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The Properties of Sustainable Fired Clay Bricks Incorporating Eggshell and Recycled Glass Waste

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ABSTRACT

Fired clay bricks have been integral to construction for centuries, valued for their inherent strength and durability. However, the substantial energy demands and greenhouse gas emissions from the high-temperature brick firing process pose pressing environmental concerns. The scarcity of quality clay deposits for brickmaking has also raised fears of resource depletion. Eggshells, comprised of nearly 95% calcium carbonate, undergo a chemical transformation during firing that enhances compressive strength and reduces porosity in bricks. A recent study showed that using eggshell waste to replace clay in brick is positive. Meanwhile, soda lime silica, produced by recycling waste glass, forms a protective glaze-like coating on brick surfaces, lowering required firing temperatures and improving thermal insulation. Different eggshell powder concrete bricks were developed by replacing 0%,5%, and 10% in the clay and soda lime silica mixture to find the best composition of the brick with the desired properties. The enhanced performance of these bricks can be attributed to the inclusion of eggshells in the clay and soda lime silica mixture. As a result, the green approach conserves natural resources while meeting sustainability goals, charting a new course for environmentally responsible brick manufacturing. The findings highlight the potential of utilising eggshells to enhance the properties of clay bricks to improve their characteristic and mitigate waste reduction associated with the egg industry. The study suggests that incorporating eggshell waste into burned clay bricks improves properties and offers a sustainable approach *to waste management. Compression and water absorption tests assess the brick's structural integrity and durability. The study output was positive, demonstrating incorporating soda lime silica and eggshell into brick formulations with weight ratios of 50/50 and 60/40 is effective. Compared to current bricks that are available on the market, these modified bricks exhibit enhanced sustainability and potentially improved material properties.*

Keywords: Fired Clay Brick; Clay; Soda Lime Silica; Eggshell; Mechanical Properties

INTRODUCTION

Bricks from fired clay represent a fundamental building material used since ancient times [1]. The average compressive strength for fired-facing is 14500 psi, and acceptable water absorption for clay brick is between 12% and 20%. The extensive utilization of clay soil in brick manufacturing raises significant sustainability concerns, given its categorization as a non-renewable resource. Paedogenic processes require millennia to produce merely centimetres of clay deposits through the weathering of other rock types, with estimates ranging from 1,000 to 5,000 years for 1 cm of clay soil accumulation [2]. This situation underscores the urgent need for alternative approaches in brick manufacturing requiring radically diminished clay content to promote resource conservation. Alternative approaches have been developed as time passes, such as incorporating additional materials in the brickmaking process to reduce the overall amount of clay required. One such promising material is eggshells, which are abundant in Malaysia and are a by-product of the food industry. Typically, eggshells are left to deteriorate in landfills due to their durability, which poses significant environmental concerns and results in the squandering of valuable natural resources [3]. Another scholar added 5% to 10% of oat husk into brick moulding to produce eco-friendly fired clay brick [4,5].

Eggshells, a plentiful byproduct of the food sector, offer a potential avenue for material upcycling as an alternative to their disposal in landfills. In recent years, there has been a growing interest in using ground eggshell powder as a potential alternative to virgin clay in producing bricks [6]. Eggshells contain significant calcium carbonate ($CaCO_3$), constituting more than 90% of their composition. The presence of calcium carbonate in the firing process of bricks can induce reactivity and pore-filling effects, hence improving the characteristics of the bricks [7]. The inclusion of eggshells in clay bricks resulted in a reduction of water absorption by around 40% compared to bricks made solely from clay. This drop can be attributed to calcium carbonate (CaCO3), a filler material believed to promote the formation of dendrites, leading to a decrease in water absorption. The utilisation of eggshell waste demonstrates potential in enhancing the properties of burned clay bricks through microstructural improvements while simultaneously addressing the issue of food waste management [8,9].

