturing process that involves the dehydration of gypsum. This characteristic colour not only defines its natural state but also supports its versatility and applicability across various industries. Whether used in art, medicine or construction, white POP serves as a basic material valued for the ease of use, strength and aesthetic possibilities it offers. Its enduring popularity and utility underscore the importance of its distinctive colour, making it fundamental in both creative expression and practical application around the world.

POP when added to water, become more soluble form of calcium sulphate returns to the relatively in soluble form, and heat is produced ($CaSO_4$. ½ H_2O) + $3H_2O$ ($CaSO_4.2H_2O$) + Heat. The setting of unmodified plaster starts about 10 min after mixing and is complete in about 45 min. Through Sharma & Prabu, (2013) POP is calcined gypsum (roasted gypsum), ground to a fine powder by milling. When water is added, the more soluble form of calcium sulphate returns to the relatively insoluble form, and heat is produced [2 ($CaSO_4$½ H_2O) + $3H_2O \rightarrow$ 2 ($CaSO_4.2H_2O$) + Heat]. The setting of unmodified plaster starts about 10 min after mixing and is complete in about 45 min, however, the cast is not fully dry for 72h.

Mixing POP should be consistency stirred with clean utensils that are free before plaster set harden. The optimum stirring time is dependent on the size of the batch and the dimension of the stirring device. POP will not be evenly mixed if it is not stirred long and if stirred too long the mixture become too thick. In both cases this has a negative effect on product characteristics. Longer stirring generally leads to great strength, reduced absorption capacity and shorter setting time. Plaster which is vacuum mixed has lower absorption capacity, reduced expansion, and increased strength. (Bill, 2010). The porosity of POP can significantly affect its performance in various applications. For example, in medical uses such as orthopaedic casts, the balance between porosity and strength is important to ensure proper ventilation and healing while maintaining structural integrity. In construction, plaster with optimal porosity ensures good adhesion to the surface and efficient drying, contributing to the durability of the structure. In this study as well, the POP porosity test is very important because at the end of the study, the POP need to test that has become a mould to absorb the water content in the slip.

POP and water mixed in proper proportion to create the mould utilized in ceramic industry. According by Ngaaje, (2021), the mould which is used for casting process in the ceramic industries is prepared by mixing POP and water in the correct proportion. Previous studies have reported by Vejmelková et.al., (2012), the best plaster moulds can be attributed to high strength and water absorption, however, the quality of the final product is directly determined by the quality of the plaster mould. Although the plaster mould plays an important role in the absorption of water through its capillary volume, it must have sufficient strength and accurate dimensions, as well as a smooth surface without bubbles and free cavities. While recycling the POP mould additives such as starch, lignosulphonates, potassium sulphate and detergents are used improve the bonding, crystal growth, flow ability of slurry and reduction of density of the mould. The most widely used blending process for POP is by preparation of the blending. The most widely used blending process for POP typically involves the preparation of the blending by combining the POP powder with water. This process, known as slaking, allows the POP powder to absorb the water and form a workable paste. The paste can then be mixed thoroughly to ensure uniformity before it's applied or moulded into the desired shape.

Through a study made by Chandara, Azizli, Zainal, Sakai (2009) the use of gypsum waste as an alternative to gypsum waste in the production of ordinary Portland cement gypsum waste is obtained from slip casting mould and ground into cement waste gypsum and cement native gypsum. The properties of natural gypsum and gypsum waste were evaluated using X-ray Diffraction (XRD), X-ray fluorescence

(XRF), and differential scanning calorimetry (DSC/TG). The results show that gypsum waste contains dihydrate and hemihydrate, while gypsum waste contains dihydrate and hemihydrate. Cement waste gypsum set faster than gypsum waste, averaging 15.29% and 13.67% faster for initial and final set times. However, the values for flexural and compressive strength are relatively the same for both materials. This shows that gypsum waste can be used as an alternative material to gypsum waste in the production of Portland cement.

During the blending process, it's essential to control variables such as the ratio of POP powder to water, mixing time, and mixing method to achieve the desired consistency and quality of the final product. Proper blending ensures that the POP paste sets correctly and forms a strong, durable material once it dries. Additionally, additives may sometimes be included in the blending process to enhance specific properties of the POP, such as setting time, strength, or workability. These additives can modify the characteristics of the final product to suit different applications, from construction to art and crafts.

Previous studies by Dunuwila, & Udayanga, (2023), POP recycling highlight the importance of factors such as calcination temperature, particle size, sample size, and POP to water ratio in determining final properties. The optimal calcination temperature is 180˚C with two hours of time. A mesh size of 125-500 µm is ideal, and a 1:1 POP to water ratio is recommended for optimal strength. Secondary materials like aluminium oxide can control strength reduction. Various chemicals can be used to create modern ceramic sculptures. The size of POP particles plays an important role in its use across various fields. In general, powders consist of particles ranging in size from micrometres to several millimetres. This range is important because it determines the material's ability to dissolve and mix uniformly with water during the mixing process. Finer particles, usually around 100 micrometres or less, allow for faster dissolution and a smoother consistency when preparing plaster mixes. This feature is particularly beneficial in medical applications such as orthopaedic casts, where smooth and fast setting is required to ensure patient comfort and efficient use.

POP is a material consisting of calcium sulphate hemihydrate which, when mixed with water, undergoes a chemical reaction to produce a firm calcium sulphate dihydrate. This process, known as hardening, involves significant heat exchange. POP is a material often used in the construction and medical industries to form plaster casts, medical tools, and models. When mixed with water, this process causes a chemical reaction that produces heat. When POP is mixed with water, the temperature of the liquid increases rapidly because an exothermic reaction occurs between calcium sulphate hemihydrate and water. This reaction produces calcium sulphate dihydrate, or gypsum, in the form of a thermal compound that produces a liquid temperature higher than room temperature.

This increase in temperature is due to the release of heat produced during agglomeration, which is an important property for the hardening process. At the beginning, the temperature of the mixture is gradually increased from room temperature. After a few minutes, the temperature of the liquid POP can rise significantly, possibly reaching 40-50 degrees celsius or higher, depending on the amount and temperature of the water used and the quantity of POP mixed. This process is known as an exothermic reaction, which occurs when a chemical reaction produces heat as a byproduct. The release of heat during the reaction of POP with water to generate gypsum is known as an exothermic reaction. Calcium Sulphate Hemihydrate ($CaSO_4 \cdot 0.5H_2O$) is the chemical formula for POP. When combined with water, it goes through a hydration process that produces gypsum, or calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$). The maximum temperature is usually reached in about 10-15 minutes after mixing, after which the temperature of the liquid may start to decrease again as the plaster hardens. This process is important in the processing of POP because it affects the usability and durability of the resulting plaster. Therefore, temperature control during use and application is important to ensure consistent results and good quality in the use of POP in various applications such as plastering and paving.

According to Dupire et al., (2023), in construction and art, the size of plaster particles affects the workability of the material and the final texture. The coarser particles, although still small, may range up to several millimetres in diameter. These larger particles provide a textured finish when mixed with water and applied to surfaces. Artists often manipulate these textures to sculpt or create detailed moulds. In construction, the particles contribute to the structural integrity of plaster when used as a coating or mould for architectural features.

The manufacturing process and quality control also affect the particle size distribution of the plaster. Modern production methods ensure consistency in particle size, which is essential to achieve predictable setting times and mechanical properties. Quality POP powder undergoes a screening and grinding process to achieve the desired particle size distribution, ensuring usability and performance across a wide range of applications.

Senff et al., (2018), also discussed about particle size of POP will give the affects to the porosity and absorption characteristics. Smaller particles tend to be more tightly packed, reducing porosity and increasing the strength and water resistance. This property is beneficial in medical castings and dental moulds, where durability and dimensional stability are paramount. On the other hand, larger particles can increase porosity, making them suitable for applications where breathability or surface texture is desired, such as in decorative finishes or certain types of art castings.

Understanding these size dynamics helps to optimize material properties, ensuring efficient handling, application and desired results across various fields of use. Therefore, the size of POP powder remains a fundamental consideration in its wide and varied applications throughout the world. POP also known as calcium sulphate hemihydrate, has a distinct crystalline structure that affects its mechanical qualities and behavior during setting and hardening. Its morphology consists of needle-like crystals generated when combined with water, a porous microstructure, crystal development, and a rough surface. Understanding this morphology is critical for determining its mechanical properties, such as compressive strength, setting time, and workability, as well as its performance in casting, construction, and art.

2.4.1 Physical Structure of Plaster of Paris (POP)

Physical tests are essential for assessing the quality and properties of Plaster of Paris, a versatile material widely used in various industries. These tests help determine its suitability for specific applications and ensure compliance with quality standards. Here are some common physical tests conducted on POP are test scanning electron microscopy (SEM).

An investigation conducted bySedon, (2019) identified the medium component in POP. The elements C, O, S, Ca, and Pb that are found in POP are concentrated, as indicated by the results of the composition analysis of elements in POP in Table 2.2. The surface C content is 11.64% on average. It was discovered that the contents of Si and Ca were, respectively, somewhat higher, at 8.10 and 8.32%. Of those, the O concentration was determined to be 69.20%, significantly greater than the other components, with the remaining elements being below 1%.

Table 2.2

Composition Analysis

Element	Weight %	Atomic %
C	6.67	11.64
O	52.79	69.20
Na	0.11	0.10
Al	0.54	0.42
Si	0.39	0.29
S	12.39	8.10
Ca	15.90	8.32
Sc	0.52	0.24
Ti	0.60	0.26
V	0.34	0.14
Ge	0.63	0.18
Rb	0.40	0.10
Y	0.74	0.17
Pd	0.15	0.03
Pt	0.70	0.08
Pb	7.15	0.72
Total	100	

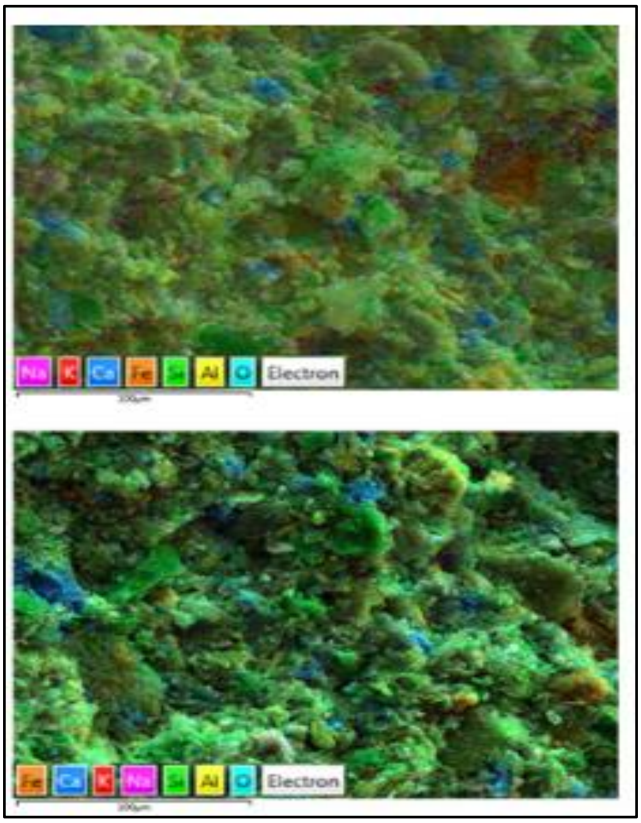


Figure 2.3 SEM Images For Ceramic Slurry Samples

SEM microscopy allows for more enhanced observation of the microstructure of ceramic slurry samples than mineralogical microscopy. The morphology of the sediments is dominated by larger quartz particles with a diameter of about 60 µm and rock facets with sharp edges due to new fractures and mullite particles with a size of about 75 µm and a rounded shape as shows as in Figure 2.3. The observed sizes are in good agreement. Larger particles are surrounded by fine formations ranging from 1 to 30 µm showing a lamellar-tabular aspect for kaolinite anda granular aspect for other minerals by investigate Avram, Tudoran, Borodi, (2024). Plaster of Paris (POP) is investigated in the study as a potential substitute medium for water-based screen-printing ink. The 'jigsaw puzzle' method is employed to investigate print properties such as consistency, workability, color densities, and impression quality. The results demonstrate that POP has special qualities that can produce opacity and brightness effects as well as have a great deal of aesthetic potential. SEM-EDS was used to analyze a polyolefin polymer's composition and identify its constituent parts. According to Sedon, (2019), the sample had an 11.64% C content, 8.10 and 8.32% Si and Ca contents, and 69.20% O content.

Recently, in vitro studies have shown that the use of calcium carbonate and plaster of Paris (POP) in conjunction to improve osteoconductive. According to in vitro testing, the composite material exhibits intriguing features as it minimizes the rate of cement deterioration and speeds up the production of new bone, making it a good option for bone grafting. The percentage of calcium carbonate added to the POP and properties of the final composition control cement biodegradation. The type of gypsum also affects the degradation of composite materials. Two types of gypsum, b-hemihydrate, and a-hemihydrate, differ in their reactivity with water and hydration product strength. A b-hemihydrate crystal framework with more important sites for water chemisorption can result in a faster degradation rate Anne et al., (2013).

The test of POP using scanning electron microscopy (SEM) can provide detailed information physical POP. The SEM works by scanning a sample with a focused beam of electrons, which interacts with the surface to produce various signals such as secondary electrons, backscattered electrons, and X-rays. These signals can be used to generate high-resolution images and elemental composition maps of the sample. SEM can reveal the internal structure of the plaster, including the arrangement of its crystals, porosity, and any defects present. This information is crucial for understanding its mechanical properties and performance. SEM images can show the surface features of the plaster, such as grain size, shape, and surface roughness. Elemental analysis using SEM-EDS (Energy Dispersive X-ray Spectroscopy) can determine the elemental composition of the plaster and identify any impurities or additives present. SEM can also be used to study how POP interacts with other materials, such as substrates or additives, which is important for optimizing its performance in various applications.

The morphological structure of POP and its compressive strength are very closely related since the material's microstructure and morphology have a direct influence on its mechanical properties, including compressive strength. This physical refers to the shape, size, and distribution of pores created during the hardening process. Meanwhile, the compressive strength of POP is determined by the density and compactness of the crystal structure as well as the pores. The size of pores in a material, such as POP, affects its compressive strength. Denser materials have higher compression strength, while fine crystals with small pores are stronger. Water mixing also affects porosity, density, and compressive strength. In short, a more compact and uniform structural morphology increases the compressive strength of Plaster of Paris, whereas a more porous and uneven morphology decreases it.

2.4.2 Compressive Strength POP

The compressive strength of POP can vary depending on factors such as the mix ratio, curing conditions, and the specific type of plaster used. POP is a type of gypsum plaster that hardens when mixed with water and then dries to a solid consistency. Increasing the flexural strength of plaster can be beneficial for various applications, especially in construction and design where durability and resilience are crucial. There are different methods to enhance flexural strength, such as modifying the composition of the plaster mix, incorporating reinforcing materials like fibers or mesh, or optimizing the curing process. Although the plaster strength increased dramatically on the first day and continued to rise on the third and fourth weeks, however according to the POP strength the results provided by Shan et al., (2014), the strength remains the same. After the eighth week, the plaster experiences a notable decline in flexural strength. This is when peak flexural strength appears. Flexural strength for room-cured plaster was steady throughout the first week before starting to rise and peaking in the eighth week. The decrease in plaster flexural strength after the eighth week can be attributable to a variety of material attributes and environmental interactions. Initially, plaster cured in the room goes through a phase of setting and hardening, during which the hydration of calcium sulphate hemihydrate (the major component of plaster) generates calcium sulphate dihydrate increases its strength. This hydration process stabilizes within the first week, establishing a firm foundation of flexural strength. As the curing process continues, the internal microstructure of the plaster becomes denser, resulting in a gradual increase in flexural strength. This process culminates around the eighth week, where the material reaches its maximum strength due to the formation of an optimal crystal structure and the completion of hydrated reactions. However, the plaster begins to experience a decrease in flexural strength due to several degradation mechanisms. One main reason is the ongoing carbonation process, where carbon dioxide from the air reacts with calcium compounds in the plaster, forming calcium carbonate. This process can lead to a reduction in the overall strength and durability of the plaster. Additionally, microcracks can develop over time due to thermal expansion and contraction, humidity variations, or mechanical stress, contributing to poor structural integrity.

Furthermore, external factors such as humidity and temperature fluctuations can accelerate the ageing process and alter the moisture content of the plaster, resulting in further deterioration. The combination of these factors resulted in a considerable loss in flexural strength after the eighth week, demonstrating that while the plaster originally acquired strength during curing, it was also subjected to a long-term deterioration process that reduced its overall durability.

According to the results that were found, it is very important to note that although the preservation is different time and environment affects the bending properties of plaster, such as compression tests, which materials still experience brittle failure. The difference in the plaster's bending strength across all samples evaluated in compression can be divided into multiple levels. Room cure samples only showed three stages, the stable stage, the slow strengthening stage, and the weak stage. This contrasts with four-stage compression samples. A recent study by Yammine et al., (2020) involved the first week of curing is the stable stage, which is followed by the weak stage starting in the eighth week and a gradual strengthening stage up until that point. There are four stages for oven-cured samples, like compression samples: a fast consolidation stage that lasts for the first three days, a stable stage that lasts until the fourth week, a slow strengthening stage that lasts for the next four weeks, and a weakened level at the end. The findings indicate that plaster dried in an oven exhibited a higher overall uniaxial compression strength than plaster left to cure at room temperature.

Increases in plaster's flexural strength can occur due to various factors such as changes in its composition, curing process, or reinforcement techniques. Adjustments in the mix design, including the ratio of water to plaster, additives, or fibers, can enhance its structural integrity. Additionally, optimizing the curing conditions, such as humidity and temperature, can lead to improved strength development. Esan, (2024) discussed incorporating reinforcement materials like fiberglass or synthetic fibers can also bolster the flexural strength of plaster, making it more resistant to bending and cracking. These enhancements are valuable in applications where plasters are subjected to significant loads or structural stresses. Increases in plaster's flexural strength can be attributed to several factors, including modifications in its composition, curing process, and reinforcement techniques. Adjustments in the mixed design, such as altering the water-to-plaster ratio, can significantly impact the plaster's mechanical properties. A lower water content typically leads to a denser and stronger matrix. At the same time, adding additives like plasticizers, retarders, or accelerators can optimize the setting time and workability, thereby enhancing strength. Incorporating fibers, such as glass, polypropylene, or natural fibers, can improve flexural strength by bridging cracks and distributing loads more evenly across the plaster matrix. Additionally, the curing process plays a crucial role; proper curing conditions, such as controlled temperature and humidity, ensure the plaster achieves its maximum potential strength. These combined factors result in a more robust and durable plaster with improved flexural strength, suitable for a variety of construction and artistic applications.

Distinct from the study findings attained by Auday and Al-Rawas, (2009), the results show that when plaster and water contents are increased during mixing, more pore water is created, which facilitates particle release and reduces coherence, which in turn lowers compressive strength. By conducting a particle size test, it can see the structure of the plaster content more deeply. The gypsum product's compressive strength increases with increasing particle size. The cause is that when particle sizes get large, the total surface area gets smaller, which results in less pore water and a higher compressive strength. Porosity and compressive strength are closely related. Less compressive strength results from increased porosity.

Gypsum products' compressive strength rises with greater particle sizes due to the link between particle size, surface area, and porosity. The overall surface area of gypsum particles reduces as their size increases. Because larger particles do not pack as firmly as smaller ones, the reduced surface area means that less pore water is trapped within the material. Consequently, the gypsum matrix has fewer pores and spaces, resulting in a denser and less porous structure. Porosity and compressive strength are inversely related, hence reducing porosity increases compressive strength. As a result, when particle size grows and total surface area falls, the gypsum product exhibits increased compressive strength due to decreased porosity and more. Therefore, as the particle size increases and the total surface area decreases, the gypsum product exhibits higher compressive strength due to the decreased porosity and more robust structural integrity. The reduced compaction strength is the result of increased porosity, while also increasing particle sliding, pore water content, and cohesion. It is commonly recognized that gypsum will react with a higher density and compressive strength if it contains bassanite, which is the highest content in the plaster mixture. Greater cohesiveness at high densities results in increased compressive strength Auday and Al-Rawas, (2009).

According to a study conducted by Al-Hadad, (2012) study plaster and stone are the materials used. He claims that the compressive strength of stone will rise when ratios of 1:3, 1:4, and 1:1 are used, while the compressive strength of stone and plaster ratios of 2:1, 3:1, and 4:1 has a compressive strength that is lower than a typical stone. This is because the dispersion of large and small rock crystals among larger plaster crystals may be the source of the poor increase in compressive strength. However, the compressive strength is reduced after a small amount of plaster is added to the stone powder at a stone to plaster ratio of 2:1, 3:1, and 4:1. This suggests that the plaster acts as an impurity, disrupting the structure of the fixing mass, and that the plaster particles impede the complete development and interweaving of crystals during fixation. Stone also consists of a blend of hemihydrates in varying sized and shaped grains. with variations in crystal shape and size influencing the amount of water required for mixing and, in turn, the set material's compressive strength. Thus, while building a full denture, a combination that is created with a stone to plaster ratio of 1:1 is probably the best to fill the upper half of the flask.

The relationship between compressive strength and porosity of plaster of Paris are important role for affecting the quality and performance of the plaster of Paris. Plaster of Paris with a high porosity has many air holes in its structure. This can diminish density and compressive strength because air spaces reduce the amount of solid material supporting the load. Compressive strength indicates how much pressure or weight the plaster can bear before breaking. Compressive strength normally declines with increasing porosity, because more voids mean less material can bear the load. In specific uses, like as construction or art, the balance of compressive strength and porosity must be considered. Plaster that is overly porous may be lighter but is unsuitable.

2.4.3 Porosity of POP

According to Freire, Veiga, Santos & Brito, (2019), the obtained and mercury intrusion porosimeter are used o calculate the pore size distribution. The quantity of pores with a radius of less than 0.3 mm is associated with the amount of calcite (air-carbonated lime). The similarity between the sample distribution curve's pore size and the crucial pore size of the primary peak of the differential distribution curve is another significant factor developing a tight relationship. There are extremely unique examples that share additional characteristics, such as the common objective of imitating stone-like materials, the significantly lower porosity compared to other gypsum-based plaster samples, and higher mechanical properties. By Bingöl, (2010), Calcium sulphate hemihydrate is the raw material used to make POP, which hardens into a solid very quickly when combined with water. Gypsum, a hardened form of calcium sulfate, can be produced by mixing partially hydrous forms of calcium sulfate powders with water. The process involves mixing 4g of POP with 2.4ml water to obtain gypsum. The conversion reaction is exothermic, and some POP may remain unreacted in the products.

Preliminary studies have used x-ray diffraction and scanning electron microscopy to analyze the morphological and chemical changes of gypsum products. The degree to which POP has minute holes or spaces throughout its composition is referred to as its porosity. The total strength, density, and absorption capabilities of the plaster can be impacted by these pores, which might differ in size and distribution. Depending on its intended purpose, POP porosity can be either desirable or undesired. For instance, a specific amount of porosity might facilitate the absorption of water or other fluids during the sculpting or mould-making process, assisting in the drying process and adding texture. On the other hand, too much porosity could weaken the plaster and increase its likelihood of cracking or crumbling.

Further analysis by Palhares, Galvão, and de Paiva, (2022) showed that when examining material morphology using Scanning Electron Microscopy (SEM), variations in the ratio of water to plaster can significantly affect the observed characteristics through Figure 2.4. In the context of plaster, which usually consists of gypsum and water, changing this ratio can affect the porosity, surface roughness and overall texture of the material. Increasing the ratio of water to plaster can lead to some changes in the structure of the material. More water in the mix can result in a higher volume of void space in the material. This increased porosity can create darker areas in SEM images due to the presence of more air or voids, which scatter or absorb electrons, leading to a reduction in signal intensity. A higher water content can affect the surface texture of the plaster, potentially leading to a rougher surface with more irregularities.

This variation in surface topography can also contribute to the appearance of darker areas in SEM images. Excess water can weaken the plaster matrix, leading to the formation of cracks or voids in the material. These defects can manifest as darker areas in SEM images due to their different electron scattering properties compared to the bulk material. Changing the ratio of water to plaster can also affect the composition of the material, potentially leading to the formation of different phases or chemical compounds. Variations in this composition can affect the contrast and appearance of features in SEM images.

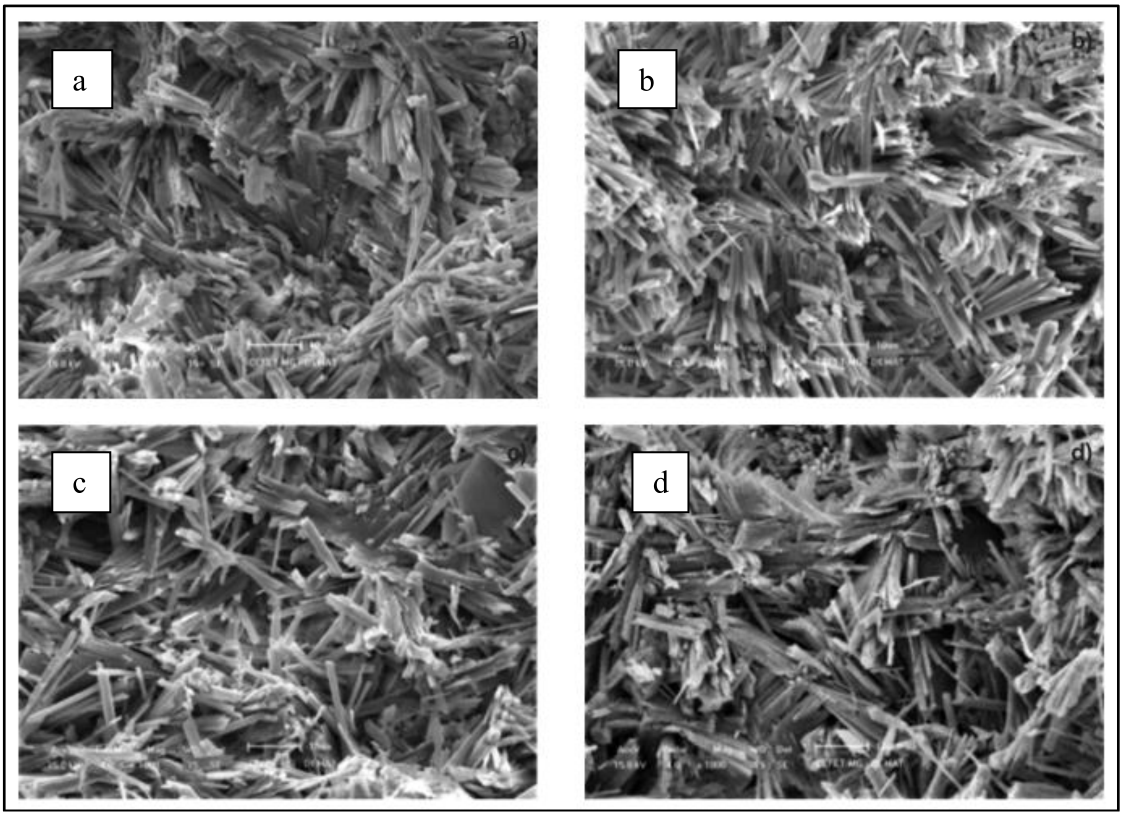
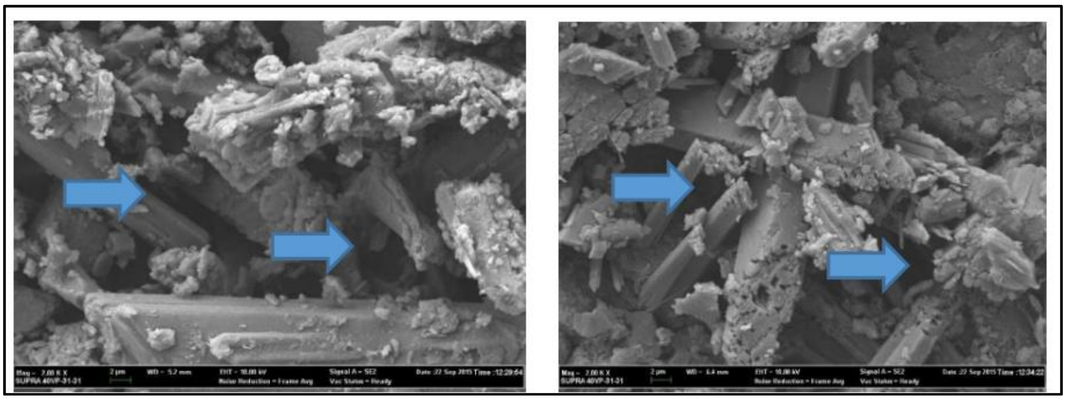


Figure 2.4 SEM Images Of POP In Variation Ratio

Overall, as the ratio of water to plaster increases, dark spaces observed in SEM images can correspond to areas of increased porosity, surface roughness, the presence of voids or cracks, or changes in composition in the plaster material. This change highlights the importance of controlling the water-to-plaster ratio to achieve desired material properties in applications such as construction, art restoration or biomedical modeling.

To distinguish between these two types of POP, Hafizan & Et al., (2017) has examined the SEM image of the morphology of the ratio of water and plaster in plaster A and B as shown in Figure 2.5. The results obtained from the test show that calcium sulfate crystals accumulate in needle structures, with dark spaces in between. This happens when the ratio of water and plaster increases and the dark space also increases, showing a linear relationship between water absorption and porosity. Calcium sulfate crystals can indeed form in a needle-like structure. This form of calcium sulfate is commonly known as gypsum. Gypsum crystals can vary in size and shape, but a needle-like or fibrous structure is one of the common morphologies that can be exhibited.



A B

Figure 2.5 Calcium Sulfate Crystals And Arrow Showing The Mould Porosity At 2000X Magnification

These crystals can be found in a variety of environments, including sedimentary rocks, caves, and soil. It is also used in industrial applications such as building materials and as a soil amendment in agriculture. Increasing the ratio of water to plaster in the mix usually results in a thinner, more fluid consistency. This increased fluidity can cause the plaster to settle differently, potentially creating more voids or bubbles in the material.

Testing the porosity of POP is important for various applications, especially in fields such as construction, art, and medicine. Porosity refers to the measure of void space in a material, indicating how much fluid (usually water or water) it can hold. The porosity of POP determines its suitability for absorbing liquids, adhesion to surfaces and strength in different applications. Conducting porosity tests on POP involves several methods, each with a specific purpose and providing valuable insight into its properties.

2.4.4 Absorption POP

Naji Kharouf et al., (2021) showed that the Polyphenol-tannic acid in plaster has two roles: strong binding to the plaster or combined in its structure, and a low fraction filling pores or weakly adsorbed on plaster surface particles. The latter remains available for release and biological applications. A larger fraction of polyphenol-tannic acid, about 50%, is released in water after 72 hours, independent of the initial polyphenol fraction. This indicates a stronger interaction between polyphenol-tannic acid and plaster than between pyrogallol and plaster. The release of polyphenol-tannic acid causes a slight decrease in pH in water in contact with the plaster mix and polyphenol-tannic acid, while the pH change is more limited when higher amounts of pyrogallol are released. Using inexpensive polyphenol-tannic acid (TA) or pyrogallol (PY) in combination with calcium sulfate for an environmentally friendly method to create bioactive plasters. PY has an antibacterial effect against Staphylococcus aureus which can multiply up to twenty times by changing the morphology of the plaster and releasing some of it. Compared to TA, PY had a greater correlation between clearance and antibacterial efficiency.

In another study, Anne Handrini Dewi et al., (2021) found that the incorporation of CaCO hydrogel into Plaster of Paris (POP) formulations to control the accumulation. Cinnamaldehyde, an anti-inflammatory agent with a unique α, β-unsaturated aldehyde, has been incorporated into CaCO hydrogels to improve their mechanical properties and resistance to heat, wear and solvent attack. Incorporation of CaCO hydrogel into Plaster of Paris (POP) formulations decreased the absorption rate of POP after deep implantation body. Dehydrothermal treatment (DHT) was applied to the hydrogen crosslinked system, and the results showed that cinnamaldehyde with DHT treatment improved the CaCO POP-hydrogel properties and biocompatibility, making it a promising bone substitute with anti-inflammatory properties.

To determine the effects of absorption POP, Eunice Salavessa et al., (2013) compared the three-layer system of historical plaster and stucco consists of a first layer with a greater capillary suction capacity, a second layer with a lower suction capacity and a third layer with better water collection. The highest water absorption coefficient is found in mortar with gypsum powder and marble. Floating Coat, which contains powdered limestone and marble, has a lower water absorption rate than Setting Coat and Rondelet's Stucco III. Floating Coat and Stucco II are suitable for the second coat, while Setting Coat and Rondelet's Stucco III are suitable for the third and final coat. The lowest coefficient of water absorption value is observed in Scagliola with cement-based glues and mortars such as Intonaco and Escaiola Cennini. The low rate of water exchange between layers facilitates water permeation, providing a decompression system. Resistance to water seepage is due to the use of limestone dust and marble dust.

For a study done by Hafizan et al., (2017) to explore two types of Gypsum plaster of unknown brand in terms of absorption properties and flexural strength. The results showed that a higher water-plaster ratio resulted in higher porosity and water absorption, regardless of the type of plaster. However, the water-plaster ratio is inversely correlated with flexural strength, indicating that some porosity must be sacrificed to increase strength. The water-plaster ratio, also known as the water-to-plaster ratio, is a critical factor in the process of creating a plaster mix. It refers to the proportion of water compared to the amount of plaster used in the mix. Achieving the correct water-plaster ratio is important to ensure proper consistency and workability of the plaster mix. Too much water can result in weak plaster that doesn't set properly, while too little water can make the mixture hard to work and can cause incomplete hydration of the plaster. The specific water-plaster ratio can vary depending on the type of plaster used and the characteristics of the final product desired. It is usually expressed as a weight ratio, such as 1:1 (equal parts water and plaster by weight) or 2:1 (two parts water to one part plaster by weight). For example, in the case of gypsum plaster, a typical ratio may be around 0.45 to 0.55 parts of water for every part of plaster by weight.

POP, when mixed with water, undergoes a chemical reaction that results in the formation of a hard substance. The amount of water absorbed by POP depends on various factors, including the porosity of the material, temperature, and relative humidity of the surrounding environment.

The water absorption test serves as an important determinant of the porosity and permeability of Plaster of Paris. Porosity refers to the volume of voids or pores in a material, while permeability refers to its ability to allow fluid to pass through it. Understanding these properties is important, especially in moisture resistance and durability is paramount.

2.5 Recycle Process Plaster of Paris (RPOP)

Geraldo, (2017) discussed the waste plaster recycling process can save environment and industrial use. The process starts by drying the waste plaster block under the sun to reduce the water in the block. Second step, crush in hammer mill and sieve using 0.297MM and oven the powder waste plaster 150 °C/1Hour = Gypsum plaster waste 1 and this process is repeatedly to get gypsum plaster waste 2 and so on. Although this process was performed repeatedly, the characteristics on the gypsum plaster waste did not change the properties, the gypsum plaster waste showed a smaller particle size than the commercial plaster. Therefore, the mechanical properties of hydrated products are better than commercial plasters and are suitable for use in building.

As reported by Ganesapillai, (2008), POP is a material produced by partially dehydrating gypsum, with its main component being calcium sulphate hemihydrate ($CaSO_4$ 1=$_2H_2O$). When dry plaster powder is combined with water, it generates gypsum as a paste that hardens into a solid and develops strength. At this stage, the heat energy provided to gypsum (heat of hydration) tends to push off water (as water vapour), rather than increasing the mineral's temperature. according to Jikan, Arshat, and Badarulzaman, (2013),POP and RPOP were ground at a speed of 230rpm for 10 minutes. Next, the POP sieved from 36 to 44 µm is used and dried at 70°C, 135–145°C, 165°C, 175°C and 170°C respectively and will undergo tests such as Melt Density and Melt Flow Index, Tensile Analysis, and Hardness test.

Gypsum rock was obtained, rinsed thoroughly with clean water, crushed into powder, and screened to remove bigger particles. To obtain POP, the powder was calcined in an electric burning kiln at 170°C. The colour of RPOP that has been dried, still retains the same white colour as NPOP. The process for manufacturing POP involves collection, selection, washing, drying, crushing, screening, calcination, and storage (Madu, 2016). According to De Moraes Rossetto & Gladis Camarini, (2016), RPOP is made from gypsum waste collected from local building construction sites. Recycle gypsum plaster (RGP) is dried and processed in a suitable machine, with 80% of passing particles size measuring less than 0.297mm.

Then, it is calcined at a constant temperature of 150°C for one, two, three, four, five, and six hours in a gypsum plaster cluster araripina kiln. Recycling gypsum plaster involves drying and processing it to achieve a fine particle size, with 80% of the particles measuring less than 0.297 mm. This fine particle size is crucial because it ensures a uniform and consistent material that can be effectively reprocessed. The drying step removes moisture, which is essential for efficient calcination. The finely ground gypsum plaster is then subjected to calcination, a thermal treatment process, in the gypsum plaster cluster araripina kiln. Calcination at a constant temperature of 150°C for varying durations—one, two, three, four, five, and six hours—ensures that the gypsum undergoes the necessary chemical transformations.

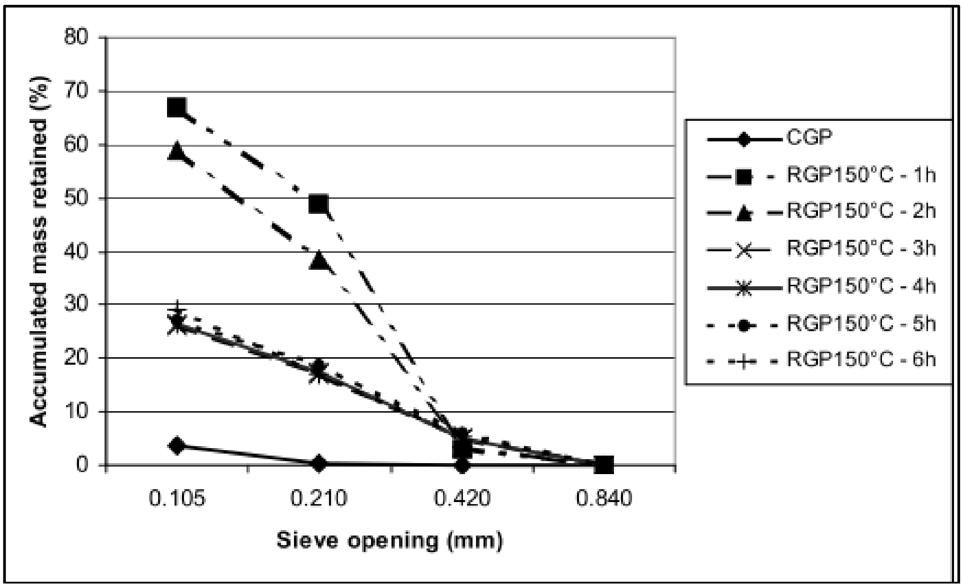


Figure 2.6 Sieve Analysis Of Passing Particles Size RGP

This controlled heating process removes any remaining water content and transforms the material into a usable form. By varying the calcination time, the process can be optimized to produce gypsum plaster with desired properties, such as setting time and strength, suitable for various applications. This systematic approach to recycling not only enhances the quality of the recycled product but also supports sustainable practices by reducing waste and conserving natural resources. Controlled heating in the plaster of Paris recycling process is an important step aimed at removing any residual water that may still be present in this used material. Plaster of Paris, which consists of calcium sulphate hemihydrate, often contains a small amount of water after use. When heated in a controlled manner, this material undergoes an important transformation in which the required temperature usually ranges from 150 to 180 degrees Celsius. At this temperature, air molecules trapped in the structure of the material can break free, gradually reducing the water content in the plaster.

In addition, this heating process also allows the calcium sulphate hemihydrate crystals to experience a return to their original, more stable form, which is calcium sulphate anhydrous. This modification causes the RPOP to be drier and more suitable for reuse. Although this process is also intended to remove air, it helps remove any additives or contaminants that may have been present in the previously applied plaster. The benefits of air reduction and removal of additives, the heating process is also important to ensure the stability and quality of the recycled material. This is because the controlled heating temperature and duration ensure that the POP is not exposed to excessively high temperatures that can cause or degrade the material. Thus, this process not only produces better materials in reuse but also ensures that the RPOP meets the performance standards required for various industrial and construction applications.

Detailed explanation and importance of each step for RPOP recycling, collection of used moulds is the first and fundamental step in this recycling process. It is important to collect moulds that are no longer usable in their current form but still contain plaster material that can be reused. An efficient collection strategy helps in collecting enough material for recycling, making the process economically viable. The crushing process is important because it breaks larger mould pieces into smaller, more manageable pieces. This increases the surface area of the material, which is beneficial for both the screening and drying stages. Crushing must be done carefully to avoid producing too much fine dust, which can be lost in the process and reduce the overall yield of recycled material. Sieving ensures that the crushed material is of a consistent size, which is important for the quality of the final recycled product. The mesh size is chosen to balance between removing larger, unusable particles and retaining a large amount of material for recycling. Uniform particle size helps in achieving consistent texture and performance in the final recycled plaster. Drying the sifted material in a controlled manner is probably one of the most important steps. The specified drying temperature and duration ensure that any moisture present in the plaster is thoroughly removed.

Moisture can significantly affect the properties of plaster, leading to issues such as reduced strength and poor setting characteristics. The gradual increase in temperature helps in preventing any thermal shock to the material, which might cause cracking or other forms of degradation. The result of this process is powdered recycled plaster of Paris, which can be used in a variety of applications just like new plaster of paris. POP recycling not only reduces waste but also provides an economically viable alternative to producing new plaster. Recycled plaster must be tested to ensure it meets the standards required for reuse, including strength, setting time and consistency.

As the application of POP as a mould product grows, POP trash contributes to the solid waste problem and has a negative influence on the environment. As a reported by Nawi and Badarulzaman (2015), has provided an alternative for recycling POP trash and assessing the feasibility of POP waste in ceramic pottery fabrication after considering POP's potential as a filler in ceramic processing. The solid POP mould is crushed with the jaws crusher to produce fractions of approximately 4mm in size. The coarse and fine fractions of POP waste are ground using a mono planet plant (Fritsch Pulverisette 6, Germany) at 230rpm for 10 minutes. Next, milling POP was carried out.

Using a 25 µm wet sieve size. The POP waste slurry is sieved with average particle size and dried at 160 °C for 12 hours. POP can usually be recycled several times before its properties deteriorate to the point where it can no longer be used. This limits the number of cycles that can go through before needing to be discarded.

Table 2.3

Example Calcination Drying On Recycle Plaster Of Paris

Year	Authors	Title	Temperatures
2010	Luqman K. Abidoye1 and R.A. Bello	Restoration of Compressive Strength of Recycled Gypsum Board Powder.	100°C for 20 minutes 100°C for 30 and 60 minutes
2010	Aly Ahmed, Keizo Ugai,Takeshi Kamei	Investigation of recycled gypsum in conjunction with waste plastic trays for ground improvement	130 °C to 160 °C
2012	Paulo Sérgio Bardella1, Gladis Camarini	Recycled Plaster: Physical and Mechanical Properties	150 °C (± 5 °C), 180 °C (± 5 °C) and 200 °C (± 5 °C) for a period of 24 hours
2013	S.S. Jikan, I. Mat Arshat and N.A. Badarulzaman	Melt Flow and Mechanical Properties of Polypropylene /Recycled Plaster of Paris	185°C for 30 minutes
2014	Gladis Camarini, a, Sayonara M. M. Pinheiro	Microstructure of recycled gypsum plaster by SEM	150 ºC for 1 hour
2015	Sayonara M. M. Pinheiro and Gladis Camarini	Characteristics of Gypsum Recycling in Different Cycles	150 ºC for 1 hour

2015	Magesh Ganesapillai, Iyyaswami Regupathi and Thanapalan Murugesan	Characterization and Process Optimization of Microwave Drying of Plaster of Paris	42°C by 300 s
2015	A Mat Nawi, N.A. Badarulzaman	Effect of Plaster of Paris Waste and Sintering Temperatures on Physical Properties of Pottery	160 °C for 12 hours.
2016	Gladis Camarini, Professor, Maria Clara Cavalini Pinto MSc, Aline Goulart de Moura	Effect of citric acid on properties of recycled gypsum plaster to building components	150 °C
2016	Rodrigo H. Geraldoa, Sayonara M. M. Pinheirob , Jefferson S. Silvac ,HeloysaM.C. Andradec , Jo Dweckd , Jardel P. Gonçalvese , Gladis Camarinia,	Gypsum plaster waste recycling: a potential environmental and industrial solution	1 hour 150 °C
2016	Jaqueline Rosalí de Moraes Rossetto, Lucas Santos Correia1, Rodrigo Henrique Geraldo, Gladis Camarini	Gypsum plaster waste recycling: analysis of calcination time	150 °C
2016	M.J. Madu, M.B. Ndaliman and B.Oche	Development of plaster of paris from gypsum deposit of north Eastern nigeria	170°C 18 hours
2018	Alexandre Erbs, André Nagalli,Vsévolod	Properties of recycled gypsum from gypsum plasterboards and commercial gypsum throughout	180 °C for 24 h

	Mymrin,Fernando Hermes Passig d, Karina Querne de Carvalho, Wellington Mazer	recycling cycles	
2018	Zhixin Li, Kaidong Xu, Jiahui Peng,Jina Wang, Xianwei Ma ,and Jishou Niu	Study on Hydration and Mechanical Property of Portland Cement-Blended Recycled Plaster Materials	180°C for 3 hours
2019	M.A. Pedre, Rojas,Flores-Colen, J. De Brito, C. Rodríguez-Li	Influence of the heating process on the use of gypsum wastes in plasters: Mechanical, thermal and environmental analysis.	3 hours at 150 °C
2020	Servas Shiyo, Jozef Nagels, Harold G. Shangali	Recycling of plaster of Paris	180°C for 2 hours

The Table 2.3 represents the evolution of lower to higher temperatures and time periods in the calcination investigation on recycled plaster. The major variables adjusted are temperature and time, which have an impact on qualities such as compressive strength and suitability for certain applications such as plaster of Paris repair. The purpose of this listed temperature from previews study is to determine the best conditions for restoring or improving the physical and mechanical properties of recycled gypsum or plaster products, hence contributing to their long-term utilisation.

Recycled plaster of Paris has significant environmental and economic benefits. It reduces the need for new raw materials, thereby conserving natural resources. In addition, it minimizes waste sent to landfills, helping to reduce environmental pollution. Economically, recycling can reduce costs associated with waste disposal and procurement of new materials, making it a cost-effective solution for industries that use POP. Along with growing awareness of environmental sustainability, initiatives to limit waste from construction materials such as plaster of Paris are becoming more significant. Plaster of Paris recycling is one of several projects that can help to reduce pollution and raw material use. In this attempt, the addition of activators to the recovered plaster of Paris mixture can assist in improved its mechanical qualities and durability, making it more competitive as a building material.

2.6 Activator in Recycle Plaster of Paris (POP)

Activator refers to has additional substances or additives mixed in to enhance its properties or modify its behaviours. The activator can serve various purposes, depending on the specific application. Here are some common types of activators in plasters and their purposes, Fiber activator such as glass or synthetic fibres can be added to plaster to increase its strength and durability. This is especially useful in applications where the plaster needs to resist cracking or impact. Next, latex activator can improve the flexibility and adhesion of plaster. This is often used in moulding and casting applications where a more flexible or adhesive material is needed. Retarders and accelerators, retarders slow down the setting time of plaster, giving more time for intricate moulding or casting. Accelerators, on the other hand, speed up the setting time, which can be useful in situations where a quick setting is desired. Some activators are included to improve the workability of plaster, making it easier to mix and apply. These activators might affect the consistency or viscosity of the plaster mixture. Pigments or colorants can be added to plaster to achieve specific colours, eliminating the need for painting after the plaster has set and water-repellent additives that make the plaster more water-resistant are useful in applications where exposure to moisture is a concern.

To make sure the recycle plaster working effective, plaster additive act as activator, which mean, additives need to be added into the RPOP mixture so that the potential as a filler in the RPOP row. Silubit G80 is an additive material that is suggested to be suitable mixed with RPOP. Silubit G80 is a deflocculant of paster. The plaster/water ratio can be increased using this additive without changing the plaster structure or pore characteristics. The mechanism of action of Silubit G80 were dependent on its surface activity. The additive has a deflocculant effect on the plaster, so the proportion of solid content in the plaster slip can be increases while maintaining the same processing consistency. However, research needs to be done on this additive to obtain the quantity that needs to be used into RPOP reported by Zschimmer & Schwarz, (2020).

According to Vidales-Barriguete, (2020) has made a study based on waste material that is plastic cable mixed with POP. The main purpose of this study is alternative to overcome the problem of moisture on the walls of buildings. The nature of plaster which easily absorbs water causes the walls of the building to be easily dampened and its quality to be easily damaged. This is because the quality of the walls of the building is very important to get the indoor air quality, comfort, and health of the occupants. Plastic cable was chosen as an additive because this material contributes to the cause of pollution due to its nature that is difficult to recycle, waterproof and lightweight as well as its good durability. Due to its waterproof nature, it is certain that if mixed with plaster most likely, water absorption will be able to be reduced. Some tests were going to see the properties of plaster with additive of plaster waste. The melting method applied to plastic cable and converted it into a small particle pallet to make it easier to mixed with plaster and easy to blend during mixing work.

It's essential to follow the manufacturer's guidelines and recommendations when using additive plasters, as the properties can vary based on the specific additives and their concentrations. The choice of additive depends on the intended use of the plaster and the desired characteristics of the final product. To improve the compressive strength and adhesive quality of Iraqi gypsum in binding and plastering projects, this study looked at the use of lime as a local material. After replacing the original material with lime for seven days, the study found a significant increase in both compressive strength and density, indicating the possibility of creating a commercially viable product in Iraq. Through Amer, Abbas, and Hussein, (2018) the compressive strength of 100% gypsum paste and gypsum-lime paste in varying percentages (10%), (20%), and 30%) as a weight-based partial replacement. The maximum strength, which complies with Iraqi requirements, is 3 MPa. Strength does not increase when lime is used instead of other materials, probably because of its low content. Stronger pastes with 20% and 30% lime, however, may result from the chemical reaction of gypsum and lime in water.

Incorporating activators into POP or RPOP can indeed create interesting reactions. POP, a gypsum-based material, can be reactivated with water to form a new mould or sculpture. Adding an activator can improve its properties or trigger a certain reaction. Table 2.4 shows some previous studies, which used activators into POP or RPOP to observe the reaction that would occur. Previous study used activators as materials to improve the physical appearance of RPOP or plaster.

Table 2.4

Some Works Add Mixtures On POP And RPOP

Year	Authors	Title	Activator/Additive
2006	Nadira A Hatim, Isam K. Al–Khayat & Mohammed A. Abdullah	Modification of gypsum products (Part I): physical and mechanical properties of adding some additives on different types of gypsum products	1. Gum arabic at concentration 2. Calcium Oxide at concentration 3. Ferric Oxide as pigment concentration
2011	Aly Ahmed, Keizo Ugai & Takeshi Kamei	Investigation of recycled gypsum in conjunction with waste plastic trays for ground improvement.	1. Waste plastic tray
2015	S. Z. M. NOR, R. ISMAIL & M. I. N. ISA	Porosity and strength properties of gypsum bonded investment using Terengganu local silica for copper alloys casting	1. Silica
2016	Prof. Karishma Sayyad, Mr. Adinath Bhagat, Mr. Nitin Chaugule, Mr. Amolsaratkar & Mr. Dhavan Umesh	Compressive strength of concrete Binderded with textile fibre waste and waste plaster of paris	1. Textile fibre waste 2. Cement 3. Waste plaster of paris
2016	Gladis Camarini & Professor Maria Clara Cavalini Pinto MSc	Effect of citric acid on properties of recycled gypsum plaster to building Components	1. Citric Acid
2018	Zhixin Li, Kaidong Xu, Jiahui Peng, Jina Wang, Xianwei Ma, and Jishou Niu	Study on Hydration and Mechanical Property of Portland Cement-Blended Recycled Plaster Materials	1. Cement Portland

2020	Ali A. Abbood, Ali F. Atshan & Ahmed S. D. AL-Ridha	Improvement of Local Gypsum Plaster Setting Time by the Combined Usage of (TGP) and (PVA) Additives.	1. Tree Glue Powder (TGP) 2. Polyvinyl Acetate (PVA)
2020	Avinash Singh and A Muniappan	Experimental investigation on the mechanical properties of wood sawdust and plaster of paris reinforced composite	1. Wood sawdust 2. Plaster of paris
2021	Naji Kharouf, Davide Mancino, Jihed Zghal, Sophie Helle, Hamdi Jmal, Marc Lenertz,Nathalie Viart,NadiaBahlouli,Florent Meyer,Youssef Haikel & Vincent Ball	Dual role of tannic acid and pyrogallol incorporated in plaster of Paris: Morphology modification and release for antimicrobial properties.	1. Tannic Acid 2. Pyrogallol
2021	Ngwe Nnoko Ngaaje	Physico-Mechanical Properties of Plaster of Paris (Gypsum Plaster) Reinforced with Paper Pulp	1. Paper pulp
2022	Farmizan Pirman & Asmahani Awang	Enhanced Mechanical Properties Plaster of	1. Rice husk fibers

The Table 2.4 presents a summary of studies on the use of various additives in plaster of Paris and recycled plaster of Paris. This illustrates various approaches to modifying plaster of Paris or recycled gypsum, with each study addressing a different goal of either increasing strength, sustainability or adaptation for specific uses. The use of natural and industrial waste reflects efforts towards sustainable development, with applications including construction, environmental management and industrial processes. This study highlights the exploration of natural and chemical additives to improve the properties of gypsum, making it more versatile for different applications and contributing to a better understanding of how various additives can change the physical and chemical properties of gypsum products.

