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Mechanical Properties of Concrete Containing Coconut Shell as Coarse Aggregate Replacement

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Abstract

The increase in the price of traditional construction materials is a serious issue. Concrete, which is made of cement, sand, coarse aggregate, and water, is widely used as a building material. However, an increase in concrete production has certain negative consequences for the environment, such as the extraction of natural resources such as aggregate. Therefore, innovation in concrete materials without neglecting strength can always be done. Coconut shells are one of the recycled materials that can be used as a replacement for conventional construction materials such as aggregate. The aim of this research is to investigate the properties of concrete by using coconut shell as a partial replacement for coarse aggregate. A total of 60 samples with 0%, 10%, 20% and 30% of coconut shells as coarse aggregate for concrete replacement were cast. The properties of fresh and hardened concrete with coconut shell as coarse aggregate replacement were determined at 7, 14, and 28 days of curing ages. The results showed that concrete with coconut shell as a coarse aggregate replacement had a positive impact on workability, porosity, density, and UPV but not on compressive and tensile strength. However, the concrete made from coconut shell aggregates satisfied the minimum requirements of normal concrete, resulting in the acceptable strength required for M30 grade concrete. It can be used as lightweight concrete. Using coconut shell as a replacement for aggregate is not only cost-effective and environmentally friendly, but it also helps solve the problem of conventional material shortages, such as coarse aggregate. It can also help to solve the problem of waste disposal.

Keywords: Coconut shell; Sustainable material; Mechanical properties; Correlation relationship

1. Introduction

In this built environment, the fact that the cost of traditional construction materials keeps going up day after day is a major cause of concern (Ravi Patil, Gunasheela P, Khamrulisham M Nalband, 2019). Concrete is one of the materials that is used in most construction projects around the world (Alif Syazani Leman, Shahiron Shahidan, Mohd. Yazid Yusuf, 2017). However, there are some negative effects of increased concrete production, including the extraction of natural resources for aggregate. This practice has the potential to deplete natural resources and can harm the environment (Mane, 2019). As a result, the cost of producing concrete has been continuously increasing due to an increase in demand. Therefore, there is a need for research on suitable materials as a replacement without affecting the strength of the concrete structure (Mokhtar et al., 2021).

Currently, most researchers are focusing on the development of materials that may lower the construction cost and save the environment without neglecting structural strength (Shahidan, Leman, Senin, & Ramzi Hannan, 2016). Some of the waste elements are used in the concrete according to their properties. For example, fly ash, rice husk, slag, and sludge from the treatment of industrial and domestic wastewater have been proven to be suitable as partial replacements for cement in concrete. Meanwhile, coconut shells can be used as a substitute for coarse aggregates (Krishnaswami et al., 2022). The use of coconut shells as a replacement for coarse aggregates in concrete is gaining importance as a way of reducing waste and providing a sustainable alternative to non-renewable natural stone aggregates. Coconut shells may also benefit the environment and the economy by being recycled. Coconut shells can be used for construction in rural areas where they are freely available and in areas where conventional aggregates are expensive (Raut, 2017; Shahidan et al., 2016).

Coconut shell has a lot of potential as an aggregate alternative because it has a lot of advantages in terms of its mechanical properties. Stated that, due to their high strength and modulus properties, coconut shells can be a new composite material in concrete mix design (Chin, Rahman, Kuok, & Chiew, 2021). An experimental investigation has been conducted to study the characterization and impact of the workability of coconut shell coarse aggregate in concrete. Found that the workability of the mixture increases directly proportional with the percentage replacement of the coconut shell (Chin et al., 2021).

In contrast, an increase in the percentage of coconut shell replacement caused a reduction in the density of the concrete (Harle, 2017). The density of coconut shell concrete at 28 days of curing is less than 2000 kg/m3 (Harle, 2017). However, an increase in the percentage of replacement can increase the porosity of the concrete (Azahar & A. Rahman, 2021). Concrete control only absorbs 2.73%, while the highest absorption value is 12%. This leads to a decrease in the concrete's strength (Azahar & A. Rahman, 2021). The researchers have stated that the coconut shell concrete (CSC) had high levels of both integrity and homogeneity according to the ultrasonic pulse velocity (UPV) test (Zaid et al., 2021).