Soda lime silica (SLS) recycled waste glass streams by finely grinding the glass [10]. The incorporation of SLS has been thoroughly investigated to improve the characteristics of masonry units made from burned clay. Using soda lime silica derived from waste glass is a feasible approach for integrating additives, owing to the extensive accessibility of recycled glass resources. SLS offers unique benefits as a brick additive, as studies suggest it can improve thermal insulation properties and create an aesthetic white glaze when fired at high temperatures [11]. Studies conducted about the potential of waste glass soda lime silica in glass ionomer cement have demonstrated comparable improvements in compressive strength (up to 45%), density (up to 22%), and decreases in water absorption (up to 38%) by the addition of 5-15% SLS in clay bricks and roofing tiles. The primary reason behind the observed enhancements in strength, hardness, and durability is creating a vitreous bonding phase that occurs when SLS undergoes melting during the firing process. This phase leads to enhanced aggregation of particles and filling of pores [12].

This study investigates the incorporation of soda-lime-silica (SLS) and eggshell (ESW) waste materials into fired clay bricks (FCB) using weight ratios of 50/50 and 60/40 to balance the beneficial properties of each component: clay provides the primary structure and plasticity, SLS enhances strength and durability, and ESW reduces the overall consumption of clay while potentially improving the thermal properties of the bricks. Previous study used an 80/20 ratio for making a brick using residue sand, by adjusting these ratios, researchers aim to achieve the desired compressive strength, ensuring that the bricks can withstand significant loads without cracking or breaking and influence the water absorption rate, reducing porosity and increasing longevity [13]. Several tests were conducted to quantify compressive strength and water absorption, with potential future investigations suggested to examine the effects of various additives or alternative weight ratios. The ramifications of this discovery may transcend the domain of construction materials, influencing other sectors reliant on material science for product advancement. This research establishes a strong basis for future investigations, providing a model for thorough and compliant research in material science while exploring the feasibility of creating environmentally friendly bricks by reducing the consumption of clay soil (CS) during brickmaking and maintaining desired physical and mechanical qualities through various compositions of CS, ESW, and SLS glass subjected to firing [14,15].

METHODOLOGY

The experimental methodology adhered to a structured procedural flow, as depicted in Figure 1, which entailed the preparation of raw materials, integrating additives, and producing test bricks. The process began with the refinement of waste eggshells and soda lime silica to achieve optimal particle sizes and morphologies, as outlined in Figure 2 and Figure 3. This preparatory step was crucial for ensuring a uniform mixture with the clay. The refined eggshell and soda lime silica were added to the clay and then mixed thoroughly. The process then continues with the moulding to make a cube shape brick. Lastly, the prepared bricks were subjected to firing at specified temperatures before mechanical testing.

