PERFORMANCE OF ULTRA FINE GGBFS BASED COCONUT SHELL LESS DENSE CONCRETE SLABS UNDER LOW-VELOCITY IMPACT

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The study concentrated on the resistance of lightweight concrete slabs against impact load using a low-velocity drop hammer impact test device. Coconut procured from nearby processing units has been observed to have high impact resistance on initial testing. The lesser density was achieved by replacing 30% of natural coarse aggregate with waste coconut shells (CS 30). In order to compensate for degradation in characteristic strength, cement was partially replaced with ultrafine Ground Granulated Blast Furnace Slag – GGBFS (Alccofine) in increasing percentage of 6% (CS 30 6A); 8% (CS 30 8A); 10% (CS 30 10A); 12% (CS 30 12A). Both strength tests (compressive strength, tensile strength, flexure strength, Impact strength) and durability tests (Water absorption, Porosity, Sorptivity, Acid resistance) were carried out for the combinations. Comparing the results, the optimum mix was fixed as CS 30 8A. Square slabs of 600 mm with 60 mm thickness were cast using the predesigned mix of M40 grade (slab-CC). Slab-CS 30 8A were cast using the optimum mix for the same dimensions. Low-velocity impact tests were performed on the slabs up to failure. Parametric analysis was carried out for crack pattern, energy absorption, crack resistance, ductility indices, crack resistance ratio for the slabs. Comparison of results shows that the coconut shell-based lightweight concrete slabs performed well under impact loading.

Keywords: *Coconut shell; Ultrafine GGBFS; Light weight concrete; strength; durability; impact; parameter analysis*

1. Introduction

Usage of concrete in the construction field is wide. The strength of the concrete decides the capacity to support the designed loads and to maintain the stability and integrity of the structure. The deadweight of the members plays a major role in contributing to the total load calculations. Lightweight concrete is a pioneering idea in reducing the magnitude of the total load. Lightweight concrete possess density between 2000 kg/m^3 to 800 kg/m^3 based on the type of material replacement (EN 206:2016) [1]. Worldwide production of coconut is contributed by more than 80 countries. India also plays a major role in the coconut contribution as well as in the generation of shells as solid waste. Due to the depletion of natural aggregates, the coconut shell may be considered as an alternate for the conventional aggregates. Some of the physical characteristics of coconut shell that matches with conventional aggregate are high modulus properties, low cellulose content, non-biodegradability, and surface texture for good bonding.

Earlier studies concentrated on partial replacement of blue metal with coconut shell to achieve satisfactory strength. The crushing strength test and cost analysis were carried out for CC (Control concrete), CS (Coconut shell), PKS (Palm Kern shell) concrete by partially replacing CA (Coarse Aggregate) by 25%, 50%, 75%, and 100%. PKS concrete showed lesser value for compressive strength compared to CS concrete. About 35% reduction in cost on average was achieved for CS and PKS based concrete [2]. The workable nature of CS concrete was concentrated and found that the smooth surface enhanced the workability of concrete [3]. The impact resistance of CS-based LWC (Light Weight Concrete) was also concentrated and concluded that the performance of CSLWC was better than CC. The characteristics of CS concrete through partial replacement of cement with silica fume and Fly ash were studied [4]. It was found that 10% of silica fume and 15% of fly ash resulted in better crushing strength and elastic modulus than individual performance of the admixtures. The added steel fibers were found to improve the performance of RC beams [5,6]. A reduction in weight of about 42% was achieved using lightweight concrete. Enhancement in ductility value was noticed for increased cement content. Impact load of FRC (Fiber Reinforced Concrete) slabs exhibited superior performance with addition of steel fibers [7]. It was found that volume fraction of fiber as 1.5% restricted the punching failure, improved the stiffness of slabs, lowered the local damage, and enhanced the crack resistance. Reinforcement was found to play a limited role in slabs governed by punching failure. The durability aspects of GGBFS concrete were concentrated [8]. The study concluded that the optimum mix was obtained by replacing 20% cement with GGBFS. It was proved that under an aggressive environment the GGBFS concrete is sustainable compared to control concrete.

The blue metal was replaced by waste CS to produce lightweight concrete [9]. About 22% reduction was achieved in density. It was also concluded that every 10% replacement with CS requires 3.6% of additional cement content. Higher wearing resistance and bonding were also achieved

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in CS-based concrete. The durability characteristics of CS-based LWC were carried out [10]. A higher value was reported for water absorption, porosity, and sorptivity. Coconut shell aggregate concrete has higher durability characteristics than other mixes and performance under an aggressive environment could be improved by using mineral additives. A numerical model for impact load was proposed for prestressed concrete slabs [11]. The model was enveloped for impact loading due to a missile hit. It was suggested to use T-headed bars for components subjected to impact loading. It was also concluded that the damping ratio would not affect the punching resistance. The mechanical and structural properties of OPS (Oil Palm Shell) and POC (Palm Oil Clinker) aggregate concrete were concentrated [12]. It was found that both aggregates produced Light Weight Concrete with reduced density. Whereas abrasion performance was not satisfying compared to CC. The addition of fly ash and GGBS were carried out and reported the improved characteristics of CS concrete.

The different treatment methods for OPS before usage for replacing CA in concrete were concentrated [13]. The OPS were treated using lime, sodium silicate, polyvinyl alcohol, heat, and saturation. Both crushing strength and modulus of elasticity were found to improve for lime-treated OPS. The same was found to perform better under the non-destruction test. The incorporation of Lightweight Expanded Clay Aggregate (LECA) in the concrete enhanced the strength and durability properties apart from producing less density [14,15]. The expanded bottom ash and dredged soil granules as lightweight aggregates in concrete for achieving a density of concrete less than 1800 kg/m^3 were concentrated [16]. The comparison of the experimental values of mechanical properties for various mixes of lightweight concrete with that from predicted equations correlated well. It was suggested to utilize similar equations for any expanded lightweight aggregate concrete.

