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Stress-strain characteristics and flexural behaviour of reinforced Eco-friendly coconut shell concrete

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HIGHLIGHTS

- Conceal cured CSC achieved the grade of M20 concrete using 401 kg/m^3 of cement.
- The stress strain behaviour of CSC is parabolic and good fit with popovics model.
- The maximum strain of CSC was arrived as 0.006.
- The capacity ratio of CSC in flexure varied from 1.00 to 1.06.
- The ductility ratio of CSC varied from 2.68 to 4.90.

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ABSTRACT

In this study the stress-strain behaviour of coconut shell concrete incorporating ground granulated blast furnace slag and manufactured sand was obtained and it was in good fit with popovics model (Mo et al., 2015). Coconut shell concrete of grade M20 was achieved using 401 kg/m^3 of cement by conceal curing. The flexural behaviour of under-reinforced and over-reinforced coconut shell concrete designed by limit state method using the actual stress-strain behaviour is analogous with the experimental values. The deflection and crackwidth of coconut shell concrete is comparable with the permissible values given by IS 456:2000, ACI-318 and EC 2:1992.

1. Introduction

Today, construction industry is in search of cleaner and greener alternatives for materials used in concrete, to provide a sustainable environment for forthcoming generation. Research was being done using many waste materials as alternatives for the constituents used in concrete to cope up with the increase in cost of raw materials and depletion of natural resources [2]. Lightweight concrete is preferred to reduce handling and transportation cost [3]. Coconut shell (CS) is a lightweight aggregate which is available naturally in abundance in tropical countries. In recent years, research was going on to study the suitability of CS in concrete. Coconut shell concrete (CSC) has better compressive strength, flexural strength and fracture toughness [4]. Flexural behaviour of under-reinforced and over-reinforced CSC beam was similar to conventional concrete and also a good bond existed between CSC and reinforcement [5]. Also, the ductility of CSC is good in case of torsion due to the natural fibre present in the coconut shell [6]. The durability properties like absorption, sorptivity, chloride penetration and resistance to elevated temperature are on par with lightweight concrete [7]. CS has a porous structure and absorbs water which paves way for internal curing of concrete thereby reducing the time spent in curing of concrete. Conceal cured CSC incorporating ground granulated blast furnace slag (GGBFS) and manufactured sand (M-sand) has shown a better compressive strength than water cured CSC, as the absorbed water in CS facilitates internal curing [4]. Also, GGBFS which is a byproduct in iron industry has shown better performance in mechanical and durability properties, when incorporated in concrete [8]. Due to the constraints posed on river sand, in recent years M-sand was used in construction industry, which proved to show better performance [9]. Also, it has been concluded that using M-sand instead of river sand in

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concrete, increases the compressive strength, flexural strength and split tensile strength to a considerable amount [10,11]. Although, research is being carried out in CSC, the true stress-strain behaviour was not addressed and need to be studied to design the CSC. In this study the stress-strain behaviour of conceal cured CSC incorporating GGBFS and M-sand was obtained. Also, under-reinforced and over-reinforced CSC section was analyzed for flexure using the actual stress-strain curve.

2. Materials used and mix proportions

Coconut shells collected from the nearby source were broken using hammers. CS's of two sizes were used. Shells passing through 12.5 mm sieve and retained on 10 mm sieve; shells passing through 10 mm sieve and retained on 4.75 mm sieve were used (Fig. 1). Packing density of two sizes of CSs was found to decide the proportion of two sizes of CSs to be used and the best packing ratio was used for further study. 70% of 10 mm–4.75 mm and 30% of 12.5 mm–10 mm has a higher packing density of 692 kg/m^3. The quantity of CS required to aid internal curing was found as 181 kg/m^3 as per ASTM C 1761-13B [12], which is less than 263 kg/m^3 used and which ensures internal curing. Cement of OPC 53 grade conforming to IS 12269:1987 [13] of specific gravity 3.15 was used. GGBFS of specific gravity 2.95 was used in this study. M-sand conforming to zone II of IS 383-1970 [14] was used. The properties of CS and M-sand are shown in Table 1. To make the mix workable, hyper plasticizer of specific gravity 1.15 was used by 1% weight of the binder. Water to binder ratio (w/b) was maintained as 0.35 for all the mixes. Potable water was used for mixing concrete. The mix ratio used and the proportions of the materials used were arrived using ACI 211.2-98 [15], meant for lightweight concrete as shown in Table 2. The workability of the mixes M1, M2 and M3 were 55 mm, 46 mm and 37 mm respectively. As conceal curing of CSC shows a good compressive strength [4], the three mixes were conceal cured and further studies were done on these mixes. After casting, the specimens were immediately covered with polythene sheet to prevent moisture loss and also after demoulding the specimens were wrapped snugly with polythene sheet of 0.1 mm thick conforming to ASTM C 171 [16], such that the surface of specimen was not exposed for 28 days to facilitate internal curing.