Plaster of Paris is known for its porous nature, making it suitable for various applications such as sculptures, moulds, and medical castings. Its porosity is a result of the way it is produced and the properties of gypsum, its main component. When Plaster of Paris is mixed with water, it undergoes a chemical reaction, forming a dense matrix of gypsum crystals interspersed with pores. These pores give it its light properties and absorbent qualities, making it ideal for absorbing moisture and creating intricate details in moulds. The porosity of Plaster of Paris can be adjusted by controlling factors such as water-to-plaster ratio and curing time, allowing customization based on specific needs in different applications. POP pores will be closely related to absorption because it is a very important process when POP becomes mould. This is because in this study POP is used for cast products. Although, the old POP mould has been recycled into RPOP and has been mixed with other materials, it must be ensured that the RPOP mould can absorb perfectly.

Brachaczek, (2013), discussed the impact of cement and selected admixtures on the hydrophobicity of cured renovation plaster. The results show that hydrophobicity is primarily influenced by the weight of cement, redispersible polymer powder, air-entraining, and hydrophobing agents. Silicon-based water repellent admixtures have the most significant influence on the hydrophobicity of renovation plasters. A 0.6% addition of this admixture reduces the ceiling rise by 10%, meeting EN-998-1: 2012 requirements for CS II resistance category. Renovation plaster's functions are primarily due to its porosity and hydrophobic properties. In humidified walls, moisture doesn't reach the plaster's exterior coat, preventing it from blooming. Salt crystallizes within the plaster, storing in its pores, protecting buildings from damage. However, salt can break the hydrophobic barrier over time, so it's essential to use it with other materials like rendering coat and porous priming plaster.

Through study by AL-Ridha et al., (2022) investigates the impact of three additives, Polyvinyl Acetate (PVA), Tree Glue Powder (TGP), and Silica Fume (SF), on the setting time and compressive strength of Local Plaster of Paris (LPOP). The study aims to enhance both characteristics by adding each additive individually, dually, or triple addition. Eight LPOP mixtures were prepared based on the weighted content of the additives, with a water/plastic ratio of 0.5. The results show that adding each additive individually enhances one characteristic and decreases the other, while adding two additives dually significantly enhances one characteristic and mitigates the other. The study concludes that adding all three additives together provides the optimum enhancement for both characteristics, with 23.8% for compressive strength and 310.4% for setting time.

In another major study, Fatima, et al., (2023), found that the use of Plaster of Paris (PKD) kiln dust as a cost-effective and environmentally friendly material to stabilize the strength and potential of scattered soil in Khushab, Pakistan. PKD was added to the soil at different concentrations and tested at various curing times. The results showed that the DP decreased from 74.12% to 8.57%, and the unconfined compressive strength increased from 124.3 kPa to 1212.5 kPa (875% increase) by increasing PKD up to 3% after 60 days. X-ray diffraction and scanning electron microscopy showed the development of cementitious products (Calcium silicate hydrate and Calcium aluminate hydrate) due to pozzolanic reaction with 3% PKD after 28 days. PKD is economical and environmentally friendly, with the lowest cost among the additives used and a large part of the treated area free from pollution and landfills. It improves the stability and strength of dispersed soil and offers a sustainable waste management solution, making it a viable option for soil improvement applications in the construction industry.

Sodium Citrate is commonly used in plaster formulations to control setting time and improve workability. As a retarder, it helps in slowing down the setting process, which is particularly useful in various applications where extended working time is required to achieve the desired finish or to allow more complex work to be completed without hardening the plaster too quickly.

Sodium citrate ($Na_3C_6H_5O_7$), chemically known as trisodium citrate, is the sodium salt of citric acid. It appears as a white powder, crystalline powder or granular material and has a slightly salty taste. It is highly soluble in water and is commonly used in a variety of applications, from food and beverages to pharmaceuticals and industrial processes. Sodium citrate can be used in various sectors including the food, medical and pharmaceutical industries, and industry.

The most important thing is that this material can be used in industrial retarders in plaster. As mentioned, sodium citrate acts as an inhibitor in plaster formulations, prolonging the setting time and improving workability. Sodium citrate is generally recognized as safe when used in accordance with good manufacturing practices. Sodium citrate is a versatile compound with wide applications across different industries. Its ability to delay setting time in plasters, control acidity in foods, and stabilize pH in medical formulations makes it a valuable additive in many fields.

With the use of this material setting time is extended by delaying the setting process, sodium citrate provides more time to mix, spread, and finish the plaster, which is especially beneficial in large-scale projects or intricate detail work. Improved workability over extended working times allows for smoother application and finishing, reducing the likelihood of defects and improving the overall quality of the patched surface. However, it is important to accurately measure sodium citrate to ensure consistent performance. Excessive use may delay setting excessively, while underuse may not provide the desired retardation effect. Make sure sodium citrate is thoroughly mixed with plaster powder before adding water to achieve uniform distribution throughout the mix.

Potassium sulfate (K_2SO_4) is a chemical compound that serves as an important source of potassium and sulfur for various industrial and agricultural applications. In its pure form, potassium sulfate appears as a white crystalline powder or granular material. It is highly soluble in water, which makes it an excellent source of potassium. Interaction of Potassium Sulfate with RPOP. When potassium sulfate is mixed with RPOP, various chemical and physical interactions can occur, affecting both the properties and applications of the material.

The main components, K_2SO_4 and $CaSO_4{\cdot}0.5H_2O$, can interact to form various complex sulfates under certain conditions. The presence of water can lead to a hydration reaction where calcium sulfate hemihydrate turns into dihydrate ($CaSO_4{\cdot}2H_2O$). This process can be affected by the presence of potassium sulfate, which has the potential to modify the rate of hydration and the properties of the final set material. The inclusion of potassium sulfate may alter the setting time of plaster of Paris. Potassium ions can affect the nucleation and growth of gypsum crystals, potentially speeding up or slowing down the hardening process. The overall structural integrity of the mixture can be affected by the proportion of potassium sulfate. A small amount may increase the strength of the material, while an excessive amount may lead to a more brittle structure due to altered crystal formation. By carefully controlling the ratio of potassium sulfate to RPOP, the composite material can be tailored for specific applications, such as enhanced strength for building materials or modified setting time for artistic purposes. A mixture of potassium sulfate and RPOP presents interesting possibilities for industrial applications. Understanding the complex chemical and physical interactions between these materials enables the development of new composites with improved properties, contributing to sustainable practices and innovative uses in recycled mould manufacturing.

Through studies made by Aagli, et al., (2005), exploring the solubility of calcium sulfate in concentrated aqueous chloride solutions, which is important for chloride hydrometallurgy and crystallization processes such as the production of potassium sulfate from phosphogypsum and potassium chloride. It measures the solubility of phosphogypsum in Potassium chloride, hydrogen chloride, and mixtures at different temperatures and concentrations. Solubility increases with temperature but decreases with Potassium chloride concentration.

Borax, chemically known as sodium borate ($Na_2B_4O_7 \cdot 10H_2O$), is a natural mineral with unique properties. When incorporated into POP, Borax affects the crystallization process of calcium sulfate hemihydrate, which leads to changes in the material's setting time, hardness and durability. Borax, when dissolved in water, dissociates into sodium ions (Na^+) and borate ions ($B_4O_7^{2-}$). These ions can interact with calcium ions (Ca^{2+}) and sulfate ions (SO_4^{2-}) present in the solution, affecting the nucleation and growth of calcium sulfate dihydrate crystals. This interaction can slow down or speed up the setting process depending on the concentration of Borax.

The use of Borax in POP gives improved workability and setting time. At lower concentrations, Borax acts as a barrier, prolonging the setting time of POP. This is especially beneficial in applications that require more work time to shape or form the material, such as in artistic sculpture and detailed architectural elements. At higher concentrations, Borax can act as an accelerator, shortening the setting time. This is beneficial in construction scenarios where rapid hardening is required. The addition of Borax can increase the hardness and durability of the final product. The modified crystal structure resulting from the addition of Borax leads to a denser and denser matrix, which increases the mechanical strength of POP. Borax improves the adhesive properties of POP, making it more suitable for use as a binding agent in construction. Better adhesion ensures a better bond with the substrate, reducing the possibility of delamination or cracking.

One such additive is calcium oxide (CaO), commonly known as quicklime. Benefits of adding calcium oxide to POP, studying how it affects the properties of the material informs the composition and properties of POP. Calcium oxide, a strong alkaline compound, can significantly alter the properties of Plaster of Paris. When added to POP, calcium oxide undergoes hydration to form calcium hydroxide (Ca $(OH)_2$), a reaction that releases heat and changes the properties of the mixture. The incorporation of calcium oxide leads to the formation of calcium hydroxide, which then reacts with atmospheric carbon dioxide to form calcium carbonate ($CaCO_3$). This process, known as carbonation, increases the mechanical strength and durability of the plaster set. The formation of calcium carbonate fills pores and voids in the POP matrix, reducing porosity and increasing compressive strength.

POP are usually exposed to moisture, which can weaken the structure. Calcium oxide, through hydration and subsequent carbonation, reduces the water absorption of the plaster set. The presence of calcium carbonate in the hardened matrix results in a more waterproof material, making it suitable for applications in humid environments.

The exothermic reaction of calcium oxide with water can affect the thermal properties of POP. The heat generated during the hydration process can speed up the setting time, which may be beneficial in time-sensitive applications. In addition, the resulting calcium hydroxide can increase the thermal stability of the final product. The addition of calcium oxide to PPOP significantly improves its mechanical strength, water resistance, thermal properties and alkali resistance. These improvements expand the potential applications of POP across a wide range of fields, from construction and medical uses to art and industrial manufacturing. The synergy between POP and calcium oxide shows how traditional materials can be innovatively adapted to meet modern needs, ensuring their continued relevance and usefulness in contemporary applications.

2.7 Overview Plaster of Paris Application

POP a powdered substance derived from gypsum, has been used for centuries across a variety of domains, from art to medicine. The flexibility and ease of application make it indispensable in various contexts. This investigates the various applications of POP, highlighting its importance in artistic expression and medical intervention.

In the field of art, POP serves as a basic material for sculptors and artists. Its softness when mixed with water allows artists to create complex shapes with ease, capturing the nuances of human anatomy or the fluidity of abstract forms. From ancient civilizations to contemporary creators, POP has been a cornerstone of sculptural endeavours, immortalizing historical figures, religious icons, and personal visions. Moreover, its uses extend beyond the realm of sculpture. POP became the basis for various artistic techniques such as bas-relief, where an image is carved into a flat surface, adding depth and dimension to a painting or architectural element. The ability to cast replicas of objects or body parts further emphasizes their importance in art restoration, educational models, and theatrical props, where accuracy and detail are paramount.

In medicine, POP emerged as an important tool for orthopaedic interventions and wound management. Its unique properties, including rapid fixation and excellent moldability, make it ideal for creating orthopaedic casts to immobilize and support broken bones during the healing process. This application not only facilitates bone alignment but also improves patient comfort and mobility, promoting faster recovery. In addition, POP finds use in prosthetic and orthotic devices, providing customized solutions for individuals with limb deformities or deformities. By forming a plaster cast directly to the patient's body, doctors can tailor prostheses and orthoses to meet specific anatomical needs, ensuring optimal function and comfort for the wearer.

Outside of orthopaedics, POP plays an important role in wound care, especially in the form of plaster bandages. This bandage, impregnated with POP, conforms to the contours of the body when moistened, creating a rigid and protective shell over a wound or injury. This not only immobilizes the affected area but also promotes tissue healing and prevents further trauma, making it indispensable in the treatment of fractures, burns and ulcers. POP is not only used to make mould casting but there are several ways of using POP that have been produced to produce art. In addition, POP is a versatile material that can be utilised in a wide range of applications, including manufacturing and medicine. POP is a versatile material commonly used in a variety of arts and crafts projects due to its ease of use, affordability, and ability to capture fine details.

2.7.1.1 Mould Application

Ceramic art refers to any art made from materials such as clay, ceramic, porcelain, or other similar materials that are shaped, fired, and often glazed to create a variety of forms, from functional objects such as pottery and tableware to purely decorative sculptures and installations -eyes. It also covers a variety of techniques, including hand-built techniques (coil, slab, and pinch techniques), wheel throwing, moulding, and carving. Although POP is not traditionally considered a ceramic material like clay, it can still be used in artistic endeavours to create sculptures and other art forms. However, it is important to note that POP differs significantly from ceramic materials such as clay or porcelain in terms of properties and firing techniques. POP is a gypsum-based material that hardens when mixed with water, but it does not undergo the same burning process as ceramics. Instead, it is set through a hydration process. Although it can be carved and shaped like clay, it does not have the same durability or heat resistance as fired ceramics. POP is widely used to create moulds, casts and prototypes in sculpting and casting processes. It can be used as a medium to create detailed sculptures, decorative objects, and even relief sculptures. However, artwork made from POP is generally not suitable for outdoor use or areas with high humidity due to its relatively fragile nature compared to fired ceramics.

A ceramic mould is an important component in the production of ceramic objects, providing a shape and structure into which molten or liquid ceramic material is poured or pressed. These moulds come in many varieties, each designed to suit a specific manufacturing technique and desired result in ceramic production.

One of the main reasons for observing the mould surface after casting is to ensure that the mould can produce components with the desired surface finish. The surface finish of cast products is important for their aesthetic appeal, functionality and suitability for further processing. Smooth and defect-free surfaces minimize the need for additional machining and finishing operations, thus reducing production costs and time. By carefully inspecting the surface of the mould, the manufacturer can detect any irregularities, such as roughness, dents or inclusions of foreign material, which may be imprinted on the cast product. Early detection of such issues allows for timely corrective action, such as mould polishing or re-whitening, ensuring that subsequent castings meet the required specifications.

Another important aspect of surface observation is defect detection and analysis. Common defects observed on mould surfaces after casting include porosity, cracking, warping and surface oxidation. Porosity, characterized by small holes or voids in the mould, can occur due to trapped gas or improper filling of the mould. These voids can lead to weak points in the final product, compromising its structural integrity. Cracks on the mould surface may be caused by thermal stress or mechanical damage during the casting process. Such defects can propagate into the cast product, leading to premature failure under load. Warping, or distortion of the shape of the mould, can affect the dimensional accuracy of the cast product, making it unsuitable for its intended use. Surface oxidation, often resulting from exposure to high temperatures, can cause a poor surface finish and reduce corrosion resistance in the final product.

The thermal characteristics of the mould during and after casting also play an important role in the surface observation process. The thermal history of the mould, including temperature distribution and cooling rate, can significantly affect the quality of the cast product. Non-uniform cooling can cause thermal stress, causing cracking and warping. Therefore, thermal imaging and temperature monitoring tools are often used during the surface observation process to ensure uniform cooling and identify any thermal anomalies. These tools help in maintaining optimal casting conditions and prevent defects related to thermal stress. In addition to defect detection and thermal analysis, the overall condition of the mould is evaluated during surface observation. This includes checking for signs of wear and tear, such as erosion, abrasion and chemical attack. Erosion and abrasion can be caused by the repeated flow of molten metal, gradually wearing away the surface of the mould. Chemical attack, often caused by reactive elements in the molten metal, can degrade the mould material, affecting its durability and performance. Regular inspection of the mould surface helps in identifying such issues early, enabling preventive maintenance and prolonging the service life of the mould.

The methodology used for surface observation of the mould after casting varies depending on the specific requirements and complexity of the mould. Visual inspection is the simplest method, where the surface of the mould is inspected with the naked eye or with the help of a magnifying device. This method is suitable for detecting obvious defects, such as cracks and warping.

Observation of the mould surface after casting is a critical process that ensures the quality and integrity of the cast product. It involves a thorough inspection of the mould surface for defects, thermal characteristics, and overall condition. The methodology used ranges from visual inspection to advanced non-destructive testing techniques, providing a detailed view of the mould condition. The information gained from this process is essential for continuous improvement, enabling manufacturers to consistently produce high-quality cast components. By prioritizing surface observation and mould maintenance, manufacturers can improve product quality, reduce production costs, and achieve higher efficiency in the casting process.

One of the most common types of ceramic moulds is the plaster mould. A plaster mould is created by pouring liquid plaster of Paris into a mould box containing a model of the desired ceramic shape. When the plaster sets, it forms a rigid absorbent material that can withstand the heat of the molten ceramic. Plaster moulds are preferred for their ability to reproduce intricate details from models and for their ease of use in both slip casting and compression moulding processes. In slip casting, molten clay (slip) is poured into a plaster mould, which absorbs water from the slip, leaving a layer of solid clay on the mould wall when the excess slip is poured. In press moulding, clay is pressed into a plaster mould, forming a solid ceramic piece when removed.

While, the master mould, also known as the master mould in British English, is an important component in the manufacture and production of various goods, especially in industries such as sculpture, ceramics, jewellery making, and in industrial contexts such as metal casting and plastic moulding. It serves as the master template or pattern from which multiple copies, replicas or transmissions are derived. Basically, a master mould is an original shape or model carefully designed by a master craftsman or using advanced digital design techniques. Its creation requires precision and attention to detail because the quality and accuracy of subsequent reproduction directly depend on it. In artisanal practice, the master mould may be carved by hand from materials such as clay or wax, embodying the artistic vision of its creator. In contrast, in modern industrial processes, master moulds can be created using Computer Aided Design (CAD) software and then manufactured using 3D printing technology, ensuring accurate dimensions and specifications.

Once the master mould is finalized, it serves as the basis for making moulds used in mass production or replication. These moulds are usually made of materials such as silicone rubber, plaster or metal, depending on the intended use and the properties required for the final product. The process of creating this secondary mould involves carefully wrapping the master mould, making sure it faithfully captures every detail and contour. This replication process may involve multiple stages, especially in complex designs where intricate features must be precisely transferred. The importance of the master mould lies not only in its role as a blueprint for reproduction but also in its capacity to preserve and maintain artistic or functional excellence. In art and sculpture, for example, master moulds ensure that the artist's original creations can be faithfully reproduced without losing the essence of their craftsmanship. For industrial applications, master moulds streamline the production process by standardizing design and specifications, thereby ensuring consistency and quality across manufactured goods. In addition, master moulds play an important role in preserving heritage and cultural artifacts. Museums and restoration efforts often rely on master moulds to recreate damaged or damaged pieces with historical accuracy. By faithfully reproducing these artifacts, master moulds contribute to the preservation and dissemination of cultural heritage for future generations.

Review by Saha,Tomkowska, Martusewicz & Sitnik, (2023), Plaster mould making is a traditional yet indispensable technique in many fields, including art, sculpture, ceramics, and industrial manufacturing. It involves creating a negative impression of the original object, which is then used to create a replica. Plaster moulds consist of negative impressions formed around the original object, allowing the reproduction of intricate details. This process usually begins with the selection of a suitable original object, which can be carved from clay, carved from wood, or made from other materials. The surface of the original object is prepared, ensuring it is clean and free of imperfections. Beginning with slightly deteriorated mould fragments, the procedure culminates in three distinct forms of genuine Venus’s figurines: bisque-kilned porcelain, glazed porcelain, and faience. Understanding outdated production techniques, conservation oversight, and cutting-edge 3D scanning, data processing, and 3D printing technologies are all necessary for the full process. A technical examination of the mould's state of degradation is part of the preservation state evaluation. The structured light approach is used to apply 3D scanning technology, and all mould fragments are incorporated into the front and rear 3D models. The mould is made using these models, which are tailored for 3D printing. The printed fragments are corrected using conventional methods by art conservators, yielding a more realistic outcome.

In 2014, Harona & Narimahreport, the mould release agent (industrial soap) is used to prevent the plaster from sticking to the original object. This step is important to ensure that the mould is easy to remove later. After the release agent has dried, the plaster mixture is poured. Plaster, usually gypsum-based, is mixed with water to form a slurry of the desired consistency. The plaster slurry is then poured or brushed onto the surface of the original object, gradually building up the layer to reach the desired thickness. After the plaster has set perfectly, the mould is carefully removed from the original object. There are several types of plaster moulds, each suitable for different applications and production needs. One common type is a waste mould, where the mould is destroyed or "lost" in the process of removing the cast object. Waste moulds are suitable for one-time use or for casting objects with complex shapes that are difficult to demolish without damaging the mould.

Another type is a sheet mould, which consists of multiple parts that can be assembled and opened to produce a cast object. Sheet moulds are often used to cast objects with undercuts or intricate details that would be challenging to reproduce with a one-piece mould. By Olsen, (2019) reported there are flexible moulds made from materials such as silicone or latex, which can be stretched or peeled away from the cast object, allowing for easy removal. Flexible moulds are ideal for casting objects with irregular shapes or fine details. Plaster mould making finds application across various industries and art disciplines. In the field of sculpture, plaster casts allow artists to reproduce their original creations. In ceramics, plaster moulds are used to mass produce pottery and porcelain items such as plates, bowls, and vases. Moulds allow ceramists to reproduce their designs with consistency and precision, producing a uniform product suitable for commercial distribution. In industrial manufacturing, plaster moulds are used in processes such as investment casting, where molten metal is poured into a plaster mould to produce high-precision metal parts. This technique is used in the aerospace, automotive and jewellery industries, among others, to create complex components with fine detail and dimensional accuracy. Plaster mould making is a versatile and time-honoured technique that combines artistic creativity with scientific precision. From sculpture and ceramics to industrial manufacturing, plaster moulds play an important role in the production of objects with intricate details and complex shapes.

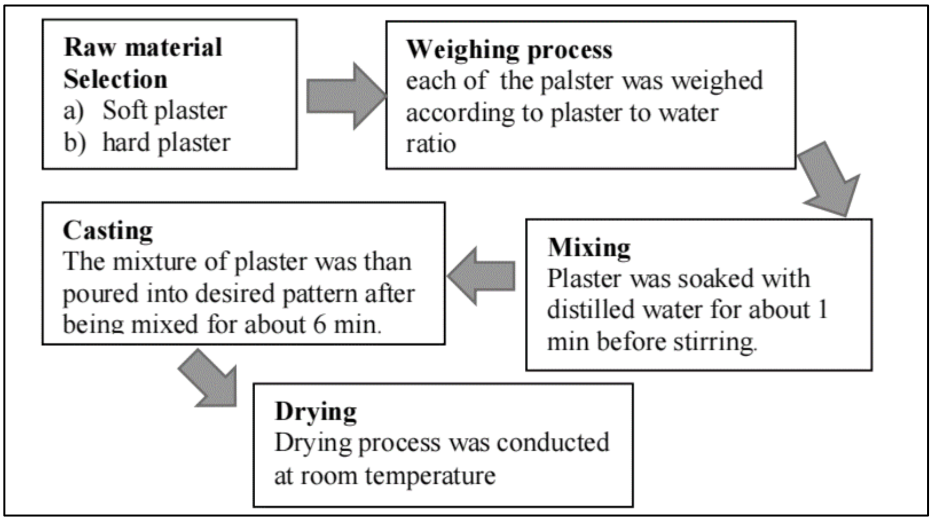


Figure 2.7 Process Flow Of Mould Making

In the realm of art, moulding serves as a cornerstone technique for sculptors, ceramists, and craftsmen seeking to replicate and manipulate forms with precision and efficiency. The process involves creating a negative impression, or mould, of an original object or design, typically using materials such as plaster, silicone, or rubber. This mould then serves as a template for casting, allowing researcher to reproduce multiple copies of their creations with fidelity and consistency. Mould is a technique used to generate a smooth surface on ceramic product. Using this technique, details that are difficult and more accurate in measurements can be made properly and correctly. In addition, the use of this technique can produce products quickly and in large quantities and can maintain product quality. Through the Themetalcasting, (2022), to produce a slurry, gypsum or calcium sulphate plaster is mixed with talc, asbestos, sand, sodium silicate, and water. The slurry is applied on the pattern pieces' surfaces. show the overall process flow of mould casting as study by Hafizan, (2017). There are two types of plaster that are used and have different ratio soft plaster and hard plaster with consistency of 1:1.3 and 1:2.33 of water to plaster ratio respectively. Before pouring into a mould, plaster powder will be left soaking in water for 1-2 minutes before mixing for 5-7 minutes using a speed of 300 - 500 rpm.

Waste moulds are single-use moulds that are specifically developed for applications where the object being cast is complex or where the mould itself may be damaged during the demoulding process. These moulds are especially useful for making intricate designs that are difficult to recreate with regular, reusable moulds. The fundamental advantage of waste moulds is that they are disposable, eliminating the need to preserve the mould's integrity after casting (Brooks, (2013). This feature is critical when working with elaborate or delicate designs since it allows for greater freedom and creativity in the casting process without compromising the mould's duration.

One of the most notable advantages of waste moulds is their capacity to capture little details and elaborate patterns. Waste moulds, which are designed for single use, can be produced from materials that are good at reproducing minute features but may not take the stress of repeated use. Materials such as plaster, silicone, and even some types of wax can be utilised to make highly detailed waste moulds. These materials are frequently simple to work with, allowing artists and manufacturers to create very accurate and sophisticated designs that would be impossible to achieve using more durable but less flexible mould materials. Through Risdonne, Hubbard, Borges, & Theodorakopoulos, (2022), wax moulds were used to create impressions of metal, wood, stone, or plaster models for reference purposes. The article offers four wax mould recipes and suggests using one part rosin and three parts white wax. Alternatively, melt paraffin wax and add sweet oil and whiting.

Aside from aptitude for precise work, waste moulds are perfect for tasks where the casting material itself may damage a regular mould. For example, certain resins, concretes, or metals used in casting can stick to mould surfaces, making it difficult to remove the finished product without harming the mould. In such instances, the ability to break away from the mould without worrying about its reuse is a big advantage. This is especially important in industrial applications where precision and detail are essential, and the cost of creating a new mould for each cast is justified by the quality of the finished product.

Another key aspect is the ease of demoulding. Waste moulds make the demoulding process easier because they are designed to break or peel away from the cast product. According to Afonso et al., (2019), this is particularly useful when casting things with undercuts, sharp angles, or complex geometries that would be difficult to release from a reusable mould without causing damage to both the mould and the cast object. Manufacturers can use a waste mould to ensure that the finished product is removed safely and intact, retaining the complex features and general integrity of the cast piece.

In conclusion, waste moulds are an important tool for one-time use or casting products with complex shapes that are difficult to remove without harming the mould. Their capacity to capture fine details, accommodate difficult casting materials, simplify the demoulding process, and provide possible cost savings makes them a key component in a variety of artistic, industrial, and manufacturing applications. Waste moulds enable the manufacture of detailed and high-quality cast objects, opening us new avenues for invention and creativity in the field of casting and mould making.

2.7.1.2 Plaster of Paris Modelling

Moulding with POP is an age-old technique that marries scientific precision with creative expression. Whether crafting intricate sculptures or replicating everyday objects, understanding the models and methods behind mould-making is essential for achieving flawless results. Plaster modelling refers to the process of creating three-dimensional forms or sculptures using plaster as the primary material. Making a model mould with POP involves several different steps. First, a prototype or original model is created using a suitable material such as clay or wax. Once the prototype is ready, it is put into a container or frame to make a mould. A release agent is used to prevent the plaster from sticking to the prototype. Next, the POP mixture is prepared and poured into the mould, allowed to set, and carefully removed after curing. The resulting plaster mould faithfully replicates the original model, ready to be used for replica casting. Achieving high quality model moulds requires attention to detail and precision. Properly sealing the prototype and ensuring thorough coverage with the plaster mix is important to prevent leakage and ensure a smooth surface finish. Additionally, incorporating vents and pour nozzles into the mould design eases the casting process by allowing air to escape and ensuring even distribution of the casting material.

The art of making model moulds with POP offers endless creative possibilities. Artists and artisans use this technique to replicate intricate sculptures, architectural details, and decorative objects with incredible precision. Model moulds can also be used in industrial applications, such as prototyping and manufacturing, where exact duplication is required. Plaster is a versatile and commonly used material for sculpting due to its ease of use, affordability, and ability to capture fine details. The challenge with modelling in plaster is the limited amount of time available. Plaster can be shaped directly at a certain point of the setting curve, before it runs off and after it hardens up, however, this only lasts a few minutes. After that, carving takes precedence over modelling. This is easiest when the plaster is still warm from setting and becomes increasingly difficult as it solidifies explanation by Andrew Werby, (2024).

Figure 2.8 Example Of Modelling Product Using Plaster Of Paris

Through Pratt, (2019), Plaster of Paris is unparalleled in the moulding and casting industries. Its thin texture allows it to record even the smallest details, making it ideal for manufacturing moulds of objects, body parts, and sculptures. Once the plaster mould has hardened, it can be utilised to create several reproductions of the original object. This technique is extremely useful for creating decorative things, theatre props, and even archaeological reconstructions. For example, museums frequently employ plaster casts to create reproductions of historic artefacts that can be shown while the originals are preserved. In addition to its aesthetic applications, Plaster of Paris serves a practical purpose in various crafts. It is often used to create prototypes and models in fields such as architecture and engineering. Its ability to accurately replicate designs makes it invaluable for creating detailed architectural models and industrial prototypes. These models can then be used for presentation, educational purposes, or further refinement of the design.

2.7.1.3 Art Craft

Ceramic art craft encompasses numerous techniques, styles, and traditions, each with its own distinct qualities and historical value. Ceramics, one of the oldest human crafts, is the process of making items out of clay and other raw materials and then firing them at high temperatures to obtain desirable attributes like hardness, durability, and, in some cases, translucence. Ceramic art craft is divided into several categories, including pottery, porcelain, stoneware, earthenware, terracotta, and modern ceramic sculpture. Each variety has unique means of creation, as well as cultural and functional contexts.

Pottery is possibly the best-known type of ceramic art. It entails sculpting clay into practical or beautiful pieces such as bowls, vases, and plates. There are three major types of pottery: earthenware, stoneware, and porcelain. Earthenware is fired at relatively low temperatures, producing a porous and soft material. It is frequently glazed to make it waterproof and more durable. Stoneware is burned at greater temperatures, which makes it denser, more robust, and often waterproof even without a glaze. Porcelain, the most refined variety, is burned at extremely high temperatures. It is distinguished by its white, transparent look and tremendous strength. Making pottery comprises numerous steps: preparing the clay, shaping the piece (by hand-building, wheel-throwing, or slip casting), drying, bisque fire, glazing, and ultimately, glaze.

One of the main uses of Plaster of Paris in arts and crafts is in sculpture. Artists appreciate its ability to capture fine details, making it ideal for creating intricate designs and realistic textures. To work with Plaster of Paris, artists usually mix the powder with water to form a paste, which can then be poured into a mould or applied directly to the surface. Mixes are set quickly, usually within minutes, allowing for rapid progression in the creation process. This fast-changing nature, however, requires artists to work quickly and efficiently.

Contemporary ceramic sculpture has expanded the boundaries of traditional ceramic arts, incorporating modern techniques and materials to create innovative and often abstract works. Artists in this field explore the limits of the medium, using advanced firing techniques, mixed media, and experimental forms. The process can be highly complex, involving multiple firings, mixed materials, and intricate construction methods. Contemporary ceramic sculpture often challenges conventional notions of ceramics as purely functional or decorative, positioning itself firmly within the realm of fine art. According to the understanding said by Gui, R. (2019), ceramic sculpture is an art form that combines earth and fire, using clay or porcelain clay to create a three-dimensional image. Firing at high temperatures affects the shape, scale and stability of the sculpture. Modern ceramic artists continue to use this technique, combining technology and art to create colorful and dynamic ceramic sculptures that break through traditional forms. It is manufactured from gypsum, a naturally occurring mineral that is ground into a fine powder before being blended with water to form a paste that hardens when dry. POP is a versatile material often used in art and craft projects due to its ease of use and ability to create detailed sculptures and moulds. POP crafts are popular in the realm of do-it-yourself (DIY) and art projects due to the material's versatility and ease of use. Create lasting memories by making hand or footprint impressions in plaster of Paris. These can be painted and decorated for a personalized touch. Decorative plaques, make personalized decorative plaques by moulding the plaster into shapes or designs. Add names, quotes, or other embellishments and painted wall art to create textured wall art by applying plaster to canvas or wood. Once dried, paint or stain the surface to your liking.

Crafters commonly employ Plaster of Paris to make personalised presents and souvenirs. The technique is pressing hands or feet into a wet plaster mixture, allowing it to harden, and then adorning the hardened cast. This easy but profound project makes a treasured keepsake that will last for years.

Plaster of Paris is also widely used in the field of home decoration. DIY enthusiasts and professional craftsmen alike use it to create wall hangings, decorative panels and ornate frames. By Ngaaje, (2021), the use of plaster is popular through moulding by artists in the production and installation of suspended ceilings (staff) and in the coating of interior walls. Its flexibility allows it to be painted, carved and sanded, providing endless possibilities for customization. Bard & Torello, (2018), in decorative plasterwork can add an elegant touch to interiors, with patterns ranging from classic motifs to contemporary designs. Ceiling medallions, cornices and friezes are some common applications in interior decoration, adding a touch of sophistication and historical charm to modern homes.

2.7.1.4 Ceramic Art

Ceramic art refers to the creation of objects from clay and other ceramic materials, which are typically fired at high temperatures to achieve a durable, hardened form. This form of art has a rich history and is found in various cultures around the world. Ceramic art encompasses a wide range of creations, from functional pottery and vessels to decorative sculptures and tiles. Creating ceramic art involves several stages, typically including clay selection, remove the air bubbles using techniques kneading or wedging and building the shape clay into the desired form. After initial shaping, the product will dry on air temperature. Next, the dried clay is fired in a kiln at a lower temperature in the range of 900°C–1060°C and the last stages is glazing to add colour on the product, glazed piece undergoes a second firing at a higher temperature, typically in the range of 1000°C–1250°C. This firing process vitrifies the glaze, making it glossy and durable, while also further strengthening the ceramic and additional processes such as polishing, sanding, or adding other finishing touches to achieve the desired aesthetic. After completed the ceramic piece undergoes a final inspection to ensure it meets the artist's standards. This may involve checking for any defects, ensuring the glaze has adhered properly, and verifying the overall quality of the finished work and the ceramic art piece will display or use, depending on its intended purpose.

Each of these stages requires skill and attention to detail, and artists often develop their own unique techniques and style through experience and experimentation in the ceramic art-making process. Ceramic art can take many forms, ranging from functional items like bowls, plates, and mugs to purely decorative pieces such as sculptures, tiles, and figurines. Artists often explore various techniques, styles, and forms, showcasing the versatility of ceramics as an artistic medium. Notable examples of ceramic art include traditional pottery from cultures like Chinese and Japanese ceramics, as well as contemporary ceramic artists who push the boundaries of the medium with innovative and experimental approaches.

Carbajal et al., (2007), explain that porcelain is a type of ceramic that is highly regarded for its delicate beauty and durability. It originated in China and has been refined over thousands of years, making it immensely desirable among European nobility and aristocrats. Porcelain is made from high-purity kaolin clay. This procedure involves steps like pottery but requires more precision because to the fine texture of the clay and the high fire temperature. Porcelain wares, such as exquisite and decorative China sculptures, frequently have intricate hand-painted motifs and are used for both functional and ornamental purposes.

Stoneware is a versatile ceramic that can be used to create useful dinnerware as well as artistic sculptures. Its strength and resistance to chipping make it excellent for daily use. According to Yesilay, Cakı, and Ergun (2017), the process of creating stoneware involves clay shape, drying, bisque firing, glazing, and glaze firing. Stoneware artists frequently experiment with different glazing techniques to create a variety of textures and finishes, ranging from smooth and glossy to rough and matte. The high firing temperature also enables for a wide spectrum of colours and effects, which increases the material's attractiveness to artists.

Earthenware is one of the earliest types of pottery, recognised for its warm, rustic appearance. It is made of natural clays high in iron and other minerals, giving it a reddish-brown colour. Earthenware is commonly used for ceramics and ornamental things. The procedure consists of shaping the clay, drying, bisque firing, glazing, and a final firing. Because earthenware is fired at a lower temperature, it is porous and less durable than stoneware or porcelain. However, Raharjo (2013) claims that its earthy look makes it attractive for artistic and traditional crafts. The purpose of developing new designs for arts and crafts pottery is to respond to worldwide trends, promote non-oil and gas exports, and improve craftsmen's economic standing. This involves using earthenware clay and local technology, observing global trends, and using interior elements as inspiration. This process involves aesthetic and economic considerations, literature and in-field studies, and market testing.

Terracotta is a form of earthenware distinguished by its reddish-brown colour that is commonly used for sculptures and architectural features. The term "terracotta" means "baked earth" in Italian, emphasising the material's natural, earthy appearance. Terracotta has been used for a variety of purposes throughout history, including roof tiles, bricks, enormous sculptures, and ceramics. The manufacturing technique is similar to that of other earthenware, but it does not often include glazing, allowing the clay's natural colour and texture to be exposed. Sanchez, Cultrone, and Quero (2011) argue that analytical techniques in ceramics are critical for analysing terracotta sculptures because they provide insight into the material's composition, technology, and behaviour. Terracotta has been employed since prehistoric times, especially during the Renaissance and Baroque periods.

Tile production is an important aspect of ceramic craft, serving both functional and decorative reasons. Ceramic tiles are created by forming clay into flat, thin sheets that are then agitated and fired. Tiles can be utilised in a variety of applications, including floors, wall coverings, and elaborate mosaics. To ensure that the tiles are uniform in size and shape, the design and manufacturing process is meticulously executed. Decorative tiles frequently have complicated patterns and colours that necessitate excellent glaze application and several firings. However, according to Rambaldi, E. (2021), conventional ceramic tiles are already offered with features and performances that extend far beyond traditional applications.

The diversity of ceramic art crafts shows clay's great possibilities as a medium. From the simplicity of a handcrafted clay bowl to the complexity of a modern ceramic sculpture, each style of ceramic art has its own set of traditions, techniques, and creative possibilities. Regardless of the type, the producing procedure requires a thorough understanding of the material and a meticulous orchestration of processes from raw clay to finished product. This meticulous process not only produces beautiful and usable products, but it also connects the artist to a long tradition of human invention and skill. Ceramic art crafts evolve via continual invention and respect for history, providing new forms of expression and function in the modern world.

2.8 Slip casting

Slip casting to create stoneware is a difficult and interesting technique that combines art, science, and careful craftsmanship. Preliminary evaluations after casting provide vital insight into the work's quality, potential, and direction as it advances through the various stages of ceramic production. When the slip hardens and the mould is opened, the true appraisal of the item begins. When the mould is first removed, it leaves an impression of a delicate and fragile shape, wet from sliding. The surface, which remains soft to the touch, frequently shows minute intricacies created by the mould. These features, from delicate textures to smooth surfaces, demonstrate the precision and quality of the moulds used. At this point, any flaws in the mould or discrepancies in slip application are immediately obvious. Small air bubbles, mould seam lines, or thickness discrepancies can be noticed, necessitating a thorough investigation and possible rectification. The colour of the cast pieces at this point is also worth mentioning. Freshly poured stoneware is usually a consistent colour, either soft white or light grey, depending on the clay body used. This colour makes an ideal background for assessing the constancy and smoothness of the action. Colour variations can indicate differences in drying rate or slip composition. A mottled look, for example, may indicate uneven mixing processes or incorrect casting, whereas a more consistent colour indicates a properly prepared slip and a good casting process.

One of the critical aspects of observing stoneware slip castings after casting is the evaluation of the structural integrity of the pieces. Wet castings must be handled with care to avoid deformation or damage. At this stage, the casting is still quite flexible, and undue pressure or mishandling can cause warping or breakage. Viewing the pieces from various angles can help in identifying any subtle curves or bends that may have occurred during the drying process. This is especially important for pieces with large flat surfaces or thin walls, where such deformation is more likely.

The drying process itself is an important factor to note. As the cast begins to dry, it gradually transitions from a brittle, moist state to a more rigid and stable form. This drying process must be carefully controlled to avoid rapid drying, which can cause cracking. Observing the rate of moisture evaporation from the casting can provide insight into the ambient conditions of the workspace. Humidity, temperature and airflow all play an important role in how evenly and effectively the pieces dry. Uneven drying can cause stress in the part, leading to cracking or splitting, especially in thin parts or areas with intricate details.

Shrinkage is another important aspect to monitor. When the slip dries, it inevitably shrinks, and this reduction in size must be uniform to avoid internal pressure. Observing the degree and uniformity of shrinkage can indicate the slip quality and consistency of the casting process. Measurements taken before and after drying can help quantify this shrinkage, providing valuable data for adjusting future slip batches or altering the casting process to ensure better consistency.

Surface texture also requires careful observation. The surface of the cast sheet, after it is sufficiently dry, should be smooth and free from noticeable defects. However, it is common to find minor surface irregularities that need to be addressed. This can include small air bubbles that burst during drying, leaving small craters, or slight roughness from mould seams. At this stage, soft sanding or other surface finishing techniques can be used to smooth out these imperfections, preparing the piece for the bisque firing stage. Additionally, the thickness of the cast piece is a crucial parameter to observe. Uniform wall thickness is essential for the structural integrity and aesthetic quality of the final piece. Variations in thickness can lead to uneven drying and firing, resulting in defects such as warping or cracking. Using calipers or other measuring tools to check the thickness at various points can help ensure that the casting process is producing pieces with consistent dimensions. Any significant deviations might require adjustments to the slip consistency, pouring technique, or mould design.

At this stage, it is also important to observe the seams and joins where the mould pieces meet. These areas often require careful attention to ensure they are smooth and well-integrated with the rest of the piece. Seam lines can be gently scraped or sponged away while the cast is still damp, or they can be sanded down once the piece has dried sufficiently. Observing how well these seams disappear into the overall form of the piece is a key indicator of the craftsmanship and attention to detail involved in the slip casting process.

Another aspect to consider is the handling of the cast piece as it transitions from the damp stage to leather-hard and finally to bone dry. Each stage presents unique challenges and opportunities for observation. At the leather-hard stage, the piece is firm enough to handle more robustly but still retains some pliability, allowing for minor adjustments or the addition of handles, spouts, or other features. Observing how the piece behaves at this stage can inform decisions about timing and technique for any additional modifications.

Finally, the observation process extends to the psychological and aesthetic evaluation of the piece. This involves stepping back and viewing the piece not just as a technical artifact but as a work of art. The form, balance, and proportions of the piece are assessed, along with its tactile qualities and the potential for glazing and final finishing. This holistic observation ensures that the piece is not only technically sound but also meets the artistic vision and standards set for the final product.

2.9 Bisqueware

According to Ribeiro (2021), bisque ceramics, also known as biscuit ceramics, are one of the key steps in the creation of ceramic products. Bisque ware is the result of the initial firing of ceramic materials, which converts soft, malleable clay into a solid, durable, and porous form. This stage is critical because it prepares the ceramic object for further processing steps such as glazing and ultimate firing. Understanding bisque ceramics necessitates an examination of its history, manufacturing method, artistic applications, and underlying science. Historically, the term "bisque" comes from the French word "biscuit," which meaning "twice cooked." However, in ceramic language, bisque firing refers to the first firing, not subsequent firings. The technique has ancient roots, with early examples found in various civilizations, including the Chinese, Egyptians, and Greeks. These early artisans discovered that firing clay not only made it more durable but also enhanced its usability and aesthetic potential. Over centuries, the bisque firing process has been refined and standardized, becoming a staple in both industrial production and artisanal pottery.

Aghanya Cosmas. C. and Aghanya Maria. O. (2022), bisque ceramics are made by first preparing clay. The clay body, which can vary in composition based on the desired qualities of the finished product, is thoroughly mixed and wedged to remove air bubbles and guarantee consistent consistency. This stage is crucial because any trapped air may expand upon firing, causing the item to shatter or explode. Once prepared, the clay is sculpted using a variety of methods, including hand-building, wheel-throwing, and slip casting. Each process has specific advantages and affects the final appearance and texture of the bisque ware. After shaping, the ceramic object is allowed to slowly dry to a leather-hard state, allowing for further refinement like trimming, carving, or adding handles and other features. This drying period is necessary because firing wet clay might produce steam, which can damage the sculpture. When the work has completely dried, it is loaded into a kiln for bisque fire. The firing process is carefully monitored, with the temperature steadily increasing to avoid thermal shock. Bisque firing temperatures typically range between 945°C and 1060 °C, depending on the clay used. The bisque firing changes the clay using a process known as sintering. During sintering, the clay particles begin to fuse together without melting, resulting in a solid yet porous structure. This porosity distinguishes bisque pottery because it improves the adhesion of glazes and other surface treatments performed in succeeding stages. Bisque ware's porosity also makes it perfect for applications requiring moisture absorption and release, such as water filtration and gardening pots.

One of the most important benefits of bisque ceramics is their simplicity of use after the initial firing, Aghanya & Aghanya, (2022). The burned pieces are substantially stronger than their unfired counterparts, lowering the possibility of breaking during the glazing and decoration steps. This longevity enables artists to explore with a variety of surface treatments, including underglazes, stains, and engobes, without concern of harming the base structure. Furthermore, the porous quality of bisque clay allows glazes to adhere well, resulting in more equal and controlled application.

According to Myzelev, Stein, and Johnson (2019), bisque ceramics provide a blank canvas for artistic expression. After the bisque firing is completed, the piece can be decorated using a variety of techniques. Glazing is one of the most prevalent techniques, in which a liquid solution of minerals is put to bisque clay. The glaze can be painted, dipped, or sprayed on the surface, and when fired, it provides a glass-like layer that improves both the piece's look and functioning. Glazes can be glossy, matte, opaque, or transparent, and can include a variety of colours and textures. In addition to glazing, bisque ceramics can be decorated with underglazes, which are applied prior to the final glaze and fire. Underglazes enable the precise creation of intricate shapes and patterns because they do not flow or change colour appreciably during firing. Other decorative techniques include slip trailing, which involves piping a liquid clay mixture onto the surface to produce raised shapes, and sgraffito, which involves applying layers of coloured slips and then scratching them away to reveal contrasting colours beneath.

From a scientific standpoint, the transition of clay into bisque ceramics causes remarkable changes in the material's characteristics. The initial firing removes physical water and organic components from the clay, resulting in a reduction in weight and volume. The procedure also strengthens and hardens the material, increasing its resistance to injury. Understanding these variations is critical for ceramic artists and manufacturers because it affects clay selection, fire cycles, and finishing methods. Bisque ceramics have practical applications in a variety of industries. In addition to art and adornment, bisque ware is used to make sanitary ware, tiles, and technical ceramics. The material's strength, durability, and porosity make it ideal for these applications, where dependability and performance are critical. Furthermore, bisque ceramics contribute to scientific research, particularly the development of new ceramic materials and methods.

The manufacturing process starts with the selection and preparation of raw materials. Manfredin & Hanuskova (2012) Clay is typically the primary material used; however, it can be blended with other natural components such as kaolin, feldspar, quartz, and different mineral oxides. The chosen components are finely ground and combined to form a homogeneous, workable clay body. This combination is frequently aged to improve its flexibility, which allows it to be easily moulded into the desired forms. Once the clay body is made, it is sculpted using a variety of methods. The most prevalent methods are wheel throwing, hand construction, slip casting, and extrusion. Wheel throwing is the process of sculpting clay on a potter's wheel using the ceramist's hands and basic tools to create symmetrical shapes. Hand-building encompasses techniques like coiling, pinching, and slab construction, allowing for more organic and unique shapes. Slip casting involves pouring liquid clay, or slip, into plaster molds, which absorb the moisture and leave a solid clay form. Extrusion uses machines to press clay through a die, producing uniform shapes that can be cut and assembled. After shaping, the greenware (unfired clay objects) undergoes a period of drying. This step is critical, as any remaining moisture can cause the piece to crack or explode during firing. The drying process must be slow and even to prevent uneven shrinkage and warping. Typically, the greenware is left to air dry in a controlled environment, sometimes for several days or weeks, depending on the size and thickness of the pieces.

Once properly dry, the greenware is ready for the bisque firing, which is usually the first of two. Bisque firing is done in a kiln, where the temperature progressively rises to drive off any leftover water and organic ingredients. This process, known as dehydration and organic burnout, typically happens between 480°C and 700°C (. Following this phase, the temperature is raised to roughly 900°C to 1000°C to accomplish sintering, in which clay particles fuse but do not become vitrified. This fire converts the brittle greenware into sturdy, porous bisque ware. The resulting bisque ware, though strong, remains porous, making it ideal for subsequent glazing. The porosity allows the glaze to adhere well to the surface, ensuring a uniform and durable coating. Before glazing, the bisque pieces are often cleaned to remove any dust or impurities that could affect the glaze's adhesion and appearance. This can involve rinsing with water, wiping with a damp sponge, or using a soft brush.

The entire bisque ceramic production process, from raw material preparation to final glaze firing, is a complicated combination of art and science. Each stage necessitates precision, competence, and a thorough knowledge of materials and procedures. The result is a sturdy, practical, and often attractively adorned ceramic product. Wanner, AJ, and Urbano Gutierrez (2016) demonstrate that current technology has led to breakthroughs in bisque ceramic manufacture. Computer-aided design (CAD) and 3D printing are becoming more popular, allowing for elaborate and exact shapes that would be difficult to produce by hand. Advanced kiln technology and materials science are helping to improve the quality and efficiency of bisque ceramic manufacture. The bisque stage is also a critical point for artistic expression. Artists and ceramists often use this phase to carve, etch, or add underglaze decorations to the bisque ware. These embellishments can create texture and visual interest that are enhanced by the final glaze. The bisque surface provides a sturdy yet workable canvas for creative exploration.

In conclusion, bisque ceramics play an important role in the ceramic-making process, bridging the gap between raw clay and completed pottery. Their durability, porosity, and historical relevance make them essential for both new and seasoned ceramicists. Bisque ceramics, whether used for useful pottery, decorative art, or elaborate sculptural pieces, offer a versatile and dependable base for creative discovery and artistic expression. Bisque ceramic manufacturing is a multifaceted process that blends traditional craftsmanship with modern innovation. From the careful selection of raw materials to the precise control of firing conditions, each step is essential in creating high-quality bisque ware. The resulting ceramics not only serve practical purposes but also offer a medium for artistic expression, reflecting the enduring appeal and versatility of this ancient craft.

2.10 Glazing

From Casasola, Ma Rincón, and Romero, (2012),glass-ceramics are ceramic materials produced through controlled crystallization of a parent glass, with a wide variety of compositions and unique microstructures. They are used in various applications, including glazes for ceramic tiles, which are common building materials in Mediterranean countries. In the 1990s, there was a growing interest in developing frits that could crystallize on firing to improve the mechanical and chemical properties of glazed tiles.

Glazing in ceramics is a basic procedure that improves both the aesthetic and utilitarian properties of ceramic items. Glazes are vitreous, glass-like coatings applied to ceramics that are usually made of silica, flux, and metal oxides. When burned at high temperatures, these materials combine to produce a glossy, matte, or textured surface that can be transparent, opaque, or coloured. The glazing procedure not only improves the appearance of the ceramic pieces, but it also increases their durability and waterproofing. The primary function of the glass is to form an impermeable barrier on the ceramic surface, making it appropriate for storing liquids and easier to clean. This is especially relevant for useful ceramics like dinnerware, cups, and vases. Without a glaze, the porous nature of fired clay will absorb liquid, leading to dirt and the material weakening over time. By covering the surface, the glass prevents this absorption and extends the life of the ceramic piece.

Other meaning glaze by Pradell and Molera, (2017), Glazes enhance ceramic's value, appearance, and waterproofness, making it fashionable and a subject of trade. Each region developed its own style, making them ideal for dating. Glazes are thin glass layers fused to a ceramic body through firing, containing amorphous, bubbles, cracks, and crystalline phases. They are also decorated with various materials and methods. This chapter discusses the technical characteristics, discovery, use, and decorative techniques of glazes, as well as the methodology and analytical techniques used. Aesthetic enhancement is another significant component of glass. Glass's great spectrum of colours and finishes enables artists and producers to make visually interesting ceramics. Glazes can be applied in a variety of techniques, including dipping, brushing, pouring, and spraying, with each process producing a unique appearance and finish. The chemical makeup of the glaze, the manner of application, and the firing temperature all influence the final appearance of the glazed ceramic. Ceramic glazes are classified into various categories, each with its own set of qualities. The transparent glaze lets the texture and colour of the clay body show through, whereas the opaque glaze totally covers the surface. A glossy finish creates a glossy finish, while a matte coating creates a softer, non-reflective surface. Additionally, special effect glazes, such as crackle glazes that create a network of fine cracks, and crystal glazes that form crystal patterns during firing, add to the variety of finishes available.

The glass process begins with the preparation of ceramic pieces, known as bisque firing. This initial firing transforms the raw clay into a hard but porous state, which is necessary for the glaze to adhere properly. After bisque firing, the pieces are cleaned to remove any dust or contaminants that could affect the glaze's adherence. The glaze is then applied using the chosen method, and the piece is allowed to dry completely before the final firing.

Firing is a vital phase in the glassmaking process. The kiln must attain the necessary temperature for the glaze being used, which varies based on the glaze's composition and desired effect. Low-fire glass is burnt at temperatures between (1,000°C and 1,150°C), but high-fire glass requires temperatures between (1,200°C and 1,450°C). During burning, the glaze components melt and fuse with the ceramic surface, resulting in a smooth, glassy coating. In short, glazing is an important technique in ceramics that enhances both the function and appearance of ceramic pieces. By applying and firing glazes, ceramists can create durable, waterproof surfaces that are visually appealing and suitable for a variety of uses. The variety of glazes and application methods allows for endless creativity and innovation in ceramic art and manufacturing, making glass the foundation of the ceramic manufacturing process.

Glazing is an important technique in ceramics because it can transform a raw clay item into a colourful work of art while also serving a decorative purpose. It entails applying a vitreous coating to a ceramic object that is subsequently burned at high temperatures to achieve a glass-like appearance. This finish not only improves the piece's aesthetic appeal, but it also adds a protective layer, making the ceramics more robust and waterproof. The glazing process is complex, requiring a thorough grasp of materials, chemistry, and firing methods to create the required results. The adventure of glazing begins with selecting the suitable glaze. By Mark Burleson (2003).

Glazes are made up of silica, alumina, and flux, which all contribute to the ultimate qualities of the glaze. Silica makes up the glass component, alumina offers stability and endurance, and flux lowers the melting point of the silica, allowing it to fuse to the ceramic body at lower temperatures. Colorants such as oxides and stains can also be added to the glaze to provide a variety of colors and effects. For example, iron oxide can produce a variety of colors ranging from earthy reds to deep browns, whilst cobalt oxide can produce strong blues. To prepare the glaze, mix these raw components with water to make a suspension. The consistency of this solution is critical; it should be like cream, thick enough to cling to the ceramic surface yet fluid enough to apply evenly. The bisque ware, or ceramic object that will be glazed, has previously been fired to harden the clay and make it porous. This porosity is necessary because it allows the glaze to properly attach to the surface.

