Compressive Behaviour of Green Concrete Partially Reinforced With Dry Coconut Shell Aggregates as a Replacement of Coarse Aggregates

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Abstract

In this work, coconut-shells were reinforced as a partial replacement of the coarse aggregate in concrete to make a lightweight concrete without compromising the properties of concrete. The coconut-shell aggregates with different percentages 5%, 10%, 15%, and 20% of coarse aggregate were added to make coconut-shell cement concrete (M25) along with plain cement concrete without reinforcement of coconut shell aggregates. Main tests on concrete like Vikat test, density computation, and slump test were done. However, the main aim was to investigate the compressive behaviour of concrete. A total of 50 samples (10 cm cubes) were prepared and tested for compressive behaviour on 14th day and compared with that on 28th day. Concrete with 10% coconut-shell produced the best results. The density computation of concrete reveals that reduction in weight of concrete could be achieved appropriately. On the basis of the results, it can be concluded that coconut-shell aggregates with 5% course aggregate could be used for primary construction components. However, other concrete with increased percentage of coarse aggregate could gratify the necessity for secondary construction components.

Keywords : Cement, coconut shell, compressive strength, course aggregate, green concrete

I. INTRODUCTION

Concrete is the second most consumed material in the world after water. It is a hybrid composite normally made by mixing four main components (cement, sand, aggregate, and water). The concrete contains cement (12%), fine aggregates (FA) (26%), coarse aggregates (CA) (42%), water (16%), and air (3%). The concrete is used in construction (bridges, buildings, industries, dams, and other structural components). Nowadays, waste materials are used as coarse or fine aggregate replacement in the conventional (plain) concrete [1] [2]. The reason for using filler material in concrete is the fast growth of many waste materials in the world and the need for their utilization and disposal. The use of waste materials saves natural resources, dumping spaces, and this helps to maintain a clean and healthy environment. Waste materials are filler materials in concrete and they can be used to make special concrete for specific applications. The filler materials are either biodegradable or non-degradable. Biodegradable materials such as agricultural waste, human waste, fruit waste, etc. are easily decomposed and not environmentally harmful. Non-degradable materials such as rubber, plastic, glass, metal, etc. do not decay. Some non-degradable materials are very harmful to the environment. Concrete can be classified according to the filler material and procedure of processing. Concrete is classified as follows on the basis of filler material:

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(1) Fiber reinforced concrete (synthetic fibers such as polypropylene, polyethylene, polyvinyl alcohol, nylon, alkali-resistant glass, etc., and natural fibers such as sisal, coconut coir, hemp, rice husk, etc.)

(2) Foam cellular concrete (foaming agent), silica fume concrete (silica fume), geopolymer or green concrete (waste materials such as granulated blast furnace slag, fly ash, etc.)

(3) Reinforced cement concrete (steel reinforcement), lightweight concrete (lightweight aggregates such as fly ash, slag, straw, hemp, coconut husk, fiber, etc.)

(4) Limecrete (lime concrete), glass concrete (glass fiber), polymer concrete (polymer), asphalt concrete (asphalt), etc.

On the basis of processing, concrete is classified as ultra-high-strength concrete, self-compacting concrete, roller compacted concrete, vacuum concrete, pumped concrete, stamped concrete, rapid strength concrete, etc. The grades of concrete are defined by the minimum strength attained by concrete in 28 days of the initial construction and composition viz. M5, M7.5, M10, M15, M20, M25, M30 etc. M is the mix design of concrete and 5, 7.5, 10 etc. is the characteristic strength in N/mm^2 at 28 days with water curing. Cement and water when combined undergo a chemical reaction and make a bond with FA and CA.

