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Effect of Cockle Shell as Coarse Aggregates Replacement on Mechanical Properties of Concrete

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Abstract

Gravel is a natural raw material used in concrete mixtures. However, more of this scarce resource was used, which reduced the amount of gravel-based coarse aggregates that could be produced. As a result, efforts to preserve natural coarse aggregates for future generations were critical. So, an innovation to replace this natural coarse aggregate was required. The dumping of cockle shell waste by the cockle trade emits a stinking smell and pollutes the environment. This study investigates the density, compressive, splitting tensile and flexural strengths of concrete containing cockle shell as a coarse aggregate substitute. Four concrete mixes were prepared by integrating diverse contents of cockle shell as 0%, 10%, 20% and 30% partial replacement of coarse aggregates by weight of gravel. Concrete becomes less dense as a large amount of cockle shell is integrated. Utilization of cockle shell up to 10% enhances the compressive strength of concrete. However, increasing the amount of cockle shell by up to 30% can improve the splitting tensile and flexural strength of concrete.

Keywords: Cockle shells; Coarse aggregates replacements; Concrete quality; Sustainability; Concrete performances

1. Introduction

Industry 4.0 is the realization of the digital transformation of the field, delivering real-time decision-making that enhances productivity, flexibility and agility. It is a synonym for smart manufacturing, which rapidly expanded to cover technology, industries, and societal norms, resulting in the optimization of manufacturing processes and supply chains. One of the manufacturing industries that was affected was construction. Steel, reinforced concrete, timber, metal, brick, and glass are the six most fundamental materials used in buildings provided by this firm.

Concrete is well-known as the most cost-effective and readily available of these six materials for building. It is a combination of cement, fine aggregate, coarse aggregate and water that hardens over time (Ruslan, Muthusamy, Ariffin, Wahab, & Mohamad, 2021). The overall cost of concrete production depends largely on the availability of the constituents. Hence, due to an increment in population ("Count_Person - Malaysia - Graph Browser - Data Commons," n.d.), as shown in Figure 1, the construction industry experienced the depletion of natural sources such as coarse aggregate, resulting in an increase in meneral rents (He, Wang, & Chen, 2024). Therefore, research must be conducted to identify alternative solutions to the sustainability challenge. Currently, using waste materials such as inorganic waste, agriculture waste or municipal waste as a replacement without compromising their mechanical properties is a well-known approach. The primary goal of this research is to limit the use of coarse aggregates.

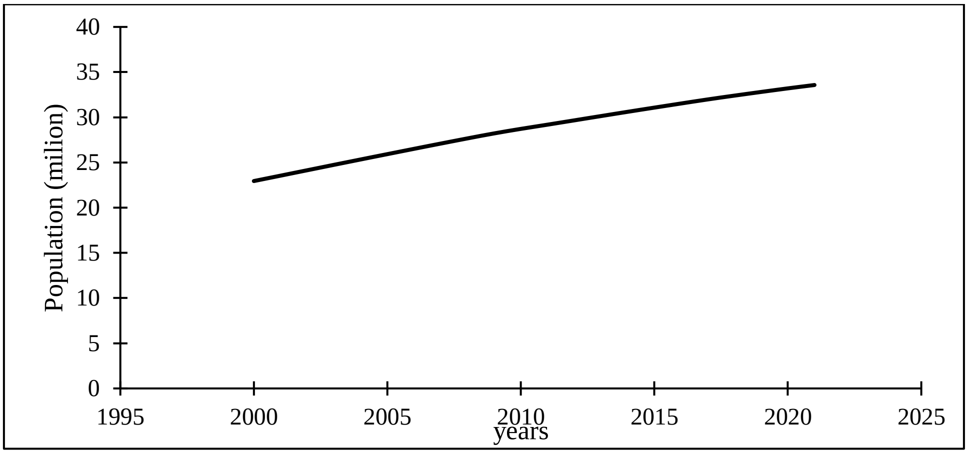

Figure 1. Population in Malaysia
(Count_Person - Malaysia - Graph Browser - Data Commons, n.d.)