Inal's (2023) glaze can be applied using a variety of ways, each providing different aesthetic attributes to the completed piece. Dipping, one of the most frequent procedures, entails immersing the bisque ware in the glaze suspension and then withdrawing it to form an equal coat. In dipping, the ceramic piece is fully submerged into a bucket or vat of liquid glaze. This method ensures uniform coverage and is efficient for large quantities of pottery. However, controlling the thickness of the glaze layer can be challenging, and drips or uneven application may occur. To mitigate this, potters often use tongs to dip pieces evenly and to remove excess glaze. Brushing enables more controlled and detailed application, which is ideal for delicate designs. Artists use soft bristle brushes to apply glaze onto specific areas of the pottery. This technique is favored for detailed work or when creating patterns and designs. Brushing enables layering of different glaze colors and textures, offering versatility in artistic expression. However, achieving even coverage without brush marks requires skill and practice. Spraying employs a spray gun to apply a fine mist of glaze, which is suitable for large objects or subtle gradients. Using an airbrush or spray gun, artists atomize the glaze into a fine mist that evenly coats the surface. This method ensures a consistent layer of glaze and can achieve smooth finishes that are difficult to replicate with other techniques. However, overspray and uneven application can be issues, requiring careful adjustment of air pressure and nozzle distance. Pouring is another process in which glaze is poured over the piece; it is commonly employed for utilitarian ware to provide a constant thickness. This technique allows for controlled application over specific areas, such as rims or edges, and can create unique drips and patterns as the glaze flows and settles. Pouring is versatile but can lead to variations in thickness, requiring careful observation and adjustment to achieve desired effects.

Additionally, some artists explore alternative methods like sponging or splattering. Sponging involves dabbing a sponge soaked in glaze onto the ceramic surface, creating textured effects or blending colors subtly. Splattering, on the other hand, involves flicking or splashing glaze onto the pottery, often using a brush or toothbrush. These methods are valued for their spontaneity and ability to create organic, unpredictable patterns. Regardless of the technique used, successful glazing requires careful consideration of factors such as glaze composition, firing temperature, and the desired aesthetic outcome. Different types of glazes, such as matte, glossy, or textured, offer varying visual and tactile qualities, influencing the overall look of the finished piece.

In conclusion, the application of glaze to pottery and ceramics encompasses a variety of techniques, each with its own advantages and challenges. Whether dipping, brushing, spraying, pouring, or exploring alternative methods like sponging and splattering, it can manipulate glaze to achieve diverse textures, colors, and finishes. Mastery of these techniques requires both technical proficiency and artistic intuition, allowing potters to create pieces that are not only visually appealing but also reflect their creative expression and craftsmanship.

Each approach has advantages and can be chosen based on the individual needs of the ceramic artwork. After the glaze is applied, the work goes through the last firing, known as the glaze firing. This stage is crucial because the glaze must melt and merge with the ceramic body without running off or causing flaws. The kiln temperature and firing schedule vary according to the glaze and clay body utilized. Earthenware glazes, for example, are commonly fired at lower temperatures (between 1000°C and 1150 °C), but stoneware and porcelain glazes require higher temperatures (1200°C to 1300 °C). The fire process is carefully managed so that the temperature steadily rises, letting the glaze grow and reach its full potential.

A variety of physical and chemical changes occur during the firing process. The water in the glaze evaporates, and the glaze's components begin to melt and flow. This melting process, known as vitrification, involves silica forming a glassy matrix that envelopes the other elements. The alumina stabilizes the glass, keeping it from becoming too fluid and flowing off the piece. The fluxes serve in decreasing the melting point and facilitating glaze fusion with the ceramic body. When the temperature reaches its peak, the glaze surface smoothest out and any bubbles or irregularities disappear. The cooling process is also crucial because it helps the glaze to set and achieve its final appearance.

The glazing process can produce drastically varying results depending on a variety of elements, including glaze composition, firing temperature, and kiln atmosphere. For example, oxidation and reduction atmospheres can have a major impact on the glaze's color and texture. Colors are brighter and more predictable in an oxidation atmosphere, which contains plenty of oxygen. In contrast, a reduction environment with restricted oxygen can produce more complex and variable effects, frequently resulting in richer, deeper colors and distinct surface textures.

According to Jamaludin (2016), the glazing process results might vary greatly depending on a variety of elements such as glaze composition, firing temperature, and kiln atmosphere. For example, oxidation and reduction atmospheres can have a major impact on the glaze's colour and texture. Colours are brighter and more predictable in an oxidation atmosphere, which contains plenty of oxygen. In contrast, a reduction environment with restricted oxygen can produce more complex and variable effects, frequently resulting in richer, deeper colours and distinct surface textures. Glazing also allows for a wide range of creative possibilities through techniques such as layering, masking, and resist. Layering entails adding numerous coatings or glazes to achieve depth and complexity in the finished piece. Masking and resist techniques use materials such as wax, latex, or paper to keep glaze from sticking to certain spots, resulting in detailed patterns and designs. These methods enable artists to experiment with and push the boundaries of ceramic art, resulting in unique pieces. One of the most exciting characteristics of glazing is its unpredictable nature. Despite painstaking planning and perfect execution, the result may nevertheless startle the artist. The interaction of glaze chemistry, kiln atmosphere, and fire dynamics can produce surprising differences and beautiful accidents, making each glazed work a testament to the balance of controlled skill and natural elements.

Glazing is more than just a finishing technique; it is an essential part of ceramic artwork that involves technical expertise, scientific knowledge, and creative intuition. It transforms raw clay into finished ceramics, giving them colour, texture, and durability. The centuries-long evolution of glazing processes shows the ceramics world's never-ending desire for innovation and expression. Glazing, whether employed for utilitarian or artistic purposes, is an important and captivating feature of ceramic work that celebrates the intersection of art and science.

Determining the quality of glaze on ceramic ware can require several factors. First, apply an excellent quality glaze to the ceramic piece's surface in a smooth and even manner. This ensures a pleasant touch feel and a consistent appearance. The glaze's colour should be uniform throughout the sculpture, with no patches or variances in hue, unless done intentionally for artistic impact. Depending on the type of glaze (glossy or matte), it should have the desired shine or lustre without being too dull or shiny. The glaze should cover the ceramic's whole surface evenly, including edges and corners, with no thin spots or missed places. A high-quality glaze should be resistant to wear, scratching, and chipping over time. Look for any defects such as pinholes, bubbles, or cracks in the glaze, which can detract from both the appearance and functionality of the ceramic ware. Consider if the glaze is suitable for its intended use (e.g., food-safe for dinnerware, water-resistant for vases).

2.11 Research Gap

Although several studies have examined the recycling of Plaster of Paris (POP), specific gaps remain unaddressed:

It is clear from reviewing the corpus of research on Plaster of Paris (POP) and its recycling potential that, despite significant advancements in our knowledge of its fundamental characteristics and uses, a number of important issues still need to be addressed. Relatively little attention has been paid to the systematic optimisation of recycling characteristics, chemical modification, and application to intricate moulding situations; much of the research to date has concentrated on general material performance and traditional casting uses. Because they have a direct impact on the viability of recycled POP (RPOP) in both industrial ceramic manufacture and design processes, these gaps in the literature are noteworthy. The main research gaps that this study aims to light on these constraints. Plaster of Paris (POP) recycling has been the focus of several studies, but there are still a few important questions that need to be answered. First, the optimal temperature for calcination needed to restore the mechanical properties of recycled POP (RPOP) is a matter of discussion. Ranges between 150°C and 180°C have been suggested by earlier studies, however these estimates are frequently based on broad observations or sparse experimental trials rather than methodical, comparative examination. It is challenging to create a trustworthy standard for industrial applications because of this inconsistency.

Secondly, there isn't much discussion in the literature about how chemical activators, such Silubit G80, can enhance the performance of regenerated POP. Few research have empirically investigated various concentrations of Silubit G80 inside POP systems, even though chemical modification is widely recognised as a viable technique for improving mechanical strength, setting time, and porosity. Because of this, there isn't much scientific data to help practitioners choose the best formulations for real-world applications.

Third, there is still much to learn about RPOP's performance in intricate geometrical applications. The difficulties of creating complex designs, which are typical in ceramic manufacturing, are sometimes overlooked in research that concentrate on basic mould shapes. Furthermore, a critical factor in both industrial and studio-based settings, the endurance and degradation of RPOP moulds under repeated slip casting cycles are the topic of relatively few studies.

When combined, these gaps show how much more thorough and rigorous research is needed to address the functional, technological, and practical elements of RPOP. Therefore, by methodically analysing the effects of thermal activation, looking into the function of Silubit G80 as a chemical activator, and evaluating RPOP's performance in realistic ceramic casting scenarios—such with intricate geometries and frequent use—this study aims to close these gaps. With this strategy, the study hopes to advance not just the scientific knowledge of recycled POP but also its usefulness in the ceramics industry and in art and design activities.

2.12 Chapter Summary

In this study observed the properties between of RPOP and NPOP. The use of RPOP can help the ceramic industry sector to reduce the cost of raw materials obtained from damaged or obsolete moulds. Through the previous study, the researchers reviewed this study on average used the same methods and materials, in addition almost the results were the same. However, more research on this topic needs to be undertaken through using activator to fine out the different result or to identify the reaction that will occur on the RPOP if the activator is used. The use of activator added into Recycle Plaster of Paris should have the appropriate percentage according to the predetermined ratio. It is possible this experiment will be repeatedly by using the difference quantity of activator that has been recommended. However, RPOP shows that it can work as a casting just like NPOP. In addition to that, the production of moulds using RPOP needs to be researched on how to use it and how to mix it. Safety considerations are important when working with Plaster of Paris. Although generally safe to use, precautions should be taken to avoid inhaling the fine powder. Working in a well-ventilated area and using a protective mask can help reduce this risk. In addition, since the plaster sets quickly and generates heat during the setting process, it is advisable to avoid skin contact with the wet mixture for a long period. Testing the porosity of POP is important to evaluate its suitability for various applications. By using various methods such as water absorption tests, porosimeter and imaging techniques, researchers and practitioners can accurately assess the porosity characteristics of materials, enabling informed decision making and optimizing their performance in specific applications. Bisque ceramics play a crucial role in the ceramics world by providing a stable, versatile foundation for both artistic and functional pottery. The bisque firing process enhances the clay's workability and durability, making it an essential step in the creation of high-quality ceramic pieces. Glazing is an important method in ceramic art because it transforms raw clay into completed ceramics with colour, texture, and durability. It can be applied in a variety of ways, according on the aesthetic requirements of the piece, including dipping, brushing, spraying, and pouring.

The environmental impact of Plaster of Paris is relatively minimal compared to other materials. It comes from gypsum, a natural mineral, and the manufacturing process is quite simple. However, disposal of excess plaster should be done carefully, as it can clog drains and pipes. Recycling or reusing plaster waste in other projects is a more sustainable approach.

In summary, Plaster of Paris is a very versatile and accessible material that has carved out an important niche in the arts and crafts world. Its ability to capture fine details, quick setting properties and ease of use make it a favourite among artists, craftsmen and DIY enthusiasts. From creating stunning sculptures and intricate moulds to creating decorative home accents and educational models, Plaster of Paris offers endless possibilities for creativity and innovation. Whether for an experienced artist or a beginner looking to explore a new medium, this material promises to inspire and enhance creative endeavours in the production of plaster art.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

This chapter contains four stages in this research as show in Figure 3.1. The first stage, a brief description of the experimental layout that has been initiated to meet the goals of this study. Also at this stage, the analyses of the chemical and physical properties of all the materials were studied. The testing is particle size analysis, SEM analysis, compressive strength, porosity and absorption test. Second, the information on experimental techniques used with in the Recycle Plaster of Paris (RPOP) properties, testing innovations or activators used in RPOP and description of improvement outlines of RPOP. The third stage, description of the application of characterization and evaluation of moulds from RPOP and the last stage is to make an aesthetic and complicated form mould by using RPOP referring to industrial raw materials used for casting ceramic products.

Plaster of Paris (POP) is a flexible gypsum-based substance that is commonly used for moulding, casting, and construction purposes. However, its use generates enormous waste because the material is often non-reusable once set. As a result, Recycle Plaster of Paris (RPOP) was created, which is recycled plaster from a previously used RPOP mould that may be reused as a casting mould. RPOP involves rehydrating and treating waste materials to restore their original qualities, making it a more sustainable alternative to creating new POP from raw gypsum. This recycling procedure not only reduces the demand for virgin gypsum, but it also helps to mitigate the environmental implications of disposal, such as landfill accumulation and potential groundwater pollution.

Every experimental method in this research was carried out according to with the Research Ethics and Environmental Management Guidelines of Universiti Teknologi MARA (UiTM) and standard laboratory safety precautions. In order to reduce the production of dust in the air and avoid possible environmental contamination, used plaster waste was handled responsibly. Using the proper personal protective equipment (PPE), such as gloves, masks, and safety goggles, all sample preparation and testing procedures were carried out in a laboratory setting that was well-ventilated and controlled. Additionally, by turning used plaster moulds into reusable materials, the recycling framework used in this study represents the principles of environmental sustainability. In line with more general global sustainability goals, this project makes a substantial contribution to waste reduction, resource conservation, and the development of circular material practices within the ceramic manufacturing discipline.

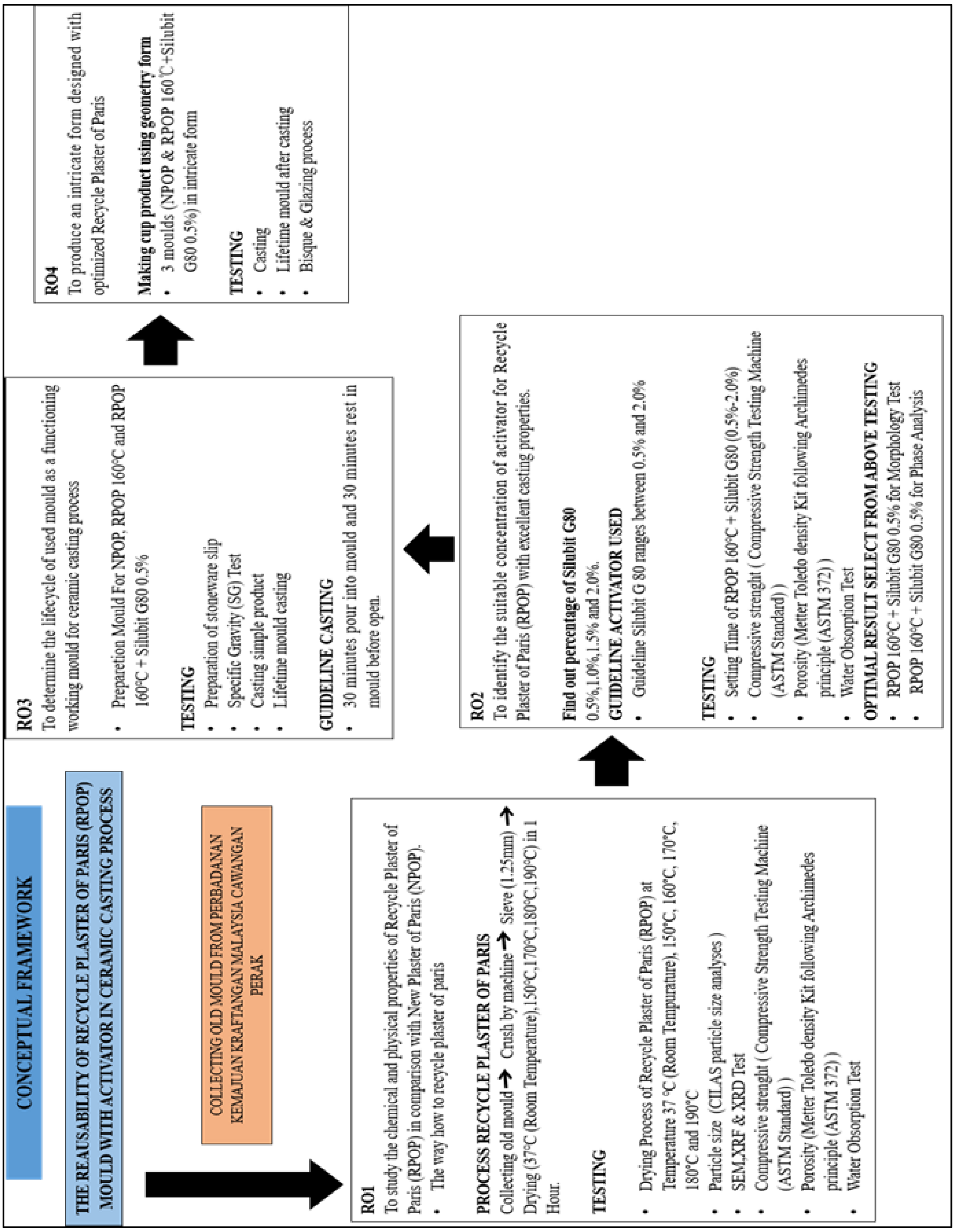


Figure 3.1 The Conceptual Framework Of The Study

As can be seen from the table Figure 3.1, this research was divided into four stages in experiment of RPOP. The resulted were collected, analyses and discussed at each stage before proceeded to the next experiment. The four stages are.

i. Stage 1: The preparation of Recycle Plaster of Paris powder is dried at 150℃-190℃ and test physical properties.

In the 1st stage is to determine the suitable temperature for drying of Recycle Plaster of Paris powder. The first step to prepare recycled plaster of Paris (POP) powder is gathering spent POP. These materials should be cleaned to remove any debris or contaminants. Once cleaned, the POP is then ground into a fine powder. This powder is spread evenly on the tray and put in the oven. The drying process is carried out at a temperature range of 150 °C to 190 °C, ensuring that the material is dried uniformly without causing any degradation of its chemical properties. After the drying process, the RPOP powder is allowed to cool to room temperature. The next step involves testing the physical properties of the dry powder. The key physical properties such as fineness, setting time, compressive strength and consistency are measured to ensure the RPOP meets the standards required for reuse. These tests are essential to determine the quality and usability of RPOPs in various applications, ensuring that they perform at par with newly produced POP. All sample RPOP that has been dried to test all physical properties testing. Then, the optimum result from the all testing goes through the next stage process.

ii. Stage 2: The reaction of RPOP when an activator is added.

At the second stage, an activator was studied to observe the reacted RPOP as an improvement in properties RPOP. When an activator is added to RPOP, a series of chemical reactions occur, effectively rejuvenating the material and restoring its usability. POP, mainly composed of calcium sulfate hemihydrate, undergoes hydration when mixed with water, forming calcium sulfate dihydrate. Over time, recycled plaster loses its reactivity due to dehydration and partial conversion back to the hemihydrate form. Adding an activator, such as potassium sulfate or another chemical agent, restarts the hydration process. The activator lowers the energy barrier for the reaction, allowing calcium sulfate hemihydrate to more easily absorb water and convert to the dihydrate form, which solidifies into a solid mass. This rejuvenation process allows RPOP to regain its original properties, making it suitable for a variety of applications once again. Studying the effect of activators on the properties of recycled plaster of Paris can offer valuable insights into how to improve its performance and properties using the Silubit G80 activator.

iii. Stage 3: Preparation of sample mould.

Making the sample mould RPOP which is chosen after passing through stages 1 and 2 of the research. The preparation of sample molds using RPOP involves several important steps to ensure the quality and usability of the material. First, collect POP waste, and break it into smaller pieces to facilitate the recycling process. The next step involves rehydrating the RPOP by adding water and mixing it until a smooth and homogeneous consistency is achieved. Pour the mixture into the prepared mold, making sure it is even to avoid air pockets. Allow the mixture to set and harden, usually requiring 24 to 48 hours. Once the POP is fully cured, carefully remove the mold and inspect the sample for any imperfections or weaknesses. This process not only promotes sustainability by reusing materials but also shows potential for high quality RPOP products. Then note down the life cycle of casting process and observe the surface of the mold before and after casting.

iv. Stage 4: Preparation of aesthetic and intricate cup mould

In the final stage, sketch a few designs of aesthetic and intricate form, then prepare the mold using the design. When the mould is ready, the last test made is to see the comparison between the NPOP mold and the RPOP 160°C + Silubit G80 in the casting process. Then observes the timer taken between the two moulds and observes the body casting and how long the mold can function properly.

Table 3.1

Stages In Experiment Of RPOP

Phase	Description	Sample(s)	Treatment/Activator	Type of Test
Stage 1	Preparation and drying of recycled POP powder, Characterization comparison.	NPOP (as a control) & RPOP	Dried at 150°C–190°C	Temperature
Stage 2	Optimization using activator.	RPOP 160°C + Silubit G80 (0.5–2.0%)	160°C drying	Setting time, Strength, Porosity, Absorption
Stage 3	Application and lifecycle test	NPOP, RPOP 160°C, RPOP+ Silubit G80 (0.5%)	Casting process	Mould life cycle
Stage 4	Intricate mould making	NPOP & RPOP+ Silubit G80 (0.5%)	Mould making and casting process until final glaze firing	Mould life cycle, surface quality, geometry design

3.2 Preparation Powder of Recycle Plaster of Paris (RPOP)

Initially, the mould used must be crushed and go through several recycling processes. Used moulds are obtained from Malaysian Crafts Perak Branch, Enggor, Kuala Kangsar, Perak, Malaysia. RPOP was produced by crushing, sieving, and drying in a dryer for one cycle. Break the used plaster of Paris into smaller pieces using a hammer to increase the surface area to facilitate drying and recycling. Breaking a used mould made of POP can be a tricky task. This is because this mould is in a very hard solid form. However, with the right approach and tools, breaking mould can be accomplished efficiently and safely.

Figure 3.2 Break Used Mould Into Small Pieces.

There are several methods used to process used moulds into powder again. In this study provides a clean and spacious workspace. Plastic canvas is used to catch any debris that may result from mould breakage. Before proceeding with the work of breaking the used mould, the uses appropriate safety equipment such as wearing gloves to protect the hands and safety glasses to protect the eyes from any flying debris. At the beginning, the chooses a suitable place on the mould where can start to break it. Look for areas where the plaster is thinner or natural lines that may indicate weak points. With the mould placed on a stable surface, tap gently along the selected break point using a hammer and chisel until it becomes small pieces as shows in Figure 3.2.

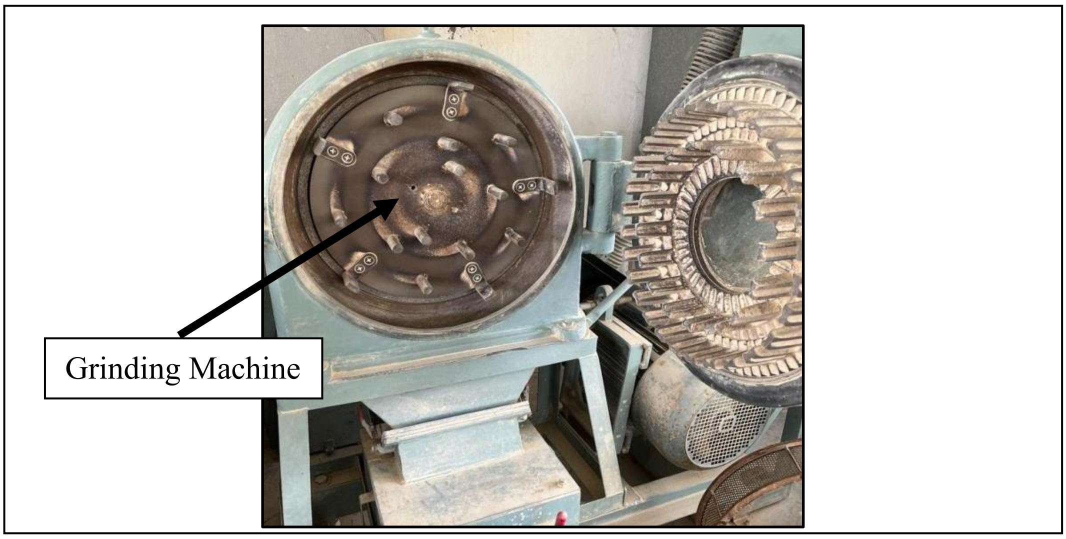


Figure 3.3 The Grinding Machine

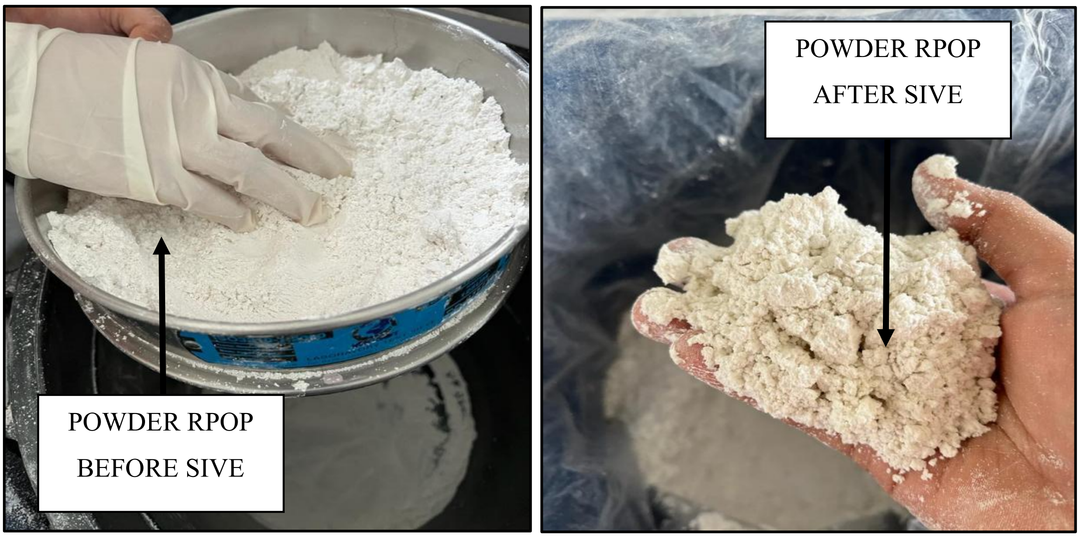
Then, grinding uses a grinding machine in to reduce the pieces of plaster to powder and it must grind the plaster pieces twice to ensure that the plaster pieces are smooth and facilitate the sieve process later. In addition to that, it can save excess plaster that is not destroyed instead of being thrown away. This can speed up the drying process and make it easier to add recycled plaster to the mix. The purpose of the old mould is destroyed because the original nature of POP is a fine powder, and it is easy to filter before mixing it into water. If the plaster is filtered first before mixing it into the water, this will facilitate the mixing process and reduce the lumps of plaster in the water.

Grinding Waste mould can be done using a grinding machine with the appropriate grinding technique. Here is the general procedure, before starting and using the grinder, make sure the grinder is clean and in good condition and use safety equipment such as glasses and gloves for personal protection. It takes numerous measures to guarantee that it is properly maintained and safe for usage. Before started cleaning the machine, follow this detailed guide. First, to avoid an accidental restart, ensure that the machine is completely turned off and unplugged from any power source. If applicable, execute facility lockout/tagout protocols to prevent machinery from being turned on during cleaning. Protective equipment is used as appropriate personal protective equipment (PPE) such as gloves, safety glasses and dust masks.

Then open all sections of the machine, including the grinder, by removing or unscrewing the exterior case. The machine's inner wall surface is cleaned with a firm bristles brush to remove any dirt, dust or loose material residue from the grinding chamber and removed parts, followed by an industrial hoover to extract finer particles and dust. Furthermore, because this machine is also used for grinding dry clay, a more thorough cleaning is required to minimise contamination with other materials. Pay special attention to nooks and crannies where dust can settle. Wipe off the inside of the blender chamber with a moist cloth or sponge. To prevent electrical damage, avoid using too much water in the machine. Dry all components fully with a clean towel or by air drying. The moisture can cause rust and other issues, so check sure everything is totally dry before reassembling. Then reassemble the disassembled machine components, ensuring that they are properly placed and safe to use. Perform a final check by assembling the machine and running tests to ensure it functions smoothly. Listen for any strange noises that could suggest faulty reassembly.

Attach plaster of Paris firmly to the work surface of the grinder. Make sure it is stable and will not move during the grinding process. Choose the right grinding tool for plaster of Paris. Diamond grinding wheels or carbide burrs may be suitable, depending on the desired finish and the hardness of the plaster. Set the grinding machine used does not have variable speed adjustment, therefore, the POP powder was ground twice to ensure that the POP powder is fine and disintegrated. Turn on the grinder and carefully start the grinding process. Put little by little pieces of POP into the blender. Make sure the movement is smooth and consistent to achieve an even finish. After achieving the desired level of grinding, stop the machine and inspect the surface for any imperfections. Turn off the grinder and thoroughly clean any dust or debris that was created during the grinding process. Dispose of any waste material properly. Safety precautions always follow safety guidelines when using a grinder, including wearing appropriate safety equipment and ensuring proper ventilation in the work area. Following these steps and using proper grinding techniques will produce a fine RPOP powder.

To achieve a constant powder size, the RPOP powder used is sieved through a screen with a mesh size of 1.25MM. As shown in Figure 3.4 (a) and the RPOP powder after sieving process in Figure 3.4 (b).



a) b)

Figure 3.4 a) The Sieve RPOP Using Mash B) Powder RPOP After Sieved

Recycling plaster of Paris powder can be a sustainable practice and sieving it through a screen with a mesh size of 1.25MM is a good method to remove impurities and lumps, ensuring a finer and more uniform powder for reuse. This process helps to separate any debris or larger particles from the finer plaster particles, allowing for effective recycling of the material. After sieving, RPOP powder can be reused in various applications such as casting moulds, carving or any other creative project that requires plaster. Make sure that RPOP powder is always stored in a dry and airtight container to prevent it from hardening early and being exposed to air.

Figure 3.5 shows the preparation process of RPOP powder. Recycling plaster of Paris powder involves several steps to ensure it is clean and suitable for reuse. This process involves several key steps, each crucial for ensuring the recycled plaster retains desirable properties for reuse. Collect mould POP from previous projects or unused moulds. This mould, having served its initial purpose, is now ready to be recycled. Used moulds are usually made of POP, a material known for its excellent moulding properties and ease of use in producing detailed and accurate moulds. Second step, break the collected plaster material into smaller pieces using a crusher or grinder. The third step, grind the POP to a fine powder and sieve to achieve a uniform particle size distribution. The next step involves crushed the old mould. This is achieved using a crusher, a machine designed to break the solid pieces of the used mould into smaller pieces. Crushing the mould is a critical step as it reduces the material to a manageable size, facilitating easier handling and further processing.

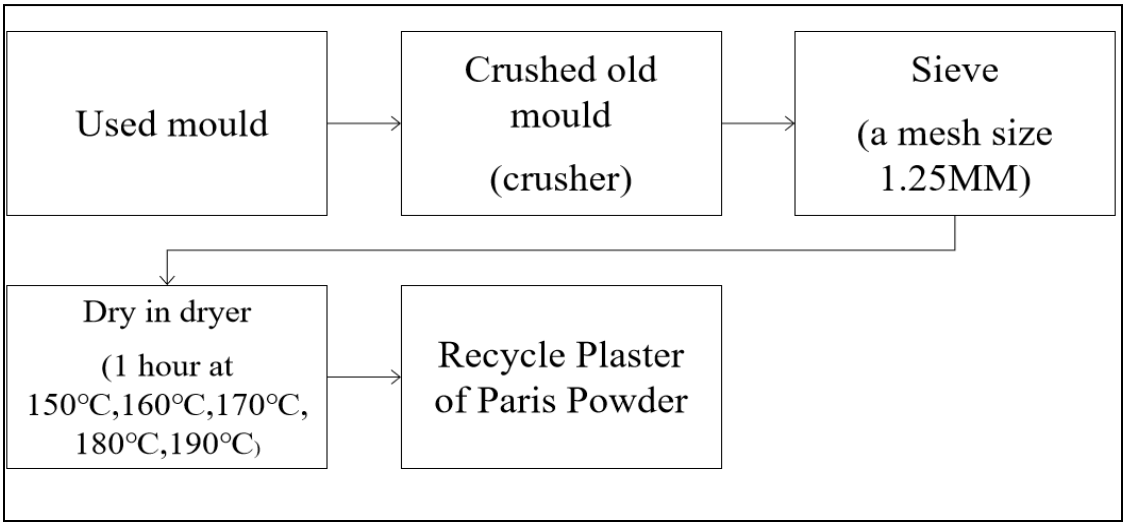


Figure 3.5 Process for preparation of powder RPOP

The crushed material should be fine enough to pass through the subsequent sieving process but not so fine that it loses its structure completely. When the old mould has been destroyed, the powder needs to sieve. Sieving involves passing the crushed mould through a sieve with a specific mesh size, in this case, 1.25 µm. The purpose of screening is to separate particles based on size, ensuring that only appropriately sized particles are passed through the recycling process. Particles that are too large are likely to affect the quality and consistency of recycled plaster. Thus, filtration ensures uniformity and consistency in the final recycled product. This step facilitates the grinding process in the next step and ensures a more uniform particle size distribution. Remove any debris or foreign particles from the collected plaster of Paris powder. This step aims to achieve a uniform particle size distribution, which is essential for the quality and consistency of the recycled plaster of Paris. Using through a fine mesh sieve or use a strainer to ensure purity. Sieve the RPOP powdered to separate any larger particles or debris. This step helps in obtaining a finer and more uniform powder, enhancing its quality and suitability for reuse. Using a fine mesh sieve or a strainer can help ensure the purity of the recycled plaster of Paris powder.

The last step, heat the crushed plaster fragments to the recommended temperature. This step is important to remove any moisture, which can affect the quality of the plaster when reused. Moisture can negatively impact the quality of the plaster when reused, leading to issues such as uneven drying or compromised strength. This step is crucial for ensuring the optimal performance of the recycled plaster of Paris. The material is subjected to a drying process. This step involves placing the sifted material in a dryer, where it is heated to an increasing temperature. The drying schedule shown in the includes heating for one hour at each of the following temperatures: 150°C, 160°C, 170°C, 180°C, and finally 190°C. A gradual increase in temperature ensures thorough drying of the material. Proper drying is essential to remove any moisture content from the recycled plaster. Moisture can cause problems in the setting and strength of the plaster when it is reapplied, so achieving a completely dry state is important.

Based on earlier research by Bardella & Camarini (2012), which showed that recycled POP hemihydrate reformation performed best at this range, the drying temperature of 160°C was selected. The integrity of the material is weakened by partial breakdown to anhydrite at temperatures higher than 170°C.

By following this step, used mould can be effectively recycled into RPOP powder for future projects. Remember to store any unused RPOP powder in a sealed container to prevent moisture absorption and maintain its quality for future use. High-quality RPOP powder can be made by meticulously following each phase, which includes crushing, filtering, drying, and recycling. This not only promotes sustainability by decreasing waste and saving resources, but it also provides practical answers for sectors that rely on plaster of Paris. Proper execution of this procedure can result in significant economic and environmental benefits, making it an important practice in the field of material recycling.

3.3 Characterization Test of New Plaster of Paris (NPOP) and Recycle Plaster of Paris (RPOP)

Plaster of Paris (POP) is a material that is commonly utilized in building, medicine, and most importantly for the purposes of this study is art because of its quick setting time, lightweight, and affordability. However, because it is made from non-renewable gypsum and produces a lot of waste which usually ends up in landfills, its broad use also raises environmental problems. Recycling POP into a reusable form must be investigated as a sustainable solution to this problem. This study focuses on the characterization of New Plaster of Paris (NPOP) and Recycled Plaster of Paris (RPOP) to evaluate the performance and suitability of these two materials for casting molds. The characterization tests involve the evaluation of their physical, chemical and mechanical properties, which are important to determine their quality, durability and effectiveness in absorbing slip.

3.3.1 Drying Process of Recycle Plaster of Paris (RPOP) at Temperature 37℃ (Room Tempurature), 150°C, 160°C, 170°C, 180°C and 190°C

POP a versatile material used in various industries including construction, art, and medicine, often leads to huge wastage. However, through innovative processes such as calcination drying, it can be efficiently recycled, reducing environmental impact and conserving resources. Calcination involves heating the gypsum to drive off water molecules, converting it to calcium sulphate hemihydrate, or "stucco", a precursor to POP. Initially, the POP waste is dried to remove any residual moisture, ensuring efficient calcination. Heating dry POP to a certain temperature (around 150-165°C) breaks down the hemihydrate into calcium sulphate and water vapor.

The drying process of POP involves the removal of water content from the material, and temperature plays an important role in this process. Drying and recycling plaster of Paris can be a cost-effective and environmentally friendly approach. Plaster of Paris is a type of gypsum that, when mixed with water, forms a hard white substance. The drying procedure needs to be completed to remove the water content of the RPOP. The temperature used is the boiling point of water, but the researcher has increased the drying temperature so that the RPOP dries completely and uses the same set time of one hour. As shown in Figure 3.6 (a), the fine powder RPOP will be dried for 1 hour at 37 ℃, 150 ℃, 160 ℃, 170 ℃, 180 ℃, 190 ℃ in the dryer. Drying is carried out to reduce or eliminate the water content in the POP powder used. Set the temperature and drying time according to the specific needs of the POP. The RPOP is dried using a pre-set temperature and time oven and stored in an airtight bin to ensure that the RPOP is not exposed to air. Industrial-scale calcination drying requires specialized equipment such as rotary kilns or fluidized bed dryers as show on Figure 3.6 (b).

(a) (b)

Figure 3.6 (a) The RPOP Inside The Kiln (B) And The Kiln Using For Dryed RPOP

3.3.2 Particle Size Analysis of New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 37°C (Room Tempurature), 150°C, 160°C, 170°C, 180°C and 190°C

In the context of the POP test, the CILAS instrument can be used to analyse the particle size distribution of plaster powder. POP, a type of calcium sulphate hemihydrate, is widely used in various applications such as construction, art, and medicine. Understanding particle size distribution is important because it affects properties such as setting time, strength, and workability of plaster. Using the CILAS particle size analyser, it can obtain detailed information about the size distribution of POP particles, from micrometres to millimetres. This data helps in quality control, process optimization and formulation adjustment in plaster manufacturing. This process usually involves dispersing plaster powder in a suitable liquid medium and subjecting it to laser diffraction analysis using CILAS equipment. Laser light interacts with the particles, and the resulting diffraction pattern provides information about their size distribution. By leveraging CILAS technology for particle size analysis, manufacturers can ensure the consistency and performance of POP products, meeting the specifications and standards required for a variety of applications. The particle size of all materials for making mould were determined using the CILAS particle size analyser as show as in Figure 3.7, to determine the particle size of RPOP.

Figure 3.7 Machine CILAS Particle Size Analysis

Sample of POP powder was taken and then mixed into water until dissolved for 15minutes using spatula to disperse the powder particles. Sample in liquid was put into an analysis tank and the particle size results are recorded in the form of a graph. The dried and conditioned POP undergoes grinding and crushing to turn it into a fine powder. This process is important to achieve a uniform particle size distribution, improving the homogeneity and workability of RPOP. The particle size of POP typically depends on the specific manufacturing process used. However, in general, POP consists of fine particles with sizes ranging from a few micrometres to around 100 micrometres (μm). The precise particle size distribution can vary depending on factors such as the method of production, drying conditions, and any additives used in the formulation.

3.3.3 Scanning electron microscopy (SEM) of New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 37°C (Room Tempurature), 150°C, 160°C, 170°C, 180°C and 190°C

Scanning Electron Microscopy (SEM) is another powerful technique used in POP analysis. Although SEM differs from laser diffraction techniques as offered by CILAS, it provides complementary information that can be useful for understanding the morphology and microstructure of plaster particles. In the POP test, SEM can offer high-resolution images of plaster particle surfaces, revealing details such as particle shape, size, surface texture and any surface features such as cracks or pores. This information is important to understand the physical characteristics of plaster and how they can affect its properties and performance.

SEM analysis of POP involves preparing a sample by mounting it on a conductive substrate, such as a metal stub, and then coating it with a thin layer of a conductive material, usually gold or platinum, to increase conductivity and reduce charging effects during imaging. The prepared sample is then placed in the SEM chamber, where a focused electron beam is scanned across the surface of the sample. The interaction of the electron beam with the sample produces signals such as secondary electrons, backscattered electrons, and characteristic X-rays, which are detected and used to create high-resolution images and elemental maps of the sample surface. By examining POP samples using SEM, it can gain insight into the material's microstructure, which can inform process optimization, quality control and product development efforts. SEM analysis can help identify issues such as particle agglomeration, impurities, or irregularities in particle shape, allowing adjustments to be made to improve product quality and performance.

Figure 3.8 Elemental Analysis Using SEM-EDS (Energy Dispersive X-Ray Spectroscopy)

3.3.4 Phase Analysis of New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 37°C (Room Tempuratur), 150°C, 160°C, 170°C, 180°C and 190°C

Phase analyses of Recycled Plaster of Paris (RPOP) and New Plaster of Paris (NPOP) examined structural alterations and thermal performance at various temperatures. Their variations at room temperature (37°C), 150°C, 160°C, 170°C, 180°C, and 190°C were investigated in this work. The processes of dehydration and recrystallisation play an important role to determining the material's mechanical and chemical characteristics at these temperatures. By analyzing the phases, it can aim to understand the impact of recycling on the material performance compared to NPOP. This study is important for optimizing the reuse of plaster in mould making applications.

3.3.5 Preparation of Setting Time New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 37°C (Room Tempurature), 150°C, 160°C, 170°C, 180°C and 190°C

Figure 3.9 shows the step-by-step procedure for preparing NPOP and RPOP sample test bars. First, thoroughly clean the silicon mould bars (4cm X 4cm X 4cm) to remove dust and debris. Apply a thin layer of release agent (coating paint) to the inner surface of the mould to prevent the mixture from sticking. Then, measure out the ingredients and weigh out the required amount of NPOP/RPOP and water. A typical ratio is 60g NPOP/RPOP powder and 40g water, but this may vary based on the application and desired mould size. Pour the measured water into the mixing container first. This helps to prevent lumps. Gradually add the NPOP/RPOP powder to the water while stirring continuously to form a smooth paste without lumps. Avoid adding water to the NPOP/RPOP, as this can cause the mixture to be uneven. Mix the components thoroughly.

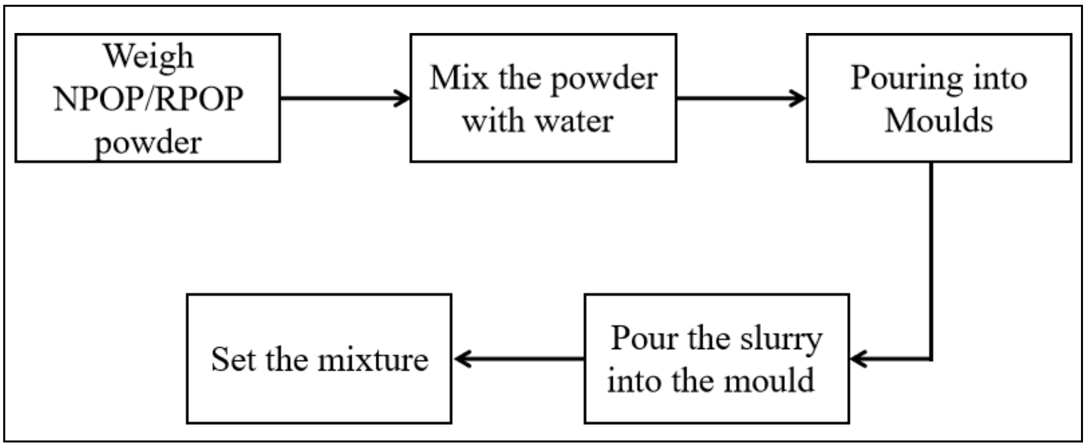


Figure 3.9 The Procedure Preparation Of Test Bar Setting

The mixture should have a thick, creamy texture, free of air bubbles or dry lumps. If necessary, tap the container gently to release trapped air bubbles. Pour the mixture into the mould. Slowly pour the prepared mixture into the mould. Fill evenly, making sure there are no gaps or voids. Smooth the surface using a spatula or straight edge. Allow the mixture to harden undisturbed. Once set, allow the bar to cure for 24 hours in a dry environment for maximum strength. Carefully remove the hardened bar from the mould.

3.3.6 Compressive Strength Test of New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 150°C, 160°C, 170°C, 180°C and 190°C

Compressive strength analyses be tested by using Compressive Strength Testing Machine (ASTM Standard). This standard outlines procedures for determining the compressive strength of gypsum products, including POP. A compressive strength testing machine applies a compressive force on a POP standard specimen until it fails. The maximum load at failure was recorded, and the compressive strength was calculated based on the cross-sectional area of the specimen. The compressive strength of plaster of Paris can be determined by a step test. The following is a basic outline of how to carry out such a test

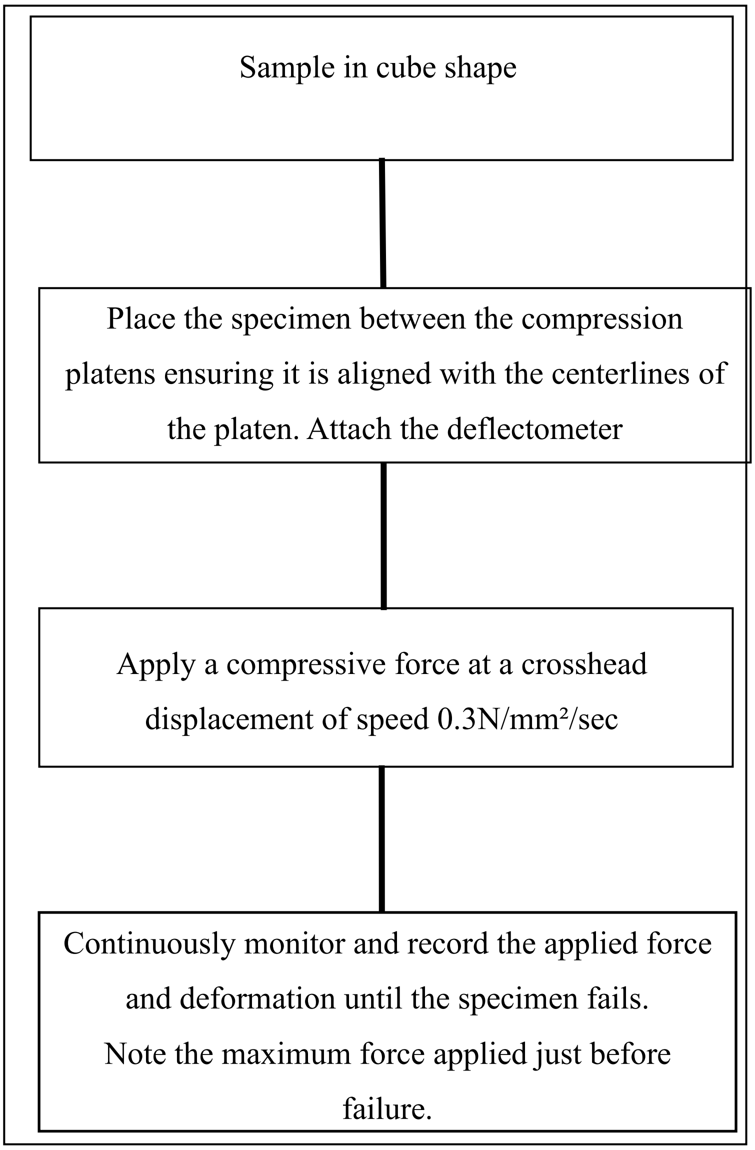


Figure 3.10 Flow Chart Of Compressive Strength

Prepare several samples of plaster of Paris according to cube-shaped specifications. Make sure each sample has the same dimensions and is mixed consistently and in the same ratio. Prepare a mould to be used in which the liquid sample will pour the plaster to form the sample cube. Make sure the mould is clean and dry to avoid any contaminants affecting the result. Follow the manufacturer's instructions to properly mix plaster of Paris. Be sure to mix it to a consistent texture and pour it into the mold immediately after mixing to avoid another shaped setting. Allow the plaster to cure in the mould for a certain period, usually 24 hours, to ensure that it reaches its maximum strength. After the curing period, it can start the step loading process.

This involves applying additional load to the sample until the sample breaks as Figure 3.11 show. Follow safety protocols during the testing process, especially when dealing with heavy loads and potentially fragile materials. Also, make sure the test equipment is properly calculated to get accurate results. The sample should be square with minimum pf 10.16cm (4 inch) and maximum 19.44 cm (36 inch). The height should be a minimum of 2.54 cm (1 inch) and the maximum height should be exceeding the width or the diameter of the specimen. In this study, the sample used is cube-shaped with a size of 50mm × 50 mm. Strict adherence to ASTM guidelines is necessary to provide reliable and consistent test results.

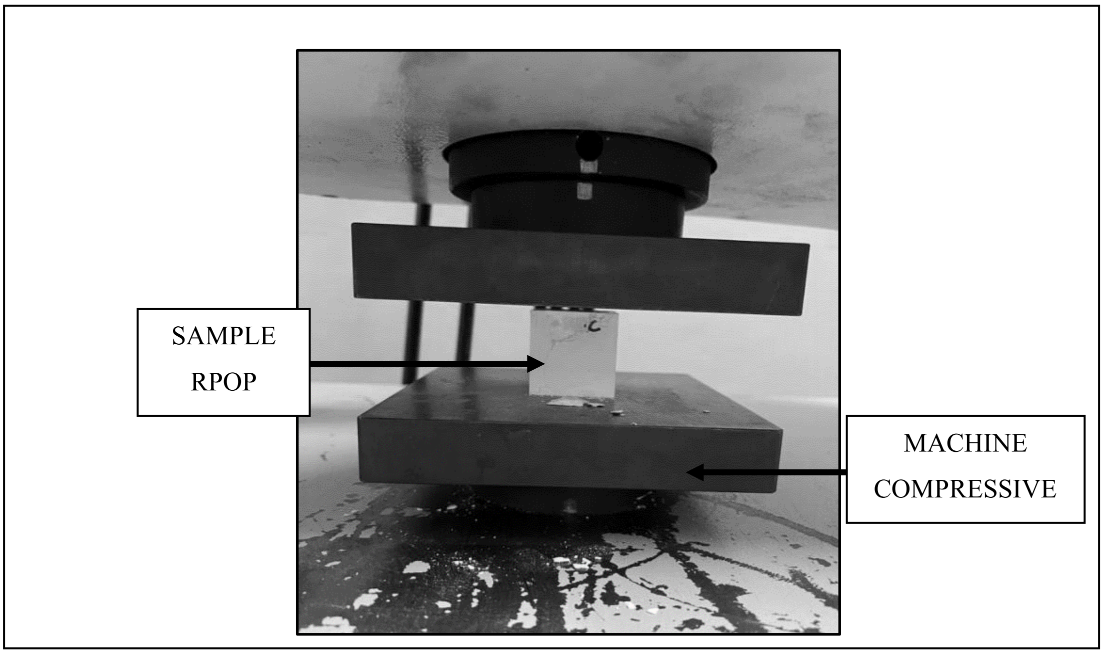


Figure 3.11 The Current Sample Is Tested Using A Machine Compressive Strength Testing Machine (ASTM Standard)

3.3.7 Porosity Testing of New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 150°C, 160°C, 170°C, 180°C and 190°C

Porosity of sintered samples were measured by using Metter Toledo density Kit following Archimedes principle (ASTM 372), Abdullah Mat Nawi, (2016), porosity and bulk density was used calculation by the Archimedes's principle as show as in below. Porosity can be determined by three measurements, which are mass of dry sample in air, (Wd), mass of the specimen that have been immersed and suspended in liquid, (Ws), and mass of the specimen that have been immersed and suspended in air, (Ww), which are respectively calculated in grams (g) and the result will present on graph plots in percentage.

$$Porosity = \frac{Ww - Wd}{Wd - Ws} \times 100\% \qquad (3.1)$$

$$Bulk\ Density = \frac{Wd}{Wd - Ws} \times 100\% \qquad (3.2)$$

A common method of testing porosity is the water absorption test. In this test, a sample of POP is weighed and then soaked in water for a certain period. After soaking, the plaster is removed, excess water is wiped off, and the sample is reweighed. The difference in weight before and after soaking indicates the amount of water absorbed by the plaster, which correlates with its porosity. Higher water absorption suggests greater porosity, which may be desirable for certain applications such as casting moulds or engraving.