Society is continuously striving for materials with better performance. Building and construction arena is also looking for better and improved concrete. The Concrete Society and the American Concrete Institute had set two expert working groups to report fiber-reinforced cement and concrete as civil engineering materials [3]. A study on the use of lightweight construction material composed of cement, sand, and fiber of waste from young coconut and durian has been reported for estimation of thermal conductivity, compressive strength, and bulk density [4]. Green concrete (GC) uses waste material as one component in concrete. Its production process does not lead to environmental destruction. It has high performance and lifecycle sustainability. The political situations accepted by various countries for green concrete along with the priorities and deregulation in various fields have been extensively discussed [5]. Over the period, various aggregates were used in GC. Specifically, coconut fibers have been utilized by various research groups. The effect of coconut fiber percentages (1%, 2%, 3%, and 5% by mass of cement) and fiber lengths (25, 50, and 75 mm) have been studied to evaluate the effect of fibers in improving the properties of concrete in comparison with plain concrete [6]. Besides, coconut-shells (CS) were also used as aggregate replacement in concrete. The properties of CS coarse aggregate concrete were studied experimentally for compressive, flexural, splitting tensile strengths, impact resistance, and bond strength. These have been compared with the theoretical values as recommended by standards [7]. The same group has investigated CS concrete beam under flexure [8], shear [9], and torsion [10]. Experiments have been performed for mechanical properties and fracture toughness of the concrete produced by using CS as coarse aggregate and blast furnace slag as a partial replacement [11.] It was found that the results are comparable with other lightweight concretes. In continuation, the flexural behavior of eco-friendly CS concrete [12] was carried out. Experiments have been aimed to compute the effects of partial replacement of the conventional CA by CS in concrete on the compressive strength and density besides the additional cement required to compensate the strength reduction of concrete due to CS addition [13].

This work involves the fabrication of coconut-shell cement concrete (CSCC) with varying percentages of CS aggregates by partially replacing it with CA in the concrete. The investigation of density variations, workability of concrete, and consistency of fine or coarse aggregate of concrete by the slump test were performed. As a main objective, further compression tests have been performed on 14^{th} day and 28^{th} day on water cured CSCC along with pure cement concrete (PCC) for comparison.

II. MATERIALS AND METHOD

In this work, to make lightweight and GC Ordinary Portland Cement (OPC) grade 43, sand, CA, and CS (disintegrated and sieved) are used. The M25 grade of concrete is used for the preparation of CSCC. M25 concrete has a ratio of the mixture of cement (1), sand (1), and aggregate (2) along with 28 litres of water per 50 kg of cement. The OPC has 1,450 kg/m^3 density and 43 MPa characteristic strength on the 28^{th} day. It has oxide compositions (CaO, SiO_2, Al_2O_3, and Fe_2O_3). The average size of sand is 0.6-2 mm, decided by a 2 mm sieve with density of 1580 kg/m^3. The average size of the CA is

10-12 mm measured by standard aggregate sieve with density of 1,500 kg/m^3. The CS used in this work was randomly selected from temples.

The best resources for CS are factories and temples. Coconut is a fruit from the coconut tree, which is a member of the palm tree family (Arecaceae), having botanical name Cocos Nucifera and is the only identified living species of the genus Cocos. The word "coconut" is mentioned for the entire palm, seed, and fruit. The fruit is a drupe, not a nut. Botanically, it has three sections, viz. husk or coir (topmost section), shell (middle section), and flesh (interior part). Fully grown coconut fruit consists of exocarp (outer skin), mesocarp (coir), endocarp (shell), testa (seed coat), and endosperm (kernel meat) along with embryo and water. Its shell has a hierarchical structure and typical features at different length scales, which are based on orientation and age. Usually, aged fruit has stronger, stiffer, and tougher endocarp than the younger fruit for latitudinal loading. The mechanical properties of the shell of coconut improves with age and induces more anisotropy, whereas a young shell is isotropic. The microstructure of the young and aged CS reveals distinct and unique features. At the course level, young shell shows hollow channels running attitudinally with smaller connecting channels longitudinally. These channels become more distinct in the older shell and run continuously through the complete cross-section of the shell. At higher resolution, the channels appear roughly elliptical, which are lined by hollow fibers (approximately elliptical), and consist of concentric rings connected in a ladder structure along the length of the fibers. At further finer length scale, an elliptical and a hollow cellular structure is found in the young shell; however, these disappear in the aged shell [14].

