Properties of concrete containing coconut shell powder (CSP) as a filler

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Abstract. Coconut shellsare a type of agricultural waste which can be converted into useful material. Therefore, this study was conducted to investigate the properties of concrete which uses coconut shell powder (CSP) as a filler material and to define the optimum percentage of CSP which can be used as a filler material in concrete. Comparisons have been made between normal concrete mixes and concrete containing CSP. In this study, CSP was added into concrete mixes in varying percentages (0%, 2%, 4%, 6%, 8% and 10%). The coconut shell was grounded into a fine powder before use. Experimental tests which have been conducted in this study include the slump test, compressive test and splitting tensile strength test. CSP have the potential to be used as a concrete filler and thus the findings of this study may be applied to the construction industry. The use of CSP as a filler in concrete can help make the earth a more sustainable and greener place to live in.

1. Introduction

In recent years, the world has been facing the problem of increasing solid waste disposal, some of which include agricultural waste. Agricultural waste has negatively affected the environment [1-2]. It is the main source of pollution in water and may lead to health problems among humans. Various methods can be used to reduce pollution caused by the disposal of solid waste produced from coconut shells. One of the ways is to use coconut shells as an admixture in the production of concrete.

Annually, 40–50 million tons of coconuts are grown worldwide in countries such as Indonesia, the Philippines and India which make up 75% of the world’s coconut production [3,4]. Furthermore, coconuts are also used for religious purposes and traditional celebrations. In Malaysia, for example, coconuts are important for the Indians during the Diwali festival. For the Malays, coconut milk is widely used in traditional cuisine and food production. However, coconut shells are also a type of solid waste which can contribute to the pollution of the environment. The annual production of coconut shells amounts to approximately 3.18 million tonnes [5-7].

The disposal of agricultural waste materials such as rice husks, groundnut husks, corn cobs and coconut shells have constituted an environmental challenge. Hence, there is a need to convert them into useful materials to minimise their negative effects on the environment [8]. In recent times,
researchers have begun to utilise these wastes as partial replacement for conventional concrete-making materials and came up with interesting findings [9].

Moreover, the reuse of agricultural waste in the production of concrete may reduce the cost of production and harmful diseases caused by the disposal of solid waste. In short, both the cost of construction materials and disposal of waste can be reduced if agricultural waste can be reused [5]. In previous studies, most researchers have focused on the use of other natural fillers in composites. Coconut shell as filler material is a potential candidate for the development of new composites because of their high strength and modulus properties [10]. There is a lack of research on the use of CSP in concrete material. Therefore, this study emphasises on the effectiveness of using CSP as filler material in normal concrete. This study focuses on the mechanical properties of CSP as a filler in concrete due to the gap identified in the literature.

2. Coconut shell properties
A coconut shell refers to the non-food part of a coconut which is considered as a type of hard, lignocellulosic agro-waste. Comparative studies on concrete properties using coconut shells and oil palm shells show that concrete containing coconut shells exhibits higher compressive strength compared to concrete containing oil palm shells [3]. The ultimate bond strength of this type of concrete was much higher compared to theoretical bond strength [5]. Thus, coconut shells have shown great potential to be used as admixtures in the production of concrete due to its excellent properties.

Previous studies have been conducted on the utilisation of coconut shells as a composite material in concrete mixes. Coconut shell concrete is able to provide ample warning before failure compared to conventional concrete; this shows that coconut shells play a vital role in the ductility of concrete. Concrete containing coconut shells can be useful for consumers as it provides warning signs before failure [11]. The average specific gravity and the apparent specific gravity were 1.05 – 1.20 and 1.40 – 1.50 respectively and these values were comparatively less than the specific gravity of conventional aggregates [12]. Thus, further studies need to be conducted to improve or increase the use of coconut shells as a composite material or admixture in the production of concrete.

3. Material and laboratory work

3.1. Material preparation
Firstly, the coconut shells were cleaned and manually broken into small pieces and then fed into a pulveriser. The powder obtained from the pulveriser was then fed into a rotor lift, coiled and passed through a dresser so that the required mesh size can be obtained. Efficient pulverising and screening are critical aspects of material preparation. All of these processes were conducted at a coconut shell factory. In this research, the percentages of CSP used in concrete were 0%, 2%, 4%, 6%, 8%, and 10% respectively. The percentage of CSP was calculated based on the weight of concrete. The cement used as the binding agent was Ordinary Portland Cement. The coarse aggregates used were those which could pass through a 20mm sieve but retained on a 5mm sieve whereas the fine aggregates used were those which could pass through a 150μm sieve and were retained on a 300μm sieve.

