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Mechanical properties of concrete with coconut shell as partial replacement of aggregates

S U Azunna[1], F N A Abd.Aziz[1*], N Abu Bakar [1] and N A Mohd Nasir [1]
[1]Housing Research Centre, Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
Email: farah@upm.edu.my

Abstract. Coconut shell is one of the most prevalent agricultural solid wastes in several tropical countries. For coconut shell aggregate to be used efficiently for construction purposes, the mechanical properties are essential. Therefore, this study examined the effect of coconut shell as fine and coarse aggregate replacement in concrete with respect to the mechanical properties. The coconut shell concrete was designed for the characteristic strength of 30 MPa with the incorporation of coconut shell as a replacement for fine and coarse aggregate at 10%, 20% and 30% by weight respectively. The compressive, flexural, tensile strengths, as well as densities and water absorption of 96 cured concrete samples, were evaluated at 7, 14, and 28 days. The results showed that increases in replacement of coconut shell volume fractions will increase the workability and water absorption of the mixtures but will decrease the mechanical properties of the concrete.

1. Introduction

Concrete is the world's most utilized man-made material, which the productions are greatly relied to on the availability of cement, fine and coarse aggregates such as sand and granite, and the costs of which have risen tremendously over the previous year's [1]. Despite the rising cost of production, the clamour for concrete is aggravating. The unfavourable consequences of the increase in demand for concrete include depletion of naturally occurring aggregate; degradation of the environment and ecological inequality [2]. As a result of the constant rise in construction cost and the need to reduce environmental, the researcher has extensively studied concrete ingredients substitute materials, especially locally available ones that can replace traditional materials used in concrete production. The use of such materials should not only contribute to a reduction in construction cost and accelerate infrastructural advancement but also to reduce stress on the environment and make engineering construction viable to help national and global poverty reduction strategies. Such materials should be low-cost and readily accessible particularly in the developing countries [3].

According to a present land survey [4], there are about 114, 000 hectares of coconut plantation in Peninsular Malaysia and the area is more or less static. Agricultural waste was disposed of in large amount in most of the tropical countries particularly in Asia for countries like Philippine, Thailand, and Malaysia [5]. If not disposed of in properly, it will lead to environmental problems. Most abandon agriculture wastes in Malaysia are oil palm shell, coconut shell, rice husk and corn cob. Coconut shell may offer itself as a coarse or fine aggregate and this would solve the environmental dilemma of reducing the solid wastes simultaneously.

Coconut shell concrete is lighter in weight than the natural aggregate. Some researchers have concluded that coconut shell can be used for lightweight concrete at different proportion for required concrete strength. In an investigation conducted by Kakade [6], the 28-days compressive strength of concrete contained 25% volume replacement by coconut shell aggregate is 21.3 MPa, which is ideal for non-

structural and structural applications. The density of coconut ranges between 550- 650 kg/m^3, which are within the specified limits for lightweight aggregate. In addition, better workability is expected because of the shape and surface texture of the coconut shells [7].
Hence this research is carried out with an aim of using waste material to reduce the cost of construction. The behaviour of concrete with up to 30% volume replacements of fine and coarse aggregates with coconut shells will be measured from the workability, density, compressive strength, flexural strength and split tensile strength.

2. Experimental Programme

2.1 Materials
Cement used is compiled to the requirement in MS EN 197-1 [8] with respect to composition, specification and conformity criteria for common cement. Coarse aggregate, crushed granite of 20 mm maximum size was clean and then dried in an oven at 105^{0}C for a duration of 24 hours to remove its moisture content [9]. This is also to ensure that the amount of water required are consistent throughout the study. The dry coarse aggregate was well graded with the passing percentage lies within the range of medium grading limit. A similar process was repeated for fine aggregates of size within 150 μm to 4.75 mm. Both aggregates fulfilled the sieve upper and lower boundaries limits for grade 30 concrete. The normal tap water was used for a water to cement ratio of 0.45 in all mixes.
The coconut shells were collected from the local market and exposed to the sun to dry for one week, then they were crushed by a mini crusher to produce fine coconut shell aggregates (CSA). Figure 1(a) and (b) show coconut shells as fine and coarse aggregates, respectively. The length of fine CSA was made between 1.18 mm to 4.75 mm. On the other hand, for coarse aggregate, the coconut shells were hammered into small chips and sieved. The coarse CSA pass through 12.5 mm and settled on 4.75 mm sieve. The surface texture of the coconut shell is fairly smooth on concave and rough on convex faces. CSAs have a relatively high-water absorption of nearly 6.71%, which is about double of sand (3%). The collected CSAs were analysed and the physical properties are as shown in table 1 below.