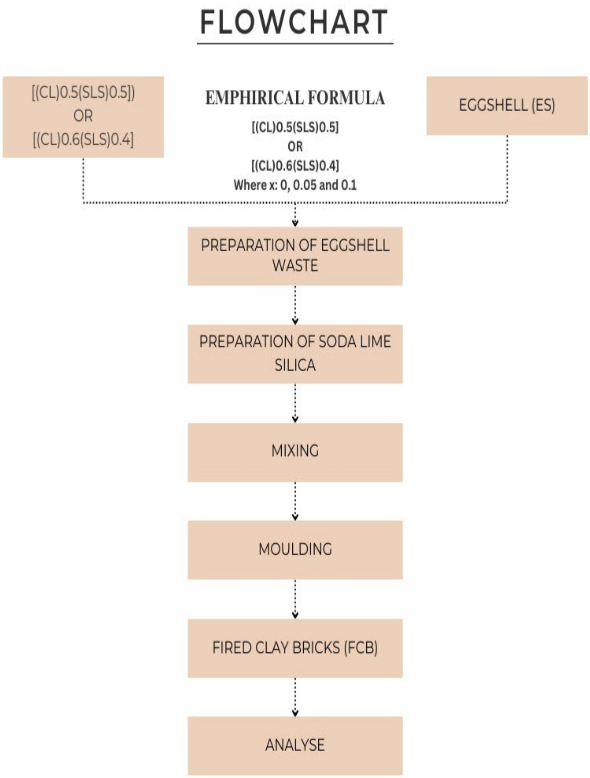

Figure 1: The general flow chart for eco-friendly bricks

Preparation of eggshell

The shells were rinsed in distilled water to eliminate the inner membrane layer and any attached debris. The washed shells were then dried in an oven at a temperature of 90°C for 5 hours to remove any remaining moisture and organic impurities. The desiccated shells were subsequently crushed into smaller pieces using a mortar and pestle. The powder underwent thermal calcination at 1000°C for 8 hours in a thermocline furnace. This process was carried out to facilitate the disintegration of calcium carbonate into calcium oxide. The calcium oxide powder obtained was gathered and preserved for integration into the clay brick samples. The preparation process for eggshells is shown in Figure 2.

Figure 2: Process preparation of eggshells

Preparation of soda lime silica

The soda lime silica (SLS) ingredient was obtained from recycled waste glass bottles, and the initial cleaning process consisted of rinsing the bottles with tap water, followed by a final rinse with distilled water to remove any pollutants and dirt stuck to them. The sanitized bottles were subjected to oven-drying at a temperature of 110°C for 6 hours to eliminate any remaining moisture. The desiccated bottles were shattered manually using a hammer to obtain glass fragments, which were then subjected to ball milling to achieve a finely uniform glass powder. The powder underwent a process of filtration using a 45-micron sieve to eliminate any unground particles and impurities. The SLS glass powder, passed through a sieve, was kept at room temperature until added to the clay brick test samples. The procedure for preparing the soda lime silica (SLS) is illustrated in Figure 3.

Figure 3: Process preparation of soda lime silica

Preparation of fired clay bricks

The mixture of clay soil (CS), soda lime silica (SLS), and eggshell waste (ESW) was formulated using the empirical formulas:

i. $[(CL)_{0.5}(SLS)_{0.5}]_{1-X}[ESW]_X$ and
ii. $[(CL)_{0.6}(SLS)_{0.4}]_{1-X}[ESW]_X$,

where X denotes the proportion of ESW 0%,5%, and 10% (0, 0.05, or 0.10). The samples were named according to their compositions, with the compositions divided into two sets: 50% CL + 50% SLS (samples A to C) and 60% CL + 40% SLS (samples D to F). For each set, variations with and without the addition of ESW (5% or 10%) were considered. The formula given above produces the composition and ratio statistics, which are displayed in Table 1. The samples labelled A and D function as control specimens.

Table 1: Composition of the prepared clay brick samples

Unit	CL (%)	SLS (%)	ESW (%)	CL content (g)	SLS content (g)	ESW content (g)
A	50	50	0.00	468.75	468.75	0.00
B	50	50	5.00	296.88	296.88	31.25
C	50	50	10.00	281.25	281.25	62.50
D	60	40	0.00	375.00	250.00	0.00
E	60	40	5.00	356.25	237.50	31.25
F	60	40	10.00	337.50	225.00	62.50

The combination of the individual components required the use of a mixer to ensure complete blending. After the mixing process, the prepared composition was moved to pre-treated moulds that had been coated with cooking oil. This was done to make removing the mixture from the moulds easier after curing and hardening. When the moulds were prepared, the composition was inserted into them using a scoop and stirred with a wooden stick to correct its adhesive properties, remove any trapped air bubbles, and ensure the production of bricks with accurate cubic dimensions. After filling, the moulded composition underwent a 48-hour curing time at room temperature with humidity ranging from 40% to 50% to achieve complete hardening before the subsequent firing operation. Curing is essential for enhancing the strength and durability of concrete, ensuring its long-lasting nature. Failure to cure the concrete surface might undermine its abrasion resistance, resulting in dusting and reduced durability. After the curing phase, the compositions were shaped and then exposed to high temperatures in a furnace at an ideal temperature of 1000°C for five hours. The heating rate was 10°C per minute. This process resulted in the creation of burnt clay bricks. The burnt clay bricks were analysed for physical parameters, including water absorption and mechanical strength, according to the American Society for Testing and Materials (ASTM) C62.

