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Mechanical and fracture characteristics of Eco-friendly concrete produced using coconut shell, ground granulated blast furnace slag and manufactured sand

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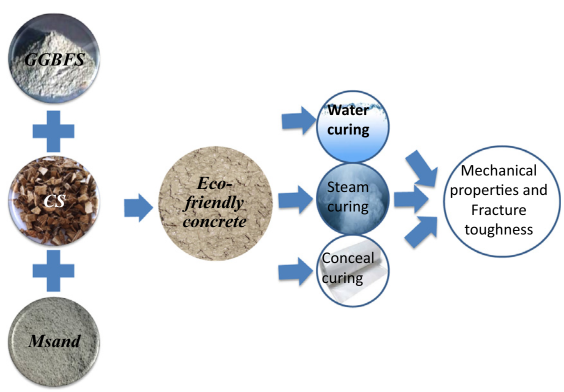
HIGHLIGHTS

- Eco-friendly concrete using coconut shell, ground granulated blast furnace slag and Msand.
- Self curable coconut shell concrete can be produced without need for external water curing.
- Compressive strength of 27.4 MPa achieved for conceal cured coconut shell concrete at 28 days.
- Modulus of rupture of coconut shell concrete ranges from 4.92 to 6.52 MPa.
- Fracture toughness of coconut shell concrete ranges from 0.89 to 1.28 MPa $\sqrt{m}$.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper deals with experimental investigation on mechanical properties and fracture toughness of Eco-friendly concrete produced, using coconut shell as coarse aggregate, blast furnace slag as a partial replacement for cement and manufactured sand as fine aggregate. Three mixes were selected and three types of curing like water curing, steam curing and conceal curing of concrete were adopted. Mechanical properties like compressive strength, flexural strength, static modulus of elasticity, Poisson's ratio and fracture toughness were investigated. The results proved that the mechanical properties and fracture toughness of coconut shell concrete are on par with other light weight concrete.

1. Introduction

In the construction industry, due to the depletion of natural resources and increasing cost of construction materials, using alternative construction materials is gaining importance [1]. Using waste materials in concrete has become a necessity to provide a sustainable environment. Light weight concrete using waste is preferred due to its low density, good acoustic and thermal insulation [2]. Coconut shell (CS) is an agricultural waste which is available in abundant in the tropical regions like Asia, America and Africa is being used successfully as low strength giving light weight aggregate [3]. Also mechanical properties of CS incorporated concrete confirm its suitability to be used as light weight aggregate. Since it is a light weight aggregate and absorbs water, CS is pre-soaked

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in water before using in concrete [2]. Coconut shell concrete (CSC) has shown good flexural and ductility behavior similar to other light weight concrete [4].

Similarly, the use of ground granulated blast furnace slag (GGBFS) as partial replacement for cement paves way for sustainable environment, as it is a waste byproduct from iron industry [5]. Also, use of GGBFS reduces heat of hydration, alkali silica reaction, permeability and porosity [6]. In addition, partially replacing cement by GGBFS produced significant improvement on other properties like compressive strength, electrical resistivity, chloride permeability and carbonation [7].

In recent years, manufactured sand (Msand) is finding its appropriate place in the concrete production as a replacement for river sand to address the scarcity for river sand. Msand is produced using rock deposits to obtain a well graded fine aggregate which has an angular and rougher surface than naturally weathered river sand. The mechanical and durability properties of concrete using Msand have shown good performance compared to conventional concrete using river sand [8]. The sharp edges in Msand provide better bond with cement than river sand and comparatively Msand is 15–25% cheaper than river sand [9].

In this experimental study, an attempt was made to evaluate the performance of CSC incorporating GGBFS and Msand. Experimental investigations were carried out to find the compressive strength, flexural strength, static modulus of elasticity, Poisson's ratio and fracture toughness. Three types of curing like water curing (*W*), steam curing (*S*) and conceal curing (*C*) were adopted and its suitability for CSC was studied.

2. Materials and experimental methods

2.1. Materials used

Coconut shells were collected from the nearby market and crushed into small pieces by mechanical means. Shells passing through 12.5 mm sieve and retained on 10 mm sieve was used. Generally wood particle retards the hydration of cement due to the presence of hemicellulose, lignin and carbohydrate compound present in it [10,11]. CS is similar to wood and it has 21% of hemicellulose and 27% of lignin [12]. Cold water extraction dissolves hemicellulose, tannins, sugar, gums and other coloring matters. Whereas, hot water extraction additionally dissolves starch and increases the compatibility between wood and cement [13]. In this experiment CS were soaked in potable water for 24 h to remove the retardants (cold water extraction) and thoroughly washed and used in concrete in saturated surface dry condition. CS has iron content of 997 mg/kg which stains the surface in which it is placed [14]. As per ASTM C641-13 [15] iron stain index of light weight aggregate should be less than 60. To reduce the iron content, CS was thoroughly washed with water. Test was conducted to show the difference in iron stain for untreated and cold water extracted CS as per ASTM C64-13 [15]. As per ASTM C64-13, the CS was kept in filter paper and steamed for 16 h. Cold water extracted CS produced less stain compared to untreated CS which can be inferred from the Fig. 1.

The specific gravity of CS was found to be 0.99. Ordinary Portland cement (OPC) of 53 grade conforming to IS12269:1987 [16] was used and its specific gravity was 3.15. GGBFS was used for partial replacement of cement, by 25% and 50% and its specific gravity was found to be 2.9. Msand was used as fine aggregate for 100% replacement of river sand which has a specific gravity value of 2.54. The sieve analysis of Msand conforms to zone II as per IS 383-1970 [17]. Carboxylic ether plasticizer with a specific gravity value of 1.15 was used with 1% by weight of binder to make the mix workable. Water to binder ratio (w/b) was kept as 0.35 for all the mixes.

2.2. Mix proportions

Mix design of CSC was done using ACI 211.2-98 [18] code meant for light weight concrete and trial mixes were arrived. The mix performed better in compressive strength had been selected and further studies were conducted on the selected mixes. The slump value of M1, M2 and M3 mixes were found to be 67 mm, 63 mm and 58 mm, respectively. The mix ratio used and the quantity of materials are shown in Table 1.

The specimens were cast and demoulded after 24 h and then cured by three different methods:

(i) Water curing (*W*) – after demoulding, the specimens were kept in potable water for 28 days and cured as per IS 516-1959 [19].
(ii) Steam curing (*S*) – after demoulding, the specimens were kept in steam for 6 h and then kept in potable water and cured up to 28 days as per IS 516-1959 [19].
(iii) Conceal curing (C) – after demoulding, the specimens were wrapped with polythene sheet to prevent the evaporation of moisture from the surface of CSC and kept concealed up to 28 days. The absorbed water in CS facilitates internal curing of CSC. The quantity of CS required to aid internal curing of concrete was calculated as per ASTM C1761-13B [20].

Fig. 1. Iron staining materials in CS.

Table 1
Mix proportioning of CSC.

Mix ID	w/b	GGBFS (%)	Cement (kg/m^3)	GGBFS (kg/m^3)	Msand (kg/m^3)	CS (kg/m^3)	Hyperplasticizer (kg/m^3)	Water (kg/m^3)
M1	0.35	0	540.54	0	938.10	262.67	5.41	189.19
M2	0.35	25	401.35	133.78	938.10	262.67	5.35	187.30
M3	0.35	50	264.91	264.91	938.10	262.67	5.30	185.44