1.1 Research significance

Earlier studies concentrated on the effect of coconut shells by partially replacing coarse aggregates at various proportions in concrete. The results reported that the increase in the replacement of coconut shell has reported concrete with less weight and low strength. To enhance the strength characteristics, the addition of mineral admixtures as partial replacement of cement could be tried. Earlier research concluded that the effect of Alccofine as mineral admixture was found to improve the strength characteristics of normal concrete. Therefore present work was concentrated on both strength and durability characteristics of alccofine based coconut shell concrete to arrive at a better mix for lightweight concrete. The structural performance of the optimum mix was to be characterized by an impact test on slab specimens.

2. Experimental Study

The grade of concrete adopted for the study was M40. The design for the mix was followed as per the procedure given in Indian standard code IS 10262-2019 [16]. The physical properties of the ingredients for the concrete mix were determined following the Indian codes. Present work was carried out as i) Study for confirming the characteristic compressive strength and monitoring the change in density and compressive strength of concrete being partially replaced with 30% of CS for CA. The decrease in strength of concrete by partially replacing CA with CS was aimed to compensate by partially replacing control concrete CC with ultrafine GGBFS (Alccofine) with an increasing percentage of 6%, 8%, 10%, and 12%. The density, compressive strength, split tensile strength, flexural strength, impact strength, water absorption, sorptivity, and acid resistance were monitored to fix the optimum mix. ii) Casting of slabs using the optimum mix was adopted to study the resistance against impact through low-velocity impact load.

2.1 Materials

The materials used for the study were Cement, Alccofine 1203, natural sand, crushed stone as coarse aggregate, crushed coconut shell aggregates, and potable water. The physical properties of all the ingredients are discussed.

2.1.1 Cement

In the present work, Ordinary Portland cement of 53 grade was used. The test on the physical properties of cement was carried out as per IS12269-1987[17]. The specific gravity was 3.12. The consistency, initial and final setting time was 33%, 32 minutes, and 605 minutes respectively. The chemical properties of cement are as shown in Table 1. (As per the Supplier's manual).

2.1.2 Alccofine

Alccofine 1203 is a high glass content slag with high reactivity. It is processed by granulation, and it was procured from the local supplier. As per the supplier's manual, the main elements present in the Alccofine are CaO, Silica (SiO_2), and Al_2O_3 which constitute 33.9 %, 35.8 %, and 21.6 % respectively. The chemical properties of alccofine are as shown in Table 1 (Supplier's manual). The physical properties are given in Table 2. (Supplier's manual)

2.1.3 Fine aggregate

The river sand was used as fine aggregate. The sieve analysis was accomplished to check the gradation. The fineness modulus and specific gravity were 3.35 and 2.7 respectively, confirming zone III as per IS383-1970 [18].

Table 1
Chemical properties of Cement and Ultrafine GGBFS (Alccofine)

Chemical composition	Cement	Ultrafine GGBFS (Alccofine)
SiO_2	23	35.8
Al_2O_3	4.98	21.6
Fe_2O_3	2.0	1.3
CaO	63.2	33.9
SO_3	0.17	0.12
MgO	0.9	6.3
Na_2O	0.62	0.42
K_2O	0.14	0.54
TiO_2	2.22	2.45

Table 2
Physical properties of Ultra-fine GGBFS (Alccofine)

S.No.	Test		Values
1	Particle size distribution (μm)	d10	1.4
2		d50	4.3
3		d90	8.9
4	Bulk Density (Kg/m^3)		675
5	Specific gravity		2.87
6	Marsh cone flow (with water to ALCCOFINE 1203 ratio as 1.5)		29

Table 3
Physical properties of CA and CS

Properties	Coarse aggregate (CA)	Coconut shell (CS)
Specific gravity	2.66	1.314
Fineness modulus	7.8	6.3
Water absorption (%)	0.49	18.68
Crushing value (%)	23.86	1.93
Impact value (%)	20.13	6.94

2.1.4 Coarse aggregate

Crushed gravel procured from local suppliers was used for coarse aggregate. The sieve analysis was accomplished as per IS2386-1963 [19] and the gradation curve is shown in Fig.1. The physical properties are displayed in Table 3.

2.1.5 Crushed Coconut aggregate

The coconut shell was procured from a local oil factory. The shells were allowed to remain under sunlight for one month. Then the shells were taken in batches and crushed manually using a hammer. The broken heap of coconut aggregates was thoroughly washed to remove dust and allowed to remain dry for another month. Then the shells were sieved Fig. 2(a) and the gradation curve is given in Fig. 2(b). The other physical tests were performed and the values are given in Table 3.

2.2 Casting of specimens

2.2.1 Mix proportion

For control mix, design Mix was arrived as per IS 10262-2019 [16], for achieving the characteristic compressive strength of 40 MPa. After few trial mixes, the mix ratio arrived was 1:1.212:2.17 with a W/C ratio of 0.4 to achieve medium workability. Water content was selected for 20 mm coarse aggregate.

The proportion of materials for the mix is as shown in Table 4.

A similar design mix was maintained for lightweight concrete, where the coarse aggregate was partially replaced by coconut shells by about 30%, based on the specific gravity of the corresponding aggregates. The past studies