Characteristics of the Test

In construction materials, the suitability of new types of bricks is rigorously evaluated through a series of tests. These tests, namely the compression and water absorption tests, are integral to the assessment process. Each test provides valuable data, contributing to a comprehensive understanding of the brick's overall performance characteristics. The collective results of these tests offer a robust evaluation of the brick's suitability for use in construction. This rigorous testing protocol ensures that every new type of brick meets the stringent quality standards required in the construction industry, thereby safeguarding the integrity and durability of our built environment.

Compressive Strength Analysis

The compression test of a brick is of utmost importance in evaluating its structural soundness and ability to sustain loads. This data is necessary for assessing the brick's capacity to endure compressive stresses, which is vital in building contexts. This test assesses the brick's robustness and resilience, providing valuable guidance to architects and engineers in creating structures capable of withstanding anticipated loads and environmental circumstances. Therefore, it is essential to have a comprehensive understanding of the compression properties of bricks to guarantee erected buildings' stability and safety.

In this work, a compression test with the loading of 1000 kN on the cube specimens (50 mm diameter x 50 mm height) was conducted using the universal testing machine. Three specimens were selected for each sample ratio, and the average reading of the compressive strength was taken. The bricks are individually positioned in the precise centre of the compression mechanism. The machine functions at a velocity of 2 millimetres per minute (2 mm/min), causing the brick to shatter. The machine halts once the brick has wholly fractured, and this sequence is resumed for the remaining bricks. Table 2 shows the grade of a brick based on the ASTM C62 that is used for standard comparison [16].

Table 2: Grade of brick based on the ASTM C62

Building Brick Grade	Minimum Compressive Strength (MPa)
Grade SW (Severe Weathering)	20.7
Grade MW (Moderate Weathering)	17.2
Grade NW (Negligible Weathering)	8.6

Water absorption test analysis

The water absorption test for bricks is a standardized process to evaluate the brick's capacity to absorb water. This test yields significant data regarding the brick's porosity and permeability, which is pivotal in assessing its appropriateness for different construction purposes [9]. Established industry norms and requirements conventionally carry out the test. The water absorption test for bricks serves several vital purposes. Firstly, it is used for quality assessment, measuring the bricks' durability and overall quality. Secondly, it allows for performance forecasting, predicting how the bricks respond to moisture in real-world environmental conditions. Lastly, it aids in determining the suitability of the bricks for construction purposes. In this test, a single specimen from each sample is selected. The specimen is weighed before being submerged in water and then weighed again after one and three days. This process provides valuable data on the water absorption properties of the bricks, contributing to a comprehensive understanding of their performance characteristics [13] as shown in Eq.(1).

$$Ma = \frac{Ms - Md}{Md} \text{ X } 100\% \quad (1)$$

In this context, the term ‘Ma’ denotes the mass of water absorbed by the Fully Immersed Water-Cured Brick (FCB). On the other hand, ‘Ms’ represents the mass of the brick post-immersion, while ‘Md’ signifies the mass of the brick before its water immersion [16]. Table 3 denotes the water absorption of bricks corresponding to ASTM standards.

Table 3: Grade of a brick based on the ASTM C62 for water absorption

Brick Type	Maximum Water Absorption (%)
First Class	20
Second Class	22
Third Class	25

RESULTS AND DISCUSSION

Compressive Strength Analysis

The brick samples displayed a significant variation in compressive strength in Table 4 and Figure 4, ranging from 12.39 MPa to 49.54 MPa, showing noteworthy differences in the quality and performance of the bricks.