Fig. 1. Sizes of CS used in concrete.

Table 1
Physical and mechanical properties of CS and M-sand.

	CS		M-sand	
Loose air dried bulk density	692	kg/m^3	1599	kg/m^3
Moisture content	10.33	%	–	
Specific gravity	0.99		2.54	
water absorption	29.60	%	0.64	%
Crushing	1.60	%	–	
Impact	3.94	%	–	
Fineness modulus	6.30		2.91	
Bulking	–		44	%
Sieve analysis	–		Zone II	

3. Experimental methods

3.1. Compressive strength test and static modulus of elasticity

Cubical (100 mm × 100 mm × 100 mm) and cylindrical (150 mm diameter × 300 mm height) specimens of CSC were made as per IS 516:1959 [17] to find the compressive strength. Digital compression testing machine of maximum of 2000 kN capacity was used for this study. The static modulus of elasticity and stress-strain curve of CSC was found using compressometer as per ASTM C 469-02 [18]. The temperature varied between 22 and 36 degrees centigrade and relative humidity varied from 65 to 82 during the course of curing.

3.2. Flexural strength test

Coconut shell concrete prism of size 100 mm × 100 mm × 500 mm was used to study the flexural behaviour. Two types of sections were tested for the three mixes like, M1 (U), M2 (U) and M3 (U) for under-reinforced and M1 (O), M2 (O) and M3 (O) for over-reinforced, which are shown in Fig. 2. In under-reinforced beam, 2 numbers of 8 mm diameter steel bar was provided as compression and tension reinforcement. In over-reinforced beam, 2 numbers of 8 mm diameter steel bar was provided as compression reinforcement and 2 numbers of 12 mm diameter steel bar was provided as tension reinforcement. Clear cover of 20 mm was provided. Steel bar of grade Fe 500 was used. Shear links of 6 mm diameter (Fe 250 grade) and 50 mm spacing was used throughout the length to prevent premature failure in shear. The flexure test was conducted in flexural testing machine. The mode of operation was manual. Two point loading set up was used to apply the load as shown in Fig. 7. The load was applied in steps of 1 kN until failure. Due to space constraint under the specimen a thin steel plate of considerable stiffness was fixed underneath the mid-point of the specimen using epoxy glue. The deflection at mid span was measured using dial gauge of least count 0.01 mm, which rests on the steel plate glued to the specimen. Before testing, the specimens were white washed to increase the visibility of crack formation. Grids were drawn on the specimen for each 50 mm which facilitate to measure the crack width. Vernier caliper of least count 0.02 mm was used to measure the change in grids width which gives the crack width. The sections were designed for limit state of flexure and checked for serviceability limit state of deflection and crack using the modified popovics [1] stress-strain model.

4. Discussion on results and design methodology

4.1. Compressive strength

After 28 days the specimens were unwrapped and tested for compressive strength. Cubical and cylindrical specimens were tested and their compressive strength is shown in Table 3. The ratio of cylindrical strength to cubical strength was slightly lesser than 0.8 as suggested by IS 456:2000 [19]. The compressive strength decreased as the percentage of GGBFS increased. Similarly, the compressive strength of oil palm shell incorporated concrete also decreased when GGFBS is incorporated in it, which is also an agricultural waste having similar properties like CS [20].

4.2. Stress-strain behaviour

The stress-strain behaviour of CSC is not similar to the conventional concrete given by IS 456:2000 [19]. Since, the strain is more at failure the static modulus of elasticity of CSC is lower than conventional concrete. The static modulus of elasticity varied from 6.9