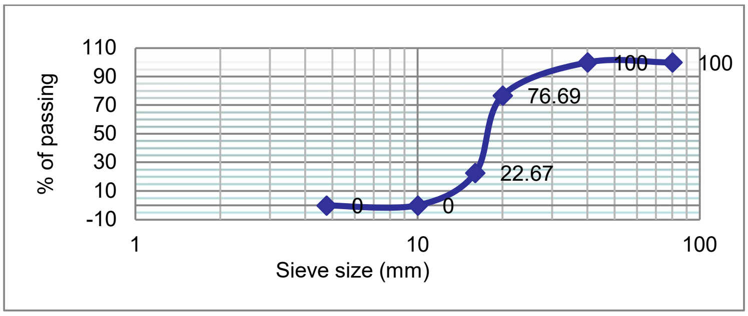
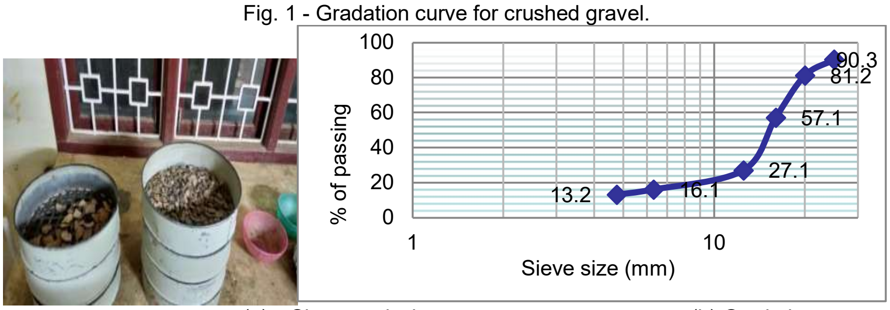


Fig. 1 - Gradation curve for crushed gravel.



(a) Sieve analysis (b) Gradation curve
Fig. 2 - Fineness modulus of CS aggregates.

Table 4

Proportion of materials (kg/m^3)

Mix ID	Cement	Fine Aggregate	Coarse Aggregate	Coconut Shell	Water Content
CC	492.9	597.55	1074.34	-	197.16
CS 30	492.9	597.55	752.03	227.2	197.16

Table 5

Mix proportions for the specimens (kg/m^3)

Mix ID	Cement	Alccofine 1203	Fine Aggregate	Coarse Aggregate	Coconut Shell	Water Content
CS 30 6A	463.33	29.57	597.55	752.03	227.2	197.16
CS 30 8A	453.47	39.43	597.55	752.03	227.2	197.16
CS 30 10A	443.61	49.29	597.55	752.03	227.2	197.16
CS 30 12A	433.75	59.15	597.55	752.03	227.2	197.16

Table 6

Details of cast specimens

Mix ID	Specimen Details	
	Strength test	Durability test
CS 30 6A CS 30 8A CS 30 10A CS30 12A	a) Compression 7days – 3 cubes 28 days-3 cubes (100 mm x 100 mm x 100 mm) b) Split tension Cylinder – (200 mm x 100 mm) c) Flexure Prism - (100 mm × 100 mm x 500 mm) d) Impact Disc – (150 mm diameter x 64 mm thick)	a) Water absorption Cubes – (150 mm x 150 mm x 150 mm) b) Porosity Cylinder – (100 mm diameter x 50 mm height) c) Sorptivity Cylinder – (100 mm diameter x 50 mm height) d) Acid resistance Cubes – (150 mm x 150 mm x 150 mm)

Table 7

Dry and wet densities of cube specimens

Mix ID	Dry density (kg/ m^3)	Decrease in dry density (%)	Wet density (kg/ m^3)	Decrease in wet density (%)
CC	2560	-	2591	-
CS 30	2168	15.3	2279	12.04
CS 30 6A	2180	14.84	2256	12.9
CS 30 8A	2120	17.18	2194	15.32
CS 30 10A	2110	17.57	2200	15.09
CS 30 12A	2210	13.67	2279	12.04

concluded that with rise in CS content will lead to rise in cement content and optimum replacement of CS was noted as 40%. Since the concrete grade adopted for the present work was 40 MPa, the replacement percentage was limited to 30% of coarse aggregate (CS 30).

2.2.2 Specimen details

A total of 12 cubes (3 cubes - 100 mm x 100 mm x 100 mm) were cast in a seasoned wooden mould, to test the 7days and 28 days compressive strength of the mix proposed for CC and CS 30 respectively. The cast cubes were removed from mould after a day duration, weighed, and moist cured. After the curing period, the cubes were surface dried weighed, and subjected to compression in CTM of 3000 kN capacity until failure. The ultimate load was noted for each cube and the characteristic compressive strength was arrived.

Cement content in CS 30 was replaced with Alccofine starting from 6%, 8%, 10%, and 12% to compensate for intense loading conditions of less dense concrete. The mix proportion for all the combinations and the specimen details are as given in Table 5 and Table 6 respectively. The slump test was conducted as shown in Fig.3(a) and samples were cast as shown in Fig.3(b). Both dry and wet densities were calculated for each mix.

(a) Workability test (b) Cast Specimens

Fig.3 - Specimens cast for strength and durability test.

3. Results and Discussion

3.1 Fresh properties of Concrete

3.1.1 Workability of Concrete mix

The slump value was checked for each mix for finding the workability of concrete. The CC mix showed a slump value of 75 mm. By partially replacing coarse aggregate with coconut shell the slump value got lowered 10%. The reduction might be as a result of absorption of a certain amount of water by the coconut shells. The partial replacement of cement with ultrafine GGBFS (alccofine) has improved the workability as an average value of 6%. The improvement was due to the smooth texture and larger surface area of the mineral binder, available for workable concrete.

3.1.2 Density of Concrete

The weight of the concrete cubes was measured after demoulding and dry density was calculated based on the volume of the cubes. After curing the cubes were replaced, surface dried, and weighted. The wet density was arrived based on the volume of the cubes. The dry and wet weights of the cube specimens are noted in Table 7.

Both the dry density and wet density of conventional concrete satisfied the standard value of 2500 kg/m^3. Whereas for CS 30 mix the reduction in density was 15.3% and 12.04% in dry and wet condition, compared to CC mix. The decrease was due to the lightweight coconut shell aggregates. The reduction in density of the specimens was gradual up to 8% replacement of cement with alccofine. The percentage reduction in dry and wet density of CS 30 8A was 17.18% and 15.32%, compared to CC. The additional replacement percentage of cement with alccofine reported in less reduction in density.