3.3.8 Water Absorption Test of New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 150°C, 160°C, 170°C, 180°C and 190°C

Water absorption tests usually involve soaking a sample of Plaster of Paris in water for a certain period and then measuring the increase in weight of the sample due to water absorption. The procedure is as follows directed in Figure 3.12, standard samples of Plaster of Paris are prepared, ensuring uniformity in size and shape to facilitate accurate measurements. The weight after drying was taken earlier. Next, making a coating on the plaster bars, Immersion in Water while recording the time. Then measure the increase in weight after soaking. Finally, the percentage of water absorption is calculated using the formula.

$$Water\ Absorption\ (\%) = \frac{(Final\ weight - Initial\ weight)}{Initial\ weight} \times 100 \qquad (3\ .3)$$

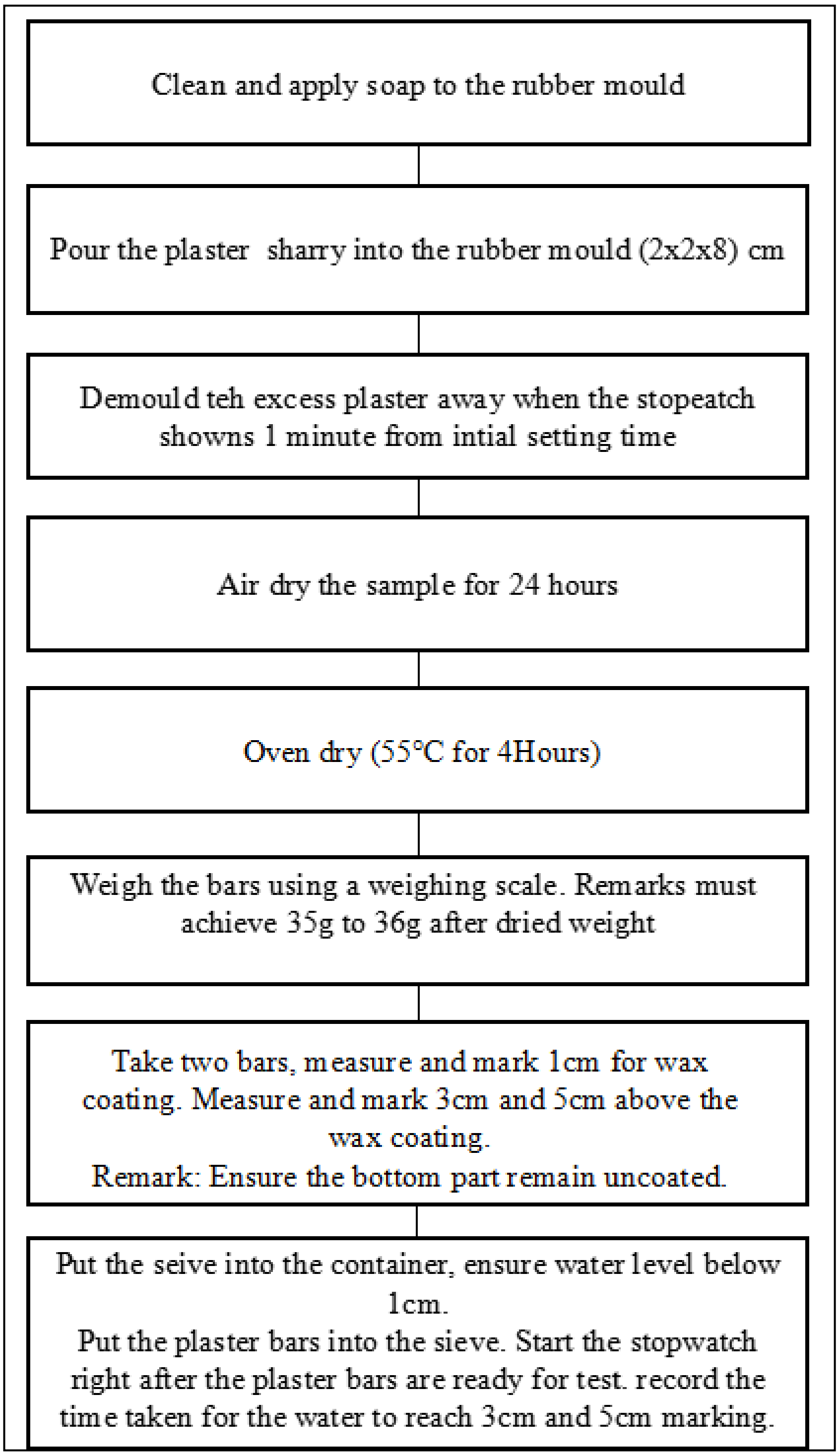


Figure 3.12 Flow Chart Of Test Absorption

POP sample bars that are being tested for their absorption level. All sample bars are placed in a vertical position so that it is easy to see the level of water absorption on the body plaster. Fill the container with water deep enough to completely submerge the sample bar. Carefully place each sample bar in the container, making sure it is completely submerged in the water. Allow the sample bar to soak in the water for a certain period. During this time, check the bar periodically for any changes in its appearance, such as darkening due to water absorption.

The results obtained from water absorption tests provide valuable insight into the quality and performance of Plaster of Paris. A low percentage of water absorption indicates higher density, reduced porosity, and increased resistance to moisture ingress, making it suitable for applications that require durability and strength, Conversely, a high percentage of water absorption indicates greater porosity and reduced durability, requiring caution or alternative materials for specific uses.

3.4 Preparation Sample Testing of New Plaster of Paris (NPOP), Recycle Plaster of Paris (RPOP) 160°C and Recycle Plaster of Paris (RPOP) 160°C Add Activator Silubit G80 0.5%,1.0%,1.5% and 2.0%

To determine the suitable formula for mixture NPOP and RPOP has been created to identify the optimum formula for add activator. Based on the formulation listed in Table 3.2 shows, there are seven formulations were reported. Every sample formulation of ratio was prepared by using 40g of water and 60g of powder RPOP for the sample size. The formula was added to the activator with a difference percentage to mix with 100gram sample Recycle Plaster of Paris. Then the sample of RPOP will be added with the activator Silubit G80 with a few percent (0.5%,1.0%,1.5% and 2.0%) dissolved in the water used to mix the sample. Silubit G80 is a type of silane-based water repellent that is often used in POP materials to provide improved properties.

Table 3.2

General Information Setting Test NPOP, RPOP And RPOP Add Activator

SAMPLE CODE	ADD ACTIVATOR (Silubit G80) Will be added to the best RPOP result
NPOP	NAL
RPOP 150°C RPOP 160°C RPOP 170°C RPOP 180°C RPOP 190°C	0.5% (A) 1.0% (B) 1.5% (C) 2.0% (D)

NAL = Zero

Silubit G80 was chosen as the chemical activator because of its shown ability to speed up the hydration reaction and improve intercrystalline bonding within the plaster matrix during the setting phase. This additive works as a fine silica-based substance to strengthen the recycled plaster's densification and structural integrity, which enhances its mechanical strength and surface quality. A concentration range of 0.5% to 2.0% by weight was chosen in order to identify the ideal dosage that might increase compressive strength while also decreasing porosity and preserving desired workability. The range was established using material safety criteria, supplier technical data, and the results of the study's initial pilot testing. These tests showed that concentrations in this range improved the recycled plaster's mechanical and physical performance in measurable ways without having a negative impact on mould handling qualities or setting time.

Recycled plaster of Paris (RPOP) plus additives such as Silubit G80 provide a sustainable solution for mould casting applications, offering better performance and enhanced properties. Evaluation of compressive strength is important in ensuring the suitability and reliability of RPOP + Silubit G80 mixture for mould casting. The addition of Silubit G80 improves the workability of the RPOP mix, facilitating smoother mould filling and reducing the risk of voids or defects in the cast object. This increases the efficiency of the overall casting process and enables the reproduction of intricate details with greater precision.

3.4.1 Setting Time of RPOP 160°C + Silubit G80 (0.5%-2.0%)

The inflow chart outlines the steps for preparing and measuring the setting time of Recycled Plaster of Paris (RPOP) at 160 °C with the addition of Silubit G80 at various concentrations (0.5%, 1.0%, 1.5%, and 2.0%). The Figure 3.13 shows a step-by-step explanation, RPOP powder, which was heat- treated at 160°C, was weighed according to the quantity required for the experiment. Silubit G80, a water-soluble additive, was weighed in different concentrations (0.5%, 1.0%, 1.5%, and 2.0%) compared to the RPOP powder. Then, the pre-weighed Silubit G80 was dissolved in water by stirring until it was completely dissolved. This ensured invariant dispersion in the mixture. The prepared Silubit G80 and water solution was then used to mix RPOP 160 powder. This resulted in a homogeneous slurry. The setting process was observed, and the time taken for the slurry to set was recorded using a stopwatch. The slurry is poured into a mould to allow it to harden and solidify to the desired shape. This process evaluates how the addition of Silubit G80 affects the setting time of the RPOP 160°C mixture.

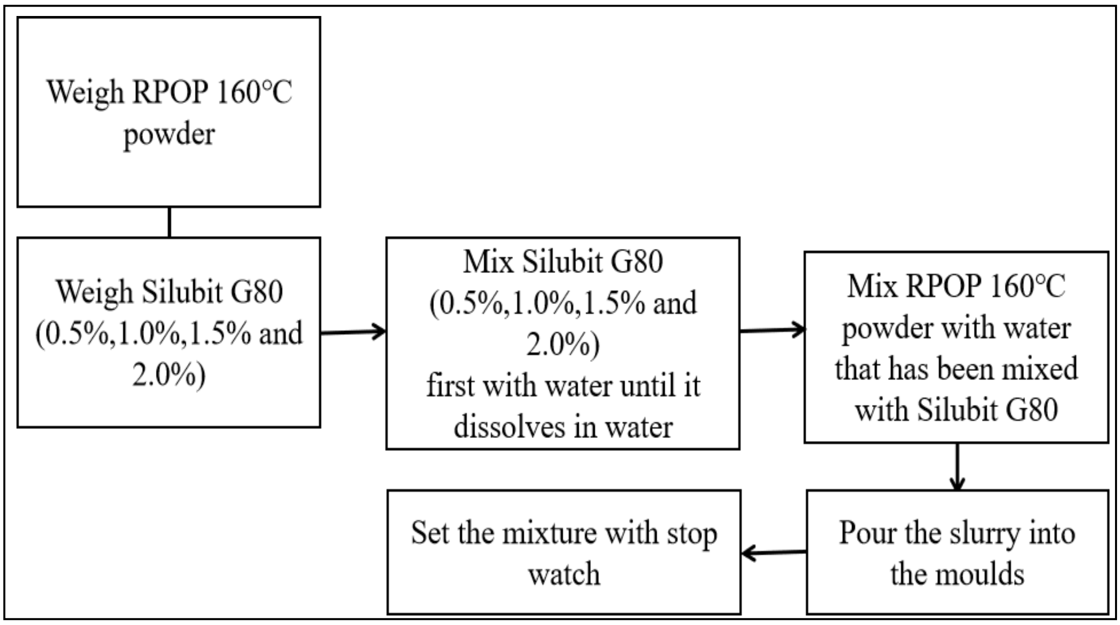


Figure 3.13 The Procedure Preparation Of RPOP 160°C + Silubit G80 (0.5%- 2.0%) Test Bar Setting

3.4.2 Compressive Strength Test of RPOP 160°C + Silubit G80 (0.5%-2.0%)

The flowchart provided from Figure 3.14 describes the process of testing the compressive strength of Recycled Plaster of Paris (RPOP) at 160°C + Silubit G80 (0.5% - 2.0%).

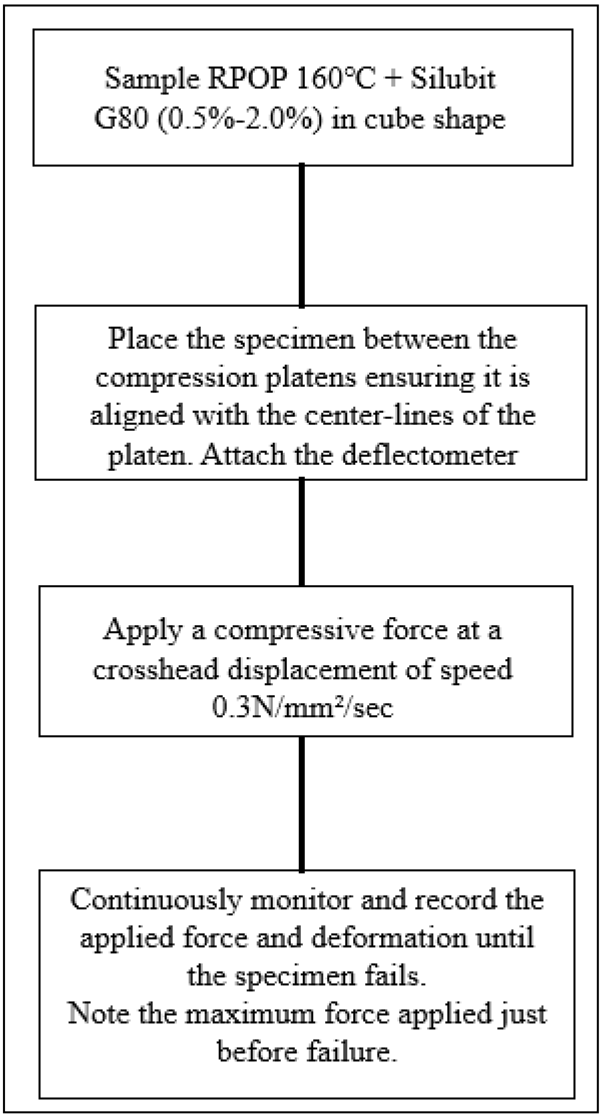


Figure 3.14 Flow Chart Of Compressive Strength RPOP 160°C + Silubit G80 (0.5%-2.0%)

The process begins with the preparation of RPOP powder, which has been pre-treated at 160°C to achieve specific properties suitable for the experiment. At the same time, Silubit G80, an additive, is directly weighed in varying percentages (0.5%, 1.0%, 1.5%, and 2.0%) before being dissolved in water to investigate its effect on the compressive strength of RPOP 160°C. Once the slurry is prepared, it's poured into a mould with destined dimensions. This mould provides a consistent shape and size for the specimen, ensuring uniformity during the compressive strength test. Proper care is taken to avoid air bubbles and ensure that the mixture is well compacted in the mould. The specimen is allowed to set in the mould for a specified period, allowing the RPOP 160°C + Silubit G80 mixture to harden. After being taken out of the mould, the hardened specimen is put through a compressive strength test. A compressive strength testing machine is used for this, applying increasing weights until the specimen breaks. The compressive strength values recorded for samples with different result of Silubit G80 (0.5%, 1.0%, 1.5%, and 2.0%) are compared and analyzed. This analysis helps determine the optimum result of Silubit G80 that maximizes the compressive strength of the RPOP 160°C.

3.4.3 Porosity Testing of RPOP 160°C + Silubit G80 (0.5%-2.0%)

Using a Mettler Toledo density kit and Archimedes' principle, the porosity of the sintered sample was determined (ASTM 372) and the same calculation steps were used during New Plaster of Paris (NPOP) and Recycle Plaster of Paris at Temperature 150°C, 160°C, 170°C, 180°C and 190°C as mention in 3.3.7 (pages 152-153).

3.4.4 Water Absorption Test of RPOP 160°C + Silubit G80 (0.5%-2.0%)

The process to carry out water absorption tests on Recycled Plaster of Paris (RPOP) at 160°C with Silubit G80 added at percentages ranging from 0.5% to 2.0% is shown in Figure 3.15 the flow chart. The test begins with the preparation of RPOP 160°C. Silubit G80, a water-soluble additive, is directly weighed in different proportions (0.5%, 1.0%, 1.5%, and 2.0%). The additive is dissolved in water and mixed thoroughly with RPOP 160°C powder to produce a slurry. The slurry mixture is poured into a mould to form a standard specimen. The cast specimen is then allowed to set and cured under controlled conditions to ensure complete hydration. After curing, the specimen is dried in dryer at a specified temperature to remove any residual moisture. This step standardizes the original condition of the specimen before it's subordinated to the water absorption test. The dried specimen is weighed to determine its initial dry weight. It's also immersed in water for a specified period, ensuring that all surfaces are in contact with water. This step simulates exposure to moisture and allows water to access the pores of the material. After the immersion period, the specimens are removed from the water, and excess surface moisture is wiped off using a damp cloth. The wet weight of each specimen is recorded. The difference between the wet and dry weights reflects the amount of water absorbed by the material. The percentage water absorption is calculated. This formula measures the ability of a material to absorb water, expressed as a percentage of its dry weight.

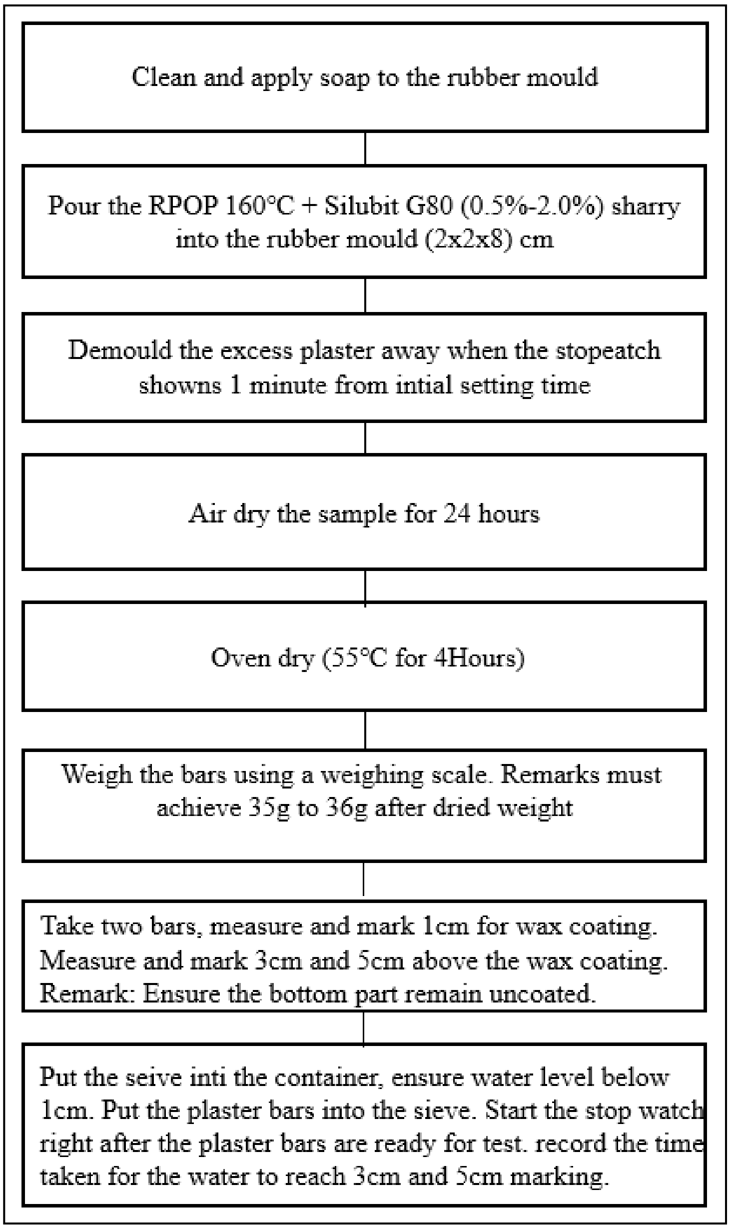


Figure 3.15 Flow Chart Of Absoption Test RPOP 160°C + Silubit G80 (0.5%- 2.0%)

3.4.5 Testing The Optimal of RPOP 160°C + Silubit G80 0.5% for Morphology Test

According to the optimal results of the testing RPOP 160°C + Silubit G80 (0.5%-2.0%) setting time, compressive test, porosity test, and absorption test, the optimal sample RPOP 160°C + Silubit G80 0.5% was chosen for the chemical test. Sample preparation is usually the first step in the SEM analysis process, and it is important for getting precise and significant results. To reduce the effects of charging during imaging, POP samples often have been coated with a small layer of conductive material, such as carbon or gold. After being ready, the sample is put into the SEM's vacuum chamber and exposed to a concentrated electron beam. Secondary and backscattered electrons are produced by this interaction, together with X-rays, which are measured to provide compositional information and high-resolution pictures.

3.4.6 Testing the Optimal of RPOP 160°C + Silubit G80 0.5% for Phase Analysis

XRD is a primary tool for phase identification. After exposing a powder sample to X-rays, the diffraction pattern is noted. Phases such gypsum (dihydrate), bassanite (hemihydrate), or anhydrite can be precisely identified by identifying peaks in the diffraction pattern that correlate to particular crystal structures. The findings provide light on how much phase shift occurs throughout the recycling process and whether RPOP is suitable for reuse. SEM can be used to visually inspect the microstructure of recycled POP. High-resolution images reveal the morphology of the crystalline phases and any impurities or changes introduced during recycling. Energy Dispersive X-Ray Spectroscopy (EDS), often combined with SEM, provides elemental composition data to complement phase identification.

3.5 Lifecycle Test of Mould of NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 0.5%

Through , the next process continues with making the model. A model casting mould, also known simply as a casting mould, is a hollow cavity into which molten material is poured to create a three-dimensional replica or casting of an original model or pattern. These moulds are used in various industries, including manufacturing, art, and crafts, to produce precise and detailed replicas of objects.

The model is created of cylindrical Plaster of Paris and moulded with a vertical lathe machine to achieve the basic shape of the cup before being shaped. This cup model takes a week to produce because the square bend design needs proper research so that there are no problems during the mould making and casting process. This is because the square design may cause problems when stuck between the 2 parts of the mould and the model. When the model is completed, continued by making the moulds are made from NPOP and RPOP (160℃ + activator). The ratio used is 40:60, the same as the ratio used in the sample making process. At the beginning of the mould making process, the surface of the model has been prepared so that the surface of the mould does not leave an unwanted effect because of the model's imperfection. The surface of the model is wiped with soap on the surface so that it does not stick to the mould when you want to use the model and the mould.

Once master model is completed to the desired specifications, it undergoes a process to create a mould, which will then be used to produce multiple copies of the original item.

3.5.1 Sample Mould For NPOP, RPOP 160℃ and RPOP 160℃ + Silubit G80 0.5%

After all the testing is done it been continuing with making sample mould for the next test for casting ability and mould life cycle. It is followed by sample mould making. Referring to objective 3, the mould test was made through selection from the physical test between NPOP and RPOP which showed results almost the same as NPOP. The mixture of gypsum and water for mould is similarly ratio sample making. The sample mould uses a cylinder-shaped cup model. Square mould can use a board or box to make a mould around it. Make sure the box is tall enough to hold the plaster. The object is in the canter of the mould box. If necessary, clay can be used to secure the object and prevent the plaster from leaking underneath. Plaster mix using a ratio of 40:60. The mixing formula refers to 3.4, if the sample is RPOP + Activator, water needs to be mixed with the activator mixture before the RPOP powder is poured. The mixture is stirred until it has a smooth consistency and no lumps. POP liquid pouring should be careful into the mould box, so that the object is protected. Tap the sides of the box to remove air bubbles and make sure the plaster fills all the details of the object. After that, the plaster is left to harden, and this usually takes several hours. When the plaster has completely set, carefully remove the mould box, and open the plaster mould from the object. If necessary, remove any rough edges or imperfections in the mould.

Observation of mould surfaces after casting is a critical process in manufacturing and materials engineering, ensuring the quality and structural integrity of cast products. Inspection of the mould surface after casting involves a comprehensive analysis of various aspects, including surface finish, defects, thermal characteristics, and the overall condition of the mould. This detailed inspection is important because it helps in identifying potential issues that could affect the performance and lifespan of the final product.

3.5.2 Preparation of stoneware slip

Stoneware slip is a liquid clay mixture applied to pottery to give a smooth and durable surface. It is usually made from a combination of clay, water, and sometimes other additives such as flux or dye. To prepare a stone pot slip, measure the appropriate amount of clay powder. This can vary depending on the consistency of the desired slip and the amount of surface area that needs to be covered. Usually, the water mixture is gradually added to the clay powder, stirring constantly to ensure that the mixture is smooth. The amount of water required depends on the specific type of clay used and the thickness of the slip desired. Once the slip is mixed and has reached the desired consistency, it is ready to be applied to the pottery. This can be done using a brush, sponge, or dipping method and in this study the casting mold technique depending on the desired effect.

In this study, stoneware slips were used in the casting process to produce a hard result from the skin. Stoneware slip is a liquid mixture of stoneware clay and water that is placed on the surface of ceramic ware before it is fired in a kiln. Stoneware was chosen because high temperature firing produced a dense, robust, and non-porous material. Stoneware includes a variety of clay bodies and fire techniques, but they are distinguished by their strength, versatility and use for functional and decorative purposes. Stone production for casting, researchers need water, stoneware clay/cake and deflocculants like sodium silicate to improve the slip consistency. The ratio of clay to water depends on the desired consistency, the slip and common starting is around

70% water and 30% clay by weight. Using a blender or blunger to mix the clay and water thoroughly. It helps break up any clumpy and ensures a smooth and consistent slip. It will test the viscosity of slip by dipping a finger into the slip and add some deflocculation to help disperse the clay particles more evenly in the slip and can improve casting quality. If the slip is too thick add more water or too thin add more clay. Overall, preparing stoneware slips requires careful measuring and mixing to ensure it has the right consistency and properties for pottery project.

Figure 3.16 shows the process of mixing the slip casting before pours the slip into the mould. Slip is a liquid mixture of clay and water, and mixing it properly ensures that it has a consistent texture and composition. This is why mixing slips are important for mixing slips ensuring that all components are thoroughly mixed, resulting in a consistent texture and composition. This uniformity is important to achieve even coverage and consistent results when using slip on pottery or ceramic pieces.

Figure 3.16 Mix Stoneware Casting Before Used For Casting Process

This process needs to be done regularly because over time, heavier particles in the slip can settle to the bottom of the container, leaving a layer of water on top. By mixing the slip before use, you redistribute these deposited particles throughout the liquid, preventing uneven application and ensuring that the slip retains its desired properties.

In addition, in this test its always ensures that this process can help remove any air bubbles that may form during storage or mixing. Air bubbles can create weak spots or imperfections on the surface of pottery or ceramic pieces, so it's important to mix the slip carefully to remove them. A well-mixed slip will have a consistent viscosity and texture, making it easier to apply evenly to the surface of pottery or ceramic pieces. This consistency ensures that the slip adheres properly and dries evenly, resulting in a smooth and uniform finish. Mixing slips before use is essential to achieve consistent results in pottery and ceramics. It ensures uniformity, prevents settling and air bubbles, and facilitates the application of a smooth and even slip on the sheet surface.

3.5.3 Specific Gravity (SG) Test of Stoneware Slip

A hydrometer, which is the piece of equipment is commonly used to determine the specific gravity (SG) of liquids or slurries, like slip for ceramic castings. Figure 3.17 shows the step-by-step process of using a hydrometer to measure SG in slip casting.

Before measuring the SG, ensure that the slip is well-mixed and homogeneous. This prevents any settled solids or air bubbles from affecting the measurement. Pour the slip into a graduated cylinder or a container tall enough to accommodate the hydrometer. Make sure there are no lumps or air pockets in the slip. Pour the slip into the graduated cylinder, ensuring it's at least three- quarters full. The volume should be sufficient for the hydrometer to float freely without touching the bottom or sides of the container. Insert the hydrometer into the slide gently. Give it time to settle and float. To avoid getting erroneous results, make sure the hydrometer is not in contact with the container's sidewalls. Give it time to settle and cease bouncing. Once the hydrometer stabilizes, observe the point at which the surface of the slip meets the scale on the hydrometer. Once the hydrometer stabilizes, observe the point at which the surface of the slip meets the scale on the hydrometer. If the measured SG is outside the desired range, adjustments can be made by adding more dry material cake clay to the slip to increase the SG or to decrease the SG it is necessary to add water or deflocculant to dilute the slip and reduce its density. After adjusting, recheck the SG using a hydrometer to ensure it is within the required range.

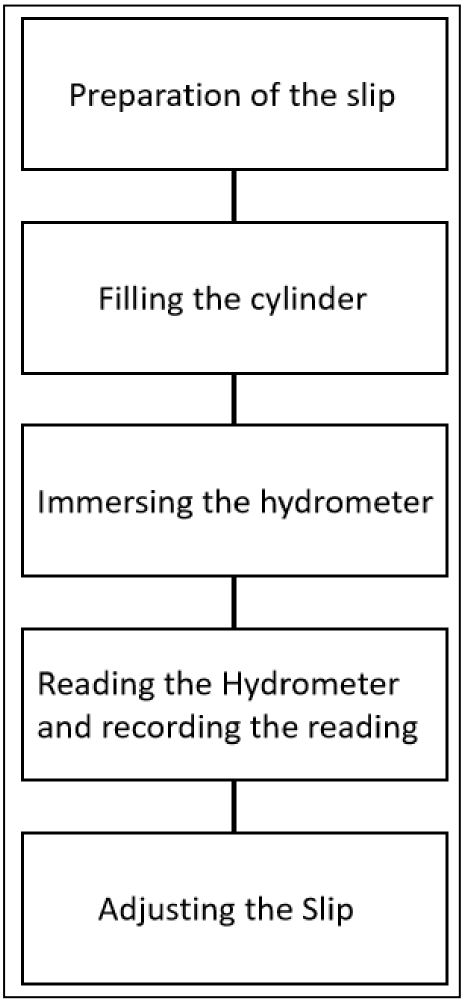


Figure 3.17 The Guide On How To Use The Hydrometer For SG Measurement

In this study, has used the Method of Checking Gravity through the Hydrometer method, which is a calibrated glass device that measures the density of a liquid with its buoyancy. By floating the hydrometer in the slip sample, the manufacturer can determine the specific gravity based on the depth to which the hydrometer is submerged. The specific gravity of an object is a measure of its density relative to the density of water. If the specific gravity of an object is less than 1, it will float on water. Specific gravity is a measure of density compared to the density of water. It is basically a comparison between the density of a substance and the density of water at a given temperature and pressure. Water, by definition, has a specific gravity of 1. If a substance's specific gravity is less than 1, it means it is less dense than water, so it will float on top of water. This principle is often used to determine whether an object will sink or float in water. If an object's density is less than water, it will float, if it is equal to or greater, it will sink.

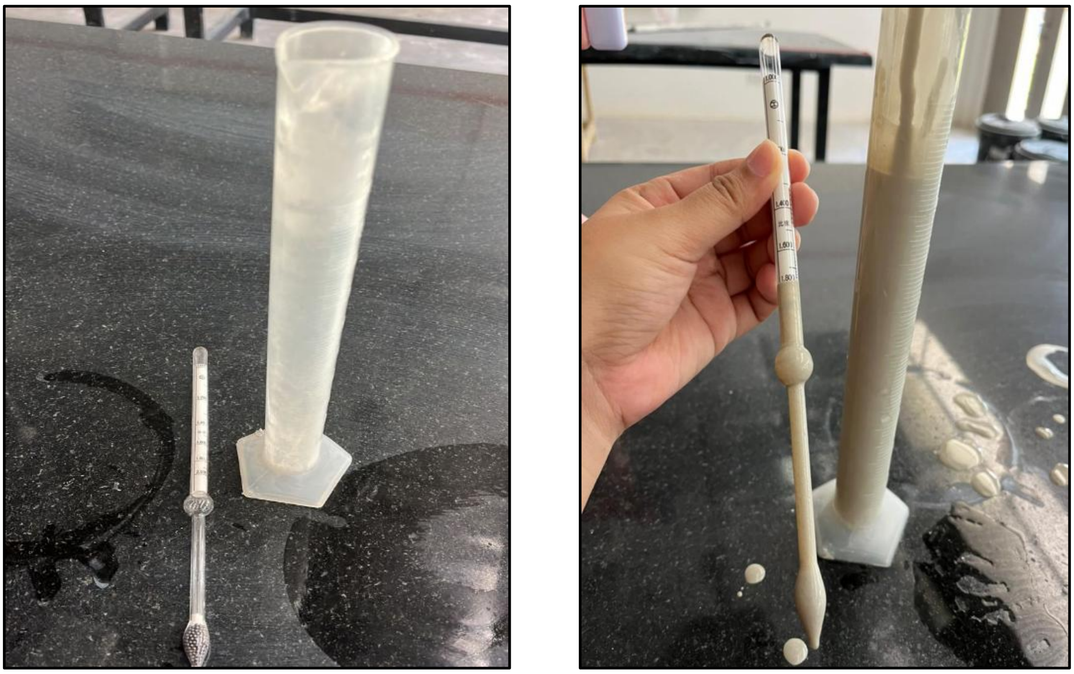


Figure 3.18 Checking Gravity Slip Casting

Checking the specific gravity is important to ensure the quality, consistency, and efficiency of slip casting in ceramic manufacturing. By carefully controlling specific gravity, manufacturers can produce high-quality castings with minimal defects, optimizing resource utilization and increasing the overall success of the production process. Therefore, careful monitoring and adjustment of gravity must be a fundamental aspect of any slip casting operation, contributing to the progress and sustainability of the industry.

3.5.4 Stoneware Slip Cast Process

The slip casting process is a common method used to produce ceramic objects with complex shapes, fine details, and smooth surfaces. Stoneware slip casting follows a similar process but uses stoneware clay slip, which contains specific materials to achieve desired properties such as strength and durability. The demonstrates that slip casting is carried out by pouring stoneware slip slowly in the mould to avoid the producers of air bubbles at the product surface, that may create big pores and pin holes on the product surface as show in Figure 3.19. Before beginning the slip casting process, the mould must be cleaned to eliminate any debris or dust from mould surface. The mould is rotated or vibrated to ensure that the slip fills all the intricate details of the mould and to remove any air bubbles that may be trapped in the slip. A precipitating layer will form on the surface of the Plaster of Paris mould, and slippage will result from the mould product wall's fluid absorption process. After 30 minutes slip in the mould reached, the balance stoneware slip is then poured and measure the thickness. The product casting test is left to dry in the mould for 1 hour before being removed from the mould.

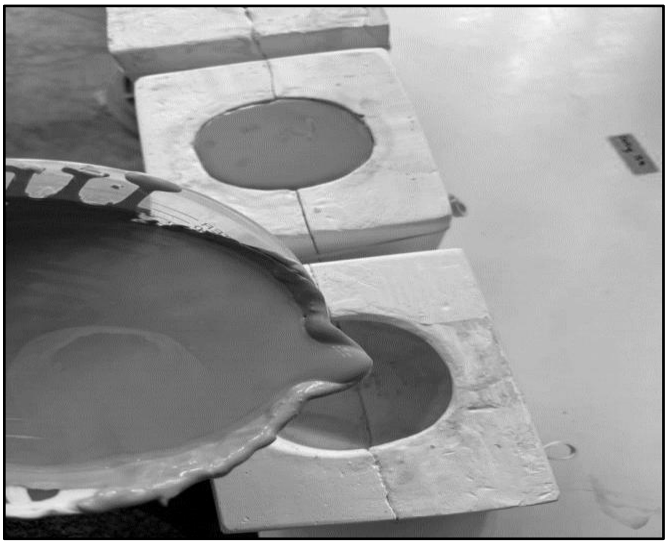


Figure 3.19 The Stoneware Slips In Sample Mould.

Slip casting to create stoneware is a difficult and interesting technique that combines art, science, and careful craftsmanship. Preliminary evaluations after casting provide vital insight into the work's quality, potential, and direction as it advances through the various stages of ceramic production. When the slip hardens and the mould is opened, the true appraisal of the item begins. When the mould is first removed, it leaves an impression of a delicate and fragile shape, wet from sliding. The surface, which remains soft to the touch, frequently shows minute intricacies created by the mould. These features, from delicate textures to smooth surfaces, demonstrate the precision and quality of the moulds used. At this point, any flaws in the mould or discrepancies in slip application are immediately obvious. Small air bubbles, mould seam lines, or thickness discrepancies can be noticed, necessitating a thorough investigation and possible rectification. The colour of the cast pieces at this point is also worth mentioning. Freshly poured stoneware is usually a consistent colour, either soft white or light grey, depending on the clay body used. This colour makes an ideal background for assessing the constancy and smoothness of the action. Colour variations can indicate differences in drying rate or slip composition. A mottled look, for example, may indicate uneven mixing processes or incorrect casting, whereas a more consistent colour indicates a properly prepared slip and a good casting process.

One of the critical aspects of observing stoneware slip castings after casting is the evaluation of the structural integrity of the pieces. Wet castings must be handled with care to avoid deformation or damage. At this stage, the casting is still quite flexible, and undue pressure or mishandling can cause warping or breakage. Viewing the pieces from various angles can help in identifying any subtle curves or bends that may have occurred during the drying process. This is especially important for pieces with large flat surfaces or thin walls, where such deformation is more likely.

The drying process itself is an important factor to note. As the cast begins to dry, it gradually transitions from a brittle, moist state to a more rigid and stable form. This drying process must be carefully controlled to avoid rapid drying, which can cause cracking. Observing the rate of moisture evaporation from the casting can provide insight into the ambient conditions of the workspace. Humidity, temperature and airflow all play an important role in how evenly and effectively the pieces dry. Uneven drying can cause stress in the part, leading to cracking or splitting, especially in thin parts or areas with intricate details. Shrinkage is another important aspect to monitor. When the slip dries, it inevitably shrinks, and this reduction in size must be uniform to avoid internal pressure. Observing the degree and uniformity of shrinkage can indicate the slip quality and consistency of the casting process. Measurements taken before and after drying can help quantify this shrinkage, providing valuable data for adjusting future slip batches or altering the casting process to ensure better consistency.

Surface texture also requires careful observation. The surface of the cast sheet, after it is sufficiently dry, should be smooth and free from noticeable defects. However, it is common to find minor surface irregularities that need to be addressed. This can include small air bubbles that burst during drying, leaving small craters, or slight roughness from mold seams. At this stage, soft sanding or other surface finishing techniques can be used to smooth out these imperfections, preparing the piece for the bisque firing stage. Additionally, the thickness of the cast piece is a crucial parameter to observe. Uniform wall thickness is essential for the structural integrity and aesthetic quality of the final piece. Variations in thickness can lead to uneven drying and firing, resulting in defects such as warping or cracking. Using calipers or other measuring tools to check the thickness at various points can help ensure that the casting process is producing pieces with consistent dimensions. Any significant deviations might require adjustments to the slip consistency, pouring technique, or mold design. At this stage, it is also important to observe the seams and joins where the mold pieces meet. These areas often require careful attention to ensure they are smooth and well-integrated with the rest of the piece. Seam lines can be gently scraped or sponged away while the cast is still damp, or they can be sanded down once the piece has dried sufficiently. Observing how well these seams disappear into the overall form of the piece is a key indicator of the craftsmanship and attention to detail involved in the slip casting process. Another aspect to consider is the handling of the cast piece as it transitions from the damp stage to leather-hard and finally to bone dry. Each stage presents unique challenges and opportunities for observation. At the leather-hard stage, the piece is firm enough to handle more robustly but still retains some pliability, allowing for minor adjustments or the addition of handles, spouts, or other features. Observing how the piece behaves at this stage can inform decisions about timing and technique for any additional modifications. Finally, the observation process extends to the psychological and aesthetic evaluation of the piece. This involves stepping back and viewing the piece not just as a technical artifact but as a work of art. The form, balance, and proportions of the piece are assessed, along with its tactile qualities and the potential for glazing and final finishing. This holistic observation ensures that the piece is not only technically sound but also meets the artistic vision and standards set for the final product.

3.6 The Testing Aesthetic and Intricate Form

Aesthetic and intricate forms in art refer to works that are visually pleasing and elaborate in design, often characterized by intricate details, careful craftsmanship, and a sense of beauty or elegance. These forms can be found across various artistic mediums, including sculpture, painting, architecture, ceramics, textiles, and more. Aesthetic refers to the quality of beauty or visual appeal in art. It encompasses elements such as composition, colour, form, texture, and harmony that contribute to the overall visual experience.

Aesthetic forms in art are those that evoke a sense of pleasure, admiration, or emotional response in the viewer. It may exhibit qualities such as balance, proportion, symmetry, rhythm, and contrast, which contribute to their aesthetic appeal. The often strive to create works that are not only technically proficient but also possess a strong aesthetic quality that resonates with viewers and elicits a positive reaction. The cup design started out as a sketch on drawing paper. The resulting cup design includes aesthetic and intricate features chosen for their applicability, which is then used to produce a design. The product size is then determined based on its suitability for usage as a daily beverage container. The height and width are 8 cm and 6 cm respectively. The shape of the ceramic cup is usually compact and easy to grip, making it more convenient for the user to use. However, in this study, the intricate shape of the cup was chosen because it matches the study to see the potential of RPOP when making a mould in addition to the aesthetic element still present in the design. Intricacy refers to the quality of being complex, detailed, or elaborate. Intricate forms in art are characterized by intricate patterns, designs, or structures that require careful attention to detail and precision in execution. Intricate forms can be achieved through various techniques, including meticulous craftsmanship, intricate line work, delicate shading, intricate carving, intricate weaving, or complex layering of materials. researchers often use intricacy to create visual interest, engage the viewer's attention, and convey depth, richness, or complexity in their work. Intricate forms may invite closer inspection, revealing hidden details or layers of meaning that enrich the viewer's experience.

3.6.1 Casting Process

The final process after the mould is ready, the mould needs to be dried at room temperature for one week by opening all parts of the mould. This is to remove the water content in the mould. This process is intended to facilitate the process of slip absorption. When this process is finished, the mould can be used for the casting process. Slip casting in Plaster of Paris is a technique widely used in ceramics to create precise and detailed clay shapes. This process involves preparing a liquid clay mixture, known as slip, and pouring it into a Plaster of Paris mould. The mould absorbs the moisture from the slip, leaving a solid clay form behind. Here is a step-by-step guide for the slip casting process into the mould. First, pour the slip into the mould and make sure to pour the slip into the mould until it is full. Before that, make sure the plaster mould is dry before pouring the slip. Wet mould will not absorb moisture properly. Then, tap the sides of the mould gently to release any trapped air bubbles. The mould is tied with rubber for the purpose of bridging between the mould joints and avoiding leakage when pouring the slip. The mould is cleaned before pouring the stoneware slip manually slowly until it is full in the mould space. Leave the slip in the mould for a period of 30 minutes, this period being consistent with the next casting. The plaster mould will absorb water from the slip, causing the clay to thicken and stick to the mould wall. After reaching the specified thickness and time, pour the excess slip back into the mixing container. These slips can be reused for future plays.

Leave the mould with the rest of the clay form for another an hour to harden. Carefully remove the clay form from the mould. The shape should be harder than the skin (firm yet flexible). Clean the edges of the form with a sponge or small knife to remove any rough edges or excess clay. After an hour later, the mould will be opened from the product cup. Product cup thickness will be measured using digital callipers. This process will be applied on all types of moulds to observe the differences in the absorption results of the materials used. Finally, the cup product is left to dry at room temperature before firing bisque.

Testing the thickness of stoneware ceramics is essential to ensure uniformity and consistency, which is essential to its structural integrity and performance. In addition, in this study, RPOP used to re-mould. It is very important to test the thickness of stoneware slip after casting to ensure that the mould made of RPOP can absorb water well. Digital callipers are used to measure slip thickness after the casting process. A digital calliper is a precision equipment that can take incredibly precise measurements. The calliper is easy to use because of having a digital display. Most can take measurements up to 0.01 millimetres (0.0005 inch).

To conduct a thickness test on stoneware, requires some basic equipment and a systematic approach. The following is the general procedure for measuring product thickness is to select a representative Sample. Choose a set of stoneware cups that represent the typical thickness of the product line. Make sure it is free of defects that could affect the measurement. Make sure the vernier calliper is properly calibrated. This ensures accurate measurements. In addition, prepare a comfortable test area. Place a flat surface where the cup can be placed safely for measurement. Place each cup on a flat surface and measure its thickness at multiple points. It is important to measure at various locations on each cup to account for any deviations in thickness and record the measurements for each cup. Can also create a table to organize data effectively. Once have measurements for all cups, calculate the average thickness for each cup and for the entire sample set. Finally, analysis of thickness results. Compare the average thickness with the cup product specifications. Determine whether the measured thickness meets the required standards.

Depicts the way the slip's thickness is measured with a digital calliper after it has been removed from the mould. Measurements are taken before the product is completely dry or after it is removed from the mould. This aims to identify the actual size of the product wall before it dries which will cause the body to shrink.

3.7 Bisque and Glazing Firing

Firing and glazing are two critical processes in the creation of ceramic pieces, important for their functional and artistic qualities. This process transforms raw clay into durable and aesthetically pleasing objects used in everyday life and art. The journey from malleable clay to finished ceramic involves intricate steps that ensure durability, functionality and beauty of the object. The first stage of firing is called bisque firing, which changes the raw clay to a semi-vitrified state. A casting product that has been completely dried is called bone dry clay. During this process, ceramic pieces are slowly heated in a kiln at a temperature usually 900°C. This initial firing drives out any water content and organic matter remaining in the clay, and begins the sintering process, where the clay particles begin to bond together. Bisque firing produces a porous, yet hard, ceramic body that is easier to handle and shiny.

The second stage, glaze firing, occurs after the bisque-fired pieces have been coated with glaze. Glazing is a ceramic covering made up of silica, nepheline syenite, zinc oxide, calcium carbonate, kaolin, zirconium silicate, and colors suspended in water. Once the glaze is applied, the piece is re-fired at a higher temperature, often 1200°C. Several significant chemical processes take place during glaze firing. The silica in the glaze melts creates a glassy surface, while colorants, commonly metal oxides, combine with the glaze matrix to generate different colors and finishes. The final glaze firing not only hardens the ceramic body, making it less porous and more robust, but it also melts the glaze onto the surface, resulting in a smooth, glass-like coating. Glass ceramics is the application of a vitreous coating to the surface of a ceramic utensil, improving its beauty, durability, and function. This method usually consists of many basic steps. A piece of pottery is first burnt in a kiln at a lower temperature to solidify the clay. This step is known as bisque firing. After bisque firing, the item is thoroughly cleaned to remove any dust, dirt, or grease that could interfere with the glaze application.

Glaze is prepared from the mixture as below:

Table 3.3

Glaze Recipe

Materials	Percent %
Nepheline Syenite	44
Zinc Oxide	13
Calcium Carbonate	7
Kaolin	8
Silica	28
Zirconium Silicate	6
+ Colour	2

This raw material is combined with water to create a suspension. The glaze mixture is then sieved to remove lumps and produce a smooth consistency. Next, a flaming piece of bisque is dipped into the glaze. This procedure produces an even coating but necessitates careful handling to avoid fingerprints and drips. A portion of glaze is allowed to air dry until it is no longer sticky to the touch. This ensures that the glaze adheres properly while firing. The layered pieces are carefully placed in the kiln. It are unable to contact each other, preventing them from combining. The kiln is fired at a greater temperature than the bisque firing, which causes the glaze to melt and form a glassy surface. After the fire cycle is completed, the kiln is let cool gradually. Rapid cooling might cause thermal shock and damage to the sheet. Once cooled, gently remove the glazed pieces from the kiln. Finished pieces are scrutinized for flaws such pinholes, crazing, and glaze run. Any necessary adjustments or extra pictures are made to get the desired effect. By following these instructions, it can create a stunning and long-lasting ceramic product.

3.8 Summary

At the end of this chapter, it will be able to produce RPOP powder with the correct method by reference PS Bardella, G Camarini, (2012). The recycling process for used moulds involves crushing, filtering, and drying the plaster of Paris (RPOP) to increase surface area and speed up the drying process. The plaster is then ground twice to ensure smoothness and facilitate the sieve process. The original purpose of the old mould is to filter the RPOP powder before mixing it into water, reducing lumps. The RPOP powder is then sieved through a screen to achieve a constant powder size.

In addition to being able to identify the appropriate temperature for drying. Plaster of Paris (RPOP) is a gypsum that forms a hard white substance when mixed with water. The drying process removes water content, and temperature plays a crucial role. The increased the drying temperature to completely dry the RPOP in one hour. The RPOP is dried at various temperatures and times, stored in an airtight bin. This cost-effective and environmentally friendly method can be used for casting moulds. Then, it can conduct tests on all materials used in the study in the correct order. In this chapter also explained how to mix slip stoneware used in this study. Next, the method of making moulds and the selection model has also been clearly explained in this chapter. Testing the thickness of stoneware ceramics is important for its structural integrity and performance. In this study, RPOP was used for reshaping, and digital callipers were used to measure slip thickness after casting. Recycling plaster of Paris is crucial for reducing environmental impact and conserving resources. A combination of mechanical, chemical, thermal, and biological methods offers a comprehensive approach to POP recycling, each with its unique advantages and challenges. Technological innovations are essential for improving the efficiency and scalability of POP recycling processes.

This chapter described the Recycled Plaster of Paris (RPOP) preparation, characterisation, optimisation, and application phases of the systematic study design. Sustainable and ethical experimental practices were guaranteed by the integration of environmental safety and ethical handling guidelines. The study's process flow was made clearer by an organised methodology that included tables and flowcharts. Scientific and empirical evidence supported the selection of the Silubit G80 concentrations (0.5–2.0%) and drying temperature (160°C). These improvements improve the research's reproducibility and methodological transparency for further investigations.

CHAPTER 4
RESULTS

4.1 Introduction

This chapter explains the results of the research that has been carried out. The test was shown on the used mould after the recycling process was done and was called as Recycle Plaster of Paris (RPOP). The testing consists of analysing chemical and physical properties using setting time for solidification test, particle size, X-ray fluorescence (XRF), compressive strength test, absorption test, porosity test, casting and followed by mixing Silubit G80 activator in RPOP. The use of RPOP again is determined by the drying temperature of the RPOP powder before it is reused in the dressing. In addition, the casting process has also determined that RPOP can function again after undergoing the recycling process. Next, the formula of the mixture ratio of the POP mould is used the same to produce a mould using RPOP . This investigation was done to determine if RPOP has the same properties as NPOP even though it has been recycled. The drying temperature was identified and the difference in effect after RPOP was solidified with the addition of Silubit G80 in the formulation through the results after drying at 160°C for 1 hour with a mixture of 0.5% Silubit G80.

As mentioned before, the investigation of chemical and physical properties aims to analysed whether RPOP has the same properties as NPOP. Then continue with the mould making and casting test. In addition, mould making also plays a role in whether RPOP can make complicated types of moulds or not. This is continued with the production of cup models that have aesthetic value and intricate form. However, the design must work well for daily use. Last part of this chapter is thickness test through process casting using mould NPOP, RPOP, RPOP + Silubit G80 is done.

4.2 New Plaster of Paris (NPOP) and Recycle Plaster of Paris (RPOP) Powder Drying at Temperature 37°C (Room Temperature0, 150°C, 160°C, 170°C, 180°C and 190°C

The main factors that influence the color difference between NPOP and RPOP at various temperatures are the drying process, impurities and phase change. NPOP appears to have a consistent white colour, this is because NPOP is a POP powder that has not been used anymore. NPOP is the reference for the difference between all RPOP that have been dried at various temperatures. Figure 4.1 shows RPOP at 37°C appears brownish white, this is due to small impurities and used materials that have not been dried using a dryer, but it still maintains a similar colour. The removal of any remaining moisture and the partial dehydration of calcium sulfate dihydrate to hemihydrate may be the reason why RPOP becomes finer, and the colour becomes white when the temperature increases to 150°C and 160°C.

Figure 4.1 The Difference Colour Of NPOP RPOP At Different Temperatures

At RPOP 170°C, the material remains relatively white, indicating more complete metamorphism. However, at 180°C and 190°C, the RPOP appears slightly darker with a grayish colour, which can be attributed to further phase transitions or slight thermal degradation, possibly due to impurities reacting at the advanced temperature

In conclusion, RPOP generated a whiteness and texture similar to NPOP at 160°C, which suggested the proper degree of dehydration without thermal disintegration. This resulted in the best visual appearance of RPOP.

4.3 Physical and Chemical Properties of New Plaster of Paris (NPOP) and Recycle Plaster of Paris (RPOP)

Plaster of Paris mainly consists of calcium sulfate hemihydrate. The chemical reaction that produces Plaster of Paris from gypsum (calcium sulfate dihydrate, $CaSO_4{\cdot}2H_2O$) involves heating the gypsum to about 150°C, which removes water molecules, resulting in the formation of a hemihydrate. However, when POP becomes RPOP, the temperature for heating should be observed, as the properties of RPOP may change.

One of the most notable chemical properties of Plaster of Paris is its reaction with water. When mixed with water, it rehydrates and returns to gypsum, forming a hard solid mass. This reaction is one of the most significant chemical properties of Plaster of Paris and is the basis for its widespread use in various applications. When Plaster of Paris is mixed with water, it undergoes a chemical reaction known as hydration. In this process, the dry powder absorbs water and turns into a slurry, which then hardens and hardens into a solid mass. The reaction can be represented by a chemical equation, $2CaSO_4{\cdot}0.5H_2O + 3H_2O \rightarrow 2CaSO_4{\cdot}2H_2O$. This equation describes how hemihydrates (half a molecule of water for each molecule of calcium sulfate) react with additional water molecules to form calcium sulfate dihydrate ($CaSO_4{\cdot}2H_2O$), commonly known as gypsum. This exothermic reaction can be represented as a setting process starting almost immediately, making it useful for rapid applications, but RPOP also requires careful handling to avoid premature hardening and can harden like NPOP. In addition, at these stages to see the changes and similarities between NPOP and RPOP. The hydration reaction of Plaster of Paris is exothermic, meaning it releases heat. This release of heat can be felt when touching the dough as it begins to set. The process begins with the powder dissolving in water to form a slurry, followed by the crystallization of gypsum. The crystallization process links the crystals, creating a rigid structure that gives the material its strength. The time required for Plaster of Paris to set can vary depending on the ratio of water to plaster and the ambient temperature. Typically, it begins to set within minutes and reaches significant hardness within an hour, although complete curing may take longer.

Plaster of Paris is a fine white powder. Particle size and purity can vary, affecting texture and usability in mould applications. Therefore, RPOP will undergo morphological analysis test and XRD, compressive strength test, porosity, and water absorption. One of the physical characteristics of Plaster of Paris is its excellent workability. When mixed with water, it forms a smooth and pliable paste that can be easily moulded into various shapes before setting. This makes it ideal for moulds, castings and intricate decorative work.

In the first stage, start with test the ability of RPOP to be hardened again after going through the recycling process, and to compare the properties of dried RPOP at various temperatures with undried RPOP at room temperature (37°C). Although recycling helps in waste reduction, the performance of Recycled Plaster of Paris may differ from new plaster. One of the challenges with recycled plaster is maintaining its mechanical properties and setting time. Repeated recycling can cause a decrease in material strength and an increase in porosity, which can affect the quality of the final mould. Setting times may also become less predictable, which can be a disadvantage in applications that require precise control over the hardening process. Following this procedure, can effectively evaluate the rehardening ability of RPOP and determine the most suitable drying temperature for post-recycling treatment.

NPOP and RPOP are characterized by high purity and consistency, ensuring uniformity in composition and performance. This consistency is important for applications that require accurate material properties and reliable results. Optimum setting time NPOP and RPOP exhibit predictable setting times, allowing to adjust working time according to specific project needs. Its controlled setting contributes to efficient workflow management and enhanced productivity. This makes it ideal for structural, moulding and casting applications where strength and rigidity are paramount. NPOP and RPOP produce a smooth and uniform surface finish, making them suitable for applications that demand high aesthetic standards. Its ability to capture intricate details and textures enhances the quality of the finished product in a variety of artistic and architectural endeavors. Variable composition and quality tested due to its recycled nature, RPOP may exhibit variations in composition and quality compared to NPOP. The explained the physics of RPOP and NPOP as a reference to identify the similarities between RPOP and RPOP + activator. In addition, at this stage, its will produce sample moulds using RPOP.