3.2. Laboratory work

3.2.1. Workability test. The workability test was performed as per ASTM C143 [13]. The apparatus for the slump test consists primarily of a hollow mould in the form of a frustum of a cone which is 305mm in height. The base of the cone which measures 203 mm in diameter is placed on a smooth surface with a smaller diameter measuring 102 mm at the top. The mould is filled with concrete in three layers of equal volume; each layer is rodded 25 times with a steel rod measuring 16mm in diameter. The mould is then lifted away vertically and the slump is measured by determining the difference between the height of the mould and the height of concrete over the original centre of the base of the specimen.
3.2.2. Compressive strength test
Cylindrical (150mm in diameter x 300mm in height) specimens of concrete were tested using digital compression according to ASTM C39 [14]. The load was applied such that the stress increases at a given constant rate until failure. The maximum load was recorded and the value was divided by the cross-sectional area of the specimen to obtain the compressive strength of concrete. The average compressive strength of three cylinders for each batch was taken.

![Figure 1. Workability test.](image1)

![Figure 2. Compressive strength test.](image2)

3.2.3. Splitting tensile strength test. The compressive splitting tensile strength test was done according to ASTM C496 [15]. The specimens used were 150mm in diameter and 300mm in height. The test specimen was placed in the centering jig with packing stripped carefully along a diametrically vertical plane at the top and bottom of the specimen. The splitting tensile strength $f_{sp}$ was calculated using the following formula:

$$f_{sp} = \frac{2W}{\pi DL}$$  \hspace{1cm} (1)

where $W = $ maximum load applied to the specimen (N), $D = $ cross-sectional diameter of the specimen (mm) and $L = $ length of the specimen (mm).
3.2.4. Modulus of Elasticity test. Cylinders measuring 150mm in diameter and 300mm in height were used to find the modulus of elasticity of concrete. The specimens were loaded up to 40% of the ultimate load as per ASTM469 [16]. The modulus of elasticity was calculated using formula Eq. 2:

$$E = \frac{(S_2 - S_1)}{(\varepsilon\gamma - 0.000050)}$$

where $E$ = chord modulus of elasticity (MPa), $S_2$ = stress corresponding to 40% of the ultimate load (MPa), $S_1$ = stress corresponding to the longitudinal strain of $50 \times 10^{-6}$ (MPa), $\varepsilon\gamma$ = longitudinal strain produced by stress $S_2$.

4. Results and discussion

4.1. Sieve analysis

A sieve analysis was conducted and the results complied with the particle size distribution with applicable specification requirements. In this study, the sieve analysis has been used for fine aggregates and coconut shell powder. Based on the results of the sieve analysis test, the cumulative percentage passing for CSP measuring 600 $\mu$m, 300 $\mu$m and 150 $\mu$m was higher than fine aggregates. It can be concluded that CSP has smaller particle size compared to fine aggregates. Figure 5 indicates the size distribution of fine aggregates and CSP.
4.2. Workability
The workability test was conducted for each mix of concrete produced namely normal concrete and concrete containing 2%, 4%, 6%, 8%, and 10% of CSP. All specimens used the same water-cement ratio which was 0.45. The concrete mixes containing 0%, 2%, 4% and 6% of CSP had a slump range between 54mm to 65mm. These mixtures had a medium degree of workability and a compacting factor of 0.92. Concrete mixes with 8% and 10% of CSP had a slump value of 46mm. This mixture had a low degree of workability and a compacting factor of 0.78. From the results, it can be seen that if there is an increase in the percentage of CSP added to the concrete mix, the degree of workability of the concrete mix will decrease. This may be because coconut shell has relatively high ability to absorb water compared to conventional aggregates [5]. Figure 6 shows the data of the workability test.