Table 8

Compressive strengths after 7 and 28 days curing (N/mm^2)

Mix ID	Crushing strength (7 days)	Loss in strength (%)	Crushing strength (28 days)	Loss in strength (%)
CC	26.8	-	43.5	-
CS 30	18.15	32.2	30.72	29.3
CS 30 6A	21.07	21.3	34.27	21.2
CS 30 8A	23.92	10.7	40.04	7.9
CS 30 10A	20.74	22.6	36.12	16.9
CS 30 12A	19.32	27.9	35.18	19.1

3.2 Strength properties of Concrete

3.2.1 Compression test on cubes (IS 516:1959) [20]

The cured specimens were surface dried and subjected to compressive load up to failure in the CTM of 3000 kN capacity. The failure load divided by the resisting area was used to calculate the characteristic crushing strength. The average strength of the three specimens was calculated for both 7 days and 28 days curing periods for all the proportions. The crushing strength for all the mix proportions has been presented below in Table 8.

After 28 days of curing, the percentage decrease in crushing strength of CS 30 was 29.3%, compared to CC specimens. The partial replacement of cement with ultrafine GGBFS (CS 30 6A) showed a corresponding reduction of 21.2%. The mineral admixture has enhanced the strength properties by 11.56%, compared to the mix having cement-based coconut shell concrete (CS 30). The mineral admixture has added value to the coconut shell concrete by enhancing strength properties. The mix (CS 30 8A) in which cement has been replaced by 8% alccofine was found to be effective, with only 7.9% decrease in compressive strength with respect to CC.

Table 9

Split Tensile strength after 7 and 28 days curing (N/mm^2)

Mix ID	Split Tensile strength	
	(7 days)	(28 days)
CC	2.0	3.5
CS 30	0.96	1.82
CS 30 6A	1.56	2.7
CS 30 8A	2.04	3.35
CS 30 10A	1.32	2.29
CS 30 12A	1.25	2.19

3.2.2 Split Tensile test on cylinders (IS 516: 1959)[20]

Splitting tensile strength of cylinder specimens was noted. Cylinders of dimensions D=200 mm and L= 100 mm were arranged in such a way that the load was applied on the longer length direction until the specimens fails along the length. The split tensile strength of concrete σ_t (MPa) was calculated as per equation (1).

$$\sigma_t = \frac{2P}{\pi DL} \quad (1)$$

(P= Failure load of the specimen (kN))

The split tensile strength for all the mix proportions has been shown below in Table 9.

The splitting tensile strength of the CS 30 specimens after 1 week and 4 weeks of curing was observed to show a decrease in value of about 52% and 48% respectively, compared to control specimens. Partially replacing cement with ultrafine GGBFS has compensated for decrease in splitting tensile strength. The strength obtained by CS 30 8A specimens after 1 week and 4 weeks of curing was

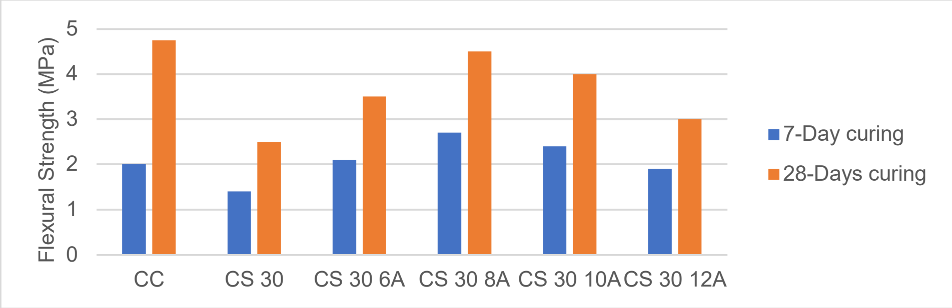


Fig. 4 - Comparison of flexural strength of specimens.

2.04 N/mm^2 and 3.35 N/mm^2 , similar to that of CC specimens. Whereas replacement of cement with 10% and 12% of alccofine has increased the brittleness of the mix leading to the reduction in the strength.

3.2.3 Flexure test on prisms (IS 516:1959) [20]

Flexural strength is a measure of the bending tensile strength of the concrete mix. Flexural strength identifies the amount of bending stress that unreinforced concrete specimens can withstand such that it could resist any bending failure. It is also referred to as the modulus of rupture of specimens. Prisms of dimensions 100 mm x 100 mm x 500 mm were subjected to bending.

Theoretically, the bending stress is calculated as per equation (2).

$$\mathrm{fb} = 3\mathrm{pa}/\mathrm{bd}^2 \qquad (2)$$

p = ultimate load (kg); b = breadth of specimen (cm);
d = depth at failure point (cm);
a = distance between the crack point and closer support (cm)

Equ.2 was used for the calculation of fb, since the value of 'a' was less than 166.6 mm but more than 130 mm.

The values are compared in Fig.4. The specimens without mineral admixture (CS 30), tested for flexure after 1 week and 4 weeks of curing showed a percentage reduction of 30% and 47.36% respectively, compared to CC. The flexural strength of CS 30 has been enhanced by 50% and 40% by partial replacement of cement with 6% of alccofine (CS 30 6A). Whereas the flexural strength for specimens (CS 30 8A) for both 7 days and 28 days were observed to have values same as that of the control specimens (CC). The other specimens having increased proportions of alccofine (CS 30 10A and CS 30 12A) could not reach the strength achieved by that of the control mix. The increased amount of alccofine have increased the brittleness of the mix, leading to early failure of the specimens.

3.2.4 Impact strength on Cylinders (ACI committee 544.2 R-89) [21]

The behavior of the specimens under impact loading was assessed based on the provisions given by ACI committee 544.2 R-89 [19]. Discs of size 150 mm diameter x 64 mm thick were cast for each mix. The impact load was applied using the fabricated drop weight impact testing setup. The drop weight machine consists of a ball made of steel weighing 4.5 kg hanged through a steel wire. The dropping and lifting of steel wire were achieved using a pulley. The discs were placed on a centered steel holder and the impact test was accomplished by dropping the steel ball to hit another ball made of steel having 63.5 mm diameter which was centered to the disc Fig.5. The drop height was maintained as 457 mm. The visual observation was made to get the count of blows necessary to cause the first crack (Nf) and ultimate failure (Nu). The energy absorbed by the specimens corresponding to Nf and Nu was calculated as per equation (3) and equation (4) respectively.