It was found that the addition of coconut shell to concrete weakens its ability to withstand compression. The compressive strength of concrete made with a 30% coconut shell aggregate fraction is only 41.07 MPa, a decrease of 9.10% compared to the control specimen. However, concrete with up to 30% coconut shell replacement can still be used as structural concrete because it has a strength of more than 30 MPa. As a result, it can be used for structural purposes (Azunna, Aziz, Cun, & Elhibir, 2019). The researchers have stated that the value of the split tensile strength decreased with 15%, 20%, and 25% coconut shell as coarse aggregate replacement, with 3.43 N/mm^2, 3.41 N/mm^2, and 2.39 N/mm^2, respectively. The split tensile strength decreased, which showed a similar trend as compressive strength with an increase in the amount of coconut shell replacement (Kumutha, Vijai, & Vijayragavan, 2018; Srinivas, Akula, & Mahesh, 2021).

However, there is limited information regarding the properties of normal concrete containing coconut shells (CS) as coarse aggregate replacement in Malaysia. Hence, the aim of this research is to determine the performance of concrete containing CS as coarse aggregate replacement in terms of compressive strength, tensile strength and ultra-pulse velocity value in Malaysia. Subsequently, the effect of CS on the workability, porosity and density of concrete containing coconut shell (CCS) was investigated. As a result, the correlation between compressive strength and workability, porosity, and tensile strength of concrete was established.

2. Methods

This section discusses the materials, design mix, preparation of the specimens and laboratory testing involved in this study.

2.1 Materials

The component materials that were used for these experiments were obtained from sources in the local area. Cement is a type of binding agent that is utilized in the process of connecting aggregates and reinforcing elements together [15]. For the purpose of this study, Ordinary Portland Cement (OPC) with a specific gravity of 2.3 was used for both normal concrete (NC) and coconut shell concrete (CCS) with 10%, 20% and 30% coconut shell replacement. OPC is mainly a compound of lime (CaO), silica (SiO_2), alumina (Al_2O_3) and ferum oxide (Fe_2O_3) [16]. The size of coarse aggregates is often more than 4.75 mm in general [17], [18]. For this study, crushed coarse aggregates with a maximum aggregate size of 10 mm were used and obtained from Kajang Rocks Quarry, located in Semenyih, Selangor. Fine aggregate is used as a filler for the voids that are left between coarse aggregate. In general, the size of fine aggregate is that which passes through a 4.75 mm sieve [19], [20]. In the experimental study, sand was used as a fine aggregate.

The coconut shells used in this study were obtained from a morning market in Batu Caves, Selangor. On the inside of the coconut shell, which is the concave area, the texture is smooth, but on the outside, it is rough. For optimal wreckage, these coconut shells were dried in a drying oven for 24 hours. A hammer was used to manually break up the coconut shells into smaller pieces, as shown in Figure 1. Afterwards, the crushed coconut shell was sieved using a 10 mm sieve to separate the various shapes, as shown in Figure 2.

Figure 1. The broken pieces of coconut shells

Figure 2. A 10 mm-sized coconut shells

2.2 Mix Design

A total of 60 specimens were collected for this research in order to achieve both the aim and the objectives. In this research, the coarse aggregate was substituted with coconut shell at four different percentages. In the mixing process, the coarse aggregate was partially replaced by 0%, 10%, 20% and 30% of coconut shell. The test specimen that serves as the control will have no replacement for the coarse aggregate at all. Table 1 shows the design ratio proportion with coconut shell as coarse aggregate replacement.