Table 4: Compression analysis of fired clay bricks samples

Unit	Maximum Load (kN)	Cross-sectional Area (mm^2)	Compressive Strength (MPa)
A	40.65	2500	16.26
B	30.97	2500	12.39
C	52.65	2500	21.06
D	123.86	2500	49.54
E	57.82	2500	23.13
F	68.24	2500	27.30

To evaluate these results, the ASTM standard C62 was employed. This standard categorizes building bricks into three grades based on their resistance to frost action and moisture penetration (Table 3). According to the ASTM standard C62, only samples D (49.54±4.33MPa) and F (27.31±2.52MPa) satisfied the minimum requirement for Grade SW, the highest grade for building bricks. Sample C (21.06±0.51MPa) met the minimum requirement for grade MW, while samples A (16.26±1.10MPa) and B (12.39±2.11MPa) met the minimum requirement for Grade NW. Sample E (23.13±2.73MPa) did not meet grade specifications, as it was lower than the minimum required for Grade SW but higher than the maximum allowed for Grade MW. When comparing two different compositions, specifically 50-50 and 60-40, it is evident that bricks with a higher proportion of eggshell, like Brick C and Brick F, exhibit superior stress resilience compared to others with lower or none. There appears to be a connection between the eggshell composition and the bricks' ability to withstand force. This discovery presents novel eco-friendly and effective brick production opportunities, potentially transforming the construction sector.

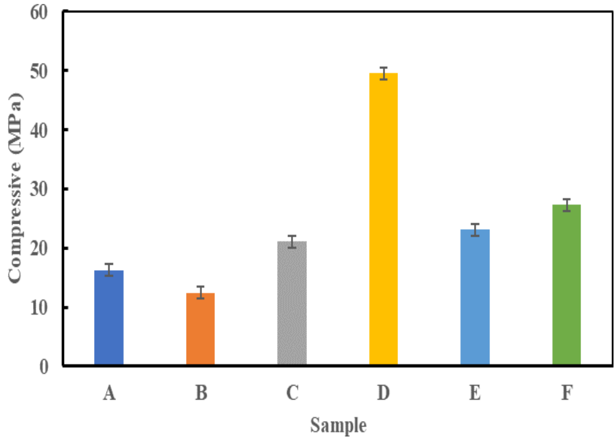

Figure 4: Compressive strength of fired clay bricks samples

The experimental results indicate that clay brick samples demonstrate differential adaptability for distinct weathering circumstances, showcasing diverse features and performances. The variation in compressive strength can be influenced by several factors, including the clay type, firing temperature and duration, brick form and size, voids and fractures, and moisture content. Improving compressive strength includes utilising premium-grade clay, optimising fire conditions, choosing suitable brick dimensions, and meticulously managing moulding, drying, and firing procedures [4].

The discrepancy found in the heterogeneous graph of sample A, the control sample, compared to bricks mixed with clay, SLS glass, and eggshell, can be ascribed to changes in composition and reactivity among the materials. Using SLS glass can increase the strength and density of bricks by forming phases including cristobalite, quartz, and mullite [17]. However, it can also introduce faults such as fractures, pores, and bubbles, which can reduce the overall uniformity and quality of the bricks. Adding eggshell to a substance acts as a filler and agent that creates pores. This increases the substance's porosity and thermal insulation. Additionally, it helps to neutralise the acidity of clay and prevents the creation of hazardous chemicals like hexavalent chromium.

Water Absorption Test

Fired clay bricks typically undergo weight gain during the stipulated time intervals of 1 day and 3 days, which implies that the bricks undergo water absorption within this time frame. The discrepancies in water absorption rates among the samples can be ascribed to disparities in the composition or porosity of the bricks. It is worth mentioning that certain bricks demonstrate a more significant rise in weight, suggesting a more extraordinary ability to absorb water. Bricks with higher water absorption rates may be more vulnerable to environmental conditions, which could impact their structural integrity as time passes [18]. Figure 5 and Figure 6 show the water absorption of clay bricks of various mixtures fired at 1000 °C.