Fig. 5 - Impact test on disc.

$$\mathrm{Ef} = (\mathrm{mgh})\mathrm{Nf} \qquad (3)$$

$$\mathrm{Eu} = (\mathrm{mgh})\mathrm{Nu} \qquad (4)$$

(Ef = Energy absorbed until first crack occurs (Joules); Eu = Energy absorbed at ultimate load (Joules); Nf = number of blows to initiate first crack; Nu = number of blows for ultimate load; m= mass of the ball (kg); g = acceleration due to gravity (m/s^2); h = drop height (m))

In the test, the ability of coconut shells to resist impact load has been observed. The total count of drops taken to cause the first crack and final cracks at the failure of the specimens is compared in Fig.6.

The impact energy absorbed by the specimens was calculated and compared in Table 10.

The energy absorbed by CS 30 specimens, both at the initiation of first crack and ultimate failure was found to have a closer value, compared to CC

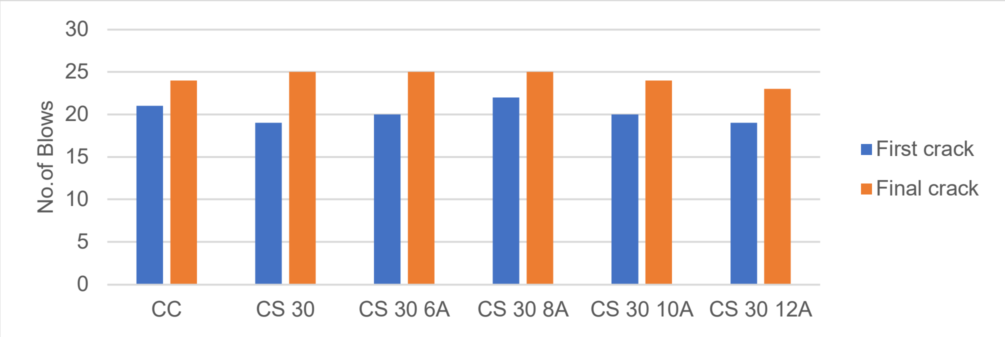


Fig. 6 - Comparison of no. of blows taken by specimens.

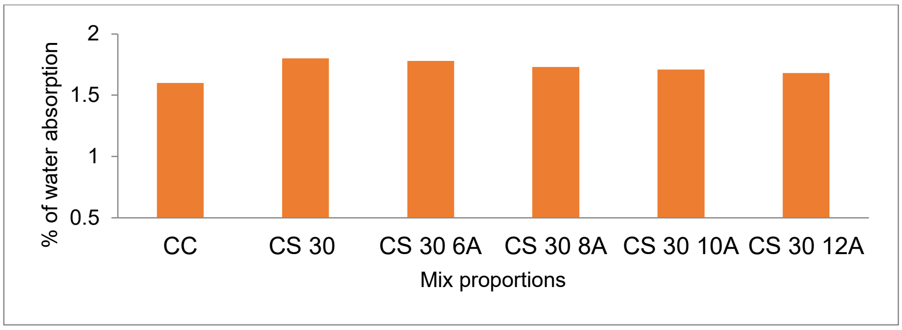


Fig. 7- Comparison of percentage of water absorption.

Table 10

Comparison of Impact Energy absorption in disc specimens

Mix ID	Impact energy - Initial crack (Joules)	Impact energy -Fracture (Joules)
CC	4156.00	4749.80
CS 30	3760.28	4947.74
CS 30 6A	3958.19	4947.74
CS 30 8A	4354.01	4947.74
CS 30 10A	3958.19	4749.80
CS 30 12A	3760.28	4551.92

specimens. Since the coconut shells offered high impact resistance, the energy absorption was not affected even without any mineral admixture. The replacement of cement with 6% of alccofine (CS 30 6A) has not shown a major difference in energy absorption. Whereas the specimens cast by replacing cement with 8% of mineral admixture (CS 30 8A) have shown more resistance to the number of blows up to first crack formation. The improved cohesiveness of the mix has enhanced the impact resistance. The percentage increase in energy absorption for CS 30 8A, compared to CC specimen was observed to be 4.76% and 4.17% up to initiation of first crack and failure respectively. Further increase in replacement of cement with alccofine (CS 30 10A, CS 30 12A) increased the brittleness of the mix and therefore decreased the effectiveness of the specimens.

3.3 Durability test

3.3.1 Water absorption in specimens (ASTM C642) [22]

The cubes of size 150 mm x 150 mm x 150 mm were water cured for 28 days and subjected to the Saturated Water Absorption (SWA) test. The specimens under saturated state were wiped at the surface and weighed. Then the cured specimens were oven-dried at a temperature of 105°C for 24 hours. The duration was maintained constant for the specimens. The oven-dried samples were weighed. The percentage of water absorption in specimens is calculated as given in equation (5).

Percentage of water absorption =

$$= \frac{Ws-Wd}{Wd} \text{ x } 100 \qquad (5)$$

(W_s = Mass of specimen in the saturated state (g); W_d = Mass of the oven-dried specimen (g))

The percentage of absorption of water has been shown in Fig. 7. Compared to the 1.6% of water absorption in the control mix (CC), coconut shell concrete specimens CS 30 had a higher percentage of water absorption as 1.8%.

Replacing cement with alccofine mineral admixture in increased percentage has ensured a gradual reduction in the rate of water absorption. The specimens CS 30 6A, CS 30 8A, CS 30 10A, CS 30 12A showed percentage of water absorption as 1.78%, 1.73%, 1.71% and 1.68% respectively. The ultrafine particles of alccofine admixture have ensured for good interlocking of pores in the concrete mix during the hydration process. This would have enhanced the water tightness of the samples, leading to less water absorption.