Table 1. The mix proportion for M30 grade coconut shell concrete

Specimens	Materials (kg)				
	Cement	**Water**	**Fine Aggregate**	**Coarse Aggregate**	**Coconut Shell**
NWC	445	205	710	985	0
10CSC	445	205	710	886.5	98.5
20CSC	445	205	710	788.0	197.0
30CSC	445	205	710	689.5	295.5

2.3 Preparation of Specimens

In this research, there were a total of two different types of moulds used in the casting process. The concrete samples were created in the shape of cubes and cylinders. A cube mould with dimensions of 100 mm x 100 mm x 100 mm was used for the compression test, the ultrasonic pulse velocity (UPV) test, the porosity test and the density test. In the meantime, a cylinder mould with dimensions of 100 mm x 200 mm was used for the split tensile test. A layer of oil was applied to the mould before the concrete mixture was poured inside. This method will make the demould stage easier after the concrete mixture has hardened. Then, the mixture proportion of the concrete, which consists of different percentages (0%, 10%, 20% and 30%), was poured and compacted in three layers after being mixed by hand. The sample was let harden for 24 hours, and then the cube and cylinder specimens were cured in a curing tank for 7, 14, and 28 days.

2.4 Laboratory Testing

There are two types of laboratory tests conducted to test the specimens, which is a test on fresh concrete and hardened concrete. The laboratory test for fresh concrete is a slump test. The test was carried out to identify the workability of the concrete to resist internal and external friction. Workability is expressed by the consistency of concrete but is more confined to the parameters of water content. Meanwhile, the laboratory tests on hardened concrete are the density test, porosity test, ultrasonic pulse velocity (UPV) test, compressive strength test, and splitting tensile strength test.

3. Results and Discussion

This section consists of six subsections, which are results on the workability, density, porosity, ultra-sonic pulse velocity value, compressive strength and tensile strength of the specimens with 0%, 10%, 20% and 30% coconut shell as coarse aggregate replacement.

3.1 Workability

The workability of the concrete is a crucial feature of fresh concrete because it affects its performance in many ways. This includes the strength of the concrete, the degree of compaction, the amount of bleeding and segregation, the quality of the finish, etc. The workability tests showed that the slump of all the batch mixes was between 62 and 75 mm. A control sample had a slump value of 75 mm. Values of 62, 65, and 68 mm were found for 10%, 20%, and 30% coconut shell coarse aggregate replacement, respectively. The fresh concrete will have a higher slump when a greater percentage of coconut shells are used as a replacement. Hence, the addition of coconut shells to concrete as a replacement for coarse aggregate will increase its workability. Figure 3 shows the graph of workability (mm) against the percentage of coconut shells (%).

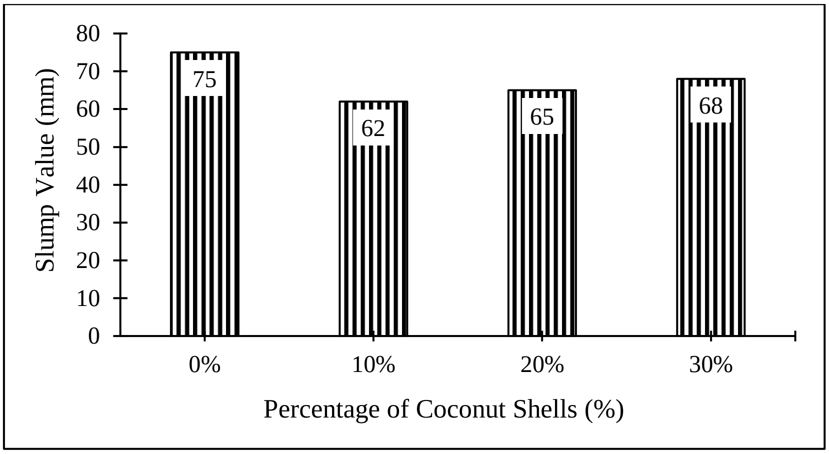

Figure 3. Slump value of concrete specimens

3.2 Density

As shown in Figure 4, the density of the concrete decreases in direct proportion to the amount of coarse aggregate that coconut shell replaces. The 0% replacement of coconut shell as coarse aggregate will act as a specimen control and give a value of 2292.70 kg/m^3. Meanwhile, for a 10% replacement of coconut shell as coarse aggregate, the density of the concrete is 2180.00 kg/m^3. The density of the concrete keeps decreasing with the increase in the percentage of replacement coconut shell as coarse aggregate. Next, the density of concrete has a value of 1986.80 kg/m^3 for the 20% replacement, while it has a value of 1830.00 kg/m^3 for the 30% replacement.