One option is to use cockle shell as a coarse aggregate replacement in concrete formulations. Cockle shell is a by-product or waste from the seafood industry (Zakaria, Mohammad, Hanifah, Kamarudin, & Ahmad, 2021). In the literature review, a few background studies revealed that a high calcium oxide (CaO) level inside the cockle shell causes sluggish hydration, which can lead to reduced concrete strength at an early age but increase at later ages (Murugan, Natarajan, Karthik, & Johnpaul, 2020). Following that, the inclusion of cockle shells in the concrete mixture results in a high initial setting, high density, and good compressive strength. Furthermore, replacing 30% of the fine particles with cockle shells will boost the mechanical properties such as compressive strength, tensile strength and flexural strength of the concrete (Karolina, Rezeki, Syahrizal, & Handana, 2019). Found that cockle shell possesses up to 99% by weight of $CaCO_3$, which is useful in concrete production as filler (Bamigboye et al., 2021).

In addition, based on previous studies, other than tackling the problem of gravel extinction, utilizing the cockle shell in concrete mixtures contributes to sustainability impacts on the environment. The production of waste materials increases annually, and they cannot be gotten rid of by orthodox (conventional) procedures. A study reported a range of 10–20 million tons of shell waste being disposed of annually from seashell processing (Tayeh, Hasaniyah, Zeyad, & Yusuf, 2019). Thus, it would be safe to eliminate those waste materials by using them as alternative materials in the construction industry.

The researcher also stated that higher percentages of replacements result in higher calcium oxide (CaO) content in the concrete, which results in decreased porosity and increased specimen density (Helsel, Ferraris, & Bentz, 2016). The cement's calcium content made it possible for a stronger bond to form between the paste and aggregates, which is likely what caused the seashell cement concrete's flexural strength to start increasing at day 28. In addition, bonding has significantly changed the tension properties, particularly the tensile and flexural strengths. To the benefit of the composite activity of steel reinforcing bars and concrete, tensional characteristics have improved (Olivia, Mifshella, & Darmayanti, 2015). An experimental study on the effect of crushed cockle shell as a fine aggregate replacement on the workability and compressive strength of lightweight concrete has been conducted. Stated that the use of crushed cockle sheel up to 10% enhances the concrete’s compressive strength. Ironically, concrete with 5%, 10%, and 15% cockle shells has decreased workability because the rough surface of the cockle shell produces friction, lowering the fluidity of the concrete mix (Ruslan et al., 2021).

An experimental study on the workability and compressive strength of concrete mixtures containing 0%, 5%, 10%, 15%, 20%, 25% and 30% of cockle shell as coarse aggregate replacement has been conducted (Muthusamy, Sabri, Resources, & Razak, 2012). It was found that an intergation of 20% cockle shell is an appropriate percentage that can enhance the strength of the concrete. Hence, it is stated in the literature review that the best percentage of cockle replacement is between 5% and 30%. However, there is limited information regarding the study of mechanical properties such as flexural and splitting tensile strength of concrete containing cockle shell as coarse aggregate replacement. Hence, the purpose of this research is to determine the workability and mechanical performances (compressive, splitting tensile and flexural strength) of the concrete with 10%, 20% and 30% cockle shells as coarse aggregate replacements.

2. Methods

2.1 Materials

The ingredients for the cockle cement concrete consisted of the raw material, such as ordinary Portland cement (OPC), water, fine aggregates, which are sand and coarse aggregate replacement, cockle shells. Ordinary Portland Cement, of cement type CEM 1, 42.5 MPa, was chosen to be added to the concrete mixtures because it is the most appropriate for all general concrete construction.

Fine aggregates are natural particles that can pass through sieve no. 4. Its size should be below 4.75 mm, as that is an acceptable range and easy to obtain. Organic impurities, usually in the form of tannic acid, typically form in fine aggregates; therefore, they must be expelled as they can interfere with the hydration reaction inside the concrete mixtures. In addition, the strength can decrease because of the fine aggregates containing tannic acid. Therefore, according to ASTM C128 07a, fine aggregates should be put into the microwave at 110 ℃ ±5 ℃, then sieved using a 600 µ sieve.