4.3.1 Recycle Plaster of Paris (RPOP) Test Drying RPOP at Temperature 37°C, 150°C, 160°C, 170°C, 180°C, 190°C After Mix With Water

Figure 4.2 shows that the RPOP sample at 37°C did not harden after being mixed with water. The sample remained soft and powdery, confirming that dehydration was incomplete and that calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$) had not been fully converted to hemihydrate ($CaSO_4 \cdot 0.5H_2O$). In contrast, the RPOP sample at 150°C began to show partial setting when mixed with water, indicating partial dehydration. At 160°C, the RPOP sample completely set and hardened, producing a surface and strength almost equivalent to NPOP. The samples dried at 170°C, 180°C, and 190°C also hardened, but their texture appeared brittle and less cohesive. At higher temperatures, the powder showed signs of over-dehydration, making it less workable. This observation confirmed that temperature has a significant effect on the rehydration reaction and setting ability of RPOP

Results temperature tests were conducted on recycled plaster of Paris (RPOP) samples at various temperatures, specifically 37°C, 150°C, 160°C, 170°C, 180°C and 190°C, to analysed the behavior and changes under thermal conditions. Some results have been observed when this test is carried out. Surprisingly, 37°C (room temperature) was found to be unsuitable for use as an accompanying process for RPOP recycling. Figure 4.2 shows that the RPOP 37°C mixed with water does not harden, and when left for one day, the sample fails to solidify and does not form the required shape. When RPOP powder and water are combined, the stirring process is very easy, and the slurry does not clump.

Figure 4.2 The RPOP In Room Temperature Does Not Harden

In addition, water has produced around the RPOP 37°C mould as shows as in Figura 4.3. This is because RPOP 37°C contains a lot of water from its past use as mould casting before being recycled into RPOP powder. The resulting water is produced by the water content in the RPOP 37°C that was not previously removed before reuse.

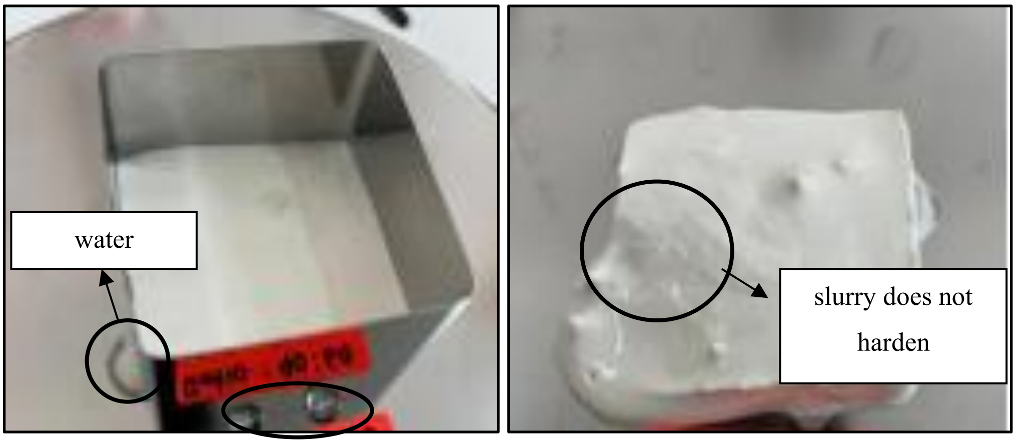


Figure 4.3 RPOP (37°C) without drying.

4.3.2 Setting time and Surface of NPOP and RPOP

Figure 4.4 shows the effect of RPOP samples at different drying temperatures compared to NPOP. Each sample represents the result of drying recycled plaster at varying temperatures, showing changes in physical characteristic.

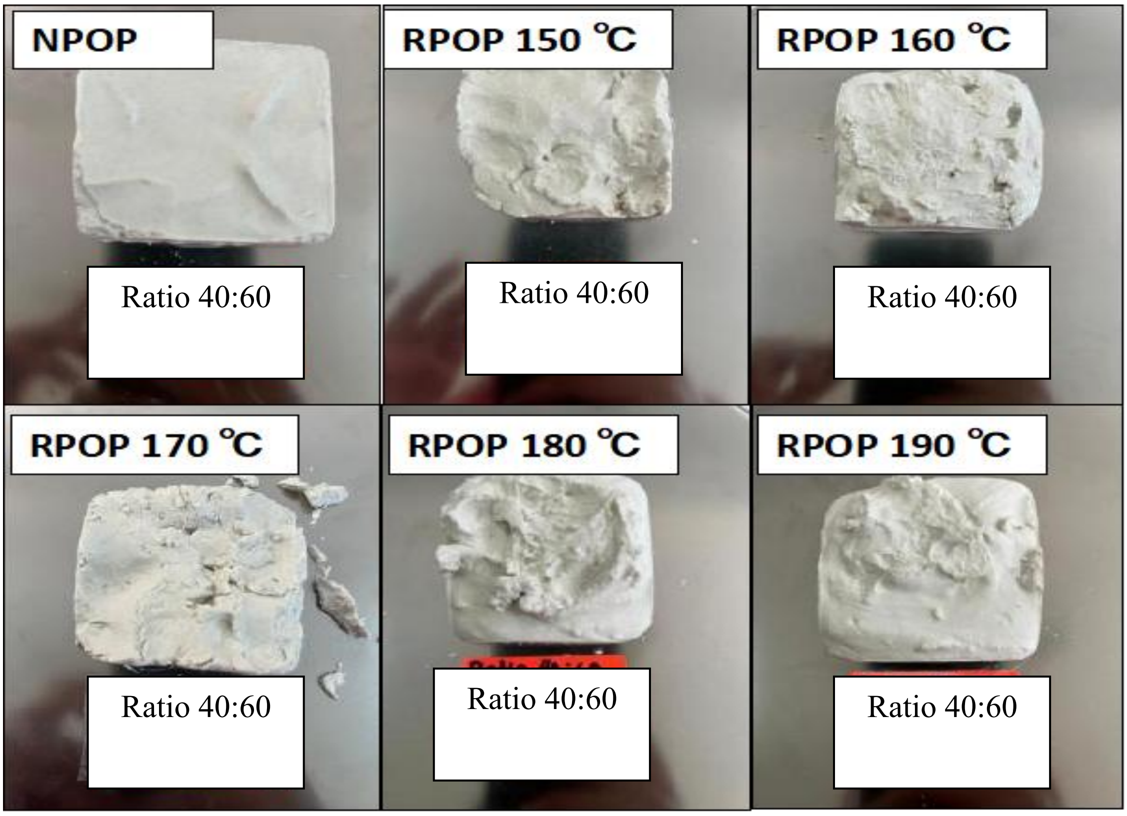


Figure 4.4 The Sample Setting Of NPOP And RPOP

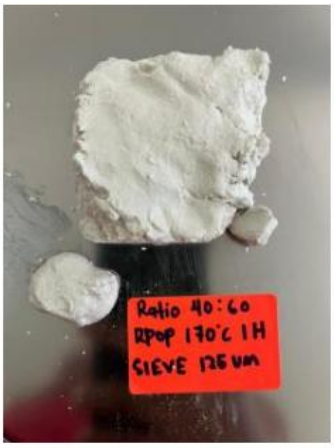
Figure 4.4 shows the surface of NPOP and RPOP (150°C, 160°C, 170°C, 180°C, and 190°C) hardens after drying. The image is divided into six sections, each showing a different sample, NPOP, this sample represents the baseline, non-recycled plaster of Paris. It appears solid and uniformly white, showing a typical and undisturbed plaster structure. The observed that the surface of NPOP is smooth and not fractured. The shape also corresponds to the square mould utilized. However, when investigating all the RPOP at different temperatures, it finds that the surface is not smooth and that many of the parts are not precisely formed. This is because all RPOP flows are far thicker than NPOP. RPOP samples stir at 150°C, 160°C, and 170°C was stired for 4 minutes.

Table 4.1

The Physical Remark Of RPOP In Several Temperature

TEMPERATURE RPOP	PHYSICAL	DRYING RPOP	REMARK
37°C (Room temperature)	DRY 0°C 500g White : White	Stir time 1minute Easy to mix Ratio 40:60 Liquid NA heat	• Around the aluminium mould got water. • Did not setting after 30minutes

150°C	DRY 150°C 1Hour Before 500g After 462g White : White	Stir time less than 4minute Easy to stir Ratio 40:60 Heat	• When plaster mix into water, the mixture becomes lumpy and difficult to stir. • The flow thick and clumpy when pour into aluminium mould • Setting after 15minutes

160°C	DRY 160°C 1Hour Before 500g After 451g	Stir time less than 4minute Easy to stir Heat Ratio 40:60	● When plaster mix into water, the mixture becomes lumpy and difficult to stir. ● The flow thick and clumpy when pour into aluminium mould ● Setting after 15 minutes 
170°C	DRY 170°C 1Hour Before 500g After 444g White : White	Stir time less than 4minute A bit difficult to stir NA Heat Ratio 40:60	● When plaster mix into water, the mixture becomes lumpy and difficult to stir. ● The flow thick and clumpy when pour into aluminium mould ● Setting after 10 minutes 

180℃	DRY 180°C 1Hour Before 500g After 431g White : White	Stir time less than 2 minutes Difficult to stir Heat Ratio 40:60	• When plaster mix into water, the mixture becomes lumpy and difficult to stir. • The flow thick and clumpy when pour into aluminium mould. • Setting after 7 minutes 
190℃	DRY 190°C 1Hour Before 500g After 426g White : White	Stir time less than 2minute Difficult to stir Heat Ratio 40:60	• When plaster mix into water, the mixture becomes lumpy and difficult to stir. • The flow thick and clumpy when pour into aluminium mould. • Setting 7 minutes • Flow plaster still can be controlled as to 180°C 

The RPOP samples at 150°C, 160°C, and 170°C when pouring the mixture liquid, it shows clumpy properties and the flow thick when pouring in the aluminum mould. The 180°C and 190°C RPOP samples take 2 minutes of stirring, which is shorter than the 150°C, 160°C, and 170°C RPOP samples. During the RPOP stir, the sample mixture is difficult to stir and pour into the aluminum mould since it is half hard. RPOP 150°C, this sample was dried at 150°C for 1 hour and sieved. The surface shows signs of slight textural changes, appearing less uniform than NPOP, suggesting early structural damage or the beginning of a recycling process. RPOP 160°C, the sample has more pronounced cracks and a less cohesive structure than the 150°C sample, indicating further decomposition and changes in material properties due to increased temperature

RPOP 170°C was dried at 170°C for 1 hour and sieved in the same way. The sample appears more brittle and fragmented, indicating significant deterioration. The structure is no longer intact, highlighting the large heat effect at this temperature. The 180°C RPOP of this sample appears to have regained some cohesion but is still less uniform than the NPOP. RPOP 190°C, the sample appears to have a smoother surface than the 170°C and 180°C samples but still shows significant structural changes compared to NPOP

This is one of the reasons that the surfaces of all RPOP samples differ from NPOP. This is because the RPOP has been completely dried, allowing it to absorb water throughout the mixing process or this happening may be due to inconsistent particle size RPOP may contain particles of varying sizes. The grinding and crushing process used to break up old plaster does not always produce uniformly sized particles, leading to a less smooth surface when the material is reused. The original fine consistency of the plaster may be lost during the recycling process. The mechanical process involved can degrade the smoothness of the material, making RPOP less smooth than NPOP. The discovered that NPOP takes 25 minutes to set, while RPOP samples at 150°C and 160°C take 15 minutes, 170°C for 10 minutes, and 180°C and 190°C take 7 minutes.

Figure 4.5 shows that once RPOP has been mixed with water and stirred manually, it begins to undergo a chemical reaction that eventually results in hardening. Once RPOP is mixed with water and stirred, its texture changes to a smooth, creamy consistency. The slurry looks thick and indicating that it has started to set, which is why it is difficult to stir. The central depression indicates resistance to stirring motion, further highlighting the high viscosity of the slurry. At first, it may feel a bit grainy as the plaster particles are suspended in the water, but with continued stirring, it becomes a homogeneous mixture. This reaction is irreversible, meaning that once the plaster has set, it cannot be returned to its original state and reused as if it were fresh.

Figure 4.5 RPOP Texture When Mixing With Water

The optimal setting time was recorded for RPOP dried at 160°C, which displayed a hydration rate comparable to NPOP. The presence of Silubit G80 further enhanced setting uniformity without excessively accelerating or delaying the process, confirming its suitability as a minor activator.

4.3.3 Particle Size Analysis of POP

The average of particle size of all the raw material sample using in this research are tabulated in Table 4.2. The particle size detected are in the range of 7.71 µm to 34.10 µm. As shown in Table 4.2, the higher the temperature used for drying, the lower the RPOP particle size. Particle size distribution can affect properties such as setting time, strength, surface finish and workability. The physical attributes of ceramic pottery are impacted by the size distribution of POP powder during the processes of slip casting, drying, and sintering. Three measurements of the particle size distribution are made because of the particle size at 10%, 30%, and 60% of the cumulative value. It demonstrates that the lowest size is 1.18 µm at the 10% point and the highest size is 8.66 µm at the 60% point. Consequently, it has been demonstrated that the distribution of particle sizes is within the range of less than 25 µm reported by Nawi & Badarulzaman, (2015)

Table 4.2

Average Particle Size For NPOP And RPOP

Sample (°C)	Cumulative value	Particle Size distribution (μm)
NPOP		11.10
RPOP 37		34.10
RPOP 150		29.49
RPOP 160	D60	22.78
RPOP 170		26.60
RPOP 180		10.55
RPOP 190		7.71

The RPOP sample dried at 160°C achieved the most desirable particle size distribution, which is beneficial for homogeneous slurry formation and consistent mechanical properties.

4.3.4 Morphological Analysis of Temperature Effect of NPOP and RPOP Drying 37°C, 150°C, 160°C, 170°C, 180°C and 190°C

To justify the behaviour of the SEM analysis, it was tested at all the temperatures of the material samples used in this study. Figure 4.6 shows SEM images obtained from RPOP at drying temperatures of 37°C, 150°C, 160°C, 170°C, 180°C and 190°C and NPOP as a reference.

Through Figure 4.6, the initial morphology of NPOP shows a compact and irregular structure. The particles appear compact with minimal porosity, showing the typical microstructure of freshly prepared plaster NPOP shows that the surface has relatively few pores and that the component's crystallinity is unclear. NPOP represents the sample's morphology in its original state, without any heat treatment. The structure appears disorganized, with no clear order or alignment within the particles. Furthermore, there is insufficient adhesion between the particles and the remainder of the matrix, and the pores are opaque. In comparison to the other samples, NPOP contains the most oxygen. Figure 4.6 b) shows that the 37 °C RPOP sample has multiple crystal clusters and interlaced crystals with varying radii. Samples heated to 37°C showed little change compared to the original state. There is the beginning of some particle alignment or slight changes in texture, but the morphology remains mostly similar to the original.

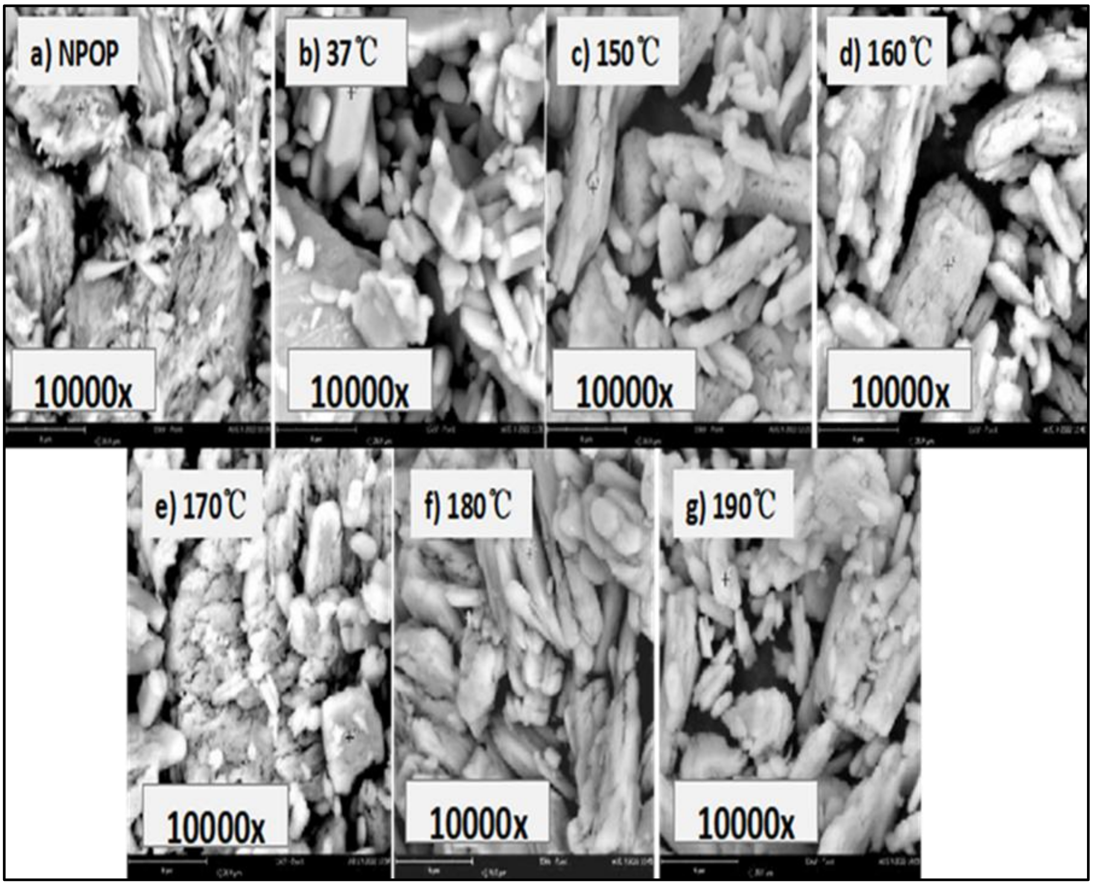


Figure 4.6 SEM Analysis Distribution Of A) NPOP, B) RPOP 37°C,(C) RPOP 150°C, D) RPOP 160°C, E) RPOP 170°C, F) RPOP 180°C And G) RPOP 190°C Showing The Mould Porosity At 10000X Magnification

At RPOP 150°C, the sample shows a more significant change. The particles begin to show signs of fusion or sintering, indicating the beginning of structural rearrangement due to increased temperature. Significant morphological changes were observed at RPOP 150°C. The particles become clearer, showing elongation and increased separation. This temperature causes significant dehydration, which leads to the formation of a more open and less cohesive structure. The appearance of needle-like or fibrous formations can be observed, suggesting the beginning of a significant recrystallization process. When heated to RPOP 160°C, the change becomes more pronounced. The particles appear more fused together, with less clear boundaries between them, suggesting a higher degree of sintering or melting. As the temperature increases to RPOP 160°C, the structure continues to expand. The particles appear more elongated and there is a significant increase in porosity.

This temperature further promotes the decomposition of calcium sulphate hemihydrate back to anhydrous calcium sulphate, significantly changing the morphology of the material. The fibrous structure is more pronounced, indicating a more advanced degree of recrystallization. At RPOP 170°C, the sample showed significant morphological changes. The structure appears denser and the particles more fused, indicating further development of thermal effects such as sintering or partial melting. Samples treated at RPOP 170°C show continuous structural transformation with more pronounced fibre-like formation. The particles are more segregated, with a coarser texture indicating advanced dehydration and phase transformation. Increased porosity and surface roughness show significant effects on mechanical properties, potentially reducing material strength and cohesion. At RPOP 180°C, the morphology of the sample continued to evolve.

The particles appear compact, and the boundaries between them are less visible, indicating a high degree of thermal fusion. The particles are further separated, and the fibrous structure is very clear, indicating an almost complete phase transformation. An increase in surface roughness and porosity indicates a highly porous and less dense material, which can affect its mechanical properties. At RPOP 180°C, the morphology of the sample continued to evolve. The particles appear compact, and the boundaries between them are less visible, indicating a high degree of thermal fusion. The particles are further separated, and the fibrous structure is very clear, indicating an almost complete phase transformation. An increase in surface roughness and porosity indicates a highly porous and less dense material, which can affect its mechanical properties. Samples at RPOP 190°C show a very dense structure and may be completely sintered or molten. The morphology shows that the material has undergone significant reorganization, resulting in a more homogeneous and compact structure. The structure is highly porous with clear fibre formation and separated particles. The material appears significantly degraded with the highest degree of dehydration and phase change. These high temperatures cause the most significant structural damage, making the material very porous and weak.

SEM observations confirmed that RPOP dried at 160°C exhibited a well-developed acicular crystal morphology equivalent to NPOP, verifying the structural restoration and suitability of RPOP for reuse.

4.3.5 Phase Analysis of Temperature Effect of NPOP and RPOP 37°C, 150°C, 160°C, 170°C, 180°C and 190°C

From the XRD test found a consistent big hump in the region of 12 - 58° for all NPOP and RPOP samples. Figure 4.7 displays the XRD patterns for NPOP and RPOP. XRD patterns were similar for NPOP and RPOP at different drying temperatures (37 °C, 150 °C, 160 °C, 170 °C, 180 °C, and 190 °C). Aside from the NPOP gypsum sample peak (Ref # 024-1067), all samples had an XRD peak of dolomite (Ref # 063-0426), with a modest concentration of Bassanite (Ref # 024-1067), which could imply some aggregate content or pH regulator additions. There is no aggregate phase in the RPOP sample, only gypsum peaks. If all the samples' XRD patterns are identical, there is a calcite component (Ref # 043-1067) as indicated in the XRD. Gismodine is a calcium aluminium silicate hydrate that forms when calcite and gypsum are present.

Calcium sulphate hemihydrate, or $CaSO_4 \cdot 0.5H_2O$, is essentially the POP is made of. Gypsum is heated to a specific temperature to remove some of the water molecules. Because water molecules have been removed, POP has a different crystal structure than gypsum, which is reflected in the X-ray diffraction (XRD) pattern. POP XRD patterns typically display peaks that match the crystalline structure of calcium sulphate hemihydrate. Since the dehydration process has affected the crystal structure, these peaks will not be the same as those observed for gypsum, particularly in terms of peak position and intensity. While the temperature history and processing circumstances that RPOP has experienced will determine its X-ray diffraction (XRD) pattern. Rehydrating calcium sulphate hemihydrate ($CaSO_4 \cdot 0.5H_2O$) to ($CaSO_4 \cdot 5H_2O$) and then drying the mixture to eliminate extra water are the normal steps in RPOP. RPOP may have peaks in its XRD pattern that are indicative of both gypsum and any leftover calcium sulphate hemihydrate. The degree of rehydration and the existence of any contaminants or additives in the recycled material determine the relative intensity and location of these peaks. The phase composition of the material after recycling is likely reflected in the XRD pattern of the RPOP, which most likely has peaks connected to both gypsum and calcium sulphate hemihydrate.

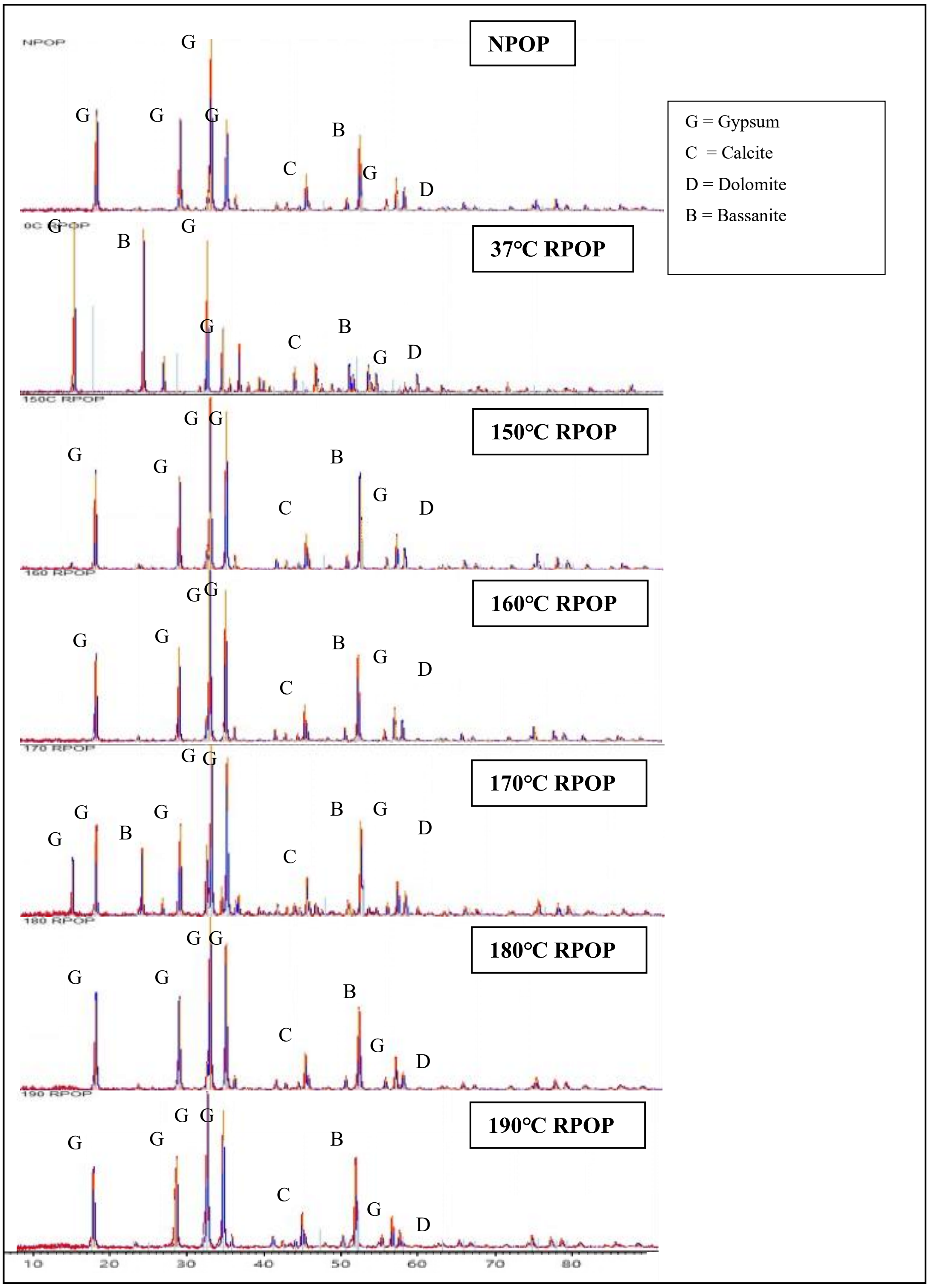


Figure 4.7 XRD Results Of Several Drying Temperature Of Plaster Of Paris, NPOP, RPOP 37℃, 150℃,160℃,170℃,180℃,190℃

As stated by Geraldo, (2017),the statement, dehydrated recycled gypsum will yield a bassanite content when combined with new gypsum. This is because both fresh and hydrated recycled gypsums will include calcite and gypsum. There is a peak in the hydrated material that corresponds to gypsum and to calcite; however, XRD did not detect calcite in the non-hydrated powder, possibly due to poor crystallisation. However, there is no bassanite in freshly hydrated gypsum, indicating that all hemihydrates have been changed to dihydrates. The findings from Geraldo show nearly the same pattern with the same peak, indicating that the recycling process does not change the characteristics of this material. Indeed, the XRD patterns of the hydrated and dehydrated subjects are very comparable to those of the unhydrated and hydrated gypsum.

XRD results confirmed that drying at 160°C effectively converts dihydrate to hemihydrate, reproducing the crystalline structure of NPOP and validating this temperature as optimal for recycling.

4.3.6 Compressive Strength Test with Temperature Effect of NPOP and RPOP

The fluctuation in compressive strength with temperature for totally recycled powder follows the trend shown in NPOP as a control reference. The compressive strength of NPOP without any heat treatment is the highest at about 14.07 kN. This value serves as a baseline to compare the effect of heating on the compressive strength of the material. The Figure 4.8 demonstrates a high compressive strength of 12.8047 kN at a drying temperature of 150 °C using a 40 (water) : 60 (powder RPOP) ratio. RPOP 150°C the compressive strength of RPOP is 12.80 kN, showing a slight decrease from control line.

The material retains most of its original strength. RPOP 160°C the compressive strength continues to decrease to 10.59 Kn. Despite the reduction, the material still maintains a relatively high strength. Heating POP leads to thermal decomposition, releasing water and forming anhydrous calcium sulfate. The reformation process during cooling can affect the strength. At moderate temperatures (RPOP 150°C and RPOP 160°C), the material loses water, causing a slight decrease in strength. However, the structure is still relatively intact. RPOP 170°C significant decrease is observed here, with the compressive strength falling to 3.98 kN. This indicates that this temperature causes a significant deterioration in the structural integrity of the material. The sharp drop at RPOP 170°C indicates a critical point where the crystal structure of the material undergoes significant breakdown, leading to a large loss in compressive strength. However, at RPOP 180°C, the compressive strength begins to grow again and continues to rise until RPOP 190°C. RPOP 180°C compressive strength increased slightly to 6.05 kN. This rebound may indicate partial recrystallization or other structural changes that increase strength slightly and RPOP 190°C strength increases further to 8.43 kN, indicating that higher temperatures may facilitate recovery or stabilization in the material structure.

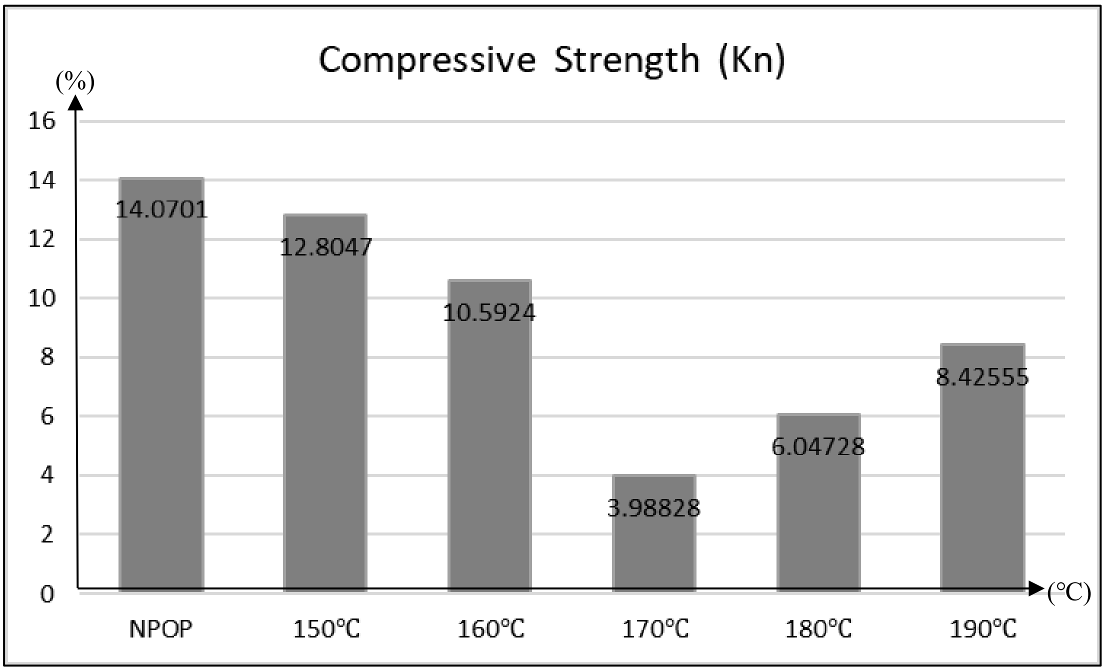
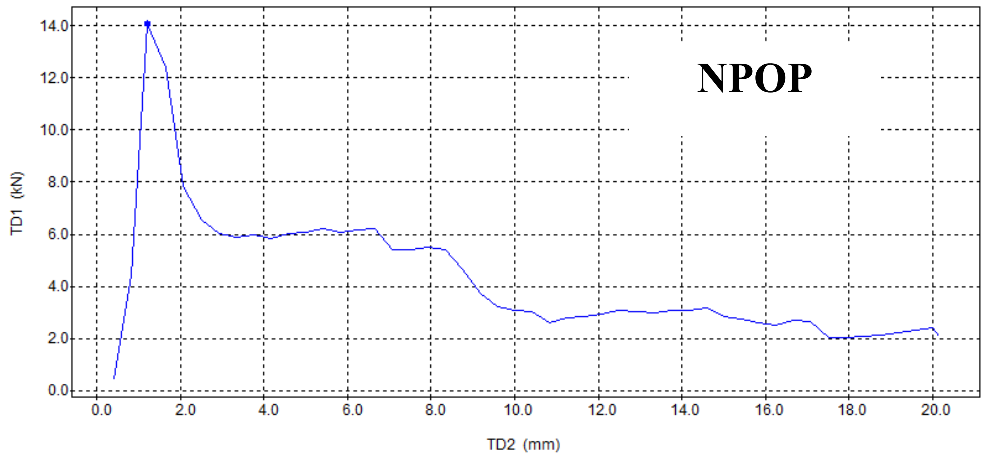


Figure 4.8 The Compressive Strength NPOP & RPOP Several Temperatures

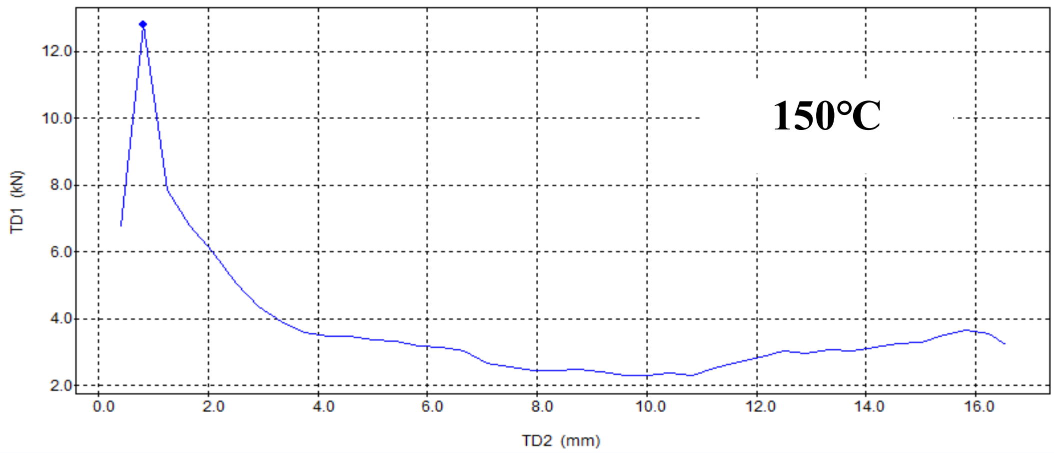
The slight increase in strength at RPOP 180°C and RPOP 190°C may be due to recrystallization or other structural changes that improve compressive properties. This phenomenon indicates that while initial heating weakens the material, further heating may induce changes that partially restore strength. This is determined by the amount of water present and the temperature at which the RPOP is combined and dried. This is determined by the amount of water present and the temperature at which the RPOP is combined and dried. According to Li, (2018), gypsum possesses dehydration characteristics and varied physical properties in addition to hemihydrate activity that vary based on the preparation temperature.

The compressive strength show that at RPOP 150 °C, the outcome is nearly identical to NPOP. Extracting water from the mild recycling process at RPOP 150 °C enhances the water content and density of the RPOP mixture during mixing. Evaluation of compressive strength helps determine optimal demoulding time and handling procedures for RPOP castings. Castings with insufficient strength may require a longer curing period or additional support to prevent damage during disassembly and handling. If look at the graph below at a temperature of RPOP 170°C, the strength is the lowest and increases again from RPOP 180°C to RPOP 190°C. This shows that at this drying temperature the RPOP viscosity is low and is not suitable for making moulds. This result can be compared with the strength result of NPOP which has a high level of compressive strength.



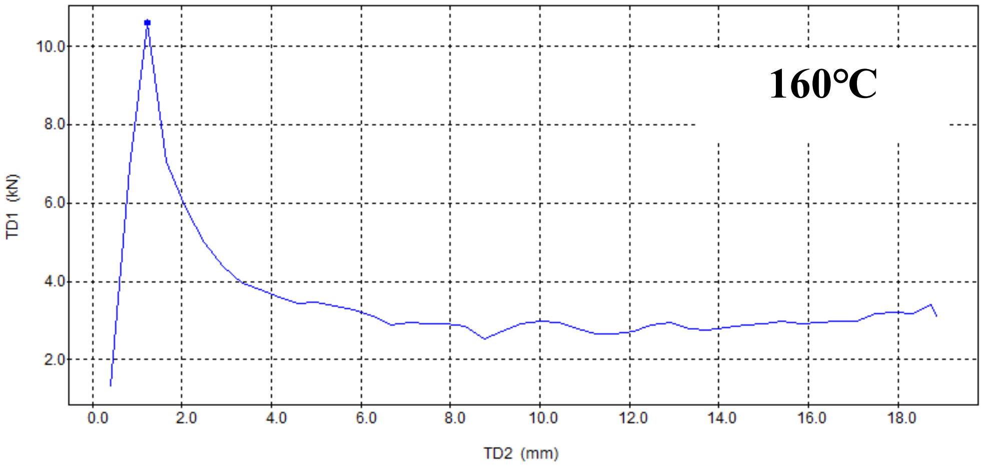
Characteristic list

	Elastic modulus	Yield strength- TD1	Max. point- TD1	Breaking point- TD2	Energy
	N/mm2	kN	kN	mm	J
	-.-	-.-	14.0701	-.-	85.9545



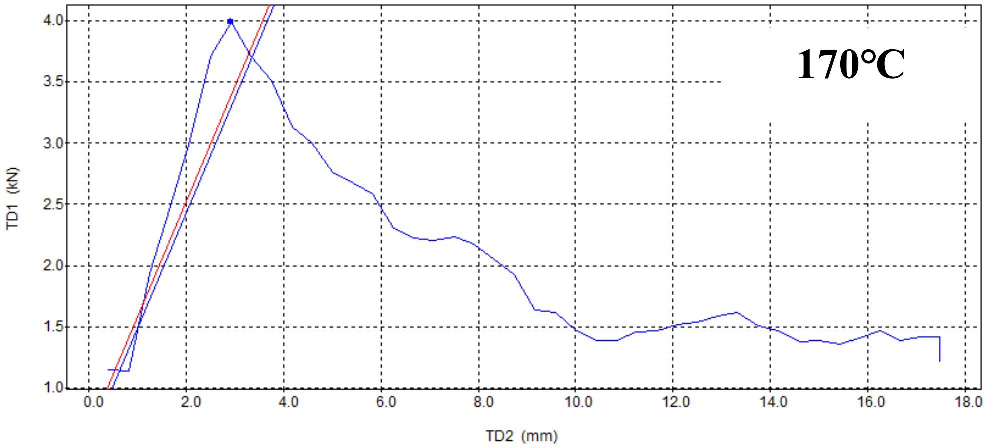
Characteristic list

	Elastic modulus	Yield strength- TD1	Max. point- TD1	Breaking point- TD2	Energy
	N/mm2	kN	kN	mm	J
	-.-	-.-	12.8047	-.-	59.4998



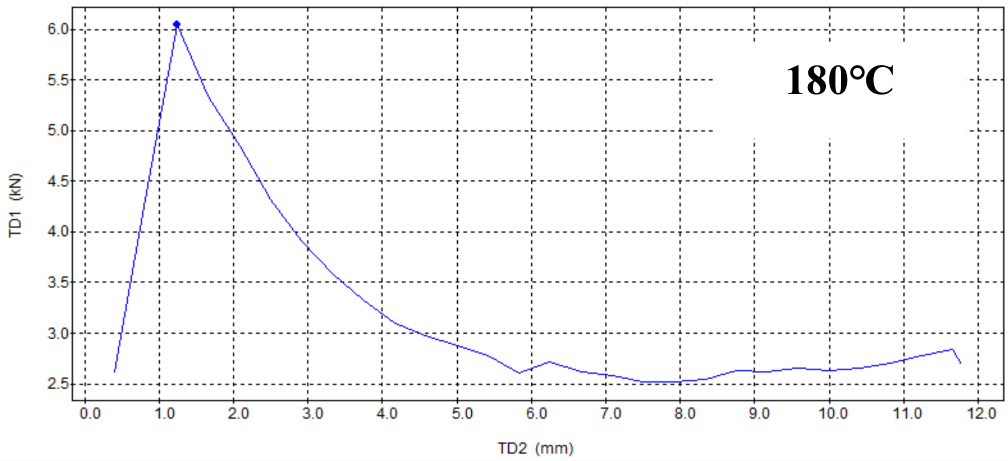
Characteristic list

	Elastic modulus	Yield strength- TD1	Max. point- TD1	Breaking point- TD2	Energy
	N/mm2	kN	kN	mm	J
	-.-	-.-	10.5924	-.-	64.7587



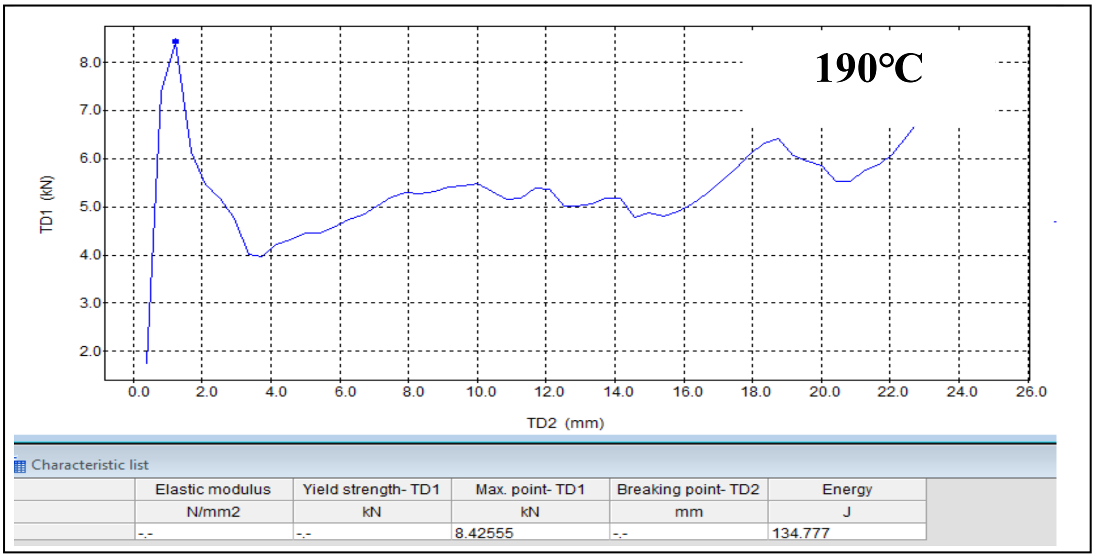
Characteristic list

	Elastic modulus	Yield strength- TD1	Max. point- TD1	Breaking point- TD2	Energy
	N/mm2	kN	kN	mm	J
	23.4883	3.50914	3.98828	-.-	34.7966



Characteristic list

	Elastic modulus	Yield strength- TD1	Max. point- TD1	Breaking point- TD2	Energy
	N/mm2	kN	kN	mm	J
	-.-	-.-	6.04728	-.-	36.5992



	Elastic modulus	Yield strength- TD1	Max. point- TD1	Breaking point- TD2	Energy
	N/mm2	kN	kN	mm	J
	-.-	-.-	8.42555	-.-	134.777

Figure 4.9 The Flow Depicted RPOP With Different Drying Temperatures

In conclusion, the highest compressive strength was obtained by recycled plaster of Paris (RPOP), which had been mixed with 0.5% Silubit G80 and dried at 160°C. This strength was roughly comparable to that of new plaster (NPOP). This result demonstrates that the performance and structural integrity of recycled plaster materials are greatly improved by controlled thermal activation with additives.

4.3.7 Porosity of NPOP and RPOP with Temperature Effect

The Figure 4.10 shows the percentage of porosity with different RPOP drying temperatures. The graph plot shows that the RPOP sample with a temperature of 180°C produced a lower porosity percentage of 144% while the RPOP sample at a temperature of 160°C produced a higher porosity percentage of 157% for each temperature increase tested. At a temperature of 150°C the percentage of porosity shows 151% and increases by 6% at a temperature of 160°C. Then, further analysis also reveals the percentage porosity decreases from a temperature of 170 °C until reaching 180°C. This may occur at an increase in temperature which causes the number of pores and voids to decrease.

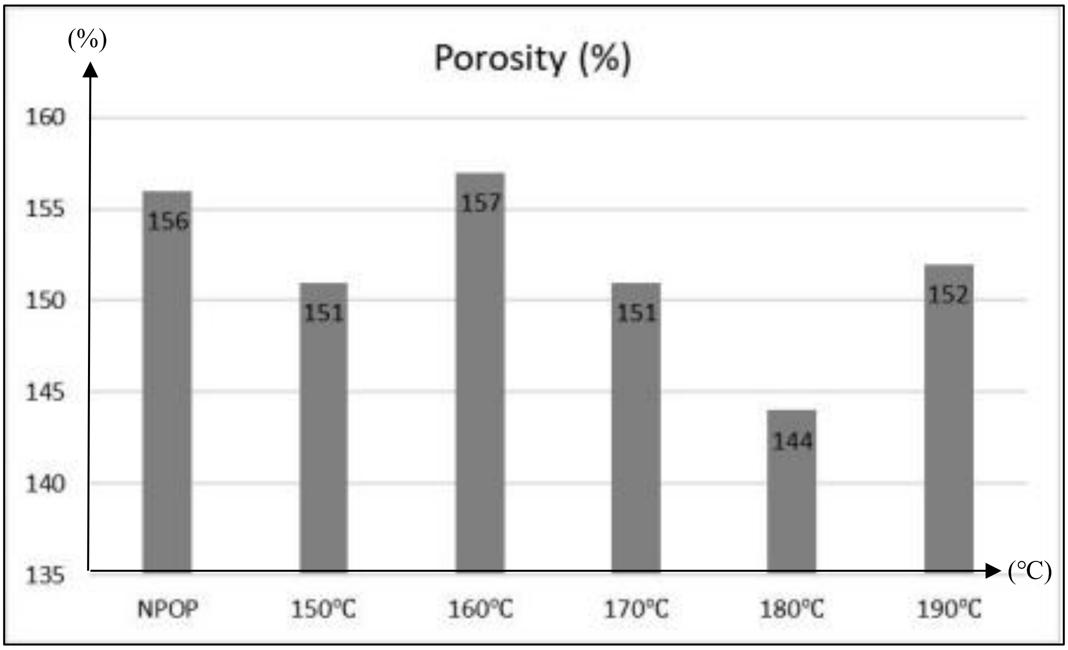


Figure 4.10 The Percentage Of Porosity With Different NPOP & RPOP Drying Temperatures

However, RPOP at a temperature of 190°C, the total percentage of porosity began to increase to 152%. This is because according to POP waste produces an increased percentage of porosity because POP is a highly porous ceramic material with a relatively large internal surface consisting of interlocking crystals. Nevertheless, if observed on NPOP as a control sample, RPOP 160°C shows almost the same percentage of porosity.

From this study, standardized the use of the same mixing ratio between the amount of water and plaster powder is appropriate to have an average water absorption level. The actual porosity for POP should have a value of not less than 20%. Nevertheless, the results in Figure 40 show that the porosity level of the samples produced from this RPOP does not exceed 20% and is comparable to the standard as they are all less than 20%. If observed, NPOP as a control also has low porosity results. However, RPOP shows that its porosity increases when the drying temperature is increased. This shows that the drying temperature has completely removed the water content in RPOP when this material is mixed with water, the time for setting is very short compared to NPOP. The recycled sample with the lowest porosity, RPOP processed at 160°C with 0.5% Silubit G80, displayed a dense and tightly packed structure. By increasing mechanical strength and decreasing water absorption, this microstructural enhancement performs on par with NPOP indicating the possibility of efficient material recovery and reuse.

4.3.8 Water Absorption of NPOP and RPOP with Temperature Effect

The increasing order of absorption percentage for each sample indicates that the rise in porosity is due to the addition of too much water to the POP. As a result, mixing POP with water produces a product with a high porosity. In general, as the water volume grows, the void fraction increases and the binding between the gypsum particles weakens, resulting in a decreased sample strength. However, the applied of the same ratio of water mixture to all the samples evaluated. The researcher discovered that the drying temperature of RPOP is the primary cause of the decrease in absorption percentage because the high temperature is unsuitable for the face cycle process of plaster of Paris. The Figure 4.11 below indicates that absorption increases between RPOP 150°C and RPOP 160°C but decreases between drying tempurature RPOP 170°C and RPOP 190°C. The findings below indicate RPOP reacts when dried at a high temperature, which affects its absorption. This is because at high temperatures, the water content in RPOP is fully eliminated, leaving no surplus water in the RPOP substance. But at low temperatures, RPOP could retain the extra water content after drying.

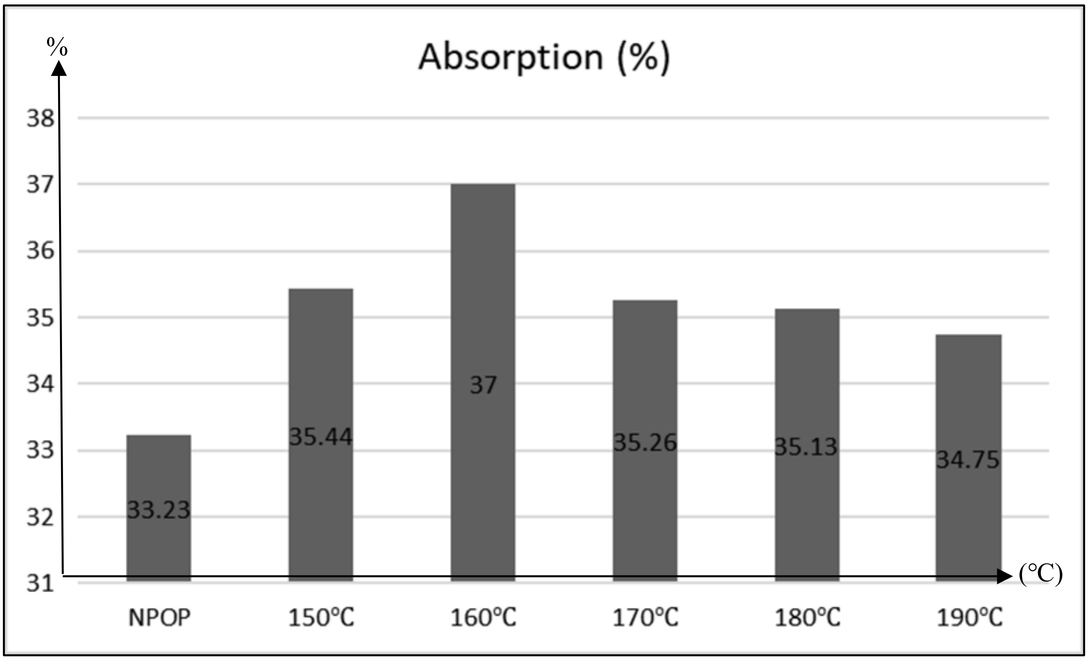


Figure 4.11 The Percentage Of Absorption With Different NPOP & RPOP At Several Drying Temperatures.

Thus, the absorption of plaster of Paris increases initially due to hydration, reaches a maximum point, and then decreases as the plaster becomes saturated and then dehydrated. the recycled samples, RPOP treated at 160°C with 0.5% Silubit G80 showed the least amount of water absorption, demonstrating superior capillary resistance and structural integrity. This improved formulation improves the consistency and durability during slip casting, demonstrating its potential as a dependable substitute for NPOP for frequent moulding applications in the ceramics manufacturing process.

4.4 Conclusion

The results of all physical and mechanical tests indicated that RPOP and new plaster of Paris (NPOP) were most similar when dried at 160°C, particularly in the lowest temperature. in terms of water absorption, porosity, mechanical strength, and time. At this temperature, the recycled material's hemihydrate phases underwent rehydration and recrystallization, yielding a microstructure that was very similar to the NPOP. Particularly at a concentration of 0.5%, the addition of the Silubit G80 additive further improved the overall material performance by enhancing particle packing, microstructural bonding, and minimizing the development of pores in the plaster matrix. These enhancements resulted in increased density and mechanical stability, which in turn decreased porosity and water absorption rate, both of which are essential. The quality and lifespan of plaster molds used in ceramic slip casting are determined by a number of factors.

The recycled POP's structural integrity was successfully brought back to par with NPOP by the synergy between thermal activation at 160°C and the addition of 0.5% Silubit G80. This treatment condition resulted in a denser and linked crystalline structure, which improved interparticle cohesion and increased resistance to capillary water infiltration. Maintaining dimensional precision and surface smoothness during the molding procedure requires the optimized RPOP to have consistent setting behavior, dependable mechanical strength, and regulated absorption characteristics.

These demonstrate that RPOP may achieve controlled thermal activation when supported by slight chemical changes using Silubit G80. The essential physical and mechanical criteria for using ceramic moulds. The study demonstrates that this method not only increases the reusability and sustainability of plaster materials but also maintains consistent performance throughout several recycling cycles. As a result, this study demonstrates that thermally treated at 160°C and strengthened with a small quantity of Silubit G80, RPOP is a viable, affordable, This alternative satisfies the industry's needs for high-quality, long-lasting ceramic mold manufacturing and is an environmentally sound substitute for NPOP.

4.5 Effect of Silubit G80 in Recycle Plaster of Paris (RPOP) 160%

Silubit G80 is a special additive formulated to improve the properties of POP. It is highly valued for its ability to improve the operability and durability of POP applications. Silubit G80 is a silane-based compound, known for its water-repellent and adhesive-enhancing properties, making it an excellent choice for modifying POP.
Next, proceeded by mixing the RPOP sample with Silubit G80. In this experiment, the aim is to observe the reaction of the additive when it is mixed into the RPOP sample. The main goal of this experiment is to study the behavior and effects of additives when introduced to RPOP samples under controlled conditions. Will monitor various parameters to understand how additives interact with RPOP samples. Make sure the mixing process is uniform across all samples to avoid inconsistencies. Make monitoring observations such as record immediate reactions when adding additives to each sample. The main parameters to monitor include visual changes such as colour and surface of the sample. Chemical changes and physical changes. Activators are often used in POP to speed up the setting time to make it harden faster and there are some activators that work as glues or dilutes the POP liquid after mixing to facilitate the process of pouring into the mould. It is important to follow the correct safety precautions and mix ratio when using the activator with POP in addition to using RPOP to ensure the desired mould result is perfect. At these stages, the additive is observed using several instances to observe its reaction when it mixes into the RPOP sample. The ratio used in all these samples is the same as the ratio used .