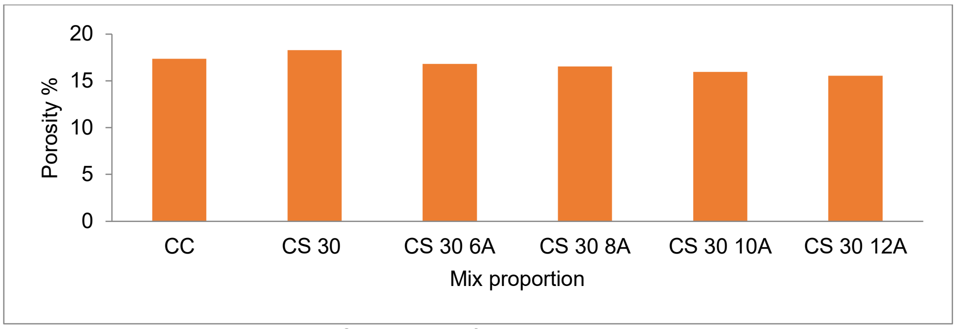


Fig. 8 - Comparison of porosity in specimens.

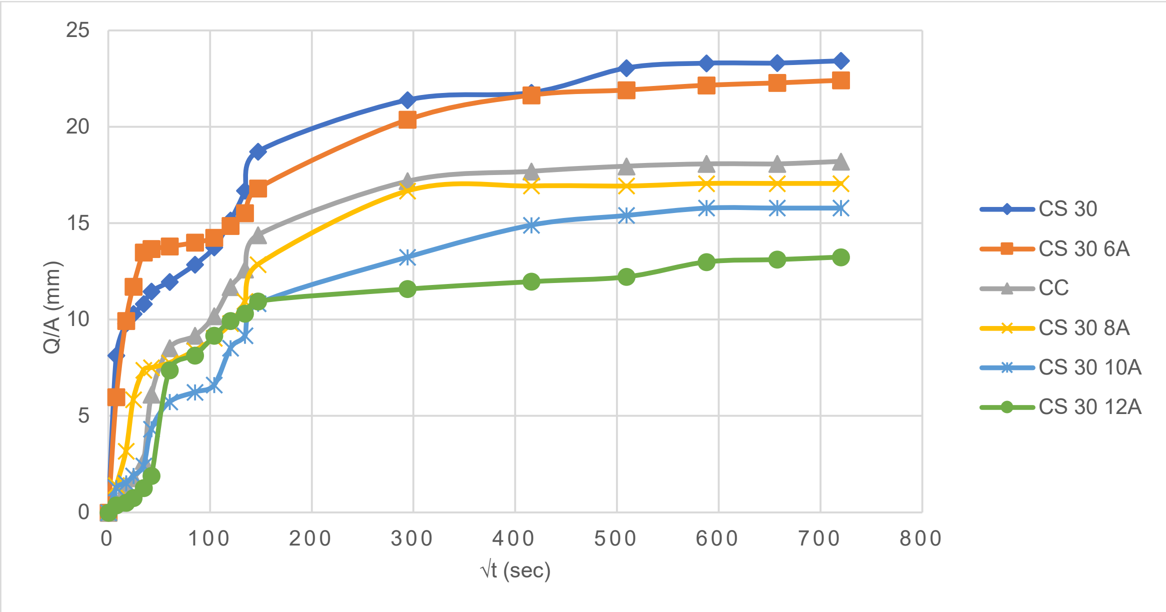


Fig. 9 - Comparison of Sorptivity values for specimens.

3.3.2 Porosity of specimens (ASTM C642) [22]

Cylinder specimens of dimensions (100 mm diameter x 50 mm thick) were cast and cured in water for 28 days. Cured samples were checked for the percentage volume of permeable voids. The porosity of specimens is arrived as per equation (6).

$$P = \frac{(W3-W1)}{(W3-W4)}\, x\, 100 \qquad (6)$$

(W1- the mass of oven-dried sample in air (g); W3 - the mass of surface-dry sample in air after immersion and boiling (g); W4 - the apparent mass of sample in water after immersion and boiling (g)).

The percentage volume of permeable voids in the specimens is compared in Fig.8. The specimens cast using CS 30 mix shows increased porosity of 18.28%, compared to 17.35% porosity in control specimens CC.

Partially replacing cement with alccofine mineral admixture in increasing percentage have brought down the porosity value to 16.78%, 16.51%,15.94%, and 15.52% for CS 30 6A, CS 30 8A, CS 30 10A, and CS 30 12A respectively. The microstructure of alccofine admixture would have filled the existing voids and resulted in fewer permeable pores, thus increasing the cohesiveness of the mixes.

3.3.3 Sorptivity coefficient for specimens (ASTM C1585-13) [23]

The cylinder specimens (100 mm diameter x 50 mm thick) were cast and cured for 4 weeks. Cured samples were kept in a water tub. The level of water was kept as 5 mm from the base of the specimens and the flow from the peripheral surface was arrested by sealing with non-absorbent material. The surface of the cured specimens was made dry and the quantity of water absorbed was measured by weighting the samples. The measurement was carried out in intervals of 15 minutes up to 120 minutes. The sorptivity coefficient for the specimens was calculated as mentioned in equation (7).

$$k = \frac{(\frac{Q}{A})}{\sqrt{t}} \qquad (7)$$

where, Q= absorbed quantity of water (mm^3); A= area of specimen (mm^2); t = time (seconds); K = sorptivity co-efficient.

The sorptivity values for all the mix proportions are plotted in Fig.9. It has been found that the intensity of capillary action was inversely proportional to time. It was found in all mixes, with an increase in time, the amount of water absorbed by capillary action got reduced.