Granite gravel was adopted as a coarse aggregate with a particle size between 5 and 10 mm. This experimental study aims to determine the performances of concrete containing cockle shell as coarse aggregate partial replacement for about 10%, 20% and 30%. First, the cockle shell or blood clam (Anadara granosa) was cleaned in order to make sure the cockle shell had good cohesion between the particles. Then, it was dried under sun exposure for up to 24 hours before being subjected to a grinding process at the proper sieve for coarse aggregates. In order to ensure that no fine aggregates were adhered to the particles, they were sieved using a sieve size between 5 mm and 10 mm. Figure 2 shows the example of cockle shell used for this study. Table 1 shows the physical properties of the cockle shell and coarse aggregate used in this study.

Figure 2. Cockle Shells

Table 1. Physical properties of coarse aggregate and cockle shell

Physical Properties	Specific Gravity
Coarse Aggregate	2.71
Cockle Shell	2.44

2.2 Design Mix

The design of a concrete mix is the process of determining the proportion of selected materials to produce a concrete with the desired strength based on Building Research Establish (BRE) (Teychenné, Franklin, Erntroy, Hobbs, & Marsh, 1997). Table 2 shows the mixture proportions of the concrete specimens in order to produce 30 MPa of characteristic strength with a slump of 60–180 mm. First mix refers to normal concrete (NC) as control specimens with 100% coarse aggregate. Followed by concrete containing cockle shells of 10%, 20%, and 30% named CS10, CS20 and CS30, respectively.

Table 2. Design mix of specimens

Samples	Cement (kg/m^3)	Cockle Shell (kg/m^3)	Coarse Aggregates (kg/m^3)	Fine Aggregates (kg/m^3)	Water (kg/m^3)
NC	445	0	985	710	205
CS10	445	98	887	710	205
CS20	445	197	788	710	205
CS30	445	295	690	710	205

2.3 Sample Preparation

The ready-mixed concrete was carried out using different proposed techniques, such as concrete casting, curing and different kinds of testing,such as workability, density, compressive strength, tensile strength and also flexural strength. To cast these concrete mixtures, the mould used were in the shape of a cube with a size of 100 mm x 100 mm x 100 mm, a cylinder with a size of 100 mm x 200 mm and a prism with a size of 40 mm x 40 mm x 160 mm. Each of these mould was used for different types of testing, where the cube mould was for the testing of compressive strength, as shown in Figure 3. The cylinder mould was for the tensile strength testing as shown in Figure 4 and the prism mould for the testing of flexural strength as shown in Figure 5.

Figure 3. Compressive strength testing

Figure 4. Splitting Tensile strength testing

Figure 5. Flexural strength testing

3. Results and Discussion

3.1 Density

The effect of replacing cockle shells with coarse aggregates on the density of the concrete was presented in Figure 6. It can be seen that the highest density value is present in cockle shell concrete with 0% replacement (CS0), with a density of 2293 kg/m^3. Then, concrete containing 10% cockle shell, known as cockle shell concrete with 10% replacement (CS10), experienced a reduction about 7.94% in density as compared to normal concrete, CS0. Then, the density of concrete gradually increased with an increase in cockle shell replacement for 20% (CS20) and 30% (CS30), with 2120 kg/m^3 and 2162 kg/m^3, respectively. The results obtained were due to the fact that the specific gravity of cockle shell is in the range of 2.06–2.64 (Essalem & Cherradi, 2023), whereas the specific gravity for coarse aggregate is 2.71 (Essalem & Cherradi, 2023). As a result, concrete density consisting of up to 15% crush cockle shell is in the range of 2202–2228 kg/m^3 which is less dense than normal concrete density, which is in the range of 2200 – 2500 kg/m^3 (Abbas et al., 2020; Ruslan et al., 2021).