By conducting this trial, expect to gain insight into the following such as Compatibility of additives with RPOP samples. The optimum concentration level for the desired reaction. Any adverse effects or unexpected reactions that may occur.

4.5.1 Setting Time of RPOP with 0.5% – 2.0% of Silubit G80

The most common weakness of gypsum plaster mix is a relatively short setting time. This shortcoming affects the plaster's slurry pouring into the mould, resulting in some areas or small spaces not being completely covered by RPOP (Abbood, (2020). This issue encouraged scientists to investigate how the Silubit G80 additive affects RPOP by limiting how much of it is used and allowing it to be used for longer periods of time with the goal of extending it as much as feasible. As in Figure 4.12 , it has made observations using RPOP 160°C which was selected after all the physical tests were the same as NPOP. If look at the surface of all these samples, it's have improved before when mixed with Silubit G80 additive. This is because the flow of RPOP increases with the presence of additives which causes, during the pouring of RPOP into the aluminum mould, it is easier and the RPOP powder mixes perfectly.

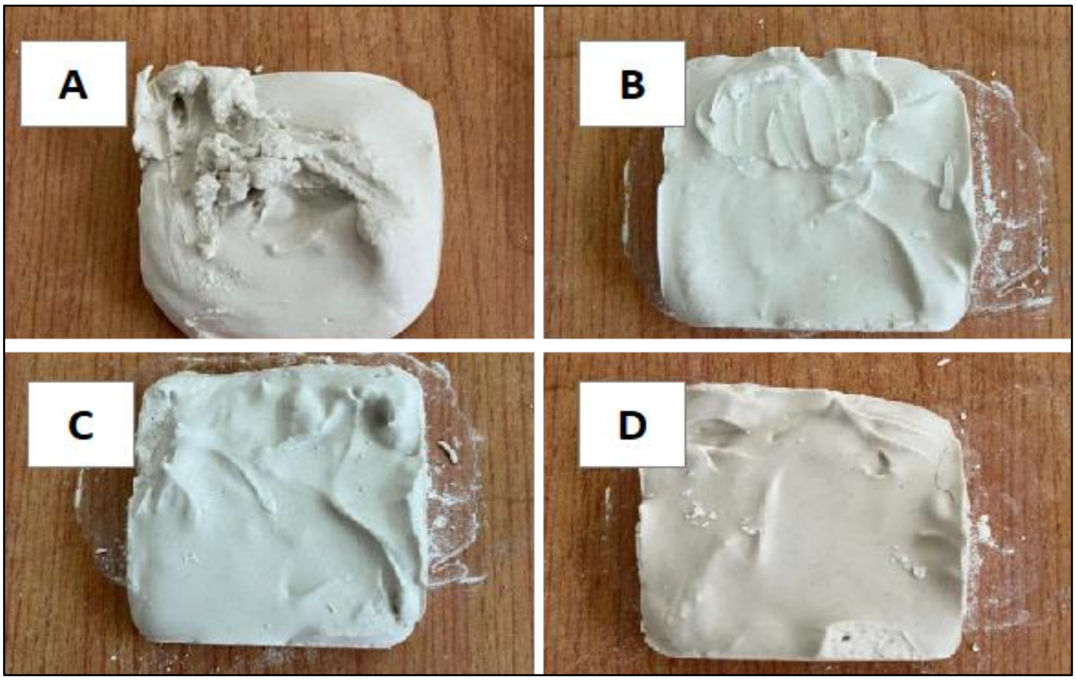


Figure 4.12 Setting Surface RPOP Mix With Silubit G80 A) RPOP+0.5% B) RPOP+1.0% C) RPOP+1.5% D) RPOP+2.0%

Stir time taken by sample A (4 minutes), sample B (4 minutes 45 seconds), sample C (5 minutes 12 seconds) and sample D (5 minutes 32 seconds). If it is observed that the percentage of Silubit G80 additive used increases, the easier it is for stir the RPOP powder with water. This shows that Silubit G80 works as an agent work as deflocculants, therefore the solids content of plaster slurry can be increased while maintaining the same processing consistency. This is clearer when going through previous studies by De Moraes Rossetto, (2016). It was demonstrated that our new plaster hydrates more quickly than the new Paris plaster. shorter settings time. This is because that the recycled gypsum plaster set up more quickly than the new Plaster of Paris, based on the same findings as the earlier study. This study's findings support this as well. The setting time of RPOP is affected by increasing the drying temperature. This is because RPOP has less water in it, however Silubit G80 can inhibit water absorption during the hemidyrate process, which explains why more water results in a longer setting time. In this work, the initial setting time for all mixtures and for both w/gp ratios were deep according to the Standard with a minimum of 4 minutes. The minimum value of the final setting time required by the Standard is 20 minutes, obtained by NPOP as a control. This increase in the ratio of plaster/water leads to an increase in mechanical resistance, which appears in the form of an increase in abrasion resistance and plaster flow will be consistent according to the quantity of use. Depending on the intended application and desired properties, additives can be incorporated into the RPOP formulation. These additives can include reinforcing fibers, accelerators, retarders, or other chemical agents intended to improve specific characteristics such as strength, setting time or workability. The customization of RPOP formulations allows flexibility in its use across different industries, meeting diverse needs and requirements. Silubit G80 is compatible with a wide range of gypsum-based materials, including recycled plaster of Paris, and can be easily incorporated into existing casting processes. Its flexibility makes it suitable for a variety of applications and casting techniques. If observed in , the surface of the sample becomes smoother and perfectly shaped as the percentage of Silubit G80 increases in the sample below. This is due to reducing adhesion between the plaster and the mold surface, Silubit G80 can help achieve a smoother and more uniform surface finish on cast objects. It is proven that Silubit G80 can increase the flow of viscous RPOP slurry to a liquid flow, making it easier for the slurry to flow in the mold. This is due to the discovery that using Silubit G80 will result in an increase in setting time. The duration increased as a result of the addition of Silubit G80 by 0.1%, 0.3%, 0.5%, 1.0%, 1.5%, and 2.0%). The three steps of the RPOP setting time process include hemihydrate dispersion, gypsum crystal nucleation, and $CaSO_4.2H_2O$ crystal growth, according to the $CaSO_4.0.5H_2O$ rapidly dissolves in water to create Ca_2+ and $2O_4^{2-}$ ions.

Sample A as RPOP + 0.5% Silubit G80, surface appears lumpy and rough, with visible lumps and uneven texture. A low concentration of Silubit G80 (0.5%) seems to be insufficient to improve the adhesion and smoothness of the plaster. The mixture may lack cohesion, resulting in a poor-quality surface. This indicates that 0.5% Silubit G80 does not provide sufficient stabilization to RPOP. Sample B as RPOP + 1.0% Silubite G80, surface is smoother than Sample A but still shows unevenness and ridges. With 1.0% Silubit G80, the mixture shows an improvement in texture and smoothness. However, there are still significant imperfections, indicating that this concentration is better but not optimal. The increased amount of Silubit G80 helps in achieving a better consistency, but the binding is still not ideal. Example C as RPOP + 1.5% Silubit G80, smoother surface with fewer imperfections and more uniform texture. At 1.5% Silubit G80, the mixture achieves a more desirable texture, with far fewer imperfections. This concentration appears to improve the binding and setting properties of RPOP effectively, leading to a more uniform and smoother surface. This indicates a more optimal interaction between RPOP and Silubit G80. Sample D as RPOP + 2.0% Silubit G80, surface is very smooth and consistent, with minimal imperfections. The highest concentration of Silubit G80 (2.0%) produced the smoothest and most uniform surface among all samples. This shows that 2.0% Silubit G80 provides excellent stabilization and binding for RPOP, leading to a high-quality setting surface. This sample shows the best reaction control and consistency, indicating optimal mixing.

Increasing with the addition of Silubit G80 percent, there is a clear trend of better surface quality with increasing concentration of Silubit G80. As the percentage of Silubit G80 increased from 0.5% to 2.0%, the setting surface of the RPOP became smoother and more uniform. The best results are seen with 2.0% Silubit G80, where the surface is almost perfect. This concentration appears to provide the binding strength and reaction control required for RPOP to set properly. But this is just an external view, it needs to undergo several tests to determine the true nature of POP.

4.5.2 Compressive Strength Analysis of NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 0.5%, 1%, 1.5% and 2%

A silane-based additive called Silubit G80 is well known for its capacity to improve the mechanical qualities of a variety of materials, including goods made of plaster. Silanes are chemical compounds that have silicon and hydrogen atoms in them.

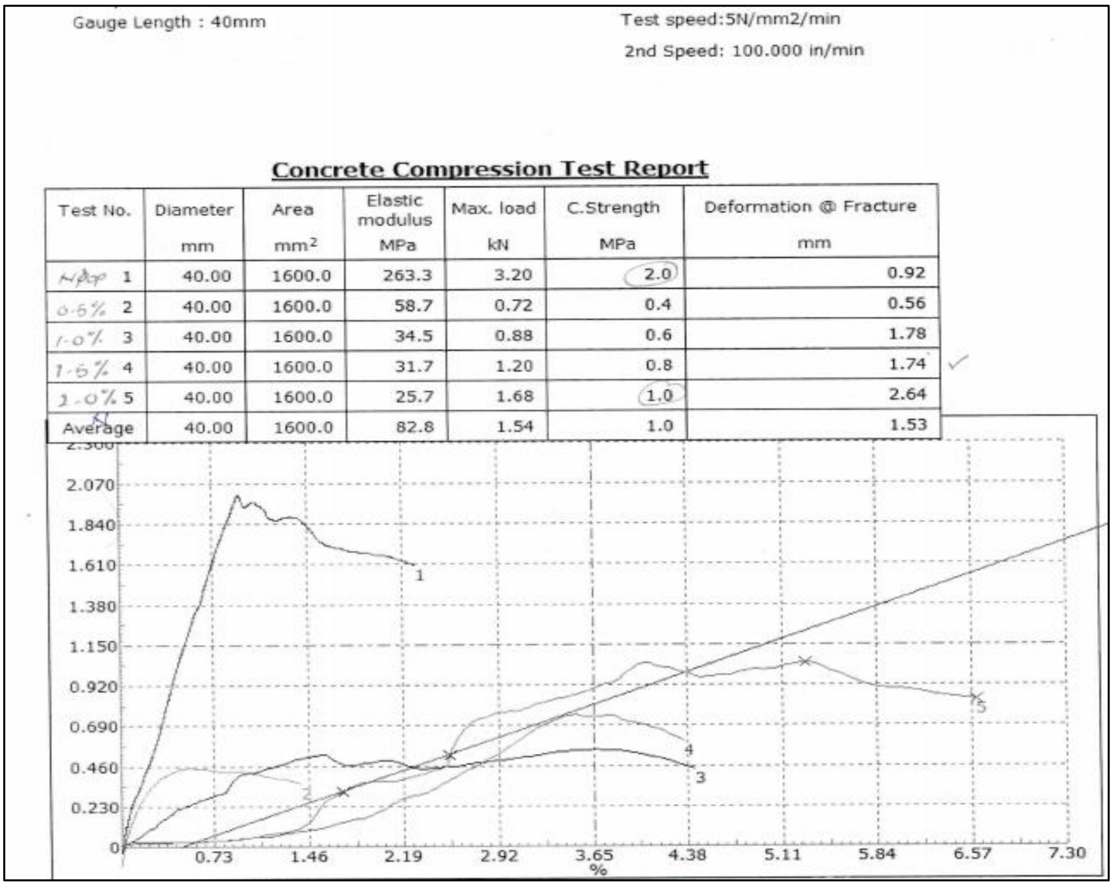
These compounds can form bonds with inorganic and organic surfaces, enhancing their strength and stickiness. When mixed with recycled plaster of Paris, Silubit G80 creates a chemical link with the plaster particles that improves cohesiveness and decreases porosity.

The compressive strength of RPOP directly affects the durability and lifespan of cast objects, especially in applications exposed to mechanical stress or environmental factors. The high compressive strength increases the structural integrity of the casting, ensuring that it withstands prolonged use and retains its shape over time. According to Shiyo, Nagels & Shangali, (2020), a study was conducted on the compressive strength of the recycled material. The results showed that the average strength of the recycled powder mixed in an equal ratio between POP and water (1:1) is 2407 kN/m^2, while the average strength of the powder mixed in a ratio between POP and water (2:3) is 1028 kN/m^2. The results for virgin POP were 1807 kN/m^2 and 798 kN/m^2, respectively. Thus, for both recycled and virgin powder, the same POP and water mixing ratio yields a compressive strength that is roughly 43% stronger than the POP and water mixing ratio (2:3). This proves that the strength of the plaster depends on the ratio of the mixture used. A lot of plaster used in the mixture will increase the strength of the plaster. Reported by Click or tap here to enter text., the values of pure plaster's compressive strength and plaster mixed with polyphenol-tannic acid (10, 30 and 50%). There was no statistically significant difference in the compressive strength value between the plaster with + 30% polyphenol-tannic acid (48 ± 8 MPa) and pure plaster (58 ± 5 MPa) ($P > 0.05$). Nonetheless, when compared to the original plaster, all plaster composites, plaster +50%TA (34 ± 7 MPa), and plaster +10% polyphenol-tannic acid (11 ± 3 MPa) showed statistically significant lower compressive strength values. Samples of plaster ($P < 0.05$). The 10% composite polyphenol-tannic acid plaster produced startling but repeatable minimum compressive stress values this could be because of the interaction between polyphenol-tannic acid and Ca_2+ cations, which causes a phase transition.

As mentioned above, Silubit G80 is used with different contents into RPOP to increase the strength of the tested soil. It is important to mention that all the RPOP 160°C samples that have gone through the cycle process all contain Silubit G80 content of 0.5%, 1.0%, 1.5% and 2.0%. this is clear, the value of compressive strength (kN) increases with the increase of Silubit G80 additive in the content volume of RPOP 160°C.

However, the peak value for the highest compression is still in favor of unconfined NPOP and the ultimate tensile strength for the tested sample treated with Silubit G80 2.0% shows the highest value among other Silubit G80 mixed RPOP. The results show that Silubit G80 mixture does not help RPOP in to increase the level of RPOP mould strength when compared to NPOP samples. Also, it is observed that increasing the content of Silubit G80 into RPOP 160°C up to 2.0% did not cause a significant increase in tensile strength compared to an increase in compressive strength. It can be observed from this figure, the increase in compressive strength for each RPOP sample mixed with Silubit G80, for example, with 0.5% and 1.0% content of Silubit G80 in the fold about 0.16 kN. Instead in this case, value the strength of RPOP should be closest to or equal to the strength value of NPOP, but if look at the

Figure 4.13, NPOP has a much higher value compared to RPOP 160°C + 2.0% silubit and none of the RPOP 160°C + Silubit G80 samples have the same value such as NPOP.



Test No.	Diameter mm	Area mm²	Elastic modulus MPa	Max. load kN	C.Strength MPa	Deformation @ Fracture mm
NPOP 1	40.00	1600.0	263.3	3.20	2.0	0.92
0.5% 2	40.00	1600.0	58.7	0.72	0.4	0.56
1.0% 3	40.00	1600.0	34.5	0.88	0.6	1.78
1.5% 4	40.00	1600.0	31.7	1.20	0.8	1.74
2.0% 5	40.00	1600.0	25.7	1.68	1.0	2.64
Average	40.00	1600.0	82.8	1.54	1.0	1.53

Figure 4.13 The Concrete Compressive Test Report

4.5.3 Porosity Analysis of NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 0.5%, 1%, 1.5% and 2%

From Figure 4.14, it can be clearly seen that the porosity decreases when the percentage of Silubit G80 is increased. When the percentage of Silubit G80 is added, the fraction of voids in the sample will decrease and the bonding between particles will increase which will cause low strength in the RPOP sample. With the presence of Silubit G80 this works at the molecular level, spreading the calcium sulphate particles more evenly throughout the mixture. By doing so, it reduces the surface tension of the water in the mixture, which in turn reduces the overall water demand. The presence of excess water in the plaster mix usually leads to higher porosity after the setting and drying process. Higher porosity means more voids in the material, which increases water absorption. When Silubit G80 was introduced, it allowed the plaster to maintain its workability and fluidity with significantly less water. If observed high porosity RPOP with Silubit G80 is 0.1% and lower porosity is RPOP 1.0%. However, the porosity started to increase after the application of 1.5% and 2.0% Silubit G80.

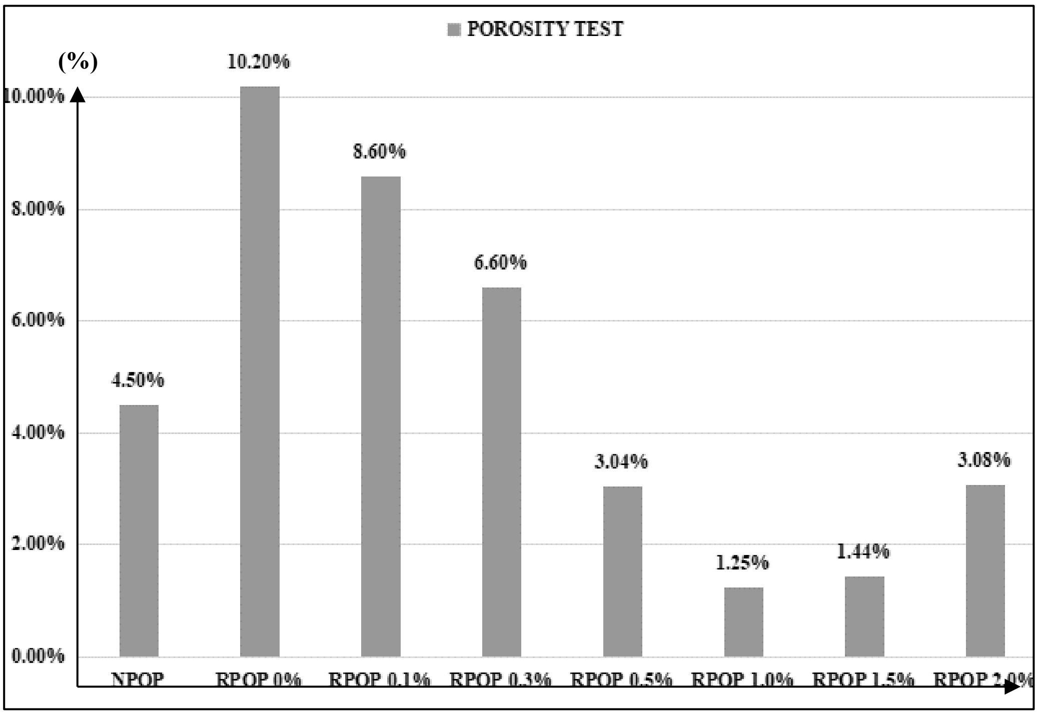


Figure 4.14 The Percentage Of Porosity Of RPOP 160 °C Add Silubit G80

Reported by Nawi & Badarulzaman, (2015)), further analysis showed that from 950 °C to 1050 °C, the percentage of porosity fell. The number of pores and voids may decrease at temperatures as high as 1050 °C. Furthermore, because POP is a highly porous ceramic material with a large internal surface made of interlocking crystals, residual POP additives result in higher porosity percentages. This phenomenon is observed when the shrinkage caused by the sintering process tends to reduce the porosity of the sintered sample.

However, if RPOP is not mixed with Silubit G80, the percentage of porosity is the highest compared to other samples including the NPOP control sample. At high temperatures, atoms and molecules within the material gain enough energy to move more freely. Additionally, the particle size distribution in recycled plaster of Paris may be less than optimal compared to NPOP. Larger or irregularly shaped particles can create more void space when the material sets, this effect will also contribute to higher porosity. During the recycling process, finer particles may be lost, which will usually fill the voids between the larger particles in the new plaster. The absence of these fines in recycled plaster results in higher porosity. This enhanced mobility allows particles to diffuse and bond together, filling in the gaps (pores and voids) between them. This can also be a problem for the mould if the pores are too high.

4.5.4 Water Absorption Analysis of NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 0.5%, 1%, 1.5% and 2%

Figure 4.17 shows the variation in water absorption of RPOP 160°C and Silubit G80 mixture with different percentages. The percentage of water absorption decreases when silubit G80 is added. The reduction in water content results in a denser and less porous final product. This is because the reduced water-to-plaster ratio minimizes the formation of voids and capillaries in the set plaster.

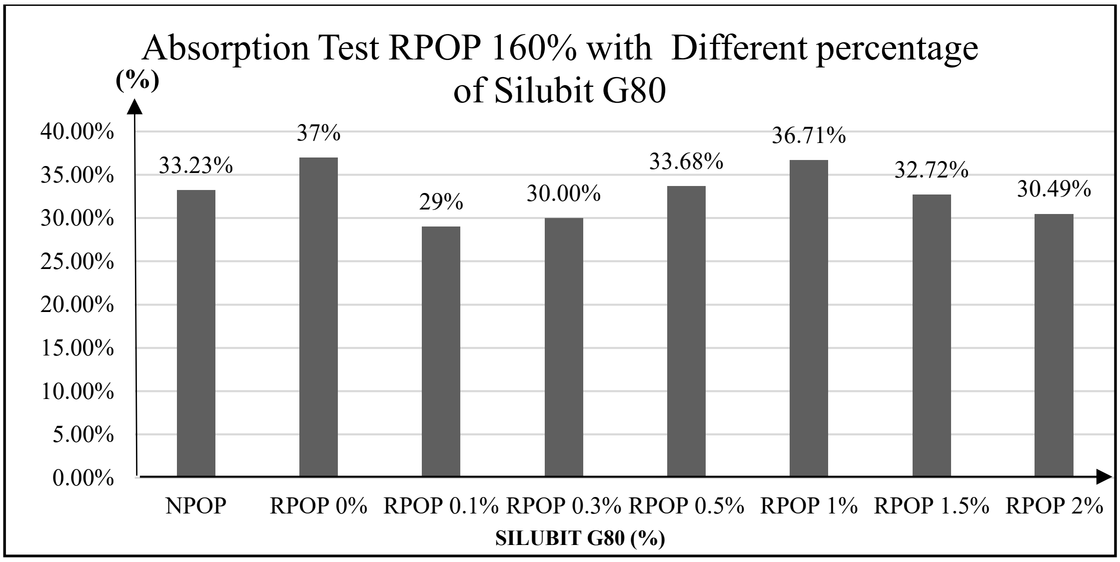


Figure 4.15 The Percentage Of Water Absorption Of NPOP, RPOP 160℃ And RPOP 160℃ Add Silubit G80

As a result, the microstructure of the material becomes denser and less permeable, directly affecting its water absorption characteristics. A denser matrix translates into fewer pathways for water to penetrate, thereby reducing the overall absorption rate. The reduction in water content results in a denser and less porous final product. This is because the reduced water-to-plaster ratio minimizes the formation of voids and capillaries in the set plaster. As a result, the microstructure of the material becomes denser and less permeable, directly affecting its water absorption characteristics. A denser matrix translates into fewer pathways for water to penetrate, thereby reducing the overall absorption rate. However, the RPOP supplemented with Silubit G80 showed absorption rose from 29% (Silubit G80 0.1%) to 36.71% (Silubit G80 1%) at 160℃, and when Silubit G80 was added in amounts of 1.5% and 2.0%, the percentage of absorption started to drop. However, without silubit G80, absorption is higher than with silubit and NPOP.

At 160℃, RPOP combined with Silubit G80 boosted absorption from 29% (Silubit G80 0.1%) to 36.71% (Silubit G80 1%). However, when Silubit G80 was increased to 1.5% and 2.0%, the percentage of water absorption decreased. From the result have found that, RPOP 160℃ containing a high amount of Silubit G80 shows lower air absorption compared to the use of a small amount of Silubit G80. It can be concluded that, the reduction of the percentage of water absorption with the increase of Silubit G80 is due to the characteristics of Silubit G80 that have guidelines in its use. as found from the observation, excessive use of Silubit G80 will affect the fluidity of

RPOP when mixed with air. According to Ayele & Balasubramanian, (2020), the maximum water absorption of the blending experiment is 0.3 cm/min for 50% recycled plaster and 50% virgin plaster. The water absorption is highest for 100% recycled plaster, 0.315 cm/min. All the values of water absorption are within the acceptable range developed by the factory for incoming inspection. Therefore, even though the ratio of water to RPOP 160°C powder is constant, the percentage of water absorption increase as the percentage was increased. It is because Silubit G80 acts as deflocculants, which means the solids content in the plaster slurry can be increased whilst maintaining the same processing consistency. Silubit G80 can increase the water resistance of RPOP, making it more durable and less prone to moisture-related damage. This is especially important for cast objects that may be exposed to external conditions or moisture over time.

From the observed in Figure 4.16, the surface of the RPOP sample mixed with Silubit G80 may turn black after drying in the oven due to several factors. First, the drying process at high temperature can cause the decomposition of organic materials or additives in Silubit G80, producing black carbon residue. The drying in the oven involves heating at a high temperature and the small size of the sample affects the colour of the sample changing during the process to remove moisture from the sample. This high temperature can cause a chemical reaction between the components in RPOP and Silubit G80. One of the main causes of colour change is the thermal degradation of organic matter in Silubit G80 which may produce carbon or carbonaceous residues.

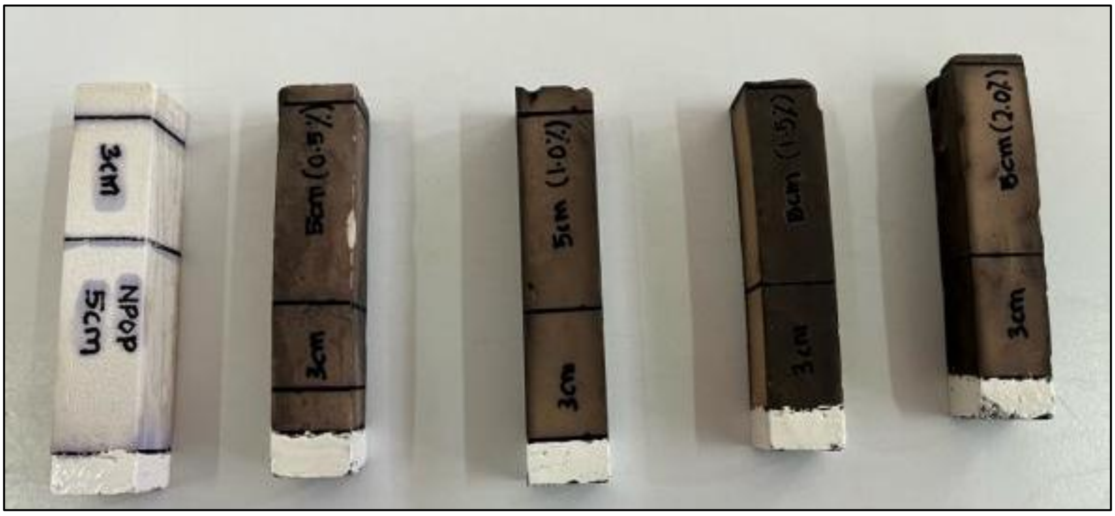


Figure 4.16 The Sample Bar After Drying At 55°C 4hours

Second, the chemical interaction between the components of Silubit G80 and RPOP during heating can form new compounds that are dark in colour. When Silubit G80 is heated, its organic components may decompose, and one of the products of thermal degradation is black carbon. This carbon can absorb into the surface of RPOP mixed with Silubit G80, resulting in a change in colour to black. In addition, drying at high temperatures can cause oxidation, where the elements in the mixture interact with oxygen in the air to produce dark-coloured oxidation products. That, the oxidizing conditions that occur in the oven can also contribute to this colour change. These factors can cause changes in the surface colour of the sample. The moisture content in Silubit G80 and RPOP also plays an important role. Excess moisture can cause a more active chemical reaction during heating, accelerate the degradation of the material and produce a dark color. RPOP may contain impurities or additives that also contribute to discoloration when heated.

The main cause of the surface of the RPOP bar sample mixed with Silubit G80 becoming black after drying in the oven is due to the chemical reaction and thermal degradation of the organic materials in Silubit G80 at high temperatures. The presence of moisture and impurities in recycled RPOP also contributes to these changes.

4.6 Conclusion

The optimal performance of recycled plaster of Paris (RPOP) was achieved at a Silubit G80 concentration of 0.5%, which provided the best balance between mechanical strength, density, and workability. At this dosage, the activator effectively enhanced particle dispersion and hydration, resulting in a dense and well-bonded microstructure with minimal porosity. This improvement contributed to higher compressive strength and reduced water absorption, both of which are critical factors for durable and reusable ceramic moulds. The 0.5% Silubit G80 level also ensured smooth handling and consistent setting behaviour without causing segregation or instability in the slurry. In contrast, concentrations exceeding 1% yielded diminishing returns, as excessive deflocculation led to over-dispersion and disrupted the structural cohesion of the plaster matrix. This condition weakened interparticle bonding, resulting in slight reductions in strength and surface uniformity. Therefore, maintaining a low yet effective dosage not only preserves material integrity but also offers economic benefits by reducing additive consumption. These findings confirm that 0.5% Silubit

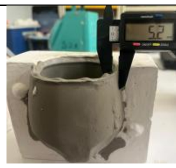
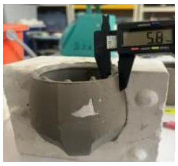
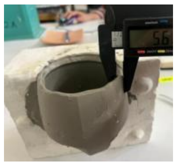
G80 represents the most efficient and sustainable formulation for enhancing recycled POP, achieving optimal physical and mechanical properties suitable for repeated ceramic moulding applications.

4.7 Slip Thickness Of NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 (0.5%) Observation after Casting Process

A critical aspect of slip casting is thickness control in the final product. Diagram investigates the physical changes in the mould that affect the variation in thickness in slip-cast stoneware and the effect of this variation on the yield of ceramic pieces. For a practical test of the workability characteristics of RPOP 160% and RPOP 160°C + Silubit G80 0.5%, standard method for filling with recycled POP slurry. The slip cast is removed after 1 hour to fix and carry out different thermoplastic procedures and RPOP thermoset with the following observations. The effect on the casting surface of RPOP 160% and RPOP 160°C + Silubit G80 0.5% compared to NPOP (control) is the same, but only the thickness changes.

Table 4.3

The Thickness Of Casting Product

Moulds	Casted Thickness (mm)			
	1st	2nd	3rd	4th
NPOP	 (9.0)	 (7.1)	 (6.1)	 (5.2)
RPOP 160°C	 (8.7)	 (7.1)	 (6.7)	 (4.9)
RPOP 160°C with SILUBIT G80 (0.5%)	 (8.1)	 (7.0)	 (5.8)	 (5.6)

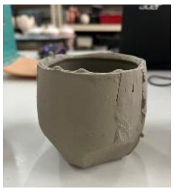
Through the observation, by standardizing the mould shape, mixing ratio and mould size used for these three samples. The slip-cast thickness is observed, all samples show a decrease in thickness after undergoing 4 casting processes. As shown in Table 4.3, at the beginning of NPOP casting for 30 minutes, it recorded a thickness of 9.0mm, RPOP is 7.1mm, while at RPOP add Silubit G80 (0.5%) increased again to 8.1mm.

According to the result, one of the causes of the lack of slip thickness is gravity which causes the ceramic particles in the slip to settle during the casting process. Larger concentrations of ceramic particles are typically found in thicker parts of the mould, causing larger deposits in these areas. As a result, thickness loss caused by particle deposition may be greater in thicker sections. This result shows that the use of Silubit G80 with the correct percentage can influence the body mould to absorb water in the slip content perfectly. The 4th casting shows a decrease for all samples, this happens because the body mould starts to get wet causing the water absorption rate to decrease. The loss of water and particle compaction cause the ceramic material to shrink during the drying and firing phases of slip casting. Because of variations in temperature gradients and moisture content, thicker portions of the casting typically shrink more than thinner parts. Consequently, the overall thickness may decrease as thicker sections shrink more.

Table 4.4 shows the slip surface that has been removed from the mould. If notice that the NPOP for the 1st casting, the surface of body slip cast is smooth and does not have any effect such as scratch or uneven, however, the surface of RPOP 160% and RPOP 160°C + Silubit G80 0.5% for the first has an effect and does not flat. This is not a problem for the casting process because it is customary in the casting process, the casting prefix will indeed experience problems on the slip casting surface. However, in the next casting process, the slip cast surface will smooth. In the 2nd casting, samples b) and c) show a change in terms of the surface which at the beginning of the rough casting becomes smooth, but there are still pinholes on the surface. These pinholes are produced when the reaction between molten metal and moisture or other contaminants present during the casting process. Air bubbles trapped in the plaster mix during mixing or pouring can create small cavities or pinholes. Also, this pinhole can occur when moisture in the mould, reacts with the molten metal to form gas, which then creates a pinhole. At the first casting, the body mould is dry and easy to absorb water content. Therefore, moisture in the mould containing water can also contribute to the occurrence of pinholes. However, this problem can be controlled by ensuring that the mould is thoroughly dried before use to remove moisture. To avoid pinholes, it is important to mix the plaster carefully, use degassing techniques, pour the mixture slowly, and ensure proper vibration of the mould. Detecting and addressing pinholes through surface inspection and finishing can help maintain plaster mould quality and accuracy, ensuring better results in the final cast product.

Table 4.4

The Surface Body Of Slip Casting

Sample	Number of Casting			
	1st	2nd	3rd	4th
a) NPOP				
b) RPOP 160℃				
c) RPOP 160℃ + SILUBIT G80 (0.5%)				

On the 4^{th} cycle, all samples started to produce excess slip in each part of the mould joint. Incomplete drying or curing can cause the mould to deform or shrink unexpectedly, leading to dimensional inaccuracies in the final casting. This may result in defects or non-compliance with specified tolerances. In addition, one of the most common issues is the formation of flash, which is excess material that escapes through the gaps and solidifies. Excessive mould wear that causes over time, the mould can wear, especially on the joint surface, creating gaps through which material can seep. In the casting process such slips are poured into the mould cavity to form the desired shape. Flashes form when molten metal flows into small gaps between mould components or between the mould and the pattern. Factors such as improper gating, excessive casting temperatures, and inadequate mould alignment can contribute to flash formation in castings.

4.7.1 Microsturcture Study of Silubit G80 in NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 0.5%

Silubit G80 has been tested under scanning microscope. The position of Silubit G80 particles is seen to be in the shape of a big blob. The generated particles are not consistently botryoidal crystal shaped, but each particle surface contains curves and longitudinal interweaving. This electronic image shows that Silubit G80 particles comprise Carbon, Oxygen, Boron, and Gold. Silubit G80 is a commercial filler used to improve the properties of composites. In SEM images, Silubit G80 displays a fibrous and elongated morphology. The fibres are well defined and have a rough surface texture, which can significantly improve mechanical interlocking and adhesion with other materials in the composite.

The fibre properties of Silubit G80 contribute to the reinforcement of the composite, potentially increasing its tensile strength and overall mechanical properties. The rough surface helps in better bonding with the matrix material, making it an excellent additive to improve composite performance. Figure 4.17 b) is a sample of New Plaster of Paris (NPOP) taken from a SEM scan image. Figure 4.17 b) clearly demonstrates that the NPOP particles are distributed, and that the particle size is not consistent in shape and size. It has particles that have the most prominent shape and have the largest in size. This sample contains the elements carbon, oxygen, boron, calcium, and sulphur. SEM images of NPOP reveal a structure composed of irregular and blocky particles. The particles are relatively large and appear to have a compact and compact arrangement. This morphology indicates that NPOP has good structural integrity.

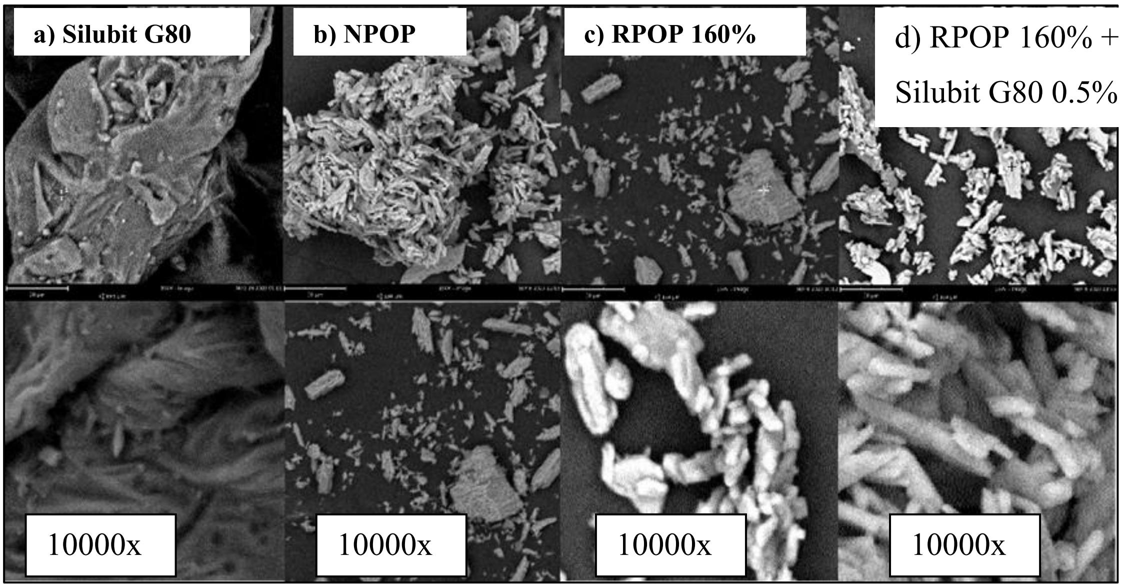


Figure 4.17 SEM Images Of Materials Use Making Mould (A) Silubit G80 (B) NPOP (C) RPOP 160°C (D) RPOP 160°C + Silubit G80

Figure 4.17 (c) has undergone a recycling process, if observed, the shape of the particles is more consistent and chained like the shape of dendritic crystals. These particles are more in the form of a short lattice that joins with other particles at the end of the lattice so that a dendritic shape is produced between the particles. The recycling process of Plaster of Paris at 160°C significantly changes its structure. The SEM image of 160 °C RPOP shows a more fragmented and finer particle size compared to NPOP. The recycling process may involve dehydration and partial rehydration cycles, which break larger particles into smaller, uniform-sized fragments. This morphological change can increase the material's reactivity and bonding potential when mixed with other components. The finer particle size of 160°C RPOP indicates that it can better fill the gaps and voids in the composite matrix, potentially improving the overall mechanical properties and surface finish of the mould. Sample Figure 4.17 (d) is lattice-shaped, crystalline prismatic. Lattices has changed the properties of RPOP pysical, such as strength, conductivity and optical behavior. This is because the RPOP sample has been dried beforehand at a certain temperature and mixed with Silubit G80.

It is clear in Figure 4.17 (d) that RPOP+Silubit G80 has increased pores if the position and close arrangement of particles is observed. But still have space for each other. The particle shape is horizontal and orthorhombic. This is because this sample contains Oxygen, Carbon, Calcium and Sulphur. Image of RPOP 160 °C mixed with Silubit G80 shows the combined structure of Silubit G80 fibres and flaky particles of

RPOP 160 °C. The SEM image reveals the intricate mixing of the two materials, with Silubit G80 fibres distributed throughout the fine particles of 160°C RPOP. This composite structure shows a synergistic effect where the strengthening properties of Silubit G80 are combined with the enhanced bonding and filler capabilities of RPOP 160°C. The presence of Silubit G80 fibres in the fine-grained 160 °C RPOP matrix can produce composite materials with enhanced mechanical strength, better stress distribution and better durability. Rough and diverse surface morphologies can lead to excellent adhesion in composites, further enhancing their performance in mould making applications.

4.7.2 Phase Analysis of Silubit G80 in NPOP, RPOP 160°C and RPOP 160°C + Silubit G80 0.5%

The study continued by testing XRD on all samples, namely, NPOP, RPOP 160°C, Silubit G80 to check the mineralogy of the samples used in this study and elemental composition before and after adding RPOP plus Silubit G80. XRD analysis was run on RPOP and RPOP + Silubit G80 to investigate the changes in soil mineralogy and the formation of RPOP compounds. Figure 4.14 shows the XRD analysis results for NPOP, RPOP 160°C, & RPOP 160°C + Silubit G80 samples. If observed all samples are the same.

At RPOP 160°C and RPOP 160°C + Silubit G80 0.5% shows the presence of gypsum at peak 12 RPOP 160% and RPOP 160% + Silubit G80. But at peak 12 NPOP no presence of gypsum is visible. However, at peak 50, Bassanite was presence of in sample NPOP is very high compared to samples RPOP 160% and RPOP 160% + Silubit G80. This may happen because NPOP it is not contaminated with other chemical content and does not go through the recycling process, therefore the gysum content in this sample has not yet been affected. The presence of Gypsum at peak 20 in sample RPOP 160% and RPOP 160% + Silubit G80is high but at peak 27 NPOP, Bassanite appears.

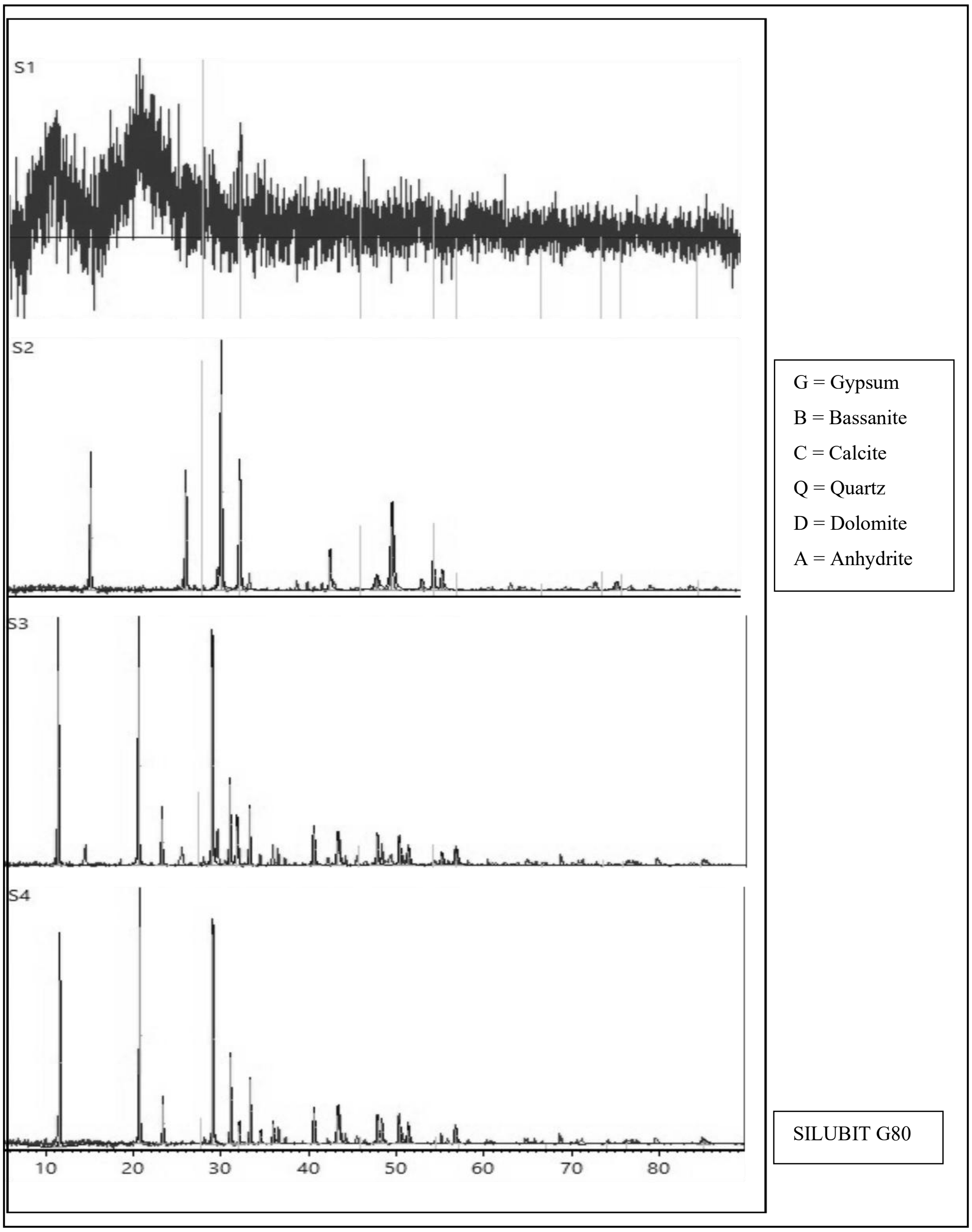


Figure 4.18 XRD Pattern Of Raw Material Of Powder Silubit G80, NPOP, RPOP 160°C, & RPOP 160°C + Silubit G80

4.8 Intricate Form for Mould Performance of NPOP and RPOP 160°C + Silubit G80 0.5%

In this discussion, will explore the mould performance of three different types of Plaster of Paris are New Plaster of Paris, Recycled Plaster of Paris dried at 160% and Recycled Plaster of Paris dried at 160°C with additive of Silubit G80 at 0.5%. Recycled mould must maintain high material integrity to ensure they can withstand the rigors of the manufacturing process. The techniques such as heat treatment and surface coating are used to restore and increase the durability of recycled mould. Studies have shown that with proper treatment, recycled mould can perform on par with new ones, exhibiting the same level of strength, durability, and accuracy. The performance of the recycling mould in terms of production efficiency is an important metric. These include cycling time, defect rates and consistency in product quality. Research shows that when recycled mould is refurbished and properly maintained, it can achieve production efficiencies nearly equal to new mould. However, initial setup and calibration may require more attention to detail.

New Plaster of Paris is newly produced and does not undergo any recycling process. It is known for its excellent mould performance due to its purity and optimal physical properties. When mixed with water, New Plaster of Paris forms a fine, homogeneous paste that can be easily poured into molds. It sets relatively quickly, usually within 20, and achieves a hard, durable finish. Setting time can be affected by factors such as temperature, humidity, and water-to-plaster ratio.

One of the main benefits of New Plaster of Paris is its small particle size, which allows it to capture subtle details in moulds with great precision. In addition, its regular setting time and mechanical strength provide dependable performance in a wide range of industrial applications, particularly mould casting.

RPOP involves reprocessing used plaster to make it suitable for reuse. This not only reduces waste but also conserves natural resources. Recycled Plaster of Paris at 160% commonly refers to the practice of rehydrating used plaster by adding water to a ratio that restores its original consistency and working properties.

4.9 Conclusion

The performance evaluation demonstrated that recycled POP, when thermally activated at 160°C and modified with 0.5% Silubit G80, achieved substantial improvements in casting consistency, surface finish, and structural durability. Its behaviour closely matched that of new POP moulds even after several casting cycles. The combination of thermal and chemical modification effectively compensated for the natural deterioration of recycled plaster, extending its functional lifespan while maintaining acceptable mechanical and aesthetic properties. These findings provide strong evidence for the feasibility of using RPOP + Silubit G80 in industrial and artistic ceramic moulding, supporting a more sustainable approach to material reuse.

4.10 Aesthetic and Intricate Moulds of Optimized RPOP.

In this study, its focused-on mould making all using RPOP. A cup-shaped mould with an additional angled shape is used to observe the potential of RPOP during the RPOP liquid casting process in angled areas and narrow gaps. The size used to produce these two moulds is the same in terms of height and thickness of the mould. This is because its need to observe these two moulds working simultaneously to get test results. Drying Plaster of Paris before use is important because drying the plaster helps to remove excess moisture, which can weaken the final product if not properly evaporated. This process increases the strength and durability of the POP once it is set. Drying allows any moisture to escape, ensuring a smoother consistency and finish on the product surface when the casting process is done. This results in a better overall appearance of the final product. Overall, drying POP before use is an important step in ensuring its workability, strength, and finish quality. Figure 4.19 the mould drying all parts of the pieces of the mould for a day before starting the casting work.

Figure 4.19 shows the process of removing the internal moisture of the mould. This process aims to prevent defects on the mould surface as well as the product casting surface. Residual moisture in the mould can cause defects in the mould pieces. In addition, by drying the mould can ensure the dimensional accuracy of product casting. Moisture can cause the material to expand or contract, affecting the dimensional accuracy of the moulded part. Drying ensures that material properties are consistent throughout the mould, leading to uniform mechanical properties in the final product. In processes such as moulding, proper drying ensures better bonding between layers or materials, increasing the overall strength and durability of the final product.

Figure 4.19 The Mould Drying Parts Of Mould On Air

By keeping the mould moist, it can prevent corrosion that will occur on the mould surface. This is because moisture can cause the mould walls to become brittle and break easily which will damage the surface of the mould and reduce its lifespan. Properly dried moulds can reduce cycle times by ensuring that the moulding process is not interrupted or slowed down by moisture-related issues. In addition, the dry mould turns into better release properties, making it easier to remove the final product without damaging it or the mould.

Figure 4.20 is observed to have a smooth surface. It is because of the properties of the material and the method used to make the mould, the surface of a NPOP mould is typically smooth. NPOP becomes a semi-liquid material that readily flows into the mould's shape when combined with water. Its fluidity enables it to completely fill the mould, producing a flat surface. In addition, POP flows freely when combined with water due to its comparatively low viscosity. This property reduces any deformation by enabling it to precisely conform to the mould's surface. POP absorbs water and hardens relatively quickly once it is placed into the mould. During this setting process, any small imperfections or irregularities in the surface of the mold will be smoothed out as the plaster hardens. The combination of the liquid properties of POP, its low viscosity, and the setting process all contribute to the creation of a smooth surface on plaster moulds.

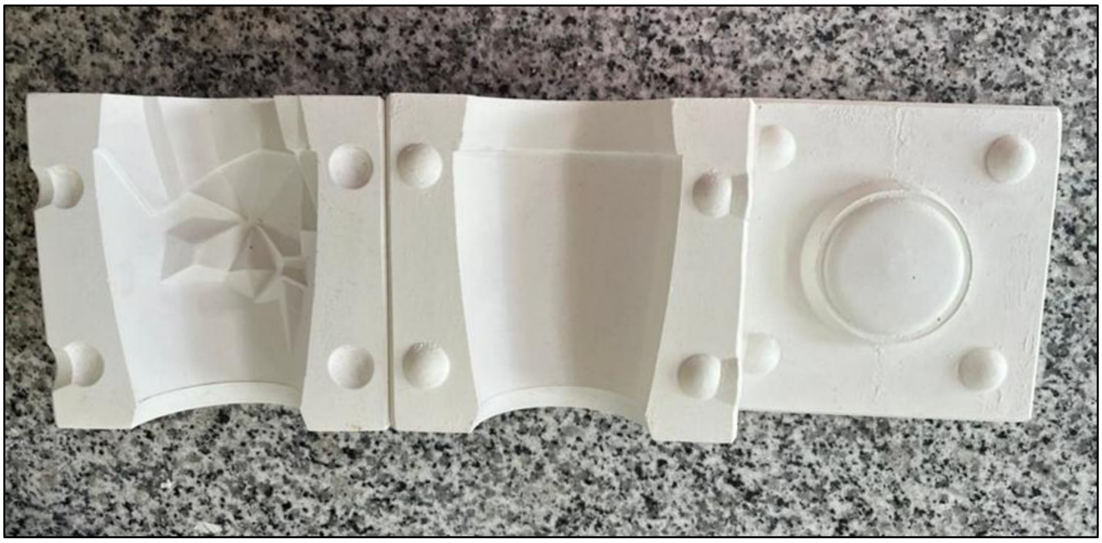


Figure 4.20 Surface Of NPOP Mould Before Casting

Figure 4.20 shows the control NPOP mould after being dried and before being used as a casting mould. If observed control surface, NPOP mould is smooth and neat while in it is RPOP 160°C + Silubit G80 (0.5%) also has a smooth and neat inner surface of the mould but there are small holes on the outside of the mould wall. Uneven drying or an absence of 'curing' time for the plaster or stucco walls can also lead to unsettling air bubbles.

Figure 4.21 Surface Of RPOP 160°C + Silubit G80 (0.5%) Before Casting

4.10.1 Casting Performance of Aesthetic/Intricate Product

RPOP has poor flow for pouring into the mould cavity. Therefore, the use of Silubit G80 increases the plasticity and flow of the RPOP slurry, making it easier to use. This is particularly useful in complex moulds and detailed work, where a smooth application is essential and Silubit G80 improves the quality of the POP adhesive, ensuring a better bond to the substrate. This is particularly beneficial in mould casting manufacturing applications where strong adherence to surfaces is important. Silubit G80 can increase the flow qualities of plaster slurry, making it more effective at filling intricate details and complex geometries shape. This ensures that the final mould captures all the small details from the original model.

The duration of casting directly affects the efficiency of the manufacturing process. Longer casting times can lead to decreased productivity and increased costs due to extended labour and energy use. The duration of the casting affects the flow of liquid material into the mould cavity. Therefore, the casting process was set for 30 minutes of slip casting into the mould to see the difference between these two samples. The duration of the casting affects the flow of liquid material into the mould cavity. Proper control of pouring time ensures uniform mould filling, reducing defects such as air entrapment, misruns, or cold closure. After the mould is filled with slip, the casting is left in the mould before being removed from the mould. The poured slip into the sample mould simultaneously to observe the difference between these two samples as shows as in Figure 4.22. Proper mould release and casting is important to minimize thickness drop in slip casting. Inadequate removal can trap air in the mould cavity, leading to air pockets and variations in thickness. Also, if the mould clearance is insufficient, the casting part may adhere more strongly to the mould surface, making it difficult to achieve a uniform thickness.