As can be seen from Figure 4, a graph of density against percentage of coconut shells was plotted. It can be seen that the density of the concrete decreases as the percentage of coconut shells used in the mix increases. Apart from that, with 30% coconut shell as a replacement, the density of the concrete was 1830.00 kg/m^3 and it lies within the range of normal lightweight concrete. The ACI Committee 213 Guide for Structural Lightweight Aggregate Concrete (ACI 213, 2001) categorizes lightweight concrete based on its unit weight or density, which typically falls between 320 and 1920 kg/m^3.

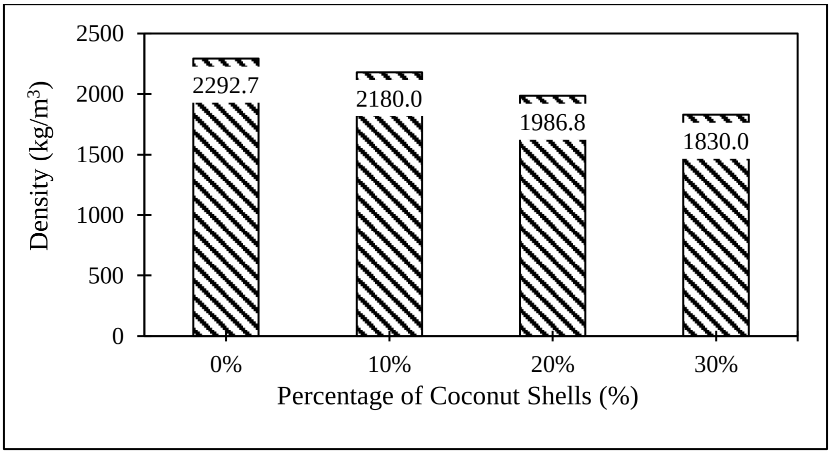

Figure 4. Density against percentage of coconut shells

3.3 Porosity

According to Figure 5, the 0% replacement of coconut shell as coarse aggregate will act as a specimen control and give a value of 0.20%. In addition to that, the value is increased when 10% of the coarse aggregate is replaced with coconut shell, which is 1.14%. The porosity value will continue to increase as the percentage of coconut shell used as coarse aggregate increases. Aside from that, it will give a value of 1.86% when coconut shell is replaced at 20%. However, when it comes to 30% of the replacement of coconut shell as coarse aggregate, the porosity value decreased to 1.75%. Figure 4.3 shows the graph of porosity (%) against the percentage of coconut shells (%).

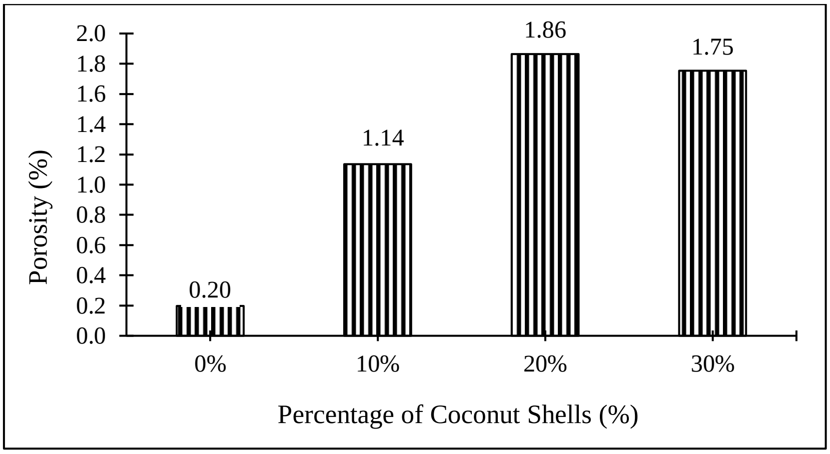

Figure 5. Porosity against percentage of coconut shells

3.4 Ultrasonic Pulse Velocity (UPV)

According to the results of ultrasonic pulse velocity (UPV) tests as shown in Figure 6, it shows that the 0% replacement of coconut shell as coarse aggregate will act as a specimen control and give a value of 2.27 km/s, 3.65 km/s and 4.31 km/s, respectively, after 7, 14, and 28 days of curing.