Table 1. Physical properties of coconut shell

Physical properties	Test results
Specific gravity	1.33
Bulk density (kg/m^3)	800
Shell thickness	2-7mm

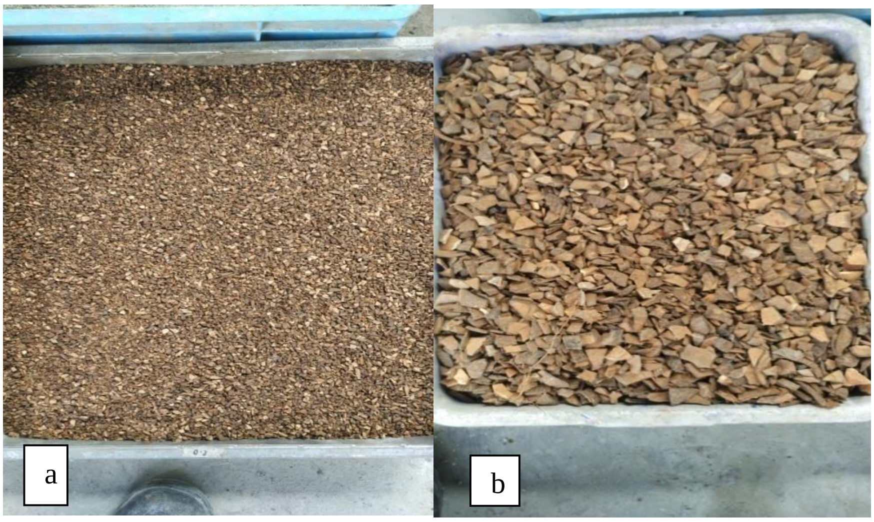

Figure 1. (a) Fine CSA and (b) Coarse CSA

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2.2 Concrete mix proportions

The mix proportion for control specimen of grade 30 concrete was made based on ACI mix method as shown in table 2. The mix proportions for control specimen, 10%, 20% and 30 % of coconut shell replacement are tabulated based on required volume as in table 3. The replacement of 10% means 10% of fine aggregates and 10% of coarse aggregates are replaced with 10% of fine and 10% of coarse CS aggregates, respectively. The specimens were de-mould after twenty-four hours and immersed in a water tank with control temperature for 7-days, 14-days, 21-days, and 28-days.

Table 2. Mix proportion for mix design

Characteristic strength (MPa)	W/C	Water (kg/m^3)	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	C : FA : CA
30	0.45	185	425	781	1031.38	1 : 1.84 : 2.43

Table 3. Mix proportions of grade 30 concrete for various CS replacements

Mix design	Concrete Volume (m^3)	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coconut shell-FA (kg)	Coarse aggregate (kg)	Coconut shell-CA (kg)
0 %	0.045	22.00	09.90	46.39	0	61.51	0
10%	0.045	22.00	09.90	41.75	04.64	55.36	06.15
20%	0.045	22.00	09.90	37.11	09.28	49.21	12.30
30%	0.045	22.00	09.90	32.47	13.92	43.06	18.45

2.3 Experimental tests

A total of 4 batches of the mixture were required. In every batch, 100 mm cubes were prepared for compression test at ages of 7, 14, 21 and 28-days, prisms of size 100 x 100 x 500 mm for flexural test and concrete cylinders of 200 x 100 mm diameter for splitting tensile test. The last two were tested at 28-days of age. Apart from the mechanical tests, sorptivity and ISAT were also included.

3. Results and discussion

3.1 Concrete slump

All concrete mixes had slump values between 0-5 mm as in table 4. The slump height increases as the percentage of coconut shell (CS) replacement increased. This is due to the increase in specific surface and lower density of CS [11].

Table 4. Result of slump test

Coconut shell volume (%)	Slump (mm)
0 (Control specimen)	0.0
10	3.0
20	4.0
30	5.0

3.2 Density

The density is based on the specific gravity of the aggregate and other properties of the concrete components. A total of 48 cubes were produced and the densities were weight at 7-days, 14-days, 21-days, and 28-days. The maximum density of concrete is 2424 kg/m^3 (control), while the minimum density is 1874 kg/m^{3}attained at 30% replacement. This is expected because coconut shells are lighter than natural aggregates. The specific gravity of CS is 1.33 while the fine and coarse aggregates are 2.5 and 2.6, respectively. The average density at 28 days is 2415 kg/m^3, 2102 kg/m^3, 2003 kg/m^{3}and 1903 kg/m^3 for control, 10% replacement, 20% replacement and 30% replacement, respectively.