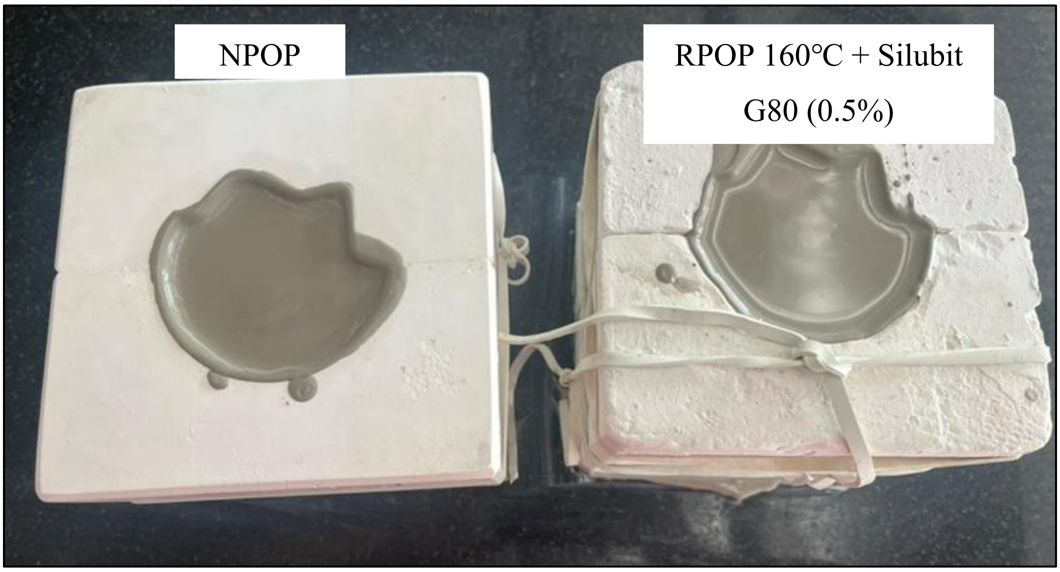


Figure 4.22 Two Differents Mould Casting Using Stoneware Slip

The casting period and the surface quality of the final product are important aspects of the casting process, which affect the production efficiency and the quality of the final product. Mould design plays an important role in determining the thickness of slip-cast stoneware. Moulds with intricate details or varying depths can result in uneven thickness across the ceramic object. In slip casting, mould design can also influence thickness reduction. Complex geometry or sharp corners in the mould design may cause uneven drying and shrinkage, which can cause thickness differences in the part.

Proper drying conditions are essential to achieve a consistent thickness in slip-cast stoneware. Rapid or uneven drying can cause cracking or warping, affecting the overall quality of the ceramic piece. The cooling period depends on factors such as the type of material, thickness, and complexity of the design. Controlling cooling time is important to avoid premature mould opening, which can result in distorted or damaged castings. Efficient casting period management involves optimizing the entire casting cycle, including mould preparation, pouring, solidification, cooling, and removal. Minimizing cycle time while maintaining quality ensures higher production and lower production costs. Thickness reduction can be affected by the method used to fill the mould with slip. When pouring the slip into the mould, the researcher pours carefully and does not interrupt the slip casting process to ensure the same slip and thickness distribution throughout the casting can be facilitated by using the correct casting technique, including maintaining a consistent casting rate and angle. Inadequate casting methods can result in reduced thickness and irregular filling.

The surface quality of the final casting is a critical factor in determining its functional and aesthetic appeal. A smooth surface improves visual appearance and may reduce the need for additional finishing processes. The casting surface should be free from defects such as porosity, shrinkage, cracks and surface roughness. These defects can weaken the casting, affect dimensional accuracy and lead to premature failure in service. Proper mould design, preparation and maintenance are essential to achieving a high-quality casting surface. Factors such as mould material, surface treatment, gating system design, and mould release agents affect surface finish and integrity.

The quality of the final cast surface in POP can be evaluated based on several criteria. The surface should be relatively smooth, free of bumps, ridges or rough patches. This is important to achieve a visually appealing finish. If observed in Table 4.5, the slip casting prosess between NPOP and RPOP 160℃ + Silubit G80 (0.5%) moulds until the surface of the casting is damaged and the mould is difficult to function as a water absorbent.

Table 4.5

The Surface Body Slip Casting Of NPOP And RPOP 160℃ + SILUBIT G80 (0.5%)

Mould	Surfaces			
	1time	4times	10times	>14 times
Control NPOP				
RPOP 160℃ + SILUBIT G80 (0.5%)				

Table 4.5, the first casting of both mould samples produced a smooth surface. Every square part of the product does not produce any effect. When removing the product slip both from the mould easily and does not stick.

In Table 4.5, the 1st time and 4th times castings of NPOP and RPOP 160°C + SILUBIT G80 (0.5%) of both mould samples produced a smooth surface. On the geometric angle, there is also no trace of breakage or cracks on the slip surface. In addition, during the process of removing the product both slip from the mould easily and do not stick to the mould wall. This is because the mould used is dry enough and the casting product is also set perfectly in the mould. In contrast to the 10 times casting, both samples began to produce an effect on the slip surface, in addition to the geometric angle. If look at the corners of the geometry start to break, and the angles start to be inaccurate. However, the surface that does not have a geometric pattern is still smooth and without pinholes. Irregular or complex shapes may have weak points where stress can concentrate, leading to potential failure or breakage during handling or during product removal. This is more obvious on the >14 times casting, the entire surface of the casting has the effect of cracks and breaks. The casting also needs a longer time to thicken and set in the mould. During the cooling and solidification process, different parts of the casting cool at different rates, which leads to thermal stress. If this stress exceeds the strength of the material, it can cause cracking. Mould design that is designed with various shapes in one product is also the cause that does not provide a uniform wall thickness can cause uneven cooling and solidification, causing cracks. This is a faucet, the design of the product on the front has a geometric design that is starting to crack. This problem can be related to mould moisture as well. Entire casting surfaces exhibiting cracks and breaks are indicative of fundamental issues in the casting process, material selection or mould design. In conclusion, optimizing the casting period and ensuring high surface quality are essential to achieve an efficient and reliable casting process. By carefully managing casting parameters, and implementing strict quality control measures, manufacturers can increase productivity, reduce costs, and deliver high quality castings.

4.10.2 Surface Observation of Mould after Casting

The nature of the stoneware clay used in slip casting also contributes to thickness variations. Factors such as particle size, plasticity, and firing temperature can affect how clay behaves during casting and drying. Thickness variations can also affect the aesthetic appeal of ceramic pieces. Consistent thickness contributes to a polished and professional appearance, while uneven thickness can detract from the overall visual effect. This happens on the tenth to fourteenth casting process of RPOP 160℃ + SILUBIT G80 (0.5%), because the mould already contains a lot of water, causing the slip absorption to become thinner. The produced slip is thin, the process to release the product casting will be complicated even though the time spent in the mould has been long. During the casting process, slip (a suspension of clay in water) is poured into the mould. With each casting, a thin layer of slip can adhere to the surface of the mould. Over time, this can build up and create imperfections in the acting product. Furthermore, repeated use of the mould can cause wear and tear on the surface, leading to imperfections or marks on the finished product. Although the mould is made of durable material, it can still deteriorate over time with continued use even if the mould has been properly rested and dried.

The surface of the mould can experience imperfections from time to time, such as cracks or small holes, which can be transferred to the cast product and cause a mark. If observed in Table 4.6, slip particles stick to the square space, this is what the observed, the gap part -small cracks on the surface of the mould are difficult to dry, causing the area to be damp and easy to break. Pin holes that exist on the surface of the mould will produce a slip effect on the surface of the mould as shown in Table 4.6 (after casting 4 times) even though this effect exists it can still be used for casting. But this problem continues to become more complicated, when the mould starts to get wet.

Table 4.6

Surface Of NPOP Mould And RPOP 160°C + SILUBIT G80 (0.5%) Mould After Casting

Mould	Number of Castings			
	1 time	After 4 times	After 10 times	After > 14 times
Control NPOP				
RPOP 160°C + SILUBIT G80 (0.5%)				

The effect is that the dry slip pieces continue to stick in the mould as shown in (after casting 14 times). When adhesion occurs on the mould, needs to clean the area in the mould. Therefore, the inner area of the mould wall will be damaged when washing it. The part of the vertices of the square shape becomes a curve. The surface finish and substance of the mould have a big impact on how much thickness is reduced. As it stands, the shape of the cup used by the researcher has a geometric shape and the complexity of the mould, including elements such as angles, undercuts, and fine details, can affect the thickness reduction. Complex mould designs have the potential to trap air or impede slip flow, which can cause uneven slip deposition and thickness changes throughout the casting. In general, thinner moulds with straight shapes and continuous surfaces show less thickness loss. Less fluctuation in thickness throughout the cast is produced by improved slip flow and uniform deposition of ceramic particles made possible by a smoother mould surface. However, slip flow and uneven thickness distribution brought on by a rough or porous mould surface might result in greater thickness loss.

The porosity of the plaster material is directly impacted by the water-to-plaster ratio. A more porous plaster structure is usually the consequence of a higher water-to-plaster ratio. The plaster can absorb more water when its porosity is higher. Excessive water absorption in mould-making applications can cause issues like longer drying periods, mould distortion, and shorter mould lifespans. Conversely, if the ratio of water to plaster is too low, the plaster mixture would not be able to absorb enough water, which would lead to incomplete hydration and weaker moulds.

Through the observation on Table 4.6 for the first-time casting both moulds there is no slip effect on the surface of the mould wall. Mould RPOP 160℃ + Silubit G80 (0.5%) which has undergone a casting process as many as 10, shows the mould that has been used resulting in some wear and residue on the surface. In addition, the effect of slip casting also appears to be attached to the mould wall. Slip casting is more attached to the geometric angle part of the mould. This is because, corners and narrow spaces in the mould create areas where capillary action is stronger. The narrow gap in this area attracts the slip more strongly, leading to a higher concentration of particles and water drawn into the corner. In mould corners, slip flow is naturally slower than in flat or open areas. This slower movement allows more time for slip particles to settle and adhere to the mould walls. Reduced flow can also lead to higher deposition of solid particles present in the slip. This causes the slip to stick tighter in this area. Just like casting > 14 times, the slip continues to stick to the mould wall even though it has been left to set in the mould for 20 minutes. The more slip slurry is poured, the more moisture is added to the mould. Corners and edges often dry at a different rate than the rest of the mould. Corners may dry slightly slower, allowing more time for slip to stick and accumulate in these areas before it hardens.

Complete dissolution of hemihydrate to dehydrate. The plaster has been set in the form of a series of interlocking dehydrates crystalline matrix (capillaries) gives the plaster the ability to absorb water after it dries. Therefore, making water absorption in the slip casting process may affect the mould as well. According to the statement made by Hafizan, Wahab, Saad, Rahim, (2017) the variation of the ratio of water to plaster plays an important role in determining the performance of the mould in terms of water absorption, porosity, and strength and if the ratio of water/plaster increases, the percentage of water absorption will also increased. In this study, the NPOP and RPOP mixture ratio was adjusted so that all samples were consistent. It shows that the physical mould mixed with Silubit G80 after carrying out the casting process several times, the RPOP + Silubit G80 mould was damaged (eroded, became soft and easily broken). The increased water content was the cause of this damage. Figure 4.23 shows the flow of liquid slip at the mould joint. This is because the wall surface between the mold parts is not flat and close after joining due to erosion or breakage.

For the plaster mould to survive the stresses placed on it throughout the casting process and retain dimensional correctness, it must be strong. The mechanical characteristics of the cured plaster are greatly influenced by the water-to-plaster ratio. Because of their decreased density and insufficient hydration of the plaster particles, plaster moulds made with a higher water-to-plaster ratio are often weaker. On the other hand, stronger moulds with greater compressive strength are typically produced when the water-to-plaster ratio is smaller. On the other side, very low water-to-plaster ratios may cause problems handling and mixing the plaster mixture, as well as poor flowability and incomplete hydration.

When it comes to tiny or complex sections of mould, POP can be particularly brittle and wet. Because of its fragility, it can easily break or cracked by pressure or impact. Because the RPOP mould is extremely susceptible to moisture, displays the deteriorated RPOP+ Silubit G80 mould on the mould surface. Overexposure to moisture can cause structural weakening and eventual disintegration. Maintaining the mold's dryness and avoiding prolonged contact with water are crucial. Compared to NPOP, RPOP + SILUBIT G80 can only be used as mould casting less than 14 times because of mould wall erosion and limpness. This is because this mould may deteriorate due to environmental factors such as temperature fluctuations, humidity, and exposure to sunlight. In addition, it is a recycled material. Aging of this mold can cause the material to weaken and increase the likelihood of wear and tear.

Figure 4.23 Mould RPOP + Silubit G80 Which Has Been Damaged After Casting

Depicts a mould that has been used in the casting process. POP is widely used in moulding and casting due to its versatility, ease of use and ability to capture fine details. However, like any material, it can suffer damage during or after the casting process. The most noticeable damage to the plaster cast is a noticeable chunk missing from the top right corner. This type of damage usually indicates mechanical stress or mishandling during the demolition process. Additionally, there are many surface imperfections and small cracks that can indicate internal stress or improper handling. The process of removing a cast object from a mould can create mechanical stress, especially if the mould is rigid or the casting material adheres strongly to the mould. Excessive force or improper technique can cause the mould or mould to break. Rough handling or accidental drops can easily damage the plaster mould, especially if it is not fully cured or has not yet been reinforced.

Adding additives to RPOP can occasionally result in problems like slippage. This happens when water coupled with POP creates a matrix of crystals of calcium sulphate hemihydrate. As the mixture solidifies, these crystals interlock to give material strength and stability. As in Figure 4.24, slippage between mold parts is caused by erosion in the mould joint area. This is because the mould needs to be cleaned in the surface area of the mould from the dry slip before pouring the slip liquid again. Additives, however, have the potential to obstruct the bonding or crystal formation processes. Interference has the potential to erode the structure, resulting in reduced strength or slippage. Furthermore, some additions can change the plaster's overall characteristics or setting time, which would exacerbate slippage problems.

Slip casting is a ceramic moulding technique in which a molten clay mixture, known as slip, is poured into a porous mould. The mould absorbs moisture from the slip, leaving a layer of solid clay on the surface of the mould. If the slip casting part is torn or stuck to the mould it will be like Figure 4.24. Even though used the same drying time for the casting, the casting still sticks to the mould surface. According to the result this is caused by a wet mould surface. In addition, if this RPOP + Silubit G80 mould is wet, the surface of the mould will become sticky like glue. This is also one of the causes of slip casting sticking to the mould wall. For all casting parts are removed from the mould too according to the time that has been adjusted. However, if the current casting is still wet or not completely dry, it can stick to the mould and tear when removed.

Figure 4.24 Mould RPOP + Silubit G80 Damaged Causes Slippage To Occur

As noted by changes in the thickness of the mould part can cause uneven drying. Thicker areas may dry more slowly and stick to the mould more strongly. The surface of the mould RPOP + Silubit G80 after undergoing the casting process more than 4 times the surface of the mould becomes rough or uneven. Rough or uneven surfaces in the mould can cause the clay to adhere more firmly to certain areas, increasing the possibility of tearing when moved as shows as in Figure 4.25.

Figure 4.25 Slip Cast Part Torn Due To Sticking To The Mould

4.10.3 Glaze Process

A smooth and glossy glaze on ceramic work is frequently a sign of effective firing and use, showing that several essential parameters were carefully managed during the ceramic cup production process. This glossy finish happens when the glaze melts sufficiently during the firing process to generate a continuous glassy layer on the ceramic piece's surface.

As show in the Figure 4.26 and Figure 4.27 , applying the correct glaze has produced a shiny appearance on the entire ceramic body. The even thickness of the glaze layer will produce the perfect colour and effect on the ceramic body. This plays an important role in the glazing process because if the glaze layer is too thick, it may flow or drip during firing, while, if it is too thin, it may appear dull or rough on the surface of the ceramic body. The technique used is dipping. Body bisque is dipped into the glaze liquid for 6 seconds. however, various techniques are used to apply the glaze layer, such as dipping, pouring, or spraying, used to apply the glaze uniformly. Each method has its nuances, and careful control is required to ensure consistent coverage throughout the piece.

A) B)

Figure 4.26 Geometry Cup Casting Use RPOP Mould After Glazing

A) B)

Figure 4.27 Geometry Cup Casting Use RPOP + Silubit G80 Mould After Glazing

The firing process is another factor in the result of a perfect glaze as shown in Figure 4.26 and Figure 4.27. The kiln used reaches the right temperature for the specific glaze used, allowing it to melt and flow evenly over the surface. The rate of temperature increase, known as the firing table, plays a role in the final appearance of the glaze. Controlled and gradual heating allows for even melting, reducing the risk of defects such as crazing or pin holing. Also, the cooling rate can affect the glaze's sheen, too fast a cooldown can cause problems with the glaze layer, such as cracking.

If observed, the ceramic body that has been glazed does not have pin holing and cracks. This shows that, from the initial casting process, the mould surface is perfect, and the burning temperature used is also consistent. The environment in the kiln, including the atmosphere and heat distribution, further affects the results. In an oxidizing atmosphere, oxygen interacts with the glaze components, often resulting in brighter, more vibrant colours. Conversely, a reducing atmosphere, where oxygen is limited, can change the colour and texture of the glaze, sometimes producing softer or more varied colours.

The melting process of glaze is influenced by its composition and firing temperature. During firing, these elements react at high temperatures to produce a liquid layer that protects the ceramic body beneath. As the kiln cools, the glaze solidifies into a glass-like layer that seals and protects the work while also increasing its visual appeal. Also, preparation of the bisque fired ceramic surface before glazing is important. A clean, smooth surface free of dust and oil ensures that the glaze adheres well, reducing the risk of defects. Bisqueware, or a pre-fired piece of clay, absorbs the glaze, which aids in even application and helps prevent blemishes.

If observed, these two ceramic cups do not have defects such as craziness (fine cracks in the glaze) or shivering (flaking glaze). Figure 4.28, there is an indentation effect on the cup, this is because the effect is produced when there is a crack in the attach part of the mould. Repeated use of the mould causes damage to the part.

Figure 4.28 Effect Of Join Line Mould In Body Cup

Compatibility of thermal expansion between the glaze and the ceramic body is important to avoid defects such as crazing or shivering. Crazing occurs when the glaze shrinks more than the clay body, leading to fine cracks, while cooling occurs when the glaze shrinks less, causing it to flake. A proper glaze and body match reduces this risk, ensuring a stable and durable finish.

4.11 Conclusion

RPOP (160°C) + 0.5% Silubit G80 moulds produced ceramic surfaces free from common glaze defects, comparable to NPOP results, confirming the functional reliability of recycled plaster in producing high-quality ceramic finishes. The absence of critical surface defects and structural distortions in glazed pieces made using RPOP + Silubit G80 moulds demonstrates that the modified recycled plaster supports consistent thermal and dimensional behaviour during firing, comparable to new POP moulds. RPOP (160°C) + 0.5% Silubit G80 is proven to be an effective and sustainable alternative for both artistic and functional ceramic production, offering surface precision, glaze uniformity, and durability comparable to conventional NPOP. The glazing outcomes validate that the recycled POP system modified with Silubit G80 performs effectively within the complete ceramics workflow from casting to firing. Its ability to produce defect-free glaze finishes confirms the stability of both material structure and mould performance. These results provide strong evidence that RPOP with minimal additive treatment can meet the quality standards demanded by professional ceramic production, while significantly reducing material waste and cost.

4.12 Summary of the Findings

As explained at the beginning of this study, the problems regarding waste are serious. If not taken care of properly, it will pollute the environment, and future generations will suffer. The problems discussed earlier include landfills, but not all of them manage solid waste perfectly. As a result, many waste disposal contractors look down on solid waste management practices such as POP. This issue becomes even more complicated when some contractors take the easy way out by disposing of this POP waste by dumping it into rivers and seas. This leads to various environmental and health problems. The materials used are prohibited substances that are very dangerous in their natural state. Dumping waste in open fields and rivers remains common even today, and a study of waste disposal behaviors in Kuala Lumpur indicated that 31.9% of waste was disposed of by open burning, while 6.5% was dumped into the river system. Hence, environmental safety concerns in Malaysia have become secondary, and most municipalities have struggled to find new disposal sites, as the existing sites are nearly exhausted. The problem of solid waste in Malaysia increasingly worries many parties.

The government has implemented various efforts to reduce the delivery and disposal of solid waste to landfills to prevent environmental pollution. Specific issues, such as the chemical properties of used RPOP, need to be identified. Recycled gypsum plaster is produced by grinding and burning the waste over three successive recycling cycles. The recycled material is evaluated based on its chemical and physical properties to serve the same purpose as the original binder. Recycled plaster of Paris often requires energy-intensive processes, such as heating, to remove moisture or contaminants. This energy consumption can be a limitation, especially if the recycling process lacks energy efficiency. Depending on the recycling method used, significant costs can be associated with equipment, labor, and maintenance. These costs can sometimes outweigh the benefits of recycling, particularly for small-scale operations.

Despite these limitations, recycled Plaster of Paris can still be a viable option in many situations, particularly when considering the environmental benefits of reducing waste and conserving resources. However, it is important to carefully evaluate the cost, quality, and feasibility of recycling based on specific circumstances and needs. This issue involves an activator whose concentration needs to be identified. Using recycled plaster in combination with fresh plaster or other additives can enhance its performance and extend its lifespan. Nevertheless, loss of mechanical strength, changes in setting time, and decreased workability often limit its applicability. The mechanical and hydration properties of recycled plaster materials mixed with quicklime were examined, and a comparison of the quality of Plaster of Paris after quicklime was added was also conducted. Activators are frequently added to improve the quality of the casting, although the optimal concentration for achieving superior results remains unknown. Identifying the right concentration of activator is essential for enhancing the quality and usability of RPOP in various fields.

Another issue with this approach is the lifecycle of used mould during the casting process. The problem statement for RPOP typically focuses on reducing waste and the environmental impact associated with its disposal. POP, commonly used in various applications such as moulds, casts, and sculptures, presents a challenge due to its non-biodegradable nature and potential for pollution when disposed of improperly. The goal of RPOP is to identify efficient methods to reclaim, process, and reuse the material, thereby minimizing waste, conserving resources, and reducing environmental harm. This study is developing techniques for collecting used plaster, creating processes to eliminate contaminants, and identifying suitable applications for RPOP to close the loop in its lifecycle. It aims to fill this research gap by methodically evaluating performance, examining durability, and assessing the casting lifecycle of RPOP moulds over several casting cycles, while providing guidance on how to extend functional life and enhance sustainability in the ceramic production process. However, challenges arise in producing the intricate shapes intended when RPOP is used as a mould. One potential issue with using Plaster of Paris for ceramic art moulds is its tendency to absorb moisture from the clay. This can lead to problems, such as warping or changes in shape over time due to moisture absorption, which can result in inaccuracies in the reproduced ceramic pieces Additionally, excessive moisture absorption can cause the clay to stick to the mould, making it difficult to remove the finished piece without damaging either the mould or the ceramic. Frequent and repeated use of Plaster of Paris moulds causes a short lifespan. Plaster of Paris moulds may deteriorate more rapidly with repeated use due to exposure to moisture, resulting in the need for frequent replacement and increased production costs. The moisture absorption can also cause surface imperfections on finished ceramic pieces, such as rough texture or uneven drying, affecting the overall quality of the artwork. With the occurrence of the above problem, the frequency of mould disposal is increasing, and the dumping of solid waste materials is increasing.

Therefore, the aim of this work is to identify the Recycled Plaster of Paris, specifically examining the chemical and physical properties of Recycled Plaster of Paris (RPOP) in comparison with New Plaster of Paris (NPOP). The initial goal was to determine the chemical and physical equivalents of NPOP and RPOP. Several tests have been conducted to determine the similarities between these two materials, including particle size analysis, SEM, XRD, compressive strength, porosity, and absorption testing. However, before these tests were carried out, RPOP underwent an essential recycling process. At this stage, various drying temperatures for RPOP were tested, including 37°C (room temperature), 150°C, 160°C, 170°C, 180°C, and 190°C. All these samples will then be evaluated using the aforementioned tests. The following investigation will focus on samples with similar chemical and physical characteristics to NPOP. By conducting these tests and analyses, we can draw comprehensive conclusions about the differences in chemical and physical properties between new and used Plaster of Paris, offering insights into its performance and durability over time. Another objective is to identify the suitable concentration of activator for Recycled Plaster of Paris (RPOP) that exhibits excellent casting properties. This approach involves using the activator in RPOP, as previously determined. At this stage, RPOP has been combined with Silubit G80 activator at the recommended percentages from the supplier, which range from 0.5%, 1.0%, 1.5%, to 2.0%. This activator is dissolved in water before mixing with RPOP. Additionally, the RPOP + Silubit G80 mixture will also be tested using various assessments, including compressive strength, porosity, and absorption. The purpose of utilizing this activator is to enhance the properties of RPOP.

This solution aims to determine the lifecycle of used moulds as functional working moulds for the ceramic casting process. At this stage, three types of moulds have been created using NPOP, RPOP at 160°C, and RPOP at 160°C combined with Silubit G80. Next, the casting process is conducted to assess the casting capabilities of RPOP at 160°C and RPOP at 160°C with Silubit G80, with NPOP serving as a reference during this process. At this stage, the casting time and the thickness of the cast product are recorded to note the differences between the RPOP at 160°C and RPOP at 160°C with Silubit G80 samples. An intricate form is designed using the optimized RPOP sample, involving the production of several moulds with various intricate designs. Elements of art are incorporated into the manufacturing of this product. The form being tested features a complex design produced through a cup product, which is created with a geometric form to evaluate the feasibility of RPOP as a mould using an intricate model. In one cup design, there are two curved sections; the first surface of the cup is flat, while the second surface is shaped with a geometric design. Then, the mould is produced using RPOP, and ultimately, the casting process will be tested to see if the mould can be used repeatedly without affecting the form or surface of the mould made from this RPOP.

Based on the provided solution, all research questions have been successfully addressed. Questions such as the key chemical composition affecting the physical properties of the used Plaster of Paris (RPOP) in comparison with New Plaster of Paris (NPOP), after the optimal cycle process, have been successfully resolved. The physical NPOP will serve as a control for the physical RPOP to observe the differences between these two materials when the Plaster of Paris mould is recycled. We need to determine whether there is an increase in the physical RPOP or a reduction in physical RPOP after undergoing the recycling process. Additionally, questions regarding the types of activator and its concentration suitable for RPOP to be reused have also been well addressed. The use of an activator enhances RPOP's ability to function properly during the mixing process. RPOP typically involves mixing a powder with a liquid to initiate a rapid polymerization reaction. Making RPOP reusable requires an activator that can effectively trigger the polymerization reaction each time the RPOP is mixed. The choice of activator and its concentration depends on the polymer and the specific conditions utilized in the RPOP system. To determine the appropriate activator and concentration for the RPOP system, it is necessary to conduct experiments evaluating the effectiveness of different options.

The question of the lifecycle of used moulds as functioning moulds in the ceramic casting process can be assessed by introducing the RPOP mould that undergoes the casting process. This needs to be tested alongside the NPOP mould to observe the differences in mould surface, product casting, and product thickness. In ceramic casting, measuring a used mould's lifecycle involves evaluating various factors that impact its integrity and performance over time. Below is an outline of the most important factors. Counting the number of castings a mould produces before it begins to deteriorate or wear out can give a general idea of its longevity. Regularly check the mould for any visible signs of wear, such as chips, cracks, or deformation. These may indicate weaknesses that compromise its functionality. Analyze the quality of the cast sheet's surface; rougher surfaces or flaws may appear in the casting as the mould ages. Evaluate the consistency of the casting process over time; damaged moulds can lead to less uniform castings. Monitor any changes in production rates; as the mould wears, it may become less efficient, resulting in slower production times. Conduct periodic tests to assess mould performance under controlled conditions, which can include evaluating dimensional accuracy, surface quality, and material integrity. Establish criteria for determining when a mould has reached the end of its useful life based on a combination of factors such as the number of castings, the level of wear, and the impact on production quality. By monitoring these aspects over time, it can develop a comprehensive understanding of the lifecycle of used moulds in ceramic casting and determine the most appropriate time for replacement or repair.

The final question concerns the preparation needed to create a challenging mould using RPOP. The selection of the mould form begins with the manufacturing of the intricate model. The researcher has decided to design a cup with a square surface to test RPOP's mixing ability in forming a mould with small square spaces. This design is chosen because a square surface for the cup can provide a clean and geometric aesthetic. This may involve the cup having a square-shaped base or perhaps a square pattern etched or embossed onto the cup's surface itself. This design choice could attract those who appreciate modern or minimalist aesthetics, as well as those who enjoy the symmetry and simplicity of geometric shapes. Additionally, the square surface could offer practical benefits, such as easier stacking or gripping.

Hence the solution is to study the inherent properties, advantages and considerations associated with both NPOP and RPOP, offering valuable insights to researchers who wish to take advantage of the unique properties of RPOP in the mould making field. Another important aspect of the hydration reaction is its reversibility. When gypsum is heated to around 150°C to 180°C, it loses water and returns to Plaster of Paris. This reversible nature enables the recycling and reuse of materials in various 257 applications, reducing waste and promoting sustainability. However, there are also considerations to keep in mind. The quick setting of Plaster of Paris requires quick work, as any delay can result in an unusable mass. Additionally, the heat released during the setting process, while generally harmless, can pose a burn risk in certain large-scale applications if not handled properly. The reaction of Plaster of Paris with water is the main chemical property that supports its flexibility and various uses. From medical and construction castings to arts and crafts, the hydration reaction allows the material to go from a mouldable paste to a hard, durable solid, making it an indispensable tool in a variety of industries.

Compressive strength evaluation plays an important role in ensuring the success of RPOP mould casting applications. By using appropriate testing methodology and considering the implications of compressive strength evaluation, mould casting facilities can optimize the casting process, improve product quality, and achieve desired performance results in a variety of applications. Continued research and innovation in this area will further advance the use of RPOP as a sustainable and resilient material for mould castings across industries. The water to plaster ratio is a critical parameter in the mould making process as it directly affects the water absorption, porosity, and strength of the plaster mould. Finding the optimal water-to-plaster ratio requires balancing these factors to achieve a mould with the desired properties for a particular casting application.

Achieving consistent thickness in slip cast stoneware requires careful attention to various factors throughout the casting process. By considering mould design, slip consistency, casting technique, drying conditions and material properties, ceramicists can effectively control thickness variations and produce high-quality ceramic pieces with both structural integrity and aesthetic appeal. Mould design plays an important role in determining the thickness drop in slip casting. Factors such as mould material, surface smoothness, geometry, venting, wall thickness, and filling technique all contribute to the uniformity of slip deposition and thickness distribution within a cast part. Optimizing mould design and fabrication parameters can help minimize thickness drop and achieve consistent casting results. To prevent tearing due to mould adhesion, it is important to ensure proper mould preparation, including the use of adequate mould release agents. Additionally, allowing adequate drying time and handling the casting with care during disassembly can help minimize the risk of tearing. Regular mould maintenance to ensure a smooth and even surface can also contribute to better disassembly results.

The nature of stoneware used in slip casting, as well as factors such as particle size, plasticity, and firing temperature, can contribute to thickness variations in ceramic pieces. This variation in thickness can affect the aesthetic appeal of the part, with consistent thickness contributing to a polished appearance and uneven thickness affecting the overall visual effect. Additionally, the use of moulds in slip casting can lead to imperfections and marks in the finished product, as well as the effect of mould surface finish and materials on thickness reduction. The ratio of water to plaster in mould making applications is also highlighted as a factor that can affect the porosity of the plaster material and lead to issues such as longer drying times and weaker moulds. The use of Silubit G80 in RPOP moulds improves the physical and mechanical properties of the mould, making it more suitable for various applications in casting and modeling. The choice between these types of mould of POP and RPOP depends on the specific needs of the application and the importance of sustainability. NPOP remains the gold standard for optimal mould performance, while RPOP options provide a valuable alternative that balances performance with environmental considerations. The addition of treatments and additives to recycled plaster can significantly improve its properties, making it a competitive choice for many use

CHAPTER 5
DISCUSSION

5.1 Introduction

This chapter provides an in-depth discussion of the experimental findings presented in Chapter 4, structured according to the four main research objectives of this study. Each section examines the relationship between the observed results and previous research findings, theoretical principles, and practical implications for ceramics manufacturing. The discussion aims to critically interpret how the data obtained from laboratory analyses, including chemical composition, physical characteristics, mechanical performance, and mould behaviour contribute to understanding the recyclability and enhancement potential of plaster of Paris (POP) materials. Furthermore, this chapter integrates both experimental observations and literature evidence to establish a comprehensive explanation of how thermal treatment and chemical modification influence the performance, reusability, and sustainability of recycled POP moulds within industrial ceramic production contexts.

This first stage corresponds to Objective 1, which aims to analyse the chemical and physical behaviour of RPOP and NPOP. The second stage focuses on determining the optimum concentration of Silubit G80 additive for improving the mechanical performance and absorption capacity of RPOP. It highlights the effect of different additive dosages on strength, porosity, water absorption, and workability characteristics. This discussion corresponds to Objective 2.

The third stage explores the lifecycle and performance of RPOP moulds during repeated ceramic slip casting processes. The discussion includes the dimensional stability, casting rate, and surface integrity of the recycled moulds, addressing Objective 3.

Finally, the fourth stage evaluates the effectiveness of RPOP moulds in producing complex geometries and their durability during casting and glazing applications. This part fulfils Objective 4, which assesses the applicability and reliability of the optimized RPOP formulation for real ceramic production conditions.

Together, these four stages provide a holistic understanding of how recycled plaster can be effectively reactivated, enhanced, and reused in ceramic manufacturing, contributing towards sustainable material innovation and waste reduction in the industry.

5.2 Thermal Behaviour of New and Recycled Plaster of Paris

Understanding the thermal behaviour of both new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP) is essential in evaluating their suitability for reuse in ceramic mould production. The thermal response determines the dehydration and rehydration mechanisms that influence the setting reaction, phase transformation, and overall mechanical performance of the material. In this section, the discussion focuses on how different drying and activation temperatures affect the structural stability, water loss, and crystallographic changes in NPOP and RPOP. The comparison between both materials highlights the critical temperature range where recycled POP can regain optimal hemihydrate formation, ensuring performance comparable to that of new POP.

In the study conducted by Madu et al., (2016), gypsum is recognised as a sedimentary rock that became trapped in lagoons as seawater evaporated. Colours of gypsum can range from white to brown, yellow, grey, and pink, depending on the type of impurities present. However, the difference observed by Luqman et al. (2010) found that as the calcination temperature increased, the recycled powder's white colour returned. At 100°C, the mould turned brownish white at 120°C, it became less brownish white and at 140°C, it turned white. The colour of raw POP was crystalline white. An excellent sign that the process had reversed from the dihydrate to the hemihydrate form is the recovered whiteness of the recycled powder as the temperature increased. The progressive change in colour suggests differences in crystallinity and particle morphology, which may affect the reactivity and workability of the material.

Therefore, the gradual restoration of whiteness with increasing temperature indicates the successful thermal conversion of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) to calcium sulfate hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$), confirming that proper heat activation enhances the purity and structural reformation of recycled plaster. This transformation not only reflects the material's regained chemical stability but also signifies its potential for reuse in ceramic mould applications with comparable visual and functional qualities to new plaster.

5.3 Physical and Chemical Performance of NPOP and RPOP

The physical and chemical performance of plaster of Paris plays a crucial role in determining its functionality and reliability as a mould material in ceramic production. This section discusses the comparative behaviour between new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP) based on various analytical tests conducted. The discussion focuses on setting time, surface characteristics, particle size distribution, microstructural development, and phase composition that collectively influence the strength, porosity, and overall workability of the material. By analysing these parameters, this section aims to identify the extent to which recycling and thermal reactivation affect the chemical integrity and physical consistency of POP, thereby assessing the feasibility of RPOP as a sustainable substitute for NPOP in industrial applications.

5.3.1 RPOP Reaction with Water

The interaction between recycled plaster of Paris (RPOP) and water plays a fundamental role in determining the material's reactivity, setting behaviour, and overall performance during reuse. When RPOP is mixed with water, the chemical reaction primarily involves the rehydration of calcium sulfate hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$) into calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), a process that governs the hardening and strength development of the plaster. This section discusses how the rehydration process in RPOP differs from that of new plaster of Paris (NPOP), particularly in terms of reaction rate, water demand, and the formation of crystalline structures. Understanding this reaction is crucial, as incomplete or irregular hydration in RPOP can lead to weaker bonding, increased porosity, and reduced mould durability compared to NPOP.

Mixing this undried (37℃) RPOP powder with water is not suitable for reuse because drying process requires a higher temperature (around 150-200°C) to convert the calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) back to the hemihydrate ($CaSO_4 \cdot 0.5H_2O$).

Figure 5.1 The RPOP In Room Temperature Does Not Harden

This is possible, the water content in RPOP powder is not removed causing a large amount of water to be produced in this process. Excess water or too much water can cause plaster particles to settle, leaving excess water on the surface of the RPOP slurry. Incomplete mixing prevents the plaster from absorbing water completely, causing the water to separate. This is caused by no dehydration process in RPOP. Then, the RPOP particles are heavier than water and tend to settle if the mixture goes too long without stirring, causing the water to rise to the surface as shows as in Figure 5.1. The drying temperature for RPOP can vary depending on a few factors, including the moisture content of the material, the desired drying rate, and the specific application requirements. Plaster is a mixture of gypsum and water and getting the correct ratiois important to achieve the desired consistency and strength. Too much water can result in a weak and brittle final product, while too little can make it difficult to use. It's all about finding that balance for optimal performance. This is closely related to the problems faced by RPOP 37℃.

From Madu, Ndaliman M & Oche B, (2016) the manner how this author used calcination method for POP are blocks of gypsum are cleaned with clean water before being crushed into powder and sieved to remove bigger particles. To obtain a POP, the powder is calcined in an electric combustion furnace at 170°C. Gypsum is rinsed properly to remove impurities like sand and clay, then dried for seven days at room temperature to prevent dust contamination. Heat the sample at 170°C to release the mixed water. The oven is then turned off, and the powder is left to cool in it for 18 hours before being opened. After calcination, the powder is placed in a polythene bag and kept dry to prevent moisture from entering the bag. The temperature range of 170°C was chosen for this work because it has a porous surface, which allows for faster water absorption, is lighter in weight, and the POP colour seems very bright. Furthermore, the stronger connections of POP particles make them extremely rigid at temperatures of 170°C.

Therefore, it is very important that the ratio of plaster and water is important for proper hardening. Too much water can prevent the plaster from setting properly. However, in general, the drying process for RPOP usually involves gentle heating at a relatively low temperature to remove moisture and restore the material to a usable state. Here are some considerations regarding the drying temperature for RPOP in this research. Assess the quality of recycled plaster. If the plaster has been contaminated or contains impurities, it can affect its drying behaviour and require an adjustment to the drying temperature. Contaminants or impurities in plaster can indeed change its drying characteristics. These changes may require adjustments to the drying temperature or other drying parameters to ensure the desired product quality and properties. Contaminants can interfere with the plaster's hydration process, affecting its setting time, strength, and overall performance. Adjusting the drying temperature is one way to reduce this effect and achieve the desired result.

Drying is the thermal decomposition of a material at temperatures, often without oxygen. In the context of RPOP, drying involves heating the material to a certain temperature range, to expel water molecules and convert calcium sulphate hemihydrate back to its original form, calcium sulphate dihydrate. This reversible reaction is important for reclaiming POP from used or discarded plaster products. The drying process requires precise control of temperature and duration of heating to avoid excessive drying or thermal degradation of the plaster. Industrial kilns or specialized calcining equipment ensure uniform heating and efficient conversion of POP into its main constituents. Once drying, the material turns into a fine powder, ready for further processing. After calcination, the RPOP powder undergoes drying to remove any remaining moisture and improve its handling properties. This method ensures thorough moisture removal without compromising the integrity of the recycled material.

During drying, careful monitoring of temperature and air flow prevents overheating or moisture reabsorption, ensuring optimal quality of RPOP. A study of temperature of drying POP by Ganesapillai, (2008) reported that at 180 Watts of input power, water molecules reach boiling point in 300 seconds, but at 540 Watts, it takes less than 180 seconds. The raw plaster temperature progressively grew to a maximum of 42°C by 300 seconds while the input power was kept around 180 Watt, but a maximum temperature of 35°C was obtained at 540 Watt. In the case of mould plaster, a few minutes of microwave irradiation, even at a low power level, boosts the slab temperature to 50°C. Using this method can increase heating rates by causing water molecules to evaporate and materials to dry. In microwave heating, areas with higher moisture content absorb more microwave energy, resulting in heat generation throughout the material. However, from another major study by M. M. Pinheiro & Camarini, (2015) found that, the temperature range for drying POP calcination is 140°C to 200°C.

$CaSO_40.5H_2O + 1.5H_2O$ comprises of calcium sulphate hemihydrate. When RPOP is dried at the proper temperature, calcium sulphate is generated, causing the water particles in RPOP to be eliminated. At this stage, the heat energy delivered to gypsum (hydration heat) prefers to push water out (as water vapour) rather to raise its temperature.

It is important to apply heat gradually to RPOP to avoid rapid evaporation of moisture, which can cause surface cracks or other defects. Slow and controlled drying helps ensure uniform moisture removal throughout the material. During the drying process, it is important to monitor the moisture content of RPOP to determine when it has reached the desired level of dryness. This can be done using a moisture meter or by periodically weighing the material to detect changes in weight as moisture is removed. RPOP may contain moisture, which requires thorough drying to prevent degradation of its properties. Drying can be achieved through natural means or with the help of a drying device, ensuring that the material reaches an optimal moisture content.

POP reacts with water and hardens at room temperature. When gypsum ($CaSO_4 \cdot 5H_2O$ - calcium sulphate dihydrate) is calcined and partially dehydrated, it produces gypsum plaster ($CaSO_4 \cdot 5H_2O$ - calcium sulphate hemihydrate). As a result, the application of RPOP requires the initial recycling step, that is the drying of powder RPOP. This procedure is critical to restoring the original physical plaster of Paris. This is due to the drying calcination method's ability to eliminate the water content of RPOP. The result got from this initial process is that RPOP does need to be dried first before being used again to maintain its hydrate properties. For the next testing, it will not test the RPOP sample (37°C) without drying.

Research on NPOP and RPOP is essential to determine their suitability in various applications and to understand the impact of recycling operations on material performance. The setting time and surface characteristics of NPOP and RPOP are not only important in determining their applicability but also have a significant influence on each other. This relationship is particularly relevant when comparing NPOP with RPOP because variations in these properties have a direct impact on the performance of the material in practical applications. By carefully controlling the factors affecting setting time and surface quality, RPOP can be tailored to meet the needs of specific applications, providing a sustainable alternative to NPOP while maintaining functional quality.

5.3.2 Setting Time and Surface Characteristics

The setting time and surface characteristics of plaster of Paris are key indicators of its workability and suitability for mould production. Setting time determines the rate of hardening and the ease of handling during the casting process, while surface quality reflects the uniformity and density of the hydrated structure. In this section, the comparison between new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP) is discussed to evaluate the effect of thermal treatment on their hydration behaviour and physical appearance. Differences in setting time can indicate variations in particle fineness, purity level, and the presence of residual dihydrate in RPOP. Similarly, the surface condition whether smooth, porous, or coarse provides insight into the material's reactivity and its potential to form durable and high-quality ceramic moulds.

Recycled plaster of Paris begins to lose its original structure. Drying causes dehydration of gypsum (calcium sulfate dihydrate) to form bassanite (calcium sulfate hemihydrate), leading to early cracking and a brittle texture. The drying treatment process involves heating the recycled plaster to 160°C, which can help in removing any residual moisture and improve the structural integrity of the material. This process can also reduce the porosity of recycled plaster, resulting in a denser and stronger final product. Higher temperatures accelerate the breakdown, making the plaster more fragmented. This stage is important because it represents a transition where the material loses its cohesive strength significantly due to dehydration and further breakdown of the crystal structure. It shows a combination of both breaking and partial resolidification, suggesting changes in the physical properties and partial reformation of the plaster. It shows that at this temperature, the recycled plaster is undergoing a further transformation, potentially leading to a new solidification phase. At this stage, the material begins to show signs of partial resolidification. An increase in temperature may cause some decomposed substances to react and form new solid structures. This suggests a potential temperature for optimizing the recycling process where the material can regain some of its solid properties. The observed changes indicate that controlled drying can be used to effectively RPOP. The drying process needs to be optimized to balance between breaking the original structure and allowing reformation to a usable state.

According to Pedreño-Rojas, (2019), the crystal phase changes during the heating process. The calcium gypsum formed after drying converts all the dihydrate gypsum particles into bassanite (hemihydrate). As a result, using additional time or a higher temperature of over 100°C for 24 hours will turn all the dihydrate particles to hemihydrate, although Pedreño claims that 3 hours at 150 °C is sufficient to convert all the dihydrate particles to bassanite. However, all these samples are the same color as NPOP, which is white after mixing with water. According to Madu, (2016) all types of POP have the same color which is white and bright in appearance. However, in study by Luqman K. Abidoye and R.A, (2010). Bello were found that the calcination temperature increases, the recycled powder regains its whitish colour. When a powder is calcined at 100°C and combined with water, it turns brownish white. The appearance improves as the temperature rises to 120°C, which results in less brown, white in the powder-water mixture. At 140 °C, the recycled powder regains the quality white colour of the original material's white dye to water powder blend. This is kept at 160°C, 180°C, and 200°C. At first, it may feel a bit grainy as the plaster particles are suspended in the water, but with continued stirring, it becomes a homogeneous mixture. This reaction is irreversible, meaning that once the plaster has set, it cannot be returned to its original state and reused as if it were fresh.

When RPOP powder is mixed with water, it forms a thick viscous slurry. This high viscosity makes it difficult to stir as it offers significant resistance to movement. In addition, the setting reaction between RPOP undergoes a chemical reaction when mixed with water, forming gypsum. This setting reaction causes the slurry to thicken and harden over time, making it increasingly difficult to stir. The homogeneity of RPOP is also one of the reasons why it is difficult to stir RPOP slurry. To achieve a uniform mixture requires careful stirring. If the slurry is not well mixed, there may be lumps of dry plaster or unevenly hydrated areas, which can make the mixing process even more difficult.

However, RPOP has the potential to be recycled. Fortunately, the mechanical and structural qualities of RPOP may deteriorate, rendering it unsuitable for several applications. Additives have been introduced to enhance the performance of RPOP. One of the most interesting additives is Silubit G80, a modifier designed to improve the material's mechanical qualities and durability. Silubit G80 is thought to enhance the properties of RPOP by improving its microstructure, compressive strength, and moisture resistance.

5.3.3 Particle Size and Its Influence on Workability

Particle size distribution is an important parameter that influences the setting behaviour, strength, and overall performance of plaster of Paris. The fineness of the powder determines the surface area available for hydration, affecting both the rate of chemical reaction and the density of the final hardened structure. In this section, the particle size characteristics of recycled plaster of Paris (RPOP) are analysed and compared with those of new plaster of Paris (NPOP) to assess the impact of thermal reactivation on particle refinement. Differences in particle size can indicate variations in calcination efficiency and mechanical processing during recycling. Understanding these differences is essential, as finer particles typically lead to faster setting, improved compaction, and greater mechanical integrity in the resulting mould material.

The larger the particle size of the gypsum product, the higher the compressive strength. The reason is that at large particle sizes the total surface area decreases which leads to less amount of pore water and therefore higher compressive strength. Use particle size analysis as part of quality control measures to ensure consistency and reproducibility in the use of RPOP. This can be proven through the next discussion in the compressive strength section. Through the results obtained, at a temperature of 37°C it has the highest particle size, however, at this temperature, RPOP powder 37°C when mixed with water cannot refreeze like NPOP. Because it is well known that the distribution of plaster particle sizes directly affects the mold's strength, water absorption capacity, and percentage of porosity, plaster powder particle size measurement is crucial for optimising plaster moulds. Calcium sulphate is represented by the needle-shaped crystal structure, while pores are indicated by the dark regions of empty spaces.

It observations indicate that the number of pores in all NPOP and RPOP samples is comparatively similar. Because of this, it is anticipated that the two plasters' capacities to absorb water will be comparable or marginally different because of the smallest variation in the capillary count shown on the SEM and depicted.

5.3.4 Morphological Changes Induced by Thermal Treatment

The morphological characteristics of plaster of Paris provide critical insight into the relationship between thermal treatment and structural transformation. Morphology determines how the particles arrange, bond, and form the crystalline network that defines the mechanical and physical performance of the material. In this section, the effect of various drying temperatures (37°C, 150°C, 160°C, 170°C, 180°C, and 190°C) on the morphology of new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP) is examined. Through microscopic observation, differences in particle shape, surface texture, and crystal formation are discussed to identify the temperature range that promotes optimal hemihydrate reformation. Understanding these morphological changes is essential for determining the ideal activation condition that restores the microstructural integrity and enhances the reusability of RPOP in ceramic mould applications. Through Pedreño-Rojas, (2019) if the crystal radius does not extend perfectly and has a flat shape this means no particles have reacted with water, predicting that bad behaviour composite plaster. However, changes in the crystal form occurred when the RPOP powder was dried at temperatures of RPOP 150°C, RPOP 160°C, RPOP 170°C, RPOP 180°C and RPOP 190°C. The crystal radii are getting longer and larger, while the pores on the surface are getting bigger. The structure of RPOP powder will change during the recycling process. The crystallinity becomes reduced, and the amount of water required to maintain the workability of the recycled plaster slurry may increase and may cause a decrease in the strength of the recycled plaster. This is more obvious when Pinheiro & Camarini, (2015) reported that additional information to determine the chemical components of gypsum include the amount of free water, degree of water crystallization, calcium oxide, and sulphur contained in POP. According Ismail, Ikmar, and Mohamad, (2015) the needle-shaped structure is a calcium sulfate crystal and the dark part between the needle shape and the empty part is the pores that are filled with water content and when hydrated. But this area will be filled with air after drying. Through 37°C, RPOP 150°C and RPOP 160°C have more dark areas compared to RPOP 170°C, RPOP 180°C and RPOP 190°C. The more the temperature increases the less water content in RPOP as evidenced by the microscopic results using the Scanning Electron Microscope (SEM) method analysis. The percentage of dark patches increases along with an increase in water content, suggesting that the mould has become more porous. Dark spots on RPOP crystals observed under a scanning electron microscope (SEM) can indicate various possibilities depending on the context and specific characteristics of the crystal. Dark spots may result from impurities found in RPOP. These impurities can be residues from previous use, contaminants from the recycling process, or materials introduced during storage or handling. Differences in crystal structure or composition in crystalline Plaster of Paris can lead to variations in electron density, causing some areas to appear darker under SEM. However, RPOP 170°C and 180°C after drying, the position of the needle size is getting closer and in the form of clumps that are joined to each other, and the number of pores is getting smaller. According to the result, RPOP 37°C to 160°C has almost the same size and shape of needles while RPOP 170°C to RPOP 190°C has the same position and distribution of needles.

SEM resulted in a clear trend of increased morphology small changes with increasing temperature. The NPOP initially shows a compact and dense structure, which gradually becomes more porous and fibrous with increasing heat treatment. These morphological changes indicate the thermal decomposition and phase transformation process that the plaster undergoes. Understanding these changes is important to optimize the recycling process and improve the properties of recycled plaster for various applications.

5.3.5 XRD Analysis of Temperature Effect

Phase analysis is a crucial aspect in understanding the thermal transformation behaviour of plaster of Paris, as it reveals the crystalline changes that occur during dehydration and rehydration processes. The heating temperature directly affects the conversion between calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$), and anhydrite ($CaSO_4$), which ultimately determines the quality and reactivity of the recycled material. In this section, the discussion focuses on the effect of different drying temperatures (37°C to 190°C) on the phase composition of new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP). The analysis aims to identify the optimal temperature range that achieves a stable hemihydrate phase without over-dehydration, which could reduce setting ability. By comparing the phase transitions between NPOP and RPOP, this section provides insights into how thermal activation influences structural stability, crystallinity, and the functional reusability of the recycled material for mould applications in ceramics production.

Heating has an impact on the crystal structure, which can alter gypsum X-ray diffraction (XRD) measurements. $CaSO_4 \cdot 5H_2O$, or gypsum, is a hydrated mineral, which means that water molecules are present in its crystal structure. Heat causes gypsum to dehydrate, shedding water molecules and changing into anhydrous calcium sulphate ($CaSO_4$). Gypsum's crystal structure is changed during this dehydration process, which modifies the XRD pattern. More specifically, new peaks linked to the anhydrous form of gypsum may emerge, while the peaks relating to the hydrated form may shift or vanish. When analysing XRD data for gypsum, it is crucial to consider the sample's thermal history because this might lead to variations in the XRD pattern. The gypsum XRD readings will be impacted by the heating process. This has been demonstrated by a study conducted by) gypsum displays XRD results following each heating procedure. Only one of the developed calcination techniques—180°C for six hours—was able to turn every gypsum particle into clean plaster. Moreover, just a small amount of gypsum remained after a 24-hour calcination at 100 °C converted most of it into bassanite. According to Ganesapillai, Regupathi & Murugesan, (2008), the X-ray diffraction of POP shows a peak corresponding to calcium sulfate, but when the pop is dried the X-ray diffraction of the microwave-irradiated product powder basically shows a peak corresponding to calcium sulfate with a large number of peaks and more spacing indicating a scattering pattern during water molecular interactions with calcium sulfate crystals. Gismodine can strengthen components. Gismodine can provide additional strength to components. The results also demonstrate that the drying temperature of NPOP and RPOP at 150 °C to 190 °C causes the emergence of Bassanite. The appearance phase of bassanite occurs at temperatures ranging from 150 to 190°C, but it can also appear at higher temperatures. Pedreno-Rojas, (2019). Based on XRD readings after each heating process. As expected, the number of gypsum particles reduces with heating. Only one calcination procedure (180 °C for 6 hours) successfully turned all gypsum particles to bassanite. Calcination at 100°C for 24 hours primarily converted gypsum to bassanite, leaving just a small percentage of permanent gypsum.