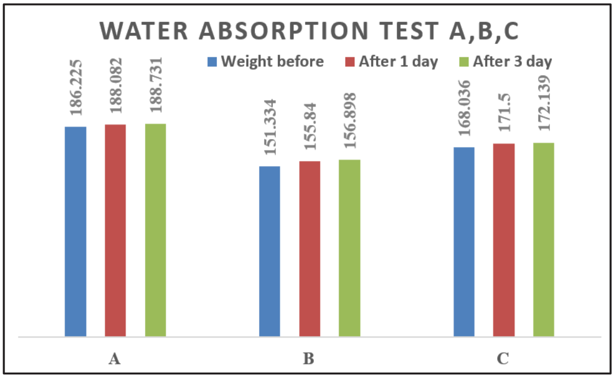

Figure 5: Water absorption of clay bricks (samples A, B, and C) fired at 1000°C

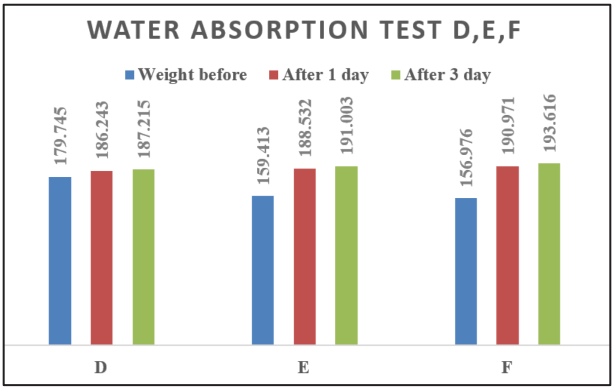

Figure 6: Water absorption of clay bricks (sample D, E, and F) fired at 1000°C

The standard weight gains of a brick in Figure 5 (sample A-C) and Figure 6 (sample D-F) exhibit varying percentages across different samples, ranging from modest increases (about 1-4%) to substantial ones (up to around 24%). The discrepancies in water absorption rates among the samples can be ascribed to disparities in the composition or porosity of the bricks. It is worth mentioning that certain bricks demonstrate a more significant rise in weight, suggesting a more remarkable ability to absorb water. The ASTM C62 specification has two grades: SW (severe weathering) and MW (moderate weathering), which indicate the resistance to damage by freezing when wet [19]. The maximum allowable water absorption for the SW grade is 17%, and for the MW grade, it is 22%. According to the graph, samples A, B, C, and D have a percentage increase in weight of less than 5% after one day and three days of immersion in water, as can be seen in Figure 4 and Figure 5. This suggests they have a low water absorption and may meet the ASTM C62 specification for either SW or MW grade. However, samples E and F have a percentage increase in weight of more than 18% (Sample E from 159.42g to 188.53g and Sample F from 156.9g to 190.9g) after one day and three days of immersion in water. This indicates they have a high-water absorption and may not meet the ASTM C62 specification for either SW or MW grade. Therefore, the samples E and F may not be suitable for building brick applications [20,21].

Samples A, B, C, and D have a slight percentage increase in weight, meaning they have a minor swelling due to water absorption. This may result in better dimensional stability of the brick when exposed to water or humid environments.

CONCLUSION

The study demonstrates the potential of incorporating eggshell and soda-lime-silica waste into burnt clay bricks, enhancing brick properties. Compression tests revealed that only Clay D and F met ASTM standards for high-quality (more than 20.7 MPa) construction bricks, emphasizing the influence of composition and size on strength. Water absorption tests provided insights into brick porosity and suitability for construction, with Samples A, B, C, and D showing low absorption rates following ASTM C62 standards. Samples E and F displayed higher absorption, raising concerns about stability. As the compressive strength showed by sample D (60/40/0) was the highest, and better water absorption rate was shown by samples A, B and C, future research should work on reduced SLS wt.% and get optimum ESW wt% incorporation. Besides that, incorporating SLS and eggshell waste into burned clay bricks also offers an environment-friendly strategy approach to waste management.

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