3.3 Compressive strength

The average compressive strengths for all batches are summarized in table 5 and presented in figure 2. From figure 2, it can be generalised that the compressive strength of all mixes increased steadily with respect to curing age. At 28 days, the compressive strength of concrete specimen with natural fine and coarse aggregate (control specimen) is 50.56 MPa. From table 5, it shows that the strength reduction increases as the percentage of replacement increased until almost half of the control strength (25.21MPa) when 30% replacement was made. As reported by Yerramala and Ramachandrudu [12] surface texture determines bond between the particles, smooth surface on the concave side of CS aggregate and coupled with the continuous presence of water will prevent good bond between the aggregate, which contributed to the lower bond strength. Hence, to overcome this, more cement required for proper bonding and to maintain strength but it is not economical.

Table 5. Compressive strength of concrete with CS replacement (MPa)

CS fine and coarse Aggregate replacement	Compressive strength at 7th day	Compressive strength at 14th day	Compressive strength at 21th day	Compressive strength at 28th day	Percentages of final difference
0%	36.16	42.11	47.12	50.56	-
10%	23.30	29.50	34.82	38.37	-24.11
20%	18.47	25.07	28.48	30.54	-39.60
30%	12.09	17.37	23.29	25.21	-50.14

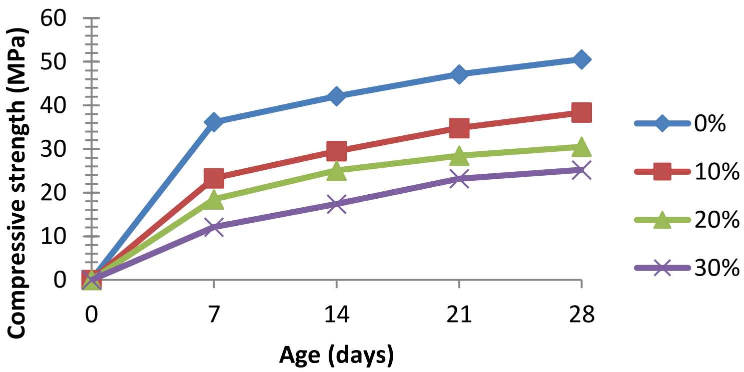

Figure 2. Development of strength with age

3.4 Flexural strength

The result for flexural strength at 28th day has been recorded in table 6. Similar to compressive strength, the flexural strength reduced linearly to the percentages of CS replacement. Obviously, a weak bond between particles was observed at 30% CS with almost 60% strength reduction measured. Low flexural strength is a result of breaking of the bond between the matrix and the surface of the aggregate [13]. Thus, the surface properties of coconut shells also play an important role in determining the flexural properties of concrete.

Table 6. Modulus of rupture and flexural strength at 28th day

Percentage of CS replacement (%)	Modulus of rupture (MPa)	Percentage of difference (%)
0 (control specimen)	4.26	-
10	3.04	-28.72
20	2.59	-39.16
30	1.88	-55.76

3.5 Split tensile strength

The result for split tensile strength test at 28 days has been recorded in figure 3. The cylinder of CS concrete and control specimen showed cracks in a form of tension failure. Tensile strengths of specimens with CS replacement reduced when the volume of replacement increases proving that the smooth surface of coconut shell is unable to produce a good bond between particles not only in compression but also in tensile.