In this work, concrete M25 grade is selected as a plane concrete for reference. The basic components of M25 grade concrete are in the ratio 1:1:2 (cement : sand : coarse-aggregate), measured in weight (kg). The size of sand varies from 0.6-2 mm and is obtained from 2 mm sieve. The average size of the CA varies from 10-12 mm. The CS is cleaned and dried before breaking (crushing by a hammer); it as an aggregate (10-12 mm) and is used as a replacement of CA in different percentages viz. 5%, 10%, 15%, and 20%. The OPC grade 43 (density = 1450 kg/m^3 and 43 MPa characteristic strength at 28 days) is used.

The experimentation on CSCC is aimed at the basis of the most common uses of concrete, ensuring that the CSCC should behave as per the expectation of the application under consideration as plane concrete. The testing of CSCC has to ensure the strength, quality, and stability of concrete without compromise. Testing is performed according to the ASTM standard. Slump test is done to check the workability of concrete and consistency of fine or coarse aggregate in the concrete by Vicat Apparatus. The dimension of the slump cone is 100 mm top diameter, 200 mm bottom diameter and 300 mm height (ASTM C1611/C1611M-18). The density variations of CSCC due to the addition of CS is also carried out. Compressive test is required for the investigation of the water-cement ratio, the strength of cement, binding of mixed materials, and quality of concrete. It is performed as per ASTM C39/C39M with a sample of 100 mm cube. The detailed compression results are obtained on 14^{th} day (atmospheric temperature) and on 28^{th} day. Further, the compressive strength of samples tested on 14^{th} and 28^{th} days has been compared.

III. RESULTS AND DISCUSSION

Concrete slump displacement (SD) increases with an increased percentage of CS (Table I) and is in the range of 26-43 mm. The SD indicates a stiff consistency grade of the concrete, which points to sufficient and acceptable workability of CSCC. The result of density variations with percentage change of CS in concrete (Table I) depicts that the density decreases with an increase in percentage of CS. Specifically, referring to PCC, density decreases by 3.03%, 4.56%, 8.05%, and 8.87%, respectively with 5%, 10%, 15%, and 20% addition of CS.

For the compression test, 5 samples of each

TABLE I.

SLUMP DISPLACEMENT AND DENSITY VARIATION OF PCC AND CSCCs

Sample	PCC	5% CSCC	10% CSCC	15% CSCC	20% CSCC
SD (mm)	26	28	34	39	43
Density (kg/m^3)	2436	2362	2325	2240	2220

composition were prepared. The compressive stress-strain variations are plotted for each composition. The average stress-strain variation is also plotted. Measurements have been carried out on 14th day of water curing. The compressive stress-strain variations are shown in Fig. 1 for PCC. Most of the samples of PCC show similar compressive behaviour. Fig. 2 shows the stress-strain variations for 5% CSCC. Both figures reveal the uncertainty in the measurements of concrete samples.

Fig. 3 and 4 show the stress-strain variations for 10% and 15% CSCC respectively. More uniform stress-strain variation is observed in Fig. 3. However, Fig. 4 shows that all samples behave like sample 1. Fig. 5 shows the stress-strain variations for 20% CSCC, which reveals that sample 1 behaves differently from the rest of the samples. It is found the PCC performed best as expected; however, 5% and 10% CSCC showed similarity. Both 15% and 20% CSCC performed poorly but consistently with each other. In greater detail, for the specimen tested on 14th day, the maximum deformation induced and the maximum load sustained by any specimen under test is 6.3 mm and 262.5 kN for PCC. Similarly, the corresponding values of