5.3.6 Mechanical Strength with Temperature

Compressive strength is a vital mechanical property that reflects the structural integrity and load-bearing capacity of plaster of Paris moulds. It serves as a key indicator of the effectiveness of thermal treatment and the overall quality of the recycled material. In this section, the compressive strength of new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP) is evaluated under different drying temperatures (37°C, 150°C, 160°C, 170°C, 180°C, and 190°C) to determine how heat activation influences the bonding strength and microstructural cohesion of the material. Variations in compressive strength are directly associated with phase composition, particle interlocking, and porosity level. This discussion aims to identify the optimum activation temperature that yields the highest mechanical performance, thereby validating the potential of RPOP as a sustainable and durable alternative to NPOP for ceramic mould fabrication.

Repeated recycling of POP can weaken its structure and reduce its strength and durability over time. This can result in moulds that are more prone to breaking or deforming, increasing the likelihood of defects in the ceramic artwork.

Appears to display a stress-strain curve from a compressive strength test, often used to characterize materials like POP. In this type of graph, the vertical axis (TD1) typically represents stress, measured in units such as N/mm² (newtons per square millimetre), while the horizontal axis (TD2) represents strain or deformation, measured in millimetres. The initial section of the curve has a high rise, showing the elastic area in which the material deforms proportionally to applied stress. This is characterised by the elastic modulus, which represents the material's rigidity.

Following the elastic region, the curve shows a peak, representing the yield strength of the material. This is the maximum stress the material can withstand while remaining in the elastic region. Beyond this point, permanent deformation occurs, and the material begins to exhibit sample behaviour. The graph then descends, showing a reduction in stress with increased strain. This indicates that the material is undergoing the sample deformation, where it continues to deform under constant or decreasing stress levels. This region may also contain fluctuations due to localized failure or microcracking within the material. Eventually, the curve reaches a point where it becomes relatively flat, signifying the breaking point or failure of the material. However, using a 90 (water) : 100 (Plaster of Paris) ratio, according to Madu, Ndaliman, & Oche, (2016), the compressive strength is 14.47 N/mm². The compressive strength of the subsequent test, which had a ratio of 100 (water) :100 (plaster of paris), was 15.92 N/mm². It demonstrates that there is a boost in strength when 100g of POP is put to water that is 100ml or less. However, after adding 110 ml of water to sample 3 and 130 ml to sample 5, respectively, it was found. With respect to the values of 8.4, 7.8, and 4.2 N/mm², the compressive strength declined. Consequently, the intensity of POP diminishes as the quantity of water supplied increases. The link between the gypsum particles weakens with increasing water volume, which results in decreased strength. However, this statement is different from the opinion of Shiyo, Nagels & Shangali, (2020), according to the study, the heat treatment is one of the methods of producing POP. The temperature and length of the firing process affect the quality of the product produced when the mold is removed in various conditions. Temperature 180°C with heating. After two hours, the best mixture was found to convert the used mold into POP powder, which has a compressive strength of 375 N.

As stated by De Moraes Rossetto, (2016), that the recycle gypsum plaster (RGP) with varying calcination times at 150 ° C, using a ratio of 0.70 (water) and 0.80 (recycle gypsum plaster), demonstrated superior compressive strength results compared to newly manufactured after 28 days of testing. Lower resistance is a direct result of greater water content, as well. RGP 150 °C-3 hours with water and gypsum plaster ratio 0.70 (13.28 MPa) and RGP 150 °C-2 hours with water and gypsum plaster ratio 0.80 (10.36 MPa) produced the best results. Recycling gypsum plaster waste can yield results that are better than commercial gypsum plaster in terms of mechanical performance. This is clearer when researchers found that at a temperature of 150°C the compressive strength is higher compared to other temperatures and is almost the same as NPOP.

A surprising discovery made by Ayele & Balasubramanian , (2020) was that, when 60% virgin plaster was added with 40% recycled plaster and the appropriate amount of water, the mixture's maximum setting time was 21 minutes. The plaster used is a combination of new plaster and recycled plaster. The findings indicate that compression and absorption strength is, the mixture's compressive strength is greater than that of the new plaster. The rate of compressive strength increased from 6.1025 to 8.6956 MPa when the fraction of virgin Plaster increased from 0 to 60%, and it subsequently reduced to 5.7010 MPa for 100% virgin POP. The compressive strength was 8.6956 MPa with 60% recycled content, and the water absorption and setting time.

5.3.7 Relationship Between Porosity

Porosity is an essential parameter that influences the strength, density, and water absorption capacity of plaster of Paris. It represents the volume of void spaces within the material structure, which directly affects the performance and durability of the mould during ceramic casting. In this section, the porosity behaviour of new plaster of Paris (NPOP) and recycled plaster of Paris (RPOP) is examined under different thermal activation temperatures ranging from 37°C to 190°C. The discussion focuses on how variations in temperature influence pore formation, distribution, and interconnectivity, which are closely linked to the dehydration–rehydration process and crystal growth mechanisms. By comparing the porosity trends between NPOP and RPOP, this section aims to identify the temperature condition that produces an optimal balance between strength and permeability, ensuring that recycled POP exhibits comparable performance to new POP in practical ceramic mould applications.

Plaster of Paris often becomes less porous over time because of a process known as "setting." A gypsum-based substance known as plaster of Paris experiences hydration, a chemical process, when combined with water. Gypsum particles take in water during the hydration process and crystallize into a solid mass. The porosity of the plaster diminishes as it settles and hardens because less room exists between the particles. Furthermore, any additional water that evaporates during the setting of POP lowers the material's porosity even more. The final product is denser and less porous because of the closer particle compaction achieved during this drying process. As a result, the hydration and setting process—in which the particles are packed together, and extra water evaporates—is mostly to blame for the decrease in porosity of POP.

It affects the homogeneity of the casting surface as well as the mould capacity to discharge trapped moisture and air during casting. The porosity of the plaster material is directly influenced by the water-to-plaster ratio. Because of the increased water content that results from higher water-to-plaster ratios, more empty spaces are created within the plaster structure, leading to higher porosity. While a certain amount of porosity is necessary for adequate venting during the casting process, too much porosity can result in flaws in the cast item, including rough surfaces or diminished mechanical qualities.

According to a study that has been made by Madu, (2016), it can be observed that the porosity increases with the proportion of water increase. The increasing of water absorption will cause an increase in water volume due to its porosity. These two physicals need cooperation because they will respond if these two physical tests are done correctly. Also, when a small volume of water was added to the POP, the mixture became very thick and stronger after it dried, with a lower percentage of porosity. The same outcomes attained by Hafizan, Wahab, Saad & Rahim, (2017), confirm the assertion. Whole hemihydrate dissolution to produce dehydration as. The plaster is shaped like a sequence of interlocking dehydrates. The plaster's crystalline matrix allows it to absorb moisture once it has dried. Therefore, in the slip casting process, mould plaster can function as a water absorbent. As was indicated in the previous sentence, mould performance about water absorption, porosity, and strength is significantly influenced by variations in the water to plaster ratio. The fraction of water absorption rises as water/plaster ratios rise.

5.3.8 Water Absorption

In the casting process, absorption is a key step in producing a product with constant thickness. Plaster of Paris tends to absorb moisture from the environment, and RPOP may have absorbed more moisture during its previous use. High moisture content can cause mould warping, sticking or surface imperfections in the produced ceramic pieces.

During the hydration and ensuing dehydration phase, POP absorption is frequently seen to increase and subsequently decrease. Gypsum (calcium sulphate dihydrate) is become when Plaster of Paris (calcium sulphate hemihydrate) and water are combined. The plaster converts into gypsum throughout this phase because of absorbing water and expanding. As the plaster absorbs water molecules, its weight and volume rise during this early absorption period. Nevertheless, plaster gypsum starts to lose its effective water-absorbing capacity to a certain degree. This occurs as the gypsum structure becomes saturated with water, which slows down additional absorption. At this point, the plaster has reached its maximum water-holding capacity, and the absorption curve tends to flatten or diminish. Additionally, the absorbed water in the gypsum evaporates via natural or controlled drying processes, such as heating, restoring the plaster to its original form as calcium sulphate hemihydrate, or plaster of Paris. The plaster's weight and volume drop throughout this dehydration phase, which lowers the plaster's absorption capability relative to its completely hydrated form.

5.4 Effect of Silubit G80 Additive on Recycled Plaster of Paris

The incorporation of chemical additives plays a crucial role in enhancing the performance of recycled plaster of Paris (RPOP), particularly in improving its mechanical, physical, and setting characteristics. In this study, Silubit G80 was introduced as a chemical activator and deflocculant to enhance the rehydration behaviour, particle dispersion, and microstructural uniformity of RPOP. This section discusses the influence of various concentrations of Silubit G80 on the setting time, compressive strength, porosity, and water absorption properties of RPOP. The analysis aims to determine the optimum dosage that yields the best balance between workability and strength without compromising the material's integrity. By comparing the performance of untreated RPOP with that of RPOP modified with Silubit G80, this section provides insights into the effectiveness of the additive in improving bonding quality, reducing internal voids, and promoting more compact crystalline structures. These findings are essential to validate the role of Silubit G80 as an activator capable of restoring the mechanical and functional properties of recycled plaster, making it suitable for sustainable reuse in ceramic mould production.

5.4.1 Modification of Setting Time by Silubit G80

Setting time is one of the most critical parameters in evaluating the workability and reactivity of plaster materials. In recycled plaster of Paris (RPOP), the addition of Silubit G80 influences the hydration kinetics and crystallisation rate, which directly affect the material's setting behaviour. This section discusses the effect of different concentrations of Silubit G80 (0.5%, 1.0%, 1.5%, and 2.0%) on the initial and final setting times of RPOP compared to untreated samples. By analysing these variations, the discussion aims to determine the optimum dosage that achieves a suitable balance between rapid hardening and manageable working time. The findings are also correlated with the physical observations and microstructural characteristics, providing a deeper understanding of how Silubit G80 modifies the reaction mechanism during the setting process.

Through a study made by Abboon, (2020), the setting of plaster can be improved if the plaster mixture is mixed with additives. efficiency of tree glue powder when setting "local gypsum" plaster containing two parts of polyvinyl acetate. It found that setting time increased significantly by simply adding tree glue powder. Through Jorgensen and Posner, (2016) the retardation factor is computed using the gypsum plaster setting time at pH. At pH 10–12, the maximum retardation factor is attained. Because protein hydrolysates include functional groups of alpha aliphatic amino acids, Kafrata has a retarding effect on gypsum plaster.

However, tartaric acid is a very good choice for an extremely alkaline spectrum. When compared to tartaric acid, potassium sodium tartrate has a smaller retardation factor at both high and low. The pH value shows less effectiveness than tartaric acid. monocalcium phosphate and sugar show retardation factors decreased significantly between pH 4 to 12 compared to the curve. While in the case of citric acid, the retardation factor increases with increasing pH. Optimum values were reached at pH 10.0. Above pH 10.0, the retardation factor decreases. The action of citric acid on gypsum plaster is associated with the formation of hydrogen citrate ions or tri- and tetra-valent citrate ions.

Through reference previous study by Jorgensen and Posner, (2016) effects of gelatin and borax, two retarders. In comparison to the reaction between hemihydrate and pure water, the reaction between the hemihydrate and borax solution results in a lesser expansion. The comparatively tiny variation in calcium sulphate concentration in the liquid dilatometer could be the cause of this. Once again, the rate at which hemihydrate enters the solution is unquestionably decreased by tarder, just as it is in trials with pure water when there is no stirring. It is because physical adsorption of Silubit G80 on the hemihydrate crystals, which causes the hemihydrate solution to be reduced, is what is causing the retarding effect on plaster setting. As a result, RPOP can be mixed for an extended period and then smoothly poured into the mould.

The production of gypsum crystals from a supersaturated aqueous solution is the cause of POP fixation. Crystal growth is inhibited and setting time is delayed when a colloidal material, such as glue, is combined with the plaster. It can be described that Silubit G80 has the same properties as glue, because if it is dissolved in water, the water becomes viscous and sticky. In POP shrinks and then swells as it hardens. Due to the latter characteristic, the material can be used to make castings because it can obtain a sharp impression of the mould. For the same reason, it is a great filler for cracks and crevices in plastered and wooden surfaces before painting or polishing. Due to the fast setup and challenging nature. By Hatim, Al-Khayat, and Abdullah (2007), the delay effect is avoided by gypsum products that contain additives. This is because the reaction mixture's calcium-slaked Ca $(OH)_2$ oxide acts as a retarder, increasing re-alkalinity and because of the gum Arabic coating, gypsum particles (nu-crystallization clear) get coated in a thin layer of gum Arabic that is soluble. There is a notable distinction between the expansion of the linear settings for plaster of Paris and Iraq plaster based on the results of the linear setting expansion for gypsum material (plaster model). Within two hours of the mixing point, the results of this gypsum product are still within an acceptable range rate. This explains that chemical composition of gypsum. The product has a balanced mix of ingredients between chemical modifiers (retarders and accelerator) and hemihydrate.

5.4.2 Improvement of Compressive Strength through Silubit G80 Addition

Compressive strength serves as a key indicator of the mechanical integrity and structural performance of plaster-based materials. In recycled plaster of Paris (RPOP), incorporating Silubit G80 as a chemical activator is intended to enhance the bonding between particles and improve the crystal interlocking network formed during hydration. This section examines the influence of varying Silubit G80 concentrations (0.5%, 1.0%, 1.5%, and 2.0%) on the compressive strength of RPOP compared with both untreated RPOP and new plaster of Paris (NPOP). The discussion focuses on how Silubit G80 modifies the microstructure, porosity, and density, all of which contribute to overall mechanical performance. These results provide insight into the optimal additive dosage that maximises strength without compromising the material's workability or reusability potential.

In general, it can be stated that the use of Silubit G80 does not act as a strength agent for the structure of RPOP after being moulded, but perhaps as another agent in the process of using or handling RPOP being moulded. Silubit G80 contributes to the optimization of compressive strength in RPOP mixes, allowing manufacturers to achieve desired strength levels while minimizing material waste. This ensures the structural integrity and reliability of the cast object in a variety of die casting applications. According to Camarini, (2016), compressive strength tests, recycled gypsum plaster without an additive (citric acid) produces the best results. However, the workability time and setting time of this mixture are short. The mixture content rises as although the mixture's compressive strength is greatly decreased, the outcome is still greater than the minimum. The material being manufactured may be impacted by moisture or voids in the internal structure of the specimen. Consequently, as the mixture content rises, the hardness falls. High citric content mixtures do not perform well.

5.4.3 Reduction of Porosity and Enhancement of Density

Porosity and water absorption are essential parameters that determine the durability, density, and overall performance of plaster moulds in ceramic production. The incorporation of Silubit G80 into recycled plaster of Paris (RPOP) aims to modify the internal pore structure and reduce excessive water uptake, which often weakens mould stability. This section discusses how different concentrations of Silubit G80 (0.5%–2.0%) influence the porosity and absorption capacity of RPOP compared with new plaster of Paris (NPOP). The relationship between additive dosage, microstructural refinement, and hydration efficiency is examined to identify the concentration that provides the best balance between strength, permeability, and dimensional stability. The findings highlight how controlled porosity contributes to improved reusability and consistent casting performance in ceramic applications.

According to Pirman & Awang, (2022), porosity after the addition of rice husk fibres of different sizes. Adding materials to the plaster has reduced its porosity while adding rice husk fibers has increased its water resistance properties. This is because reduced porosity indicates fewer pore water spaces between the crystal structure, which results in a lower percentage of water absorption. With the addition of rice husk fibre, water absorption decreased from 33.989% to 25.107%, making the plaster appear less porous. Rice husk fibre causes the fraction of voids to decrease and the bonding between gypsum particles increases leading to a higher strength of the sample. The addition of fibres clearly shows the occurrence of reducing the porosity of recycled plaster of Paris.

RPOP starts to decrease when the Silubit G80 additive is added. This is because Silubit G80 is a hydrophobic silica-based additive commonly used in building materials such as POP to increase water resistance and durability. The presence of Silubit G80 can increase the packing density of plaster particles. This means that the particles are packed more tightly together, leaving less room for pores. The fibres create a network in the plaster matrix, which minimizes void space and increases the overall density of the material. Here may be a chemical interaction between Silubit G80 and plaster of Paris components that results in a denser microstructure. For example, additives may promote the formation of a denser crystal structure in the plaster matrix. Additives may affect the drying process by reducing the amount of water remaining in the plaster after drying. Less water means fewer pores formed due to water evaporation during the drying process. But Silubit G80 can improve the bonding between plaster particles, leading to a stronger and less porous material. Additives may promote better adhesion between particles, resulting in a more compact final product.

If the mould pores are too high, it will cause the rate of water absorption to be faster and the mould will contain a lot of water quickly, the body mould will be fragile and break easily and cannot be used for longer in the casting process. Pores and voids represent regions of high surface energy within a material. As the material is heated, there is a thermodynamic driving force to minimize this energy by reducing the surface area of the pores, which leads to their elimination.

During its initial use, NPOP undergoes a hydration reaction that produces calcium sulphate dihydrate. When this material is recycled as RPOP, it loses some of its original microstructural integrity or degradation, resulting in increased porosity. Recycled plaster of Paris may not rehydrate as evenly as the new material. This partial rehydration can result in a less dense microstructure with more voids and thus increased porosity.

RPOP typically has increased porosity due to microstructure deterioration, insufficient rehydration, the presence of impurities, suboptimal particle size distribution, and fine particle loss. These variables together result in a material that is less dense and more porous than NPOP.

The results clearly indicate that the inclusion of Silubit G80 effectively modifies the pore structure of recycled plaster, leading to reduced porosity and lower water absorption rates. Among the tested concentrations, 0.5% Silubit G80 demonstrated the most balanced performance, minimizing water uptake without compromising the mould’s permeability needed for slip casting. The improved pore uniformity and reduced capillary channels contribute to enhanced mechanical integrity and dimensional stability of the recycled plaster moulds. Overall, the findings confirm that the optimized addition of Silubit G80 enhances the functional lifespan of RPOP moulds, ensuring consistent quality and superior performance during repeated casting cycles.

5.4.4 Water Absorption Control in Modified RPOP

Water absorption is a critical factor influencing the performance and durability of plaster moulds during the slip casting process. High absorption may cause excessive water penetration, leading to rapid mould degradation, dimensional instability, and surface defects in ceramic products. In this study, the addition of Silubit G80 was explored as a means to regulate the water absorption capacity of Recycled Plaster of Paris (RPOP). The discussion in this section focuses on how varying concentrations of Silubit G80 influenced the capillary behaviour, pore structure, and overall water resistance of RPOP, thereby determining the optimal formulation for improved casting efficiency and prolonged mould lifespan.

In general, POP can absorb water easily, especially if it is not properly sealed or coated with a waterproofing agent. This absorption can cause softening, weakening, and eventual deterioration of the plaster over time, especially in humid environments or when exposed to water for long periods. Another aspect to consider is the interaction between Silubit G80 and the RPOP hydration process. The hydration of calcium sulfate hemihydrate to calcium sulfate dihydrate is an exothermic reaction that leads to the formation of a crystalline structure. Silubite G80 modifies this process, potentially leading to the formation of more ordered and compact crystals. The optimized hydration process reduces the possibility of creating micro-cracks and voids, which are the main contributors to the increased water absorption in the plaster.
Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include type of material, additives used, temperature and length of exposure. The water absorption test for POP is a method used to determine the ability of the material to absorb water. This test is particularly important in applications where the plaster will be exposed to moisture, such as in construction or mould-making.

The mixture of Silubit G80 into RPOP significantly reduces its water absorption percentage by producing a denser and less porous material. This is achieved through the super plasticizing effect of Silubit G80, which reduces the water content required for mixing, increases particle dispersion, improves internal bonding and optimizes the hydration process. These changes lead to a final product with better mechanical properties and reduced permeability, making RPOP more durable and functional for a variety of applications. The findings reveal that Silubit G80 significantly influences the moisture regulation capability of recycled plaster by refining its microstructural arrangement and reducing the connectivity of capillary pores. Among the tested formulations, RPOP incorporated with 0.5% Silubit G80 achieved the most effective balance between reduced water absorption and maintained permeability, which is essential for optimal slip casting performance. This controlled absorption ensures better dimensional stability, minimizes deformation, and prolongs the mould's functional lifespan. Overall, the results demonstrate that the strategic use of Silubit G80 enhances the water management characteristics of RPOP, making it a more reliable and efficient alternative to conventional plaster in ceramic mould applications.

5.4.5 Slip Thickness and Casting Performance of Modified RPOP

Slip thickness plays a crucial role in determining the casting rate, dimensional accuracy, and overall quality of ceramic products. The ability of a mould to regulate water absorption directly affects the formation of slip layers during casting. In this study, the slip thickness behaviour of New Plaster of Paris (NPOP), Recycled Plaster of Paris (RPOP) at 160°C, and RPOP 160°C modified with 0.5% Silubit G80 was examined to assess the impact of thermal treatment and chemical modification on casting performance. This section discusses how variations in mould composition and structure influence the slip deposition rate, uniformity, and efficiency, providing insights into the practical suitability of RPOP moulds for repeated and precise ceramic casting processes.

According to the understanding observed by the results, the mould takes longer for the thicker part of the casting to dry than the thinner part. Differential shrinkage, where thicker sections shrink more than thinner areas, can be caused by uneven drying rates throughout the section. When the part dries, this can cause an overall decrease in thickness. This is clear in Figure 5.2, all moulds have water marks outside the mould wall due to exposure to moisture or water because of the casting process.

This shows that the mould is in a wet state and is not suitable for use in the next casting process. Water formed around the RPOP mould, probably due to moisture absorbed by the plaster during its previous use.

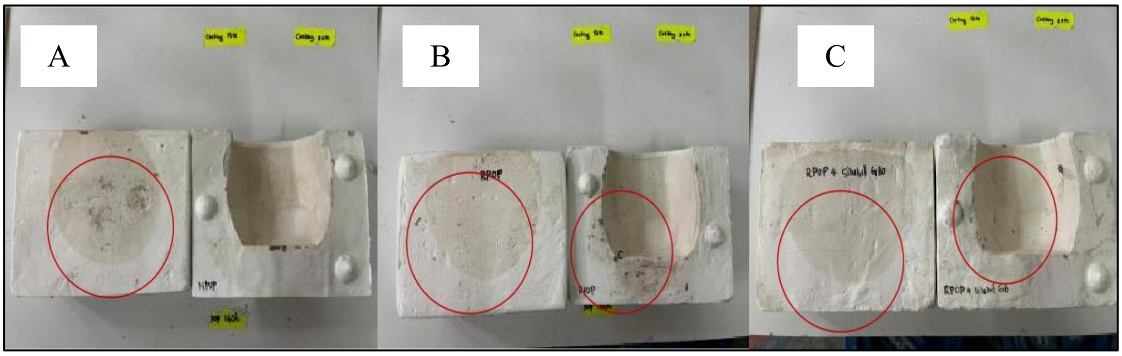


Figure 5.2 Water Mark On Body Mould After Casting

POP is known for its ability to absorb water easily, which is why it is often used for casting moulds. When recycled, any residual moisture trapped in the plaster can be released when exposed to certain conditions, such as humidity or temperature changes. This can cause water droplets to form on the RPOP mould surface. This is a common phenomenon with materials such as POP, and it is generally harmless, although it can affect the quality of the subsequent casting if not managed properly. Even though both parts of the mould have the same size, the convex shape of the cup causes the middle part of the mould to be a little thin, therefore, if look at the mould in Figure 5.2 (A)(B)(C), only the middle part of the mould starts to have a water mark. This is more obvious that the middle part of the mould contains a lot of water, and the area is relatively thin. Figure 5.2 (C) shows some of the traces of chipped debris on the wall. The effect of this damage occurs because the mould wall starts to become fragile and easily broken due to the high-water content on the mould wall.

This problem can be seen in all three samples, especially in the joint between the moulds (refer to the red circle in Figure 5.2). Plaster of Paris is quite easy to break because it is a soft and fragile material. Plaster of Paris is made from gypsum, which is a mineral that, when heated, loses its water content, and forms a dry powder. When this powder is mixed with water and allowed to harden, it forms a hard and relatively light material. However, despite its hardness, plaster of Paris is still quite brittle, meaning it lacks flexibility and tends to break easily when subjected to pressure or stress. This is more obvious if the RPOP breaks easily because the RPOP has undergone repeated drying. This fragility causes the mould to break easily, especially if mishandled or dropped, especially when the mould is wet. The study Kanouni, (2004) states that the current results appear to be in line with previous studies that discovered that the casting samples were loaded to test the physical characteristics following several casting cycles

(0 to 60). If noticed the surface of the sample that was in contact with the slip before it was taken out of the mould is the one that is shown to be in tension on the slip surface. Even when small portions of the mould are disturbed, the data demonstrate a constant decline in flexural strength during a cycle of 60 casts. Up till the casting material becomes brittle, the fracture deformation increases correspondingly.

These findings collectively demonstrate that the durability and usability of RPOP moulds decrease progressively after repeated casting due to moisture accumulation, microstructural fatigue, and surface degradation. Although the introduction of Silubit G80 improved the initial casting quality and thickness uniformity, continuous exposure to moisture weakens the mould's mechanical integrity. Proper drying and controlled reuse intervals are therefore essential to maintain consistent slip thickness and surface quality across casting cycles.

The results indicate that the slip thickness of the cast pieces was strongly influenced by the mould's microstructural characteristics and water absorption behaviour. The RPOP 160°C + Silubit G80 (0.5%) mould exhibited the most consistent and optimal slip growth rate, producing even wall thicknesses and smooth surfaces, comparable to those achieved using new plaster moulds. This improvement can be attributed to the additive's ability to control pore size distribution and water migration within the mould, resulting in more stable and efficient casting dynamics. Overall, the findings confirm that the incorporation of 0.5% Silubit G80 enhances the casting uniformity and productivity of recycled plaster, supporting its practical application as a sustainable alternative in ceramic manufacturing.

5.4.6 Microstructural Development with Silubit G80 Addition

The microstructural characteristics of plaster play a significant role in determining its mechanical strength, porosity, and overall mould performance during ceramic casting. The arrangement and bonding of calcium sulfate crystals influence the mould's ability to absorb water, maintain dimensional stability, and resist degradation under repeated use. In this study, the microstructure of New Plaster of Paris (NPOP), Recycled Plaster of Paris (RPOP) thermally treated at 160°C, and RPOP modified with 0.5% Silubit G80 were examined using Scanning Electron Microscopy (SEM) to identify morphological variations induced by recycling and chemical modification. This section discusses the influence of Silubit G80 on the crystalline structure, particle interlocking, and surface compactness, which collectively determine the improved physical and mechanical performance of the optimized recycled plaster formulation.

Mould porosity as a function of water content has been addressed with the presence of silica in POP through research and findings by Ismail, Ikmar, and Mohamad, (2015). The findings demonstrate that porosity rises as water content does. Following microscopic investigations employing Scanning Electron Microscope (SEM) examination, these results are more clearly analyzed. The needle-shaped structure is a calcium sulphate crystal, based on the results, and the dark area inside is an empty space, or what are known as pores, that fills with air when dry and water when hydrated. A substance for investments made of silica particles, pores, and crystals of calcium sulphate. The percentage of dark regions grows together with the water content due to the silica in POP. SEM images illustrate structural are differences and potential advantages of each material used in mold manufacturing. Silubite G80, with its fibrous and coarse morphology, serves as an excellent reinforcing agent. New Plaster of Paris (NPOP) provides a solid but somewhat less mechanically enhanced structure. The recycling process at 160°C transforms NPOP into a more reactive and finer particle size material (RPOP 160°C), which can improve its bonding and filling ability. RPOP 160°C and Silubit G80 combine the strengths of both materials, creating a mould-making material that gains the physical enhancement of RPOP 160°C from the reinforcing properties found in Silubit G80 and the enhanced reactivity and filler capabilities of RPOP 160°C. This combination is likely to lead to superior composite materials with enhanced mechanical properties, making them well suited for a variety of mould aking applications.

The microstructural analysis revealed that the incorporation of Silubit G80 significantly enhanced the crystal packing and interlocking within the recycled plaster matrix. The modified RPOP 160°C + Silubit G80 (0.5%) exhibited denser and more uniform needle-like crystal formations, indicating improved hydration kinetics and reduced porosity compared to untreated RPOP. This compact structure contributes to greater mechanical strength, lower water permeability, and improved mould stability during repeated slip casting cycles. Overall, the microstructural evidence confirms that Silubit G80 effectively refines the internal morphology of recycled plaster, restoring its structural integrity and ensuring performance comparable to new plaster moulds, thus validating its suitability for sustainable ceramic production.

5.4.7 Phase Interaction Between Silubit G80 and Recycled POP

The phase interaction analysis aims to interpret how the incorporation of Silubit G80 influences the crystalline transformation and phase stability of Recycled Plaster of Paris (RPOP) in comparison with New Plaster of Paris (NPOP). Understanding these interactions is crucial in determining the chemical compatibility and effectiveness of the additive in enhancing recycled plaster performance. This section discusses the X-ray Diffraction (XRD) results presented in Chapter 4, focusing on the changes in crystalline phases such as hemihydrate ($CaSO_4 \cdot ½H_2O$) and dihydrate ($CaSO_4 \cdot 2H_2O$), as well as the structural integrity of the RPOP matrix after modification with 0.5% Silubit G80. Through this evaluation, the role of Silubit G80 in promoting phase stability and reinforcing the recycled plaster's chemical resilience is critically examined.

The 160°C RPOP sample mixed with 0.5% Silubit G80 activator also did not change any component in the sample. When a recycled plaster of Paris sample mixed with 0.5% Silubit G80 activator is heated to RPOP 160°C and shows no change in components during X-ray diffraction (XRD) analysis, several factors could be at play. First, drying at 160°C may not be sufficient to cause significant chemical or structural transformations in the material or the activator. The temperature might be below the threshold needed to induce the formation of new phases or to activate chemical reactions. Additionally, the low concentration of Silubit G80 may not be enough to influence the overall crystalline structure or phase composition detectable by XRD. The activator's role might also be limited to affecting properties not detectable by XRD, such as particle size or surface characteristics, rather than causing measurable changes in the crystal lattice.

The absence of significant changes in the XRD patterns of RPOP 160℃ + Silubit G80 (0.5%) suggests that the addition of a small quantity of Silubit G80 does not alter the crystalline structure of the plaster matrix. This may be due to several factors. Firstly, the drying temperature of 160℃ may not be sufficient to trigger any substantial chemical or structural transformation in the material or the activator. This temperature could be below the threshold necessary to initiate phase transitions or the formation of new compounds. Secondly, the 0.5% concentration of Silubit G80 may be too low to create detectable differences in the crystal structure through XRD analysis.

The activator's function might instead be confined to improving surface morphology, particle dispersion, or hydration kinetics properties that XRD cannot directly detect. The observed differences in the intensity of gypsum and Bassanite peaks between NPOP and RPOP samples indicate the influence of thermal recycling and rehydration cycles. NPOP, which has not undergone any recycling process, retains a higher Bassanite content due to its unaltered structure. In contrast, RPOP 160°C and RPOP 160°C + Silubit G80 exhibit more visible gypsum phases, reflecting partial rehydration and microstructural rearrangement that occur during the recycling process.

Overall, the XRD results confirm that thermal activation at 160°C and Silubit G80 addition at 0.5% have minimal influence on altering the crystalline phase composition of RPOP. However, these treatments may still contribute to microstructural and performance improvements observable through other analytical techniques such as SEM or mechanical testing.

The phase analysis confirmed that the addition of Silubit G80 did not introduce any undesirable secondary phases into the recycled plaster matrix but instead promoted greater phase stability of the hemihydrate form. The RPOP 160°C + Silubit G80 (0.5%) sample maintained consistent crystalline peaks comparable to those of new plaster, indicating that the additive effectively reinforced the transformation process without altering the fundamental composition of calcium sulfate. This stability suggests improved chemical uniformity, reduced structural degradation, and enhanced performance under repeated thermal and hydration cycles. Overall, the interaction between Silubit G80 and RPOP strengthens the recycled material's crystalline framework, ensuring long-term reliability and compatibility for sustainable ceramic mould production.

5.5 Performance of Optimized RPOP Mould in Intricate Casting

The ability of plaster moulds to reproduce intricate and detailed ceramic forms is a key indicator of the quality and functional performance. In this section, the discussion focuses on the casting behaviour and surface characteristics of moulds made from the optimized Recycled Plaster of Paris (RPOP) formulation activated at 160°C with 0.5% Silubit G80. The performance of these moulds is compared with New Plaster of Paris (NPOP) to assess their capability in achieving fine detailing, dimensional accuracy, and consistent slip casting results. This analysis provides insight into how the improved physical, mechanical, and microstructural properties of modified RPOP contribute to enhanced aesthetic replication, mould durability, and sustainable production efficiency in ceramic manufacturing.

To improve the properties of recycled Plaster of Paris, additives and modifications can be used. One such modification is the combination of recycled Plaster of Paris with Silubit G80, a silane-based additive, at a concentration of 0.5%. In addition, heating the recycled plaster at a temperature of 160 °C can help improve its performance. The addition of Silubit G80 further improves the properties of recycled plaster. Silubit G80 acts as a bonding agent, increasing adhesion between plaster particles and reducing setting time. It also increases the mechanical strength and water resistance of the final mould.

5.5.1 Aesthetic Quality and Detail Reproduction of Optimized Moulds

The fabrication of aesthetic and intricate moulds requires a material with excellent surface quality, fine particle structure, and stable mechanical strength to capture delicate design details accurately. In this study, the optimized Recycled Plaster of Paris (RPOP) activated at 160°C with 0.5% Silubit G80 was evaluated for its ability to reproduce complex mould geometries comparable to those produced using New Plaster of Paris (NPOP). This section discusses how the improved formulation of RPOP influences the reproduction fidelity, surface smoothness, and overall aesthetic outcomes of the cast forms. The discussion also highlights the significance of these improvements in demonstrating RPOP's potential as a sustainable alternative for creating high-precision ceramic moulds with consistent quality and visual refinement.

Damp mould may be prone to fungal growth; fungi need moisture to grow and multiply. When the mould dries in the air, it basically releases the moisture needed to survive and maintain the body mould. This drying process inhibits its growth. Air-drying mould also has another benefit of helping prevent the spread of mould spores. When mould dries, spores become less likely to become airborne and spread to other areas. However, it's important to note that while air-drying mould can help prevent mould growth, it may not eliminate it completely, especially if the source of the moisture isn't addressed.

When RPOP to make a mould, inconsistencies such as smooth inner surfaces and small holes on the outer surface of the mould can arise due to several factors. If the plaster is poured too hard or unevenly, it can create air bubbles that result in small holes in the outer surface. Furthermore, the semi-liquid is quite lumpy and difficult to flow in each area of the mould enclosure. In addition, air bubbles can be trapped in the plaster mixture, especially if it is not mixed thoroughly or if it is poured too quickly. These air bubbles can cause imperfections on the outer surface of the mould. This problem occurs with RPOP casting, because semi-liquid RPOP needs to be poured immediately to avoid the casting hardening before being inserted into the mould enclosure. The quality of the RPOP itself can play an important role. If impurities are present in the RPOP or if it has been recycled several times, it may not set smoothly or evenly, resulting in variations in the mould surface. If a mould release agent is used to facilitate the removal of plaster from the mould, it can produce a smoother inner surface but can also cause small holes or imperfections on the outer surface if not applied evenly.

The moisture in the damp plaster may react with the permanent temperature, particularly if the application is uneven or unfinished, resulting in the development of air bubbles. The reason that may see bubbles is that the mould shape provides undercut circumstances that trap air during casting. However, this mould can still be used right because pinholes or water bubbles only occur on the outside of the mould wall and the inside is still smooth and does not have an effect that interferes with the process of casting the product.

According Ramesh, (2015) similar procedures to slip casting are used in the production process of plaster mould casting. Plaster mould casting is an industrial process that can be used to make items like valves, appliances, gears, and essential components. As with the initial step of making anything, POP is initially combined with water. The process involves mixing POP and water with other additives, like talc and silica flour, to create a plaster casting mould. Additives function to regulate the plaster's time and strengthen it. The casting pattern is then covered with a combination of POP. The slurry must settle for around. Plastic or metal should be utilised as the pattern when producing this kind of metal casting. Wood cast patterns are prone to warping since they are exposed to water from the plaster mix for an extended period.

The results demonstrate that the optimized RPOP mould activated at 160°C with 0.5% Silubit G80 successfully produced intricate and aesthetically refined ceramic forms comparable to those made with new plaster. The enhanced surface smoothness and fine replication of design details reflect the improved particle bonding and reduced porosity of the modified material. This performance confirms that the combination of thermal activation and Silubit G80 modification restores the visual and structural quality of recycled plaster, enabling it to achieve high aesthetic standards without compromising functionality. Consequently, the optimized RPOP formulation offers a viable and sustainable solution for high-quality mould production in the ceramics industry.

5.5.2 Casting Efficiency and Reproducibility

This subsection focuses on the casting performance of moulds produced from the optimised RPOP formulation. The discussion relates the improved water absorption control and surface hardness to higher casting efficiency, consistent thickness, and reduced surface defects across multiple uses. Casting performance is a critical indicator of mould efficiency, influencing the uniformity, surface finish, and dimensional accuracy of the final ceramic product. In this section, the discussion focuses on the casting behaviour of aesthetic and intricate ceramic forms produced using the optimized Recycled Plaster of Paris (RPOP) activated at 160°C with 0.5% Silubit G80, compared with New Plaster of Paris (NPOP). The analysis examines the flow characteristics of the slip, mould filling capacity, and demoulding quality to determine the capability of the modified RPOP in handling complex geometries. This evaluation highlights the effectiveness of the optimized RPOP formulation in achieving consistent casting performance, reduced defects, and enhanced production reliability in ceramic manufacturing.

The results indicate that Silubit G80 significantly improves the casting workability of RPOP by increasing its flowability and plasticity, which allows the slurry to fill narrow and complex areas of the mould more effectively. This enhancement leads to better replication of fine details and smoother surfaces, particularly during the early casting cycles. These findings are consistent with the deflocculating function of Silubit G80, which enables better particle dispersion and water distribution within the plaster matrix.

However, as the number of casting cycles increases, both NPOP and RPOP + Silubit G80 (0.5%) begin to show surface degradation, cracking, and dimensional inconsistencies. This indicates moisture saturation in the mould body and possible weakening of the plaster structure due to repetitive wetting and drying cycles. Irregular or complex shapes further exacerbate stress concentration, resulting in visible cracks at sharp edges and thin sections. The geometric regions of the mould, especially corners and edges, are more prone to early deterioration because these areas experience higher stress and uneven drying rates. Over multiple castings, the internal capillary structure of the mould becomes saturated, reducing its ability to absorb water efficiently, thus extending setting time and causing defects such as surface cracks and breakages.

These findings suggest that while Silubit G80 enhances initial casting performance and aesthetic quality, the long-term durability of recycled moulds still depends on proper drying, maintenance, and limited reuse cycles. Optimizing the casting period and controlling environmental conditions—such as humidity, temperature, and pouring rate are essential to prolong mould lifespan and maintain surface integrity. Ultimately, effective process control and mould conditioning can ensure that RPOP + Silubit G80 performs comparably to NPOP in producing intricate and high-quality cast products.

5.5.3 Surface Durability and Mould Reusability

This part discusses the durability of RPOP moulds after repeated casting cycles. The interpretation covers surface wear, dimensional stability, and resistance to deformation. The discussion links these improvements to the densified structure achieved through thermal activation and Silubit G80 modification.

The deterioration of the RPOP + Silubit G80 mould after repeated casting cycles can be attributed to moisture saturation and surface erosion. As the mould absorbs more water over successive casts, its porosity increases, leading to weakening of the plaster matrix. Excessive water retention reduces the mould's ability to absorb further moisture during slip casting, resulting in thinner slip walls and longer setting times. The cracks and pinholes observed after multiple castings are common signs of fatigue in plaster moulds subjected to cyclic wetting and drying. Damp areas within the mould create micro-expansions, while the subsequent drying phase induces shrinkage stresses that eventually cause fine cracking. These imperfections act as initiation points for surface wear and structural weakening.

The geometric complexity of the mould especially at angular intersections intensifies localized stress concentration and capillary absorption. Corners and tight spaces retain moisture longer, allowing more slip accumulation, which later dries unevenly and accelerates erosion. This explains why damage tends to begin in geometric edges before spreading across the mould wall.

The relationship between the water-to-plaster ratio and mould performance, as noted by Hafizan et al. (2017), supports these observations. Increased water content results in greater porosity and absorption, which ultimately shortens mould life. In this study, despite maintaining a consistent mixing ratio, the addition of Silubit G80 appears to modify the hydration behaviour of RPOP, increasing initial workability but reducing long-term mechanical strength after repeated exposure to moisture.

Mechanical degradation such as erosion at mould joints and wall softening also leads to dimensional inaccuracies and slip leakage during casting (Figure 4.24). This is compounded by incomplete cleaning between cycles, where dry slip residues prevent proper sealing of mould sections, encouraging further slippage and uneven deposition. The observed adhesion of slip to wet mould surfaces in later casting cycles indicates that the hydrophilic nature of RPOP has been enhanced by moisture accumulation. The sticky, glue-like surface effect arises from partial rehydration of calcium sulphate hemihydrate, which reduces rigidity and increases surface tackiness.

Overall, while Silubit G80 improves early-stage flow and detail reproduction, prolonged use of RPOP + Silubit G80 moulds results in reduced durability, increased fragility, and adhesion issues due to cumulative moisture effects and matrix fatigue. Proper drying intervals, surface maintenance, and limited casting cycles are necessary to sustain mould performance and product quality.

5.5.4 Glazing Compatibility and Surface Finishing

This section discusses the compatibility of RPOP moulds with glazing processes, focusing on surface texture and absorption characteristics. The interpretation highlights how optimised RPOP allows even glaze application and better adhesion, leading to improved finishing quality in ceramic products.

The success of the glazing process in this study demonstrates effective control of multiple production parameters, including glaze consistency, dipping duration, firing temperature, and kiln atmosphere. The smooth and glossy finish indicates that the glaze reached its optimal melting point, forming a uniform vitreous coating on the ceramic surface.

The glaze's even thickness ensures proper colour development and surface uniformity. A layer that is too thick can cause glaze run-off during firing, whereas a thin layer may appear matte or incomplete. Dipping for six seconds provided sufficient coverage, confirming that glaze viscosity and immersion time were well balanced. Controlled heating during firing allows the glaze components primarily silica, alumina, and fluxes to react and form a homogeneous glass layer. Gradual temperature increase minimizes thermal shock and surface defects such as crazing or pinholing. Similarly, a controlled cooling rate ensures a smooth finish and prevents glaze cracking caused by thermal stress.

The absence of pinholes and cracks suggests that air release during firing was complete and that the body-glaze interface achieved strong adhesion. This indicates an ideal match between the glaze's coefficient of thermal expansion (CTE) and that of the ceramic body, preventing defects such as *crazing* (fine cracking) or *shivering* (flaking).

The firing atmosphere also influences the glaze's visual qualities. In an oxidizing atmosphere, oxygen promotes brighter and cleaner colours, while a reducing atmosphere can mute tones or create variable surface effects. The consistent and bright surface finish observed here implies the use of a stable oxidizing environment throughout the firing cycle.

Meanwhile, the minor indentation on the moulded cup (Figure 4.29) illustrates the effect of mould fatigue on final product quality. Repeated casting cycles likely weakened the mould at the joint area, creating an uneven surface imprint on the glazed ceramic. This highlights that even when glazing and firing conditions are optimized, defects originating from the mould stage can propagate through to the final ceramic product.

Overall, the findings confirm that glaze quality and ceramic aesthetics depend not only on firing and glaze control but also on mould condition, surface preparation, and compatibility between glaze and clay body composition.

5.6 Summary of Discussion

This section summarises the main findings and interpretations discussed throughout the chapter. It reiterates the key outcome that RPOP activated at 160°C with the addition of 0.5% Silubit G80 provides the best balance of strength, density, and workability. The discussion concludes that the recycling of POP can be effectively achieved with proper thermal treatment and additive modification, ensuring both material performance and environmental sustainability in ceramic mould production.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The provision of Recycled Plaster of Paris (RPOP) represents a sustainable approach to waste management and responsible resource utilisation within the ceramic design field. By recycling discarded plaster of Paris, this research addresses material wastage while contributing to environmental conservation. The findings also demonstrate the relevance of this study to ceramic design practice, where mould quality, material performance, and casting consistency directly influence the final aesthetic and functional outcomes of ceramic products. Through systematic collection, processing, and reactivation, RPOP provides a viable alternative material that supports both environmental sustainability and practical application in ceramic mould production.

The findings of this study are consistent across chemical, physical, and performance-based evaluations. All tests converge toward the same conclusion, namely that 160°C is the optimal temperature for recycling plaster of Paris, producing material properties closest to New Plaster of Paris (NPOP). This consistency ensures that the conclusions drawn align well with the research objectives (RO) and research questions (RQ), particularly RO1 and RQ1, which focus on identifying the most effective recycling temperature for RPOP. Particle size analysis revealed that the NPOP sample measured 11.10 µm, whereas RPOP dried at 160°C measured 22.78 µm. Although RPOP demonstrated a wider particle size distribution, the material still achieved acceptable performance for ceramic mould making. Findings from SEM and XRD further support this observation: RPOP exhibited a more porous microstructure with partial phase changes, yet the material remained structurally suitable when properly processed. These findings confirm the earlier hypothesis that thermal activation plays a major role in restoring hemihydrate properties. At 37°C, incomplete dehydration resulted in RPOP failing to harden, directly answering RQ1 by confirming that low temperatures are unsuitable for recycling. Conversely, higher temperatures (170–190°C) caused material degradation, which, while achieving full dehydration, negatively affected structural integrity. Thus, the results across all tests consistently point to 160°C as the balanced temperature that ensures chemical stability and physical usability.

The second objective (RO2) is addressed through the addition of Silubit G80 as an activator. When 0.5% Silubit G80 was added to RPOP 160°C, the material showed enhanced strength, reduced porosity, and better casting consistency. This demonstrates that RPOP can be adapted and improved for ceramic design applications through material additives. The integration of Silubit G80 is meaningful for RQ2, as the additive successfully increased durability and mould performance without compromising sustainability. Comparative testing of mould performance revealed notable differences between NPOP, RPOP 160°C, and RPOP 160°C with 0.5% Silubit G80. NPOP consistently demonstrated the highest overall performance, exhibiting optimal setting time, superior detail resolution, and enhanced mechanical strength, making it particularly suitable for high-precision ceramic production. RPOP 160°C emerged as an environmentally friendly alternative, suitable for applications where extreme precision is not critical, while the addition of Silubit G80 to RPOP 160°C improved strength and stability, offering a balance between sustainability and high-quality mould production. These findings address RO3 and RQ3, confirming that recycled materials can achieve adequate performance for both simple and intricate ceramic forms.

A major highlight of this study is the successful performance of RPOP 160°C and RPOP 160°C + Silubit G80 0.5% in producing intricate moulds, which is essential in ceramic design where detailed geometry influences the final artistic outcome. The ability of recycled moulds to retain form accuracy demonstrates their potential application in both artistic and industrial ceramic practices.

A key outcome of this study is the successful use of RPOP 160°C and RPOP 160°C + Silubit G80 in producing intricate moulds, which is critical in ceramic design where precise geometry impacts the final artistic result. Recycled moulds demonstrated the capacity to retain form accuracy, highlighting their potential for both artistic and industrial applications. Nevertheless, prolonged use revealed signs of wear and surface defects, indicating a need for improved formulations or regular maintenance, consistent with external examiner feedback regarding the acknowledgment of practical limitations. The study contributes to the ceramic industry by providing a sustainable alternative to conventional NPOP, reducing production costs through mould reuse, and offering strategies to minimise material waste in ceramic workshops. These benefits are particularly relevant for craft-based industries, such as Labu Sayong production, where moulds are frequently used and discarded. Moreover, the research encourages material innovation aligned with Malaysia's sustainability initiatives, reinforcing its industrial relevance.

In the context of art and design practice, the findings demonstrate that RPOP can support experimental and complex mould designs while reducing material costs, enabling designers to explore innovative geometries within a sustainable framework. The study also underscores the interplay between material science and creative practice, suggesting avenues for future research on how recycled moulds affect surface aesthetics, glazing behaviour, and overall ceramic form expression

6.2 Recommendation

From the finding and conclusion of this research, recommendations for further study can be suggested as follows.

1. Further investigation of the mould effect of RPOP can be done by testing different types of slip clay in the mould casting process. Moulding using different types of clay is an approach to the mould casting process, which is a critical technique in ceramics, where slip clay is poured into moulds to form various shapes and structures. this proposal aims to investigate how different types of slippery clay interact with RPOP moulds, focusing on the quality, consistency, and durability of RPOP moulds as well as the final product. Assessing the quality and consistency of ceramic pieces produced with different slip clays. Analysis the interactions between different types of slip clay and RPOP moulds, including adhesion, release and surface finish. Assessing the long-term durability of RPOP moulds when used with different slip clays.

2. Furthermore, optimizing the ratio of RPOP powder and water can be explored to involve determining the best mix, which is believed to achieve the desired properties such as workability, setting time and strength. Workability, setting time and strength are all key factors in determining the effectiveness of a mixture. To find the best mix, it may involve a process of experimentation and analysis. Start with some initial ratio of RPOP powder to water. This can be based on existing literature, suggestions, or preliminary guesses. Mix each ratio

and evaluate its workability. This involves how easily the mixture can be handled and manipulated. It is often assessed subjectively but can also be measured using standard tests such as slump tests for concrete. Measure the setting time of each mixture. This is the time it takes for a material to change from a plastic state to a solid state. It is important to the timeline and construction process. After the material is set, test its strength. This can be done through various methods such as compression testing or bending testing depending on the application. Throughout this process, it is important to keep detailed records of experiments and results to inform results and facilitate future optimization or troubleshooting.

3. Another important practical implication is to multiply the types of castings in future studies. Shape can also significantly affect the result of the casting process. Different shapes can affect some aspects of pouring such as affecting how quickly or slowly the liquid material solidifies. Complex shapes or thicker parts may cool more slowly, affecting the microstructure and properties of the final casting. Irregular shapes or thickness variations can cause differential cooling and subsequent shrinkage, which can cause defects such as porosity, cracks, or distortion. In addition, the flow of liquid material into the mould cavity is affected by the shape of the casting. Complex shapes may require special gating and riser systems to ensure proper filling and minimize defects such as air entrapment or misalignment. Different shapes have different surface areas and geometries, which affect the rate of heat transfer during both the solidification and cooling stages. This can affect the final metallurgical structure and mechanical properties of the casting. The complexity of the casting shape often dictates the mould design, including considerations for mould material, drains, and spacers. Certain shapes may require more complicated moulds, increasing production costs and complexity. Overall, the shape of the casting plays an important role in determining its final quality, performance, and manufacturability.

4. Future research should focus on developing new additives to enhance fine-detail capture and mould durability, investigating RPOP performance with various ceramic slip formulations, assessing aesthetic outcomes of ceramics

cast in recycled moulds, and conducting long-term industrial testing for large-scale production. Expanding these investigations can further integrate eco-materials into design innovation, promoting sustainability without compromising artistic and industrial quality.

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APPENDICES

APPENDIX 1

Calculation on ratio powder RPOP, water and Silubit G80 to prepared mould casting :

a) For powder RPOP 60% per one side mould

$$RPOP = \frac{60}{100} \times -1000\text{g}$$

b) For water 40% per one side mould

$$water = \frac{40}{100} \times 1000\text{g}$$

c) For Silubit G80

$$Activator = \frac{0.5\%, 1.0\%, 1.5\%, 2.0\%}{100} \times 1000g$$

APPENDIX 2

Type	Formula
3.1	$Porosity = \frac{Ww - Wd}{Wd - Ws} \times 100\%$
3.2	$Bulk\ Density = \frac{Wd}{Wd - Ws} \times 100\%$
3.3	Water Absorption (%) = $\frac{(Final\ weight - Initial\ weight)}{Initial\ weight} \times 100$

APPENDIX 3

ZSCHIMMER & SCHWARZ

CERAMIC
AUXILIARIES

SILUBIT G 80

Plaster additive

Chemical basis:
Melamine preparation

Characteristics:

Appearance:	white powder
Solubility:	water-soluble
Bulk density:	approx. 600 g/l
pH (1 %):	approx. 9

Shelf-life / Packaging:
12 months when stored properly and dry
bags of 25 kg

Application:
SILUBIT G 80 is a deflocculant for plaster. The plaster/water ratio can be increased using this additive without changing the plaster structure or pore characteristics.

This increases the mechanical resistance of the plaster mould, i.e. the abrasion resistance is considerably improved. This can lead to an increase in the service live of the plaster moulds.

The mechanism of action of SILUBIT G 80 depends on its surface activity. The additive has a deflocculating effect on the plaster, so that the proportion of solids content in the plaster slip can be increased while maintaining the same processing consistency.

The amount to be added depends on the type of plaster used. In general it ranges between 0.5 and 2.0 % of the solids content of the plaster.

SILUBIT G 80 should be dissolved in the make-up water shortly before adding the plaster.

AUTHOR'S PROFILE

Ainun Fathiah Binti Hamdan obtained her Bachelor of Industrial Ceramic (Hons.) First Class in 2021 from Universiti Teknology Mara (UiTM), Shah Alam. In 2021, she has continued studies, in PhD level at Universiti Teknology Mara (UiTM), Cawangan Perak, Campus Seri Iskandar in the field of DOCTOR OF PHILOSOPHY (ARTS AND DESIGN). Her PhD thesis is about the recycling of moulds from Plaster of Paris collected from mould dumps resulting from casting works in the ceramic manufacturing industry. The purpose of this recycling is to restore the original properties of the used Plaster of Paris (POP0 and the mould Plaster of Paris can be reused as a mould making material. At the same time, she has been UiTM Postgraduate Assistance (UPTA) for 4 semesters under the supervision of Dr. Nor Nazida Binti Awang which is Co-SV in PhD level.

LIST OF PUBLICATION:

Ainun Fathiah Hamdan, Oskar Hasdinor Hassan, and Nor Nazida Awang. 2024.8 International Journal of Art & Design (IJAD) Pg. 31-37 Characteristics of Recycled Plaster Of Paris At Several Different Temperatures Between 150°C-190°C During Recycling Process. https://journal.uitm.edu.my/ojs/index.php/IJAD/index.

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