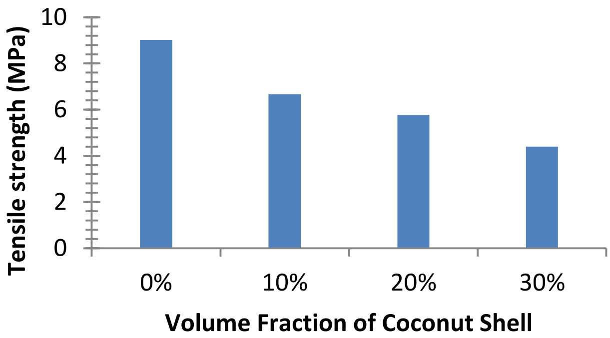

Figure 3. Split tensile strength (MPa) vs percentage of CS replacement

3.6 Sorptivity

Sorptivity give a practical warning of the pore structure of a concrete. Lower sorptivity values indicate the higher resistance of concrete towards water absorption. Sorptivity also give an indication of the durability rate of the concrete, if the rate of sorptivity is higher, the durability of concrete will be lower. The results of sorptivity for all concrete mixes are tabulated in table 7. Initial absorption is between 0.007 - 0.011 mm/*s*0.5, with the lowest was obtained from control concrete and the highest from a mix with 30% CS. For the secondary absorption, the range is between 0.001 - 0.003 mm/*s*0.5 with the highest was obtained by the control and the lowest was obtained by concrete mix with 10% to 30% CS concrete. A higher absorption rate at the earlier stage of CS specimens shown weaker resistance to water absorption than the secondary stage. According to Yerramala and Ramachandrudu[12], sorptivity of concrete is influenced by the volume of paste matrix, the pore structure of the bulk matrix and the interfacial zone around the aggregate particles. This explained why at an early stage the CS have low resistance to water absorption due to its elongated and curved shape and lack of bond between the paste and aggregate particles. At a later stage, the cement and water interaction to improve the bond between CS and other particles giving better water resistance of CS samples than control specimen.

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Table 7. Sorptivity of concrete with different CS replacement

Specimen	Average initial absorption ($mm/s^{0.5}$)	Average secondary absorption ($mm/s^{0.5}$)
0 (control specimen)	0.007	0.003
10	0.008	0.001
20	0.009	0.001
30	0.011	0.001

3.7 Initial surface absorption test (ISAT)

The purpose of ISAT is similar to the sorptivity test, the earlier was conducted with water penetrates from top of the concrete using the applied pressure of 200 mm head whereas, for sorptivity, capillary action is taking place when water is sucked up into the concrete. This test is important for concrete quality to ensure that water would not absorb into the concrete from the pores and subsequently corrode the reinforcement. The ISAT results at different percentages of CS are shown in figure 4. The absorption rate of specimens increased uniformly with the addition of CS replacement from 0% to 30% for absorption of 10 min to 60 min. For the 30% CS replacement concrete, the value decrease from 0.87 ml/m^2s to 0.45 ml/m^2s for 10 min to 60 min, however, it shows the highest value compared to other concretes mixes. The absorption at 10 min was higher than 60 min due to higher porosity of the samples but later the pores are mostly filled with water. The CS concrete shows higher water absorption capacity (6.38%) than fine and coarse aggregate (3%) because moisture retaining of coconut shell are greater than natural aggregates [14].

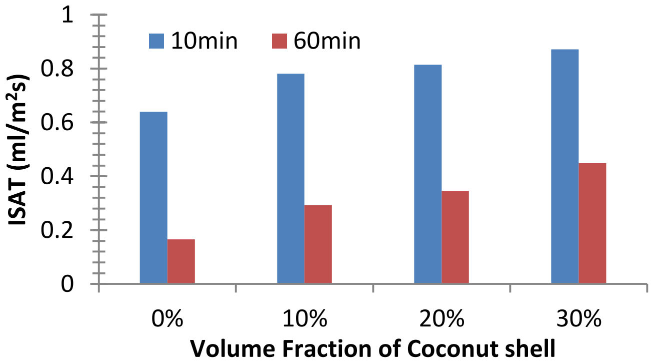

Figure 4. ISAT result at different percentages of coconut shells

4. Conclusions

The overall conclusion of each experiment is stated as below:

- Coconut shell concrete (CSC) showed better workability as the concrete slump increased uniformly to 5mm when the CS fine and coarse aggregate replacement increased to 30%. While lower density was measured on CS concrete of between 2102 kgm-3 to 1903 kgm-3than the control.
- The compressive strength of CS reduces with respect to the percentages of replacement. The reduction varies from 25-50% of the control specimen. Similar behaviour was observed on flexural and split tensile strength of the CS mixes. The optimum replacement accepted is with 10% where the reduction in all strength are less than 30%.
- In conclusion, strength, and water absorption are dependent on pore structure of the concrete and are inversely proportional to one another, that is, if porosity increases, strength decreases, and absorption increases. In another word, replacement of 10% CS mixes are the optimum and only suitable for low strength, indoor and dry applications.

5. References

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