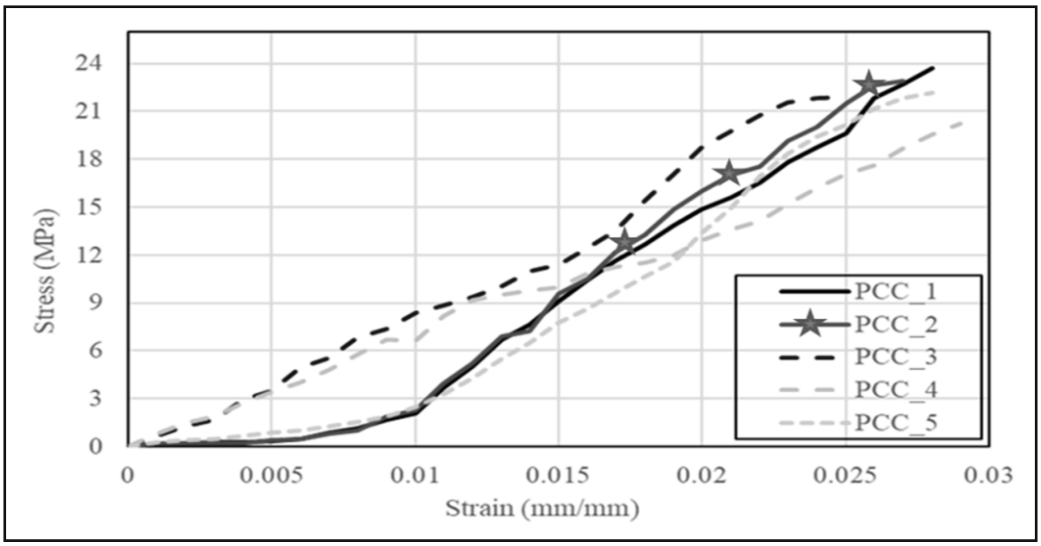

Fig. 1. Compressive Stress-Strain Variation of PCC

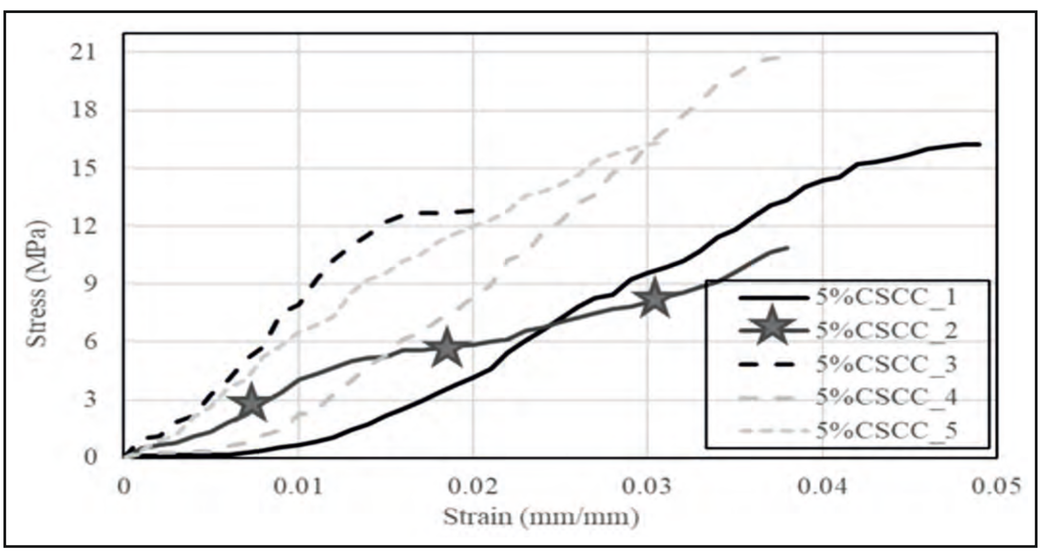

Fig. 2. Compressive Stress-Strain Variation of 5% CSCC

maximum deformation induced and the maximum load sustained for 5%, 10%, 15%, and 20% are 4.9 mm, 3.9 mm, 5.7 mm, and 4.3 mm; and 207.94 kN, 130.1 kN, 106.6 kN, and 104.6 kN respectively.

