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Performance of coconut shell as coarse aggregate in concrete

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HIGHLIGHTS

- We prepared coconut shell modified-concrete.
- Coconut shell was utilized as coarse aggregate as partial replacement of conventional coarse aggregates.
- Its utilization is a sustainable approach to consume the non-biodegradable coconut shell waste.

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ABSTRACT

A large amount of waste coconut shell is generated in India from temples and industries of coconut product and its disposal need to be addressed. Researchers have proposed to utilize it as ingredient of concrete. This experimental investigation was aimed to quantify the effects of replacing partially the conventional coarse aggregate by coconut shell to produce concrete. The research work was divided into two parts. First part was aimed to observe the effect of such replacement on compressive strength and density of concrete. In the second part, the aim was to find out the additional quantity of cement required to compensate for reduction in strength of concrete resulted due to this replacement. It was found that with increasing proportion of coconut shells, there is decrement in compressive strength. Results revealed that with 40% replacement of conventional coarse aggregate by coconut shell, 7 days compressive strength of concrete decreased by 62.6%; whereas decrease in 28 days compressive strength was only 21.5%. 40% replacement makes the concrete lighter by 7.47%. Further, it was revealed that for mix design of concrete of 20 N/mm^2 characteristic strength, no additional cement is required for 5% replacement and only 3.6% additional cement was required for 10% replacement. The results confirm that although there is an increase in cost due to additional cement requirement, the advantages being many, including efficient utilization of waste coconut shell, reduction in natural source depletion *etc*, the use of coconut shell in concrete seems to be a feasible option. Such study will help to arrive at final decision regarding quantity of coconut shell for replacing conventional aggregates in concrete production.

1. Introduction

In the present scenario, no construction activity can be imagined without concrete. It is one of the most commonly used material in construction industry and is the 2nd most consumed substance in the world after water [23]. More than 10 billion tons of concrete is produced every year. Annual production represents approximately 1.5 ton for every person on the planet. Aggregates are the largest constituent in the concrete. About 70–80% of the volume of structural concrete is occupied by aggregates, in which 25–30% is occupied by fine aggregate and 40–50% is occupied by coarse aggregate [27]. Quantity and properties of coarse aggregate has considerable impact on various characteristics and properties of concrete. Conventionally, crushed rocks are used as coarse aggregate and river sand as fine aggregate. Both are naturally available material. Due to rapid growth of construction activities, conventional aggregate sources are depleting very fast resulted in scarcity of resources. For sustainable development, these materials should be used wisely and at the same time alternative materials need to be searched to replace conventional aggregate. Besides, these crushed aggregates may contain a percentage of irrespirable crystalline silica or free silica which releases during the production and handling and could pose health problems or skin irritation [25].

Further, with increased population and modern living habits, production of waste material is increasing at fast pace and its disposal has become a genuine problem. To resolve the problem,

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solution is either (i) to minimize the waste at production level or (ii) to utilize the waste materials for some positive activity. In view of these issues, reuse of various types of waste materials for concrete production has been investigated and reported such as fly ash [26]; industrial slag [20]; waste plastic [14]; over burnt bricks [2]; coconut shell [1]; oil palm shell [24]; waste rubber tyres [4]; Waste glass [22]; recycled coarse aggregate [16]; papercrete *etc.* [19]. Ismail and Jaeel [15] reported an extensive study on use of Giant reed to replace aggregate in concrete. From such studies, it may be believed that innovation in the construction industry will mainly focus on use of industrial and agro wastes or by-products that are suitable for partial replacement of conventional ingredients of concrete. Waste coconut shell has potential of being used as coarse aggregate in concrete [17]. The present study focuses on use of waste coconut shell (CS) as partial replacement of conventional coarse aggregate (CA) for concrete production.

2. Application of coconut shell as coarse aggregate

Coconut is grown in more than 86 countries. India occupies the premier position in the world with an annual production of 13 billion nuts [21]. The coconut industry in India accounts for about one sixth of the world's total coconut oil output and is set to grow further with the global increase in demand. Table 1 shows the world's top five countries by coconut production [5].

However, it is also the contributor to the nation's pollution problem as a solid waste in the form of waste coconut shells. In view of huge demand, naturally available conventional aggregates are depleting fast and becoming scarce. Waste coconut shell may also be considered as one of the replacement alternative.