However, for the 10% replacement of coconut shell as coarse aggregate, the value of the ultrasonic pulse velocity (UPV) of the concrete is 3.67 km/s, 4.22 km/s, and 4.38 km/s, respectively. The results of the UPV test on the concrete show an increase in velocity directly proportional to the replacement coconut shell as coarse aggregate.

Apart from that, the value of the ultrasonic pulse velocity (UPV) of the concrete is mainly decreased for the 20% replacement, which is 4.08 km/s, 4.12 km/s, and 4.16 km/s after 7, 14 and 28 days of curing. Aside from that, the value of the ultrasonic pulse velocity (UPV) continued to increase for the 30% replacement after 7, 14, and 28 days of curing, which is 4.11 km/s, 4.19 km/s, and 4.44 km/s. A concrete is considered in 'good' condition as long as its UPV value ranges between 3.66 km/s and 4.58 km/s (Prakash, Thenmozhi, Raman, & Subramanian, 2020).

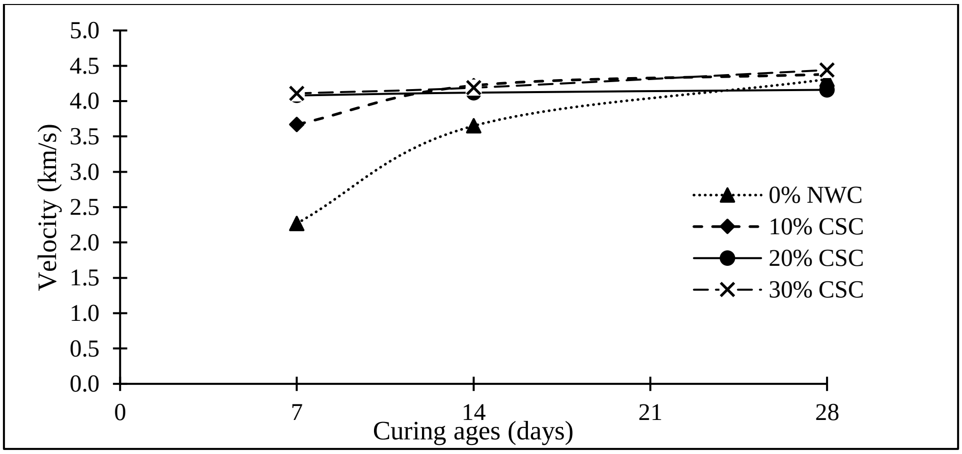

Figure 6. Velocity at 7, 14, and 28 days of curing

3.5 Compressive Strength

According to the researchers, one of the most vital characteristics of concrete and mortar is its compressive strength. The concrete will be tested for its compressive strength using an NL Scientific Automatic Touch Screen Compression Testing Machine, in accordance with BS EN 123903. According to Figure 6, the 0% replacement of coconut shell as coarse aggregate will act as a specimen control and give a value of 30.03 MPa, 36.83 MPa and 41.60 MPa at 7, 14, and 28 days of curing ages, respectively.

Meanwhile, the compressive strengths of the concrete containing 10% replacement of coconut shell as coarse aggregate are 29.17 MPa, 31.93 MPa and 36.3 MPa after 7, 14 and 28 days of curing, respectively. The compressive strength of the concrete decreased with the increase in the percentage of replacement coconut shell as coarse aggregate. The compressive strength of concrete has a value of 23.90 MPa, 27.43 MPa, and 33.13 MPa for the 20% replacement, while it has a value of 19.10 MPa, 25.83 MPa, and 31.87 MPa for the 30% replacement after 7, 14, and 28 days of curing, respectively.

It can be noticed that the compressive strength of coconut shell concrete is significantly influenced by the strength of the coconut shell. At early ages, the compression failure of coconut shell concrete was mostly caused by the failure of the bond between cement paste and coconut shell aggregates. However, at later ages, compression failure is due to the strength of the coconut shell aggregates themselves. Due to the relatively smooth surface of the coconut shell aggregate, the interparticle connection plays a less significant role in the formation of strength in coconut shell concrete. As a result, the low strength, low stiffness, and light weight of the coconut shell aggregate control the strength development in coconut shell concrete. Figure 7 shows the trend of compressive strength in specimens that contain various percentages of coconut shell.