The average compressive behaviour of all samples is given in Fig. 6. Since the range of measurement of samples is different, for simplification, the averaging is done for at least three samples. For a safe estimate, the readings with a higher side of stress and stain have been eliminated during averaging. As seen from the average results, the PCC appears the best performing; however, the rest of the sample shows reduced behaviour. Since the range of measurement was different for each sample, averaging was done for atleast three samples and the rest of the readings, which were at the higher side of stress and stain were eliminated. Similarly, the corresponding values of maximum deformation-induced and the maximum load sustained for 5%, 10%, 15%, and 20% were 4.9 mm, 3.9 mm, 5.7 mm, and 4.3 mm; and 207.94 kN, 130.1 kN, 106.6 kN, and 104.6 kN, respectively. The applications of

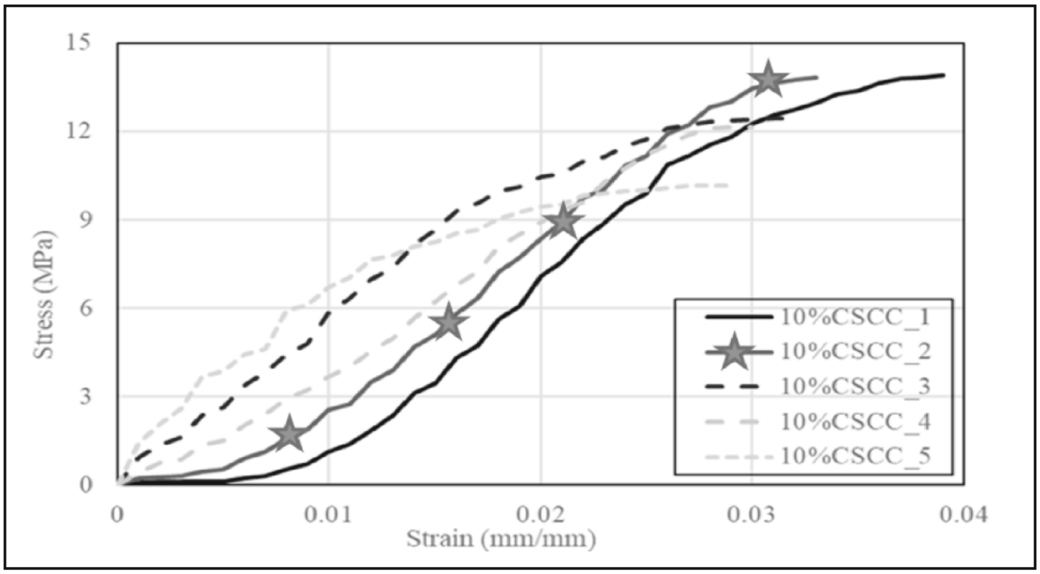

Fig. 3. Compressive Stress-Strain Sariation of 10% CSCC

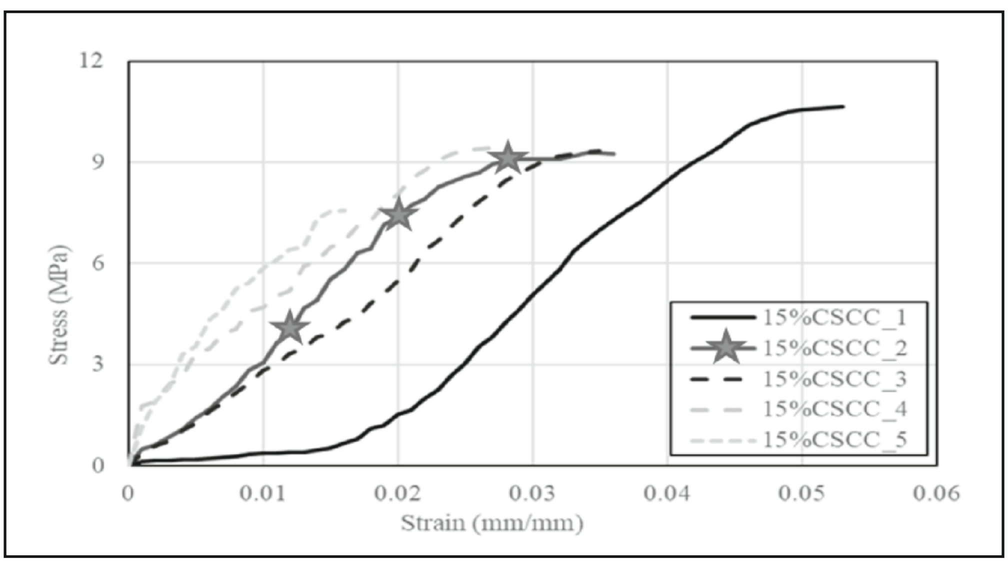