Compared to control specimens (CC), the sorptivity was high in CS 30 specimens. The coconut shell as aggregates in the mix has increased the permeability of the specimens. The replacement of cement with 6% of alccofine (CS 30 6A) was noticed to be less effective in bringing down the permeability of CS 30 mix. The increased level of alccofine into coconut shell concrete (CS 30 8A, CS 30 10A, and CS 30 12A) has effectively reduced the capillary action of water, compared to CC. The specimens CS 30 12A with 30% coconut shell replacement and 12% alccofine replacement in place of coarse aggregate and cement respectively have been observed to have the least capillary water absorption compared to all other mixes. The precipitation formed between calcium hydroxide and alccofine during the hydration process would have filled the permeable pores and resulted in the lower sorptivity coefficient.

3.3.4 Acid resistance test (ASTM C-267) [24]

For the acid resistance test, sulphuric acid (H_2SO_4) was dissolved in potable water as 5% by volume of water. The samples were cured for 4 weeks in potable water and after curing they were soaked in the acidic solution for 56 days Fig.10(a) as per (ASTM C-267) [22]. After the period of acid soaking, the attacked specimens were removed and displayed as given in Fig.10(b). The cubes were weighed and tested in CTM to failure.

(a) Specimens immersed in acid solution (b) Affected specimens

Fig. 10 - Test specimens under acid attack for 56 days.

Post acid curing, the weight of the samples and the compressive strength were estimated. The calculated values are compared in Table 11.

The control mix CC shows a reduction of 5.17% and 16.7% for weight and compressive strength, due to acid attack. The corresponding reduction in CS 30 was 10.48% and 32.45% respectively. The reduction was twofold due to the replacement of 30 % of coarse aggregate with coconut shell aggregates. With the replacement of 6 % cement with mineral admixture in CS 30 6A specimens has brought down the reduction in the loss in weight and compressive strength to 8.91% and 29.53% respectively. For a higher level of replacement of cement with alccofine (CS 30 8A, CS 30,10A, CS 30 12A) the reduction in weight and compressive strength were still brought down. The lower reduction may be due to the ultrafine particles of the mineral admixture that would have filled the pores of the concrete, thus ensuring less ingress of acid in concrete.

Table 11

Comparison of density and compressive strength after acid attack testing

Mix ID	Density (kg/m^3)	Compressive strength (MPa)
CC	2457	36.23
CS 30	2040	20.75
CS 30 6A	2055	24.15
CS 30 8A	2007	28.46
CS 30 10A	2020	25.91
CS 30 12A	2089	25.77

3.4 Selection of optimum mix and casting of slabs

Based on the performance of the specimens in both strength and durability conditions, the mix with 30% replacement of coarse aggregate with coconut shell along with 8% replacement of cement with alccofine (CS 30 8A) was fixed as optimum.

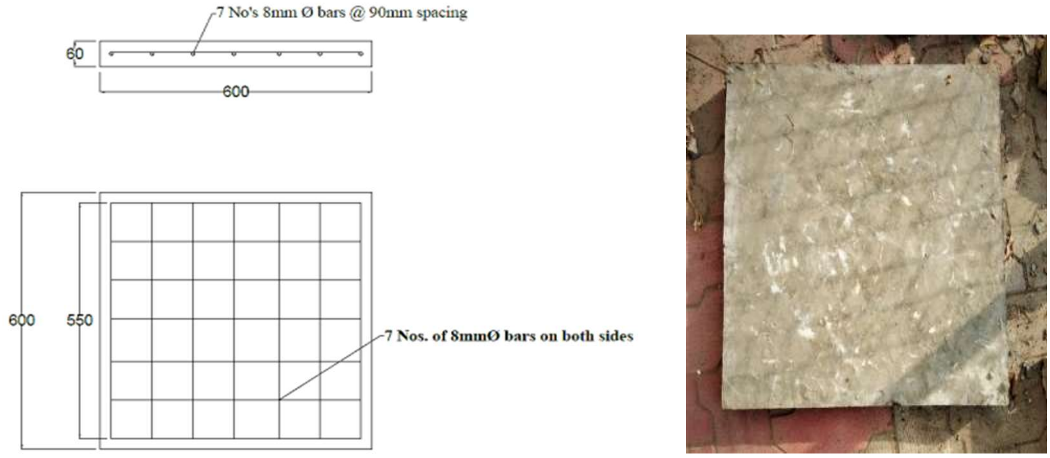
A similar mix was used to cast slab specimens for an impact study. Slab specimens (600 mm × 600 mm × 60 mm) were reinforced as shown in Fig.11(a). Specimens were cast for both control mix and optimized mix as shown in Fig.11(b). The cast slabs were removed from mould after day duration and moist cured for 4 weeks.

3.5 Impact test on slabs (ACI committee 544.2 R-89)[21]

The cured specimens were surface dried and subjected to low-velocity impact. The test was achieved in the same fabricated drop weight impact setup, used for testing the disc specimens. The slabs were simply supported on fabricated channel support and centered to drop ball. The drop weight machine consists of a ball made of steel weighing 4.5 kg hanged through a steel wire. The dropping and lifting of steel wire were achieved using a pulley. The height of the fall was maintained as 457 mm. The visual observation was made to get the count of blows required to initiate the first crack (Nsf) and ultimate failure (Nsu) in the slabs. Various properties like the crack pattern, energy absorption, ductility index, ultimate crack resistance, crack resistance ratio was observed and analyzed.

3.5.1 Crack pattern of slabs

Both the Slab-CC (Fig.12(a)) and Slab-CS 30 8A (Fig.12(b)) have undergone punching failure with the formation of a hole in the middle. The cracks which emerged from the middle do not get extended up to the edges. The width of the cracks widened with the increased number of blows.



(a) Reinforcement detailing for slabs (b) Cast slabs

Fig. 11 - Impact test on slabs.

(a) Slab-CC (b) Slab-CS 30 8A

Fig.12 - The crack pattern in slabs.