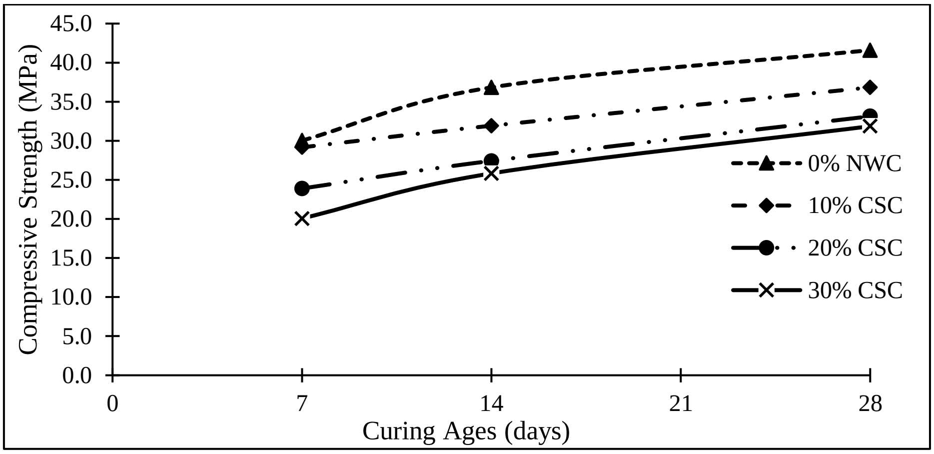

Figure 7. Compressive strength against percentage of coconut shells

3.6 Splitting Tensile Strength

Figure 8 below shows the 0% replacement of coconut shell as coarse aggregate, which acts as a specimen control and gives an astress value of 10.02 kPa in tensile strength. Meanwhile, the tensile strength of concrete with a 10% replacement of coconut shell as coarse aggregate is 8.28 kPa. However, it can be noticed that as the percentage of coconut shell replaced increased, the tensile strength decreased. For the tensile strength of concrete with a 20% replacement of coconut shell as coarse aggregate, it will have a value of 6.76 kPa. The tensile strength continues to decrease with 30% replacement, and it will give a value of 4.52 kPa after 28 days.

As the percentage of coconut shell as a coarse aggregate increased, the tensile strength decreased. The tensile strength of coarse aggregate and cement paste is related to shear strength, the bond strength between aggregate and cement paste, and crack resistance. The split tensile strength was reduced for a variety of reasons, some of which include a failure due to the binder, a failure due to the connection between the binder and aggregate, a failure due to the aggregate and perhaps even a human error.

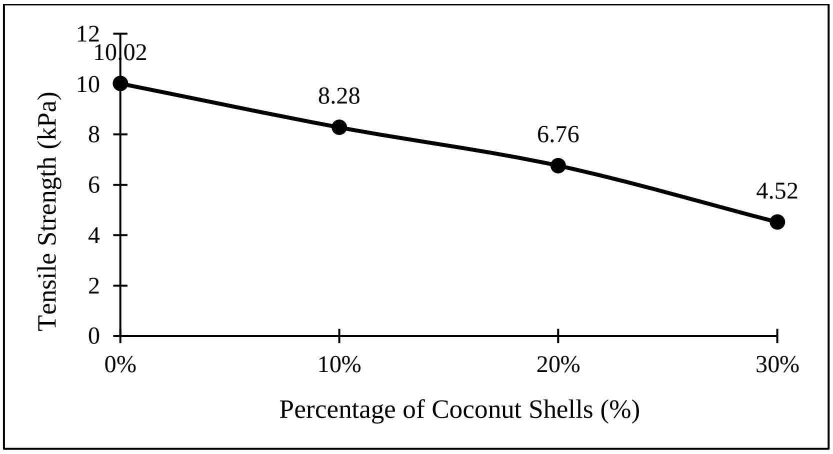

Figure 8. Split tensile strength against percentage of coconut shells

3.7 Relation between Compressive Strength and Tensile Strength

It was discovered that there is a relationship between the tensile strength value and the compressive strength value at the 28th day, and this relationship has a regression value (R^2) value of 0.9068 with equation y = 1.7825x + 22.676 for the M30 concrete mix. Both of these values can be found in Figure 9 below. It has been found that the compressive strength of coconut shell concrete increases along with its tensile strength. R^2 = 0.9068 obtained from experimental findings and a positive regression equation justifies that 90.68% of experimental results were correlated to the regression equation and a satisfactory relationship between splitting tensile strength and compressive strength was seen. If the correlation coefficient in the regression results is negative, this gives statistical proof that the variables do not have a positive association with one another.