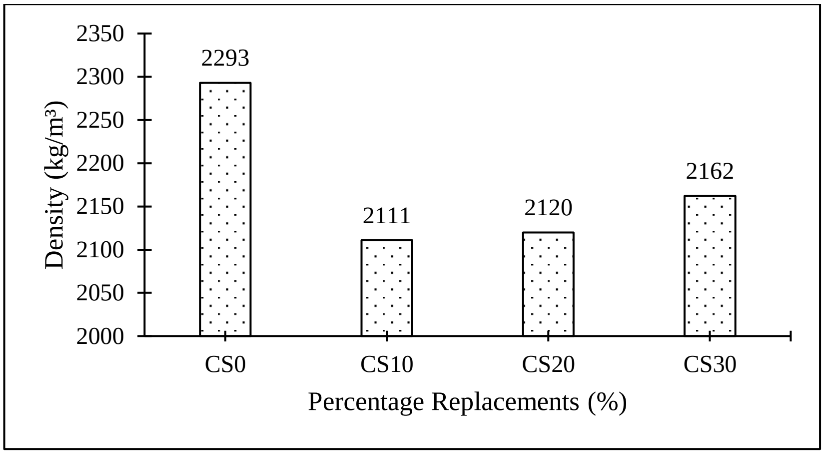

Figure 6. Density of CS0, CS10, CS20 and CS30 at 28 days of curing ages

3.2 Compressive Strength

Figure 7 presents findings on compressive strength for CS0, CS10, CS20 and CS30 at the ages of 7, 14 and 28 days. At 7 days of curing, CS10 shows the highest compressive strength value of 32.5 MPa, followed by CS0, CS20 and CS30 with 31.2 MPa, 29.4 MPa and 27.9 MPa, respectively. At 14 days of curing, the results show that CS30 experienced the highest compressive strength of 39.4 MPa and CS10 showed the lowest with 35.6 MPa. At 28 days of curing age, CS10 shows the highest compressive value of 43.1 MPa and CS30 presents the lowest value of 41.1 MPa. It can be concluded that the optimum percentage of crushed cockle shell content in concrete is 10%, whereby the strength is 43.1 MPa.

Evidently, the intergration of crushed cockle shell influences the compressive strength of the concrete. It shows a significant increment of about 21% as compared to the compressive strength of CS10 at age 14 of curing days. Stated that the aggregate with a rough textured surface will improve the mechanical component of the bond (Meesaraganda, Dhar, & Rama Prasad Reddy, 2023; Muthusamy et al., 2012; Prusty & Patro, 2015). However, an increase in the amount of cockle shell led to a higher effective area, which caused an insufficient proportion of cement paste. This condition results in poor bonding properties of the mixture with aggregates (Muthusamy et al., 2012).

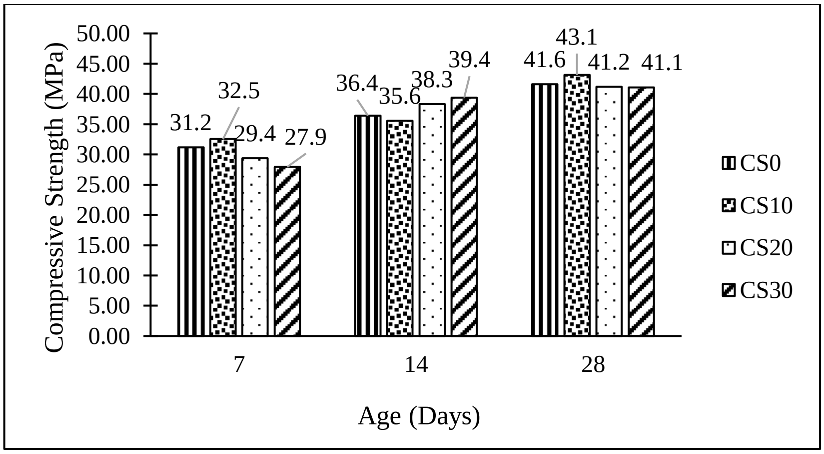

Figure 7. Compressive strength of CS0, CS10, CS20 and CS30 at 7, 14 and 28 days of curing ages

3.3 Splitting Tensile Strength

Figure 8 shows the result of splitting the tensile strength of CS0, CS10, CS20 and CS30 at 28 days of curing. CS30 shows the highest splitting tensile strength with 3.98 MPa and CS10 shows the lowest value of 2.05 MPa. The addition of 30% cockle shells as coarse aggregates significantly increased the tensile strength. Improved interfacial adhesion between the cement paste and the particles was most likely responsible for the improved tensile strength. The field seashell will raise concrete density, altering the Interfacial Transition Zone (ITZ) at the aggregate-cement paste interface. As a result, there is a significant improvement in bond strength, bond modulus, slip at maximum bond, and overall ductility (Scrivener, Crumbie, & Laugesen, 2004).