Table 12

Impact behavior of slabs using control and optimum mix proportions

	Slab-CC	Slab-CS 30 8A
No. of blows for first crack Nsf	50	150
No. of blows for ultimate load Nsu	182	220
Ultimate crack measurements (mm) (Length x Width x Depth)	481 x 0.1 x 60 = 2886	376 x 0.1 x 60 = 2256
Ductility index	3.64	1.46
Energy absorption (Joules)	3671.71	4438.33
Ultimate crack resistance (N/mm^2)	1272	1967
Crack resistance ratio	29.24	49.13

3.5.2 Energy Absorption

The quantity of energy absorbed by the body was calculated based on the number of blows the specimen has taken. The number of blows was converted into the absorbed energy based on equation (8) and equation (9) respectively.

$$\mathrm{Esf} = (\mathrm{mgh})\mathrm{Nsf} \tag{8}$$

$$\mathrm{Esu} = (\mathrm{mgh})\mathrm{Nsu} \tag{9}$$

(Esf = Energy absorbed by the slabs at first crack; Esu = Energy absorbed by the slabs at ultimate load; m = mass of the ball (kg); g = gravitational acceleration (m/s^2); h = drop height (m); Nsf = Number of blows to initiate first crack in slab; Nsu = Number of blows to initiate failure in slab).

3.5.3 Ductility index

The ratio of the number of blows taken to initiate failure to the number of blows taken to initiate the first crack was quantified through ductility index Di as mentioned in equation (10).

$$\mathrm{Di} = \left(\frac{\mathrm{Nsu}}{\mathrm{Nsf}}\right) \qquad (10)$$

3.5.4 Ultimate crack resistance

The ultimate crack resistance Cu (MPa) was calculated by quantifying the energy absorbed at ultimate load to the volume of crack developed as given in equation (11).

$$\mathrm{Cu} = \frac{\mathrm{Esu}}{(\mathrm{Lc \times Wc \times Dc})} \quad (11)$$

(Esu=Energy absorbed by the slabs at ultimate load (Joules); Lc = Crack length (mm); Wc = Crack width (mm); Dc = Crack depth (mm))

3.5.5 Crack resistance ratio

The crack resistance ratio was calculated by quantifying the ultimate crack resistance (Cu) to that of the cube crushing strength fck (MPa) of the particular mix proportion as given in equation (12).

$$C\mathrm{rr} = \frac{Cu}{fck} \qquad (12)$$

The values calculated for both Slab-CC and Slab-CS 30 8A under impact loading are compared in Table12.

Compared to the Slab-CC, the Slab-CS 30 8A specimens shows an increment of about 20.89% for the number of blows for failure. Even though the Slab-CS 30 8A specimens sustained more load before the first crack, the ductility index was less than that of Slab-CC specimens. The energy absorption and ultimate crack resistance in Slab-CS 30 8A specimens were enhanced by 20.88% and 54.64% respectively to Slab-CC specimens. The crack resistance ratio in Slab-CS 30 8A specimens was increased by 68.02%, compared to Slab-CC specimens.

4. Conclusion

The present study concentrated on the resistance of lightweight concrete slabs under impact loading using a low-velocity drop hammer impact test device. From the study the following conclusions have arrived:

- Preliminary investigations on impact value and crushing value for coconut shell aggregates have resulted in 6.94% and 1.93% respectively. As per IS 383: 1970, the coconut shell aggregates are falling under extremely strong aggregates.
- In CS 30 specimens, the reduction in density were 15.3% and 12.04% in dry and wet condition, compared to CC specimens. The reduction in density of the specimens was achieved up to 8% replacement of cement with alccofine (CS 30 6A, CS 30 8A). Increasing the replacement percentage of cement with alccofine (CS 30 10A, CS 30 12A) resulted in less reduction in density.
- Compared to the control mix (CC), for CS 30 specimens, the reduction in compressive strength was 29.3%. The mineral admixture has added value to the coconut shell concrete by enhancing strength properties. The mix (CS 30 8A) in which cement has been replaced by 8% alccofine was found to be effective, with only 7.9% reduction in crushing strength compared to CC specimens.
- The effect of ultrafine GGBFS (Alccofine) in CS 30 mix (CS 30 8 A) also has helped in compensating the splitting tensile strength and flexural strength by restoring the values equal to that of CC specimens.
- The energy absorbed by CS 30 specimens, both at the initiation of first crack and ultimate failure was found to have a closer value, compared to CC specimens. Since the coconut shells offered high impact resistance, the energy absorption was not affected even without any mineral admixture. The percentage increase in energy absorption for CS 30 8A, compared to CC specimen was observed to be 4.76% and 4.17% up to formation of first crack and failure respectively. The improved cohesiveness of the mix and the good impact resistance of coconut shell aggregates have enhanced the impact resistance of specimens.
- Durability characteristics like water absorption, porosity, and sorptivity of all the tested specimens were observed. The specimens cast with CS 30 mix showed a higher value for water absorption, porosity, and sorptivity due to increased permeability. Whereas in other specimens (CS 30 6A, CS 30 8A, CS 30 12A), the ultrafine particles of alccofine admixture have ensured for good interlocking of pores in the concrete mix during the hydration process. This would have enhanced the water tightness of the samples, leading to improved durability properties.
- The percent reduction in density and crushing strength of coconut shell concrete CS 30 during the acid attack test were observed to be 10.48% and 32.45% respectively. Whereas for CS 30 8A the reduction in density and compressive strength were brought down. The lower reduction may be due to the ultrafine particles of the mineral admixture that would have filled the pores of the concrete, thus ensuring less ingress of acid in concrete.
- Based on the performance of the specimens in both strength and durability conditions, the mix my replacing 30% of coarse aggregate with coconut shell along with 8% replacement of cement with alccofine (CS 30 8A) was fixed as optimum.
- In the impact resistance test on reinforced slabs, the specimens Slab-CS 30 8A cast using optimum mix performed well, compared to Slab-CC. The energy absorption, ultimate crack resistance, and crack resistance ratio of Slab-CS 30 8A showed enhancement of 20.88%, 54.64%, 68.02% respectively.

The coconut shell concrete has been observed to attain good results in terms of its lower unit weight and higher impact resistance. The reduction in the mechanical and durability characteristics have been compensated by the replacement of cement with Alccofine mineral admixture.

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