Fig. 4. Compressive Stress-Strain Variation of 15% CSCC

concrete developed in this work may range primarily from lightweight partitions, walls, and secondary structural components (members that are not connected directly to columns; floor and roof construction; and bracing members not supporting gravity loads) in a better way rather than the primary structural components.

For comparison, the compressive strength of all samples was also determined on 28th day and the results are given in Table II, alongwith similar results on 14th day. The compressive strength results of all samples on 14th day show that PCC is showing the best results. However, when the PCC samples were compared with 5% CSCC, 31.19% reduction in compressive strength was observed. This reduction in compressive strength is very high and may be due to localized crushing of CS reinforcement under the applied compressive load. The localized

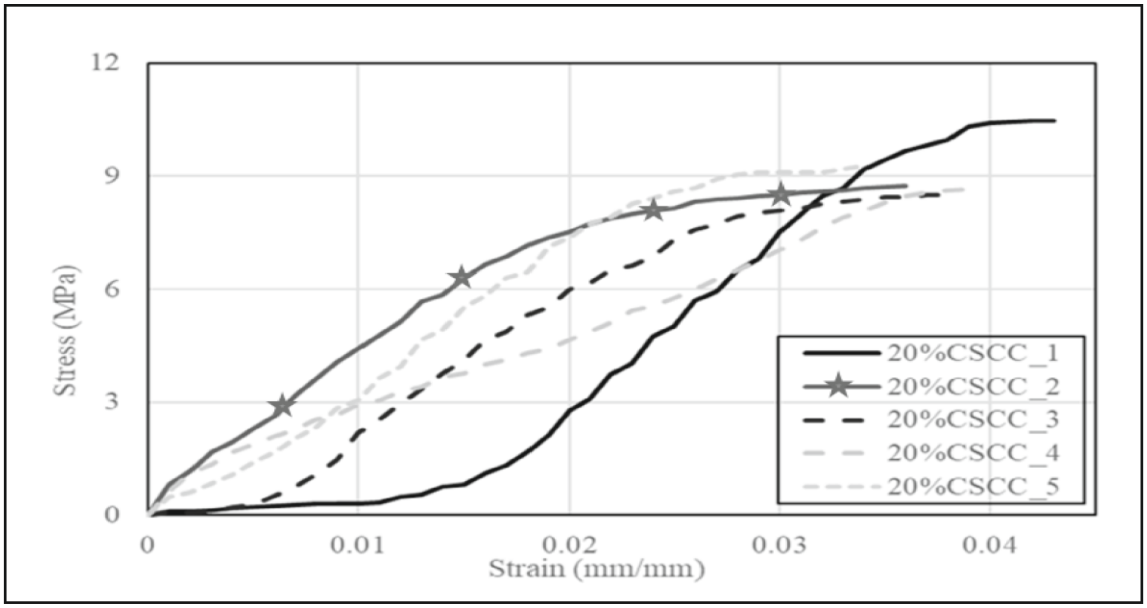

Fig. 5. Compressive Stress-Strain Variation of 20% CSCC