![Figure 6. Workability test data.](image)

4.3. Compressive strength test
The data for the compressive strength and density of concrete were recorded for each specimen. Figure 7 shows the data collected including the age of concrete tested according to the percentages of CSP added in concrete as well as compressive strength. The compressive strength of concrete increases when the density of concrete increases. Thus, the strength of concrete specimen decreases when the percentage of coconut shell added increases. This occurs when the percentage of coconut shell powder added is higher. This is because the density of cement is higher than coconut shell [8]. The compressive strength of normal concrete cured for a period of 7 days was 38.9MPa whereas the compressive strength for 2% CSP concrete was 29.7MPa which was 23.6% lower than the strength of normal concrete. The compressive strength for 4% CSP concrete and 6% CSP concrete was 26.5MPa and 25.6MPa or 31.9% and 34.2% lower than normal concrete respectively. Concrete containing 8% CSP recorded with lowest compressive which was 23MPa or 40.1% lower than normal concrete.
However, the compressive strength of concrete containing 10% CSP recorded a compressive strength of 24.4MPa or 37.3% lower than the compressive strength of normal concrete. Therefore, the compressive strength results for a curing period of 28 days differ. The compressive strength for normal concrete was 41.8MPa while the average strength for concrete containing 2% CSP was 33.1MPa or 20.6% lower than the strength of normal concrete (the optimum percentage of CSP as filler material in concrete). The compressive strength of 4% CSP concrete was 32Mpa or 23.45% lower than the strength of normal concrete. The results for 6% and 8% of CSP concrete were lower than 4% CSP concrete which were 28.5MPa and 26.1MPa respectively. However, when 10% of CSP was added into the concrete mix, the strength of concrete obtained was more than that obtained by 8% CSP concrete.

![Figure 7. Compressive strength for a curing period of 7 days and 28 days.](image)

4.4. Density of concrete

Figure 8 shows of the density of normal concrete and concrete containing different percentages of coconut shell powder as filler material. The results indicated that the density of normal concrete was the highest at 2438 kg/m³. From the results shown, it can be concluded that the density of concrete containing coconut shell powder decreases as the percentage of coconut shell powder used in concrete increases.

![Figure 8. Density of concrete](image)

4.5. Splitting tensile strength

Figure 9 shows the graph percentage versus splitting tensile strength. The highest value of splitting tensile strength recorded for normal concrete was 6.58MPa (15.74% of compressive strength). Concrete containing 2% of CSP concrete had the lowest splitting tensile strength which was 4.63MPa (13.98% of compressive strength). However, the value of splitting tensile strength increased when4% up to 10% of CSP was used in concrete. Thus, the highest splitting tensile strength was recorded for concrete containing 10% CSP at 6.25MPa (21.48% of compressive strength). It can be concluded that the use of CSP enhances the tensile strength of concrete. The tensile strength increases with the increase of filler content [17].
4.6. Modulus of Elasticity
Based on results tabulated in table 1, the modulus of elasticity varied between 20.47 GPa to 27.82 GPa. The highest modulus of elasticity of 27.82 GPa was achieved by concrete containing 4% of coconut shell powder while the lowest modulus of elasticity of 20.47 GPa was achieved by concrete containing 8% of coconut shell powder. The typical range of the modulus of elasticity for concrete (cured for a period of 28 days) with a compressive strength of 30 MPa is 20 GPa – 32 GPa [18-19].

Table 1. Compressive strength and modulus of elasticity of concrete containing different percentages of CSP.

| Percentage (%) | Compressive Strength, $\sigma$ (MPa) | 40% of ultimate load, $\sigma$ (MPa) | Strain, $\epsilon$ x10^4 (mm) | Modulus of Elasticity, $E_c$ (GPa) |
|----------------|-------------------------------------|-----------------------------------|-------------------------------|---------------------------------|
| 0 CSP          | 39.30                               | 15.72                             | 6.6                           | 25.77                           |
| 2 CSP          | 33.10                               | 13.24                             | 5.9                           | 24.51                           |
| 4 CSP          | 32.00                               | 12.80                             | 5.1                           | 27.82                           |
| 6 CSP          | 28.50                               | 11.40                             | 4.7                           | 27.14                           |
| 8 CSP          | 26.10                               | 10.44                             | 5.6                           | 20.47                           |
| 10 CSP         | 29.10                               | 11.64                             | 5.4                           | 23.76                           |

5. Conclusion
This early study found that the addition of CSP as filler material in concrete reduces the workability of concrete because coconut shell has a higher level of water absorption. Hence, the compressive strength of concrete decreases when an increasing percentage of CSP is added into concrete. The highest compressive strength obtained for normal concrete was 38.9 MPa and the highest compressive strength for CSP concrete was recorded at 33.1 MPa which is 2% of CSP in concrete. However, the result shown CSP concrete was good in splitting tensile strength where the strength was increasing by the percentage of CSP is increasing. The modulus of elasticity of normal concrete and CSP concrete was varied in range of 20.47 GPa to 27.82 GPa.

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