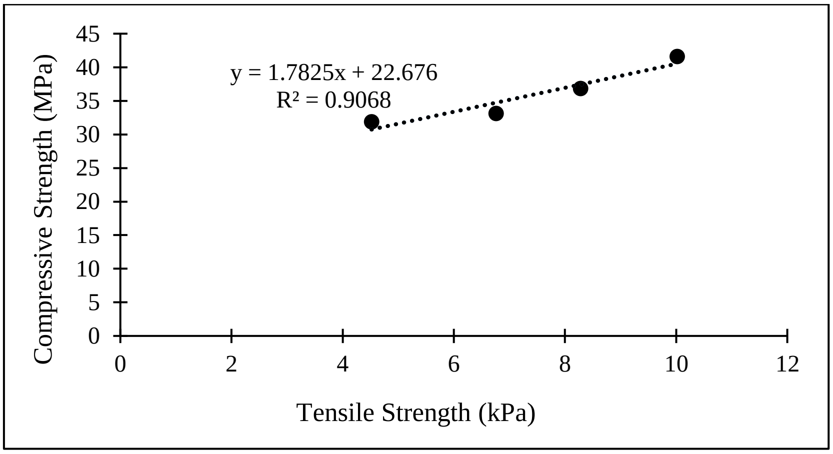

Figure 9. Correlation between compressive strength and tensile strength

3.8 Relation between Compressive Strength and Workability

It was found that there is a relationship between the value of the compressive strength and the value of the workability, and this relationship has a regression value (R^2) value of 0.3399 with the equation y = 0.4575x + 4.9781 for the M30 concrete mix. Both of these values can be found in Figure 10 below. According to Figure 4.8, it has been found that the compressive strength of coconut shell concrete increases along with its workability. R^2 = 0.3399 was obtained from experimental data and the positive regression equation demonstrates that 33.99% of the experimental results were related to the regression equation and an acceptable relationship between compressive strength and workability was seen. If the correlation coefficient in a regression analysis is negative, it indicates that there is a negative relationship between the variables.

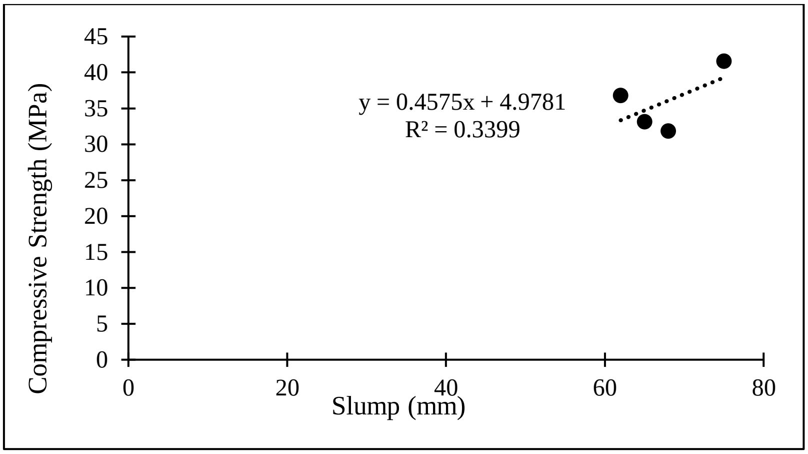

Figure 10. Correlation between compressive strength and workability

3.9 Compressive Strength

Figure 11 shows the correlation graph between the compressive strength and the porosity of the concrete containing coconut shell as coarse aggregate replacement. It was discovered that the compressive strength of coconut shell concrete declined along with its porosity. R2 = 0.9652 was obtained from the experimental results with the equation y = -5.6214x + 42.815. The negative regression equation justifies that 96.52% of the experimental results were related to the regression equation, which means there was a dissatisfactory relationship between compressive strength and porosity.