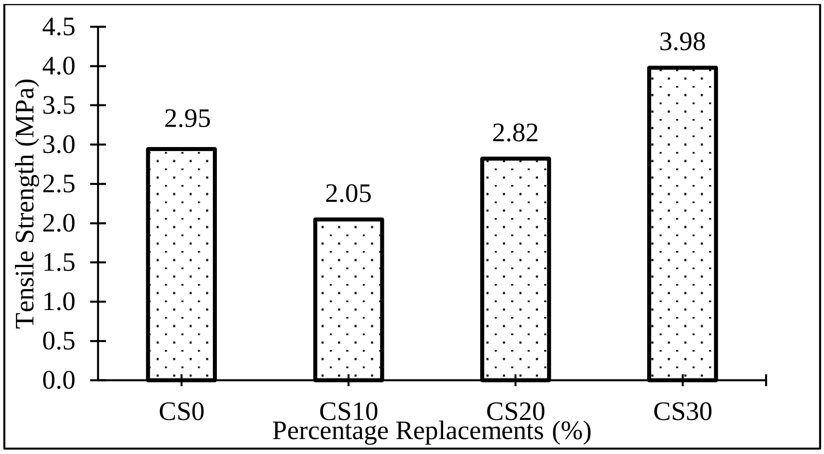

Figure 8. Splitting tensile strength of CS0, CS10, CS20 and CS30 at 28 days of curing ages

3.4 Flexural Strength

Figure 9 shows the result of flexural strength for concrete containing 0%, 10%, 20% and 30% of cockle shells as coarse aggregate partial replacement after 28 days of curing. It was observed that CS30 shows the highest flexural strength of 1.75 MPa and CS0 has the lowest strength of 0.90 MPa. Overall, the value varies in the range 0.90 to 1.75 MPa. Stated that the fleral strength of seashell concrete tends to increase at 28 and 91 days of curing ages (Olivia et al., 2015). Hence, it gets stronger as it matures (Hazurina, Bakar, Johari, & Don, 2013). This is due to the calcium content of the cement, which produces better bonding between paste and aggregates. It can be concluded that the cockle shell can improve concrete flexural strength, as the flexural strength is directly proportional to the amount of cockle shell replacement.

The cement's calcium content, which improved the bonding between paste and aggregates, probably contributed to a significant increase in strength after 28 days. In order to improve the composite action between steel reinforcing bars and concrete, the additional increase in tension characteristics was advantageous.

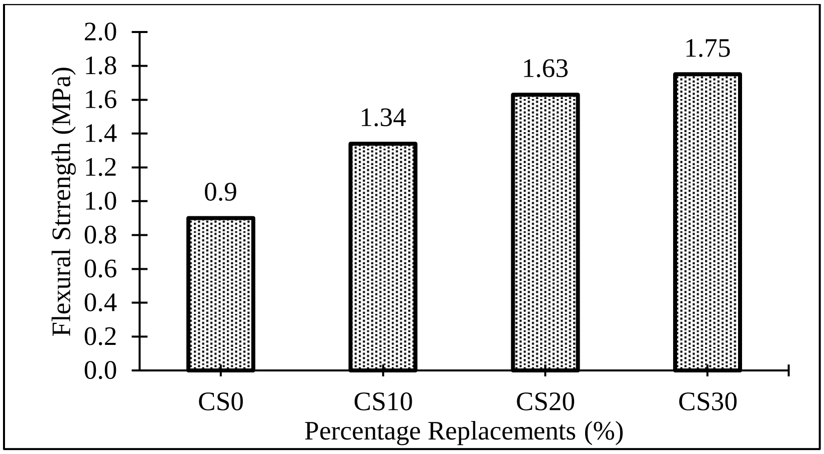

Figure 9. Flexural strength against percentage replacements if cockle shells

4. Conclusion

In summary, there are few findings that can be listed out from this experimental study:

- The inclusion of crushed cockle shell as coarse aggregate replacement in concrete reduces density.
- Smart combination of 10% cockle shell enhances compressive strength of concrete.
- In contrast with splitting tensile strength and flexural strengths, 30% replacement exhibits higher results.
- However, the use of cockle shell waste would help in reducing usage of natural sources and massive waste in landfills that can affect the environment.

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Declaration of Conflicting Interest

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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