Properties of coconut shell which may make it suitable coarse aggregate for concrete are (i) its high strength and modulus properties; (ii) its high lignin content that makes the composites more weather resistant; (iii) its low cellulose content due to which it absorbs less moisture as compared to other agricultural waste; (iv) its shells are non-biodegradable; (v) they can be used readily in concrete which may fulfill almost all the qualities of the original form of concrete; (vi) sugar in the coconut shell is not in a free sugar form, and therefore does not affect the setting and strength of concrete; (vii) its surface texture is fairly smooth on concave and rough on convex faces [3]. Kulkarni et al. [18] in their experimental study observed that there is no need to treat the coconut shell before use as an aggregate except for water absorption. They found that there was adequate bonding between the coconut shell aggregate concrete and the steel bars. Ganiron [6] used coconut shells and fiber as substitute for aggregates in developing concrete hollow block. The study was carried out for various percentage of coconut shell content as partial replacement of conventional aggregate. They observed that replacement of appropriate coconut shell content produces workable concrete with satisfactory strength.

3. Experimental investigation

The present study was carried out for M20 grade concrete, the mix which has characteristic strength of 20 MPa. Mix design was done as prescribed by Indian standards [7,8]. A total of 138 concrete cubes were tested in this experimental investigation. Tests, as prescribed by Indian Standards, were performed to determine the properties of the ingredients. The study was carried out in two phases. In the first part, mix design of M20 grade of *control concrete* (i.e. concrete with no coconut shell) was carried out for maximum permissible w/c ratio of 0.55. Then, CA was replaced by CS in the proportions (i) 10%, (ii) 20%, (iii) 30% and (iv) 40% by volume respectively, keeping w/c ratio and quantity of other ingredients constant. 7 days and 28 days compressive strength and density of concrete was obtained for these concrete mixes.

In the second part, the mix design for obtaining M20 concrete was carried out for varying proportion of CA & CS. Six ratios of CA and CS considered were (100:0); (95:5); (90:10); (85:15); (80:20) and (75:25). Proportioning of ingredients was carried out at three different w/c ratios (0.55; 0.50; 0.45) and the w/c ratio, which resulted into desired target strength, was arrived at from compressive strength versus w/c ratio curves.

Table 1
Availability of coconut shell [5].

S. No.	Country	Coconut production (in 2012)	Percent of world total
1	Indonesia	18,000,000 t	30.0%
2	Philippines	15,862,386 t	26.4%
3	India	10,560,000 t	17.0%
4	Brazil	2,888,532 t	4.8%
5	Sri Lanka	2,000,000 t	3.3%

3.1. Material used

In this study, the materials used were Ordinary Portland Cement, Potable Water, Natural Sand, and Crushed Coarse Aggregates. Waste coconut shell was used as a partial replacement of conventional crushed coarse aggregate. Details of materials used are provided in following section.

3.1.1. Cement

Ordinary Portland cement of 53 grade was used in this study. Tests for cement were carried out according to standards [9] and the results are presented in Table 2.

3.1.2. Fine aggregate

Natural sand conforming to Zone I was used as fine aggregate in this work. Various tests were conducted on natural sand as per standards [10,11] to find the properties of natural sand. Sieve analysis for the fine aggregate is presented in Table 3 and the test results for its properties are presented in Table 5.

3.1.3. Crushed coarse aggregates

Crushed coarse aggregate (CA) of two types with respect to particle sizes were used for the experimental work. Two were mixed in proportion of (2:3) to satisfy the grading requirement of 20 mm size nominal aggregate. The aggregates were tested in accordance with standards [10,11] to know their properties. Its sieve analysis is presented in Table 4 and the test results for its properties are presented in Table 5.

Table 2
Test results of cement.

S. No.	Particulars	Test results	Requirements of standards [9]
1.	Standard consistency (%)	32	–
2	Setting time (minutes)		
	a. Initial	58	30 (minimum)
	b. Final	278	600 (maximum)
3.	Soundness (mm)		
	Le-chatelier expansion	1.0	10.0 (maximum)
4.	Compressive strength (MPa)		
	a. 72 ± 1h (3 days)	30.5	≥27
	b. 168 ± 1h (7 days)	41.3	≥37
	c. 672 ± 1h (28 days)	54.7	≥53
5	Fineness		
	a. By sieve of 90 μ (%)	5	10 (maximum)
	b. Blain apparatus (m^2/kg)	287.5	225 (minimum)