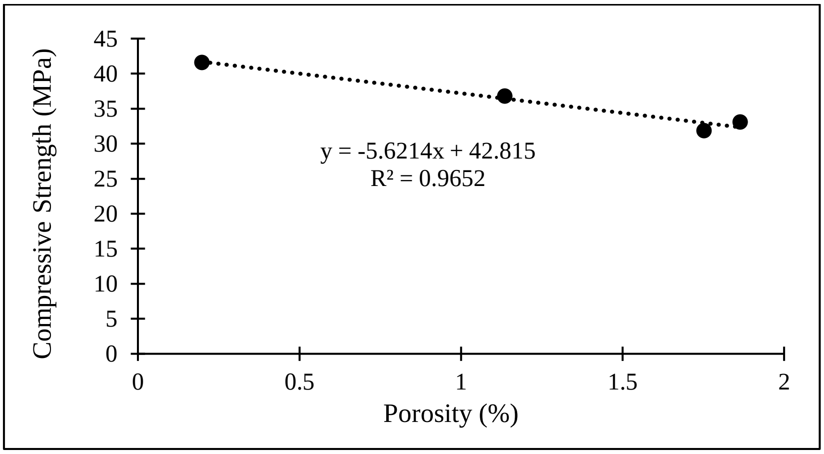

Figure 11. Correlation between compressive strength and porosity

4. Conclusion

This research study aims to determine how varying the percentage of coarse aggregate replaced with coconut shells from 0%, 10%, 20%, and 30% affects the properties of the resulting concrete. In conclusion, it can be concluded that:

- The workability of concrete will increase as the proportion of concrete containing coconut shell as a coarse aggregate replacement increases. Normal concrete has a measured slump within the range of 50 mm to 75 mm. According to the findings of the research study, it can be deduced that the concrete has a satisfactory degree of workability.
- The value of concrete density will decrease as the percentage of concrete that contains coconut shell as a coarse aggregate replacement increases. According to the research findings, the concrete has standard concrete density, and with 30% coconut shell as a coarse aggregate replacement, the density of the concrete was 1830.00 kg/m^3, which is within the range of normal lightweight concrete.
- The value of concrete porosity will increase as the proportion of concrete containing coconut shell as a coarse aggregate replacement increases. The majority of normal-weight aggregates, both fine and coarse, have absorption capacities that fall somewhere between 1 and 2% by weight of aggregate. High-porosity aggregates, such as those with abnormally high absorption capacities, may have durability issues (Alhozaimy, 2009).
- Ultrasonic Pulse Velocity (UPV) for concrete reduces as the percentage of coconut shell as coarse aggregate replacement increases According to IS CODE 13311 (Part 1), concrete samples with an UPV of more than 4.5 km/sec are considered excellent quality, while those with a velocity of between 3.5 and 4.5 km/sec are considered satisfactory quality (Sharan & Raijiwala, 2017). Therefore, it is concluded from the research study that most of the Ultrasonic Pulse Velocity (UPV) values have achieved the satisfactory quality of normal concrete.
- The value of compressive strength for concrete will decrease when the percentage of concrete that contains coconut shell as a coarse aggregate replacement is increased. The minimum compressive strength (MPa) for M30-grade concrete in 7 days is 19.25 MPa. Meanwhile, the minimum compressive strength (MPa) for M30-grade concrete in 14 and 28 days is 27 and 30 MPa, respectively. Therefore, it is concluded that the research study achieved the standard strength of the concrete.
- As the percentage of concrete containing coconut shell as a coarse aggregate replacement increases, the value of the tensile strength of concrete decreases.
- The relationship between the splitting tensile strength value and the compressive strength value at the 28th day was established. Based on the research findings, a satisfactory relationship between splitting tensile strength and compressive strength was seen.
- The relationship between the value of the compressive strength and the value of the workability was established. According to experimental results, an acceptable relationship between compressive strength and workability was seen.
- There is a relationship between the value of the compressive strength and the value of the porosity. From the experimental results, there was a dissatisfactory relationship between compressive strength and porosity.

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Declaration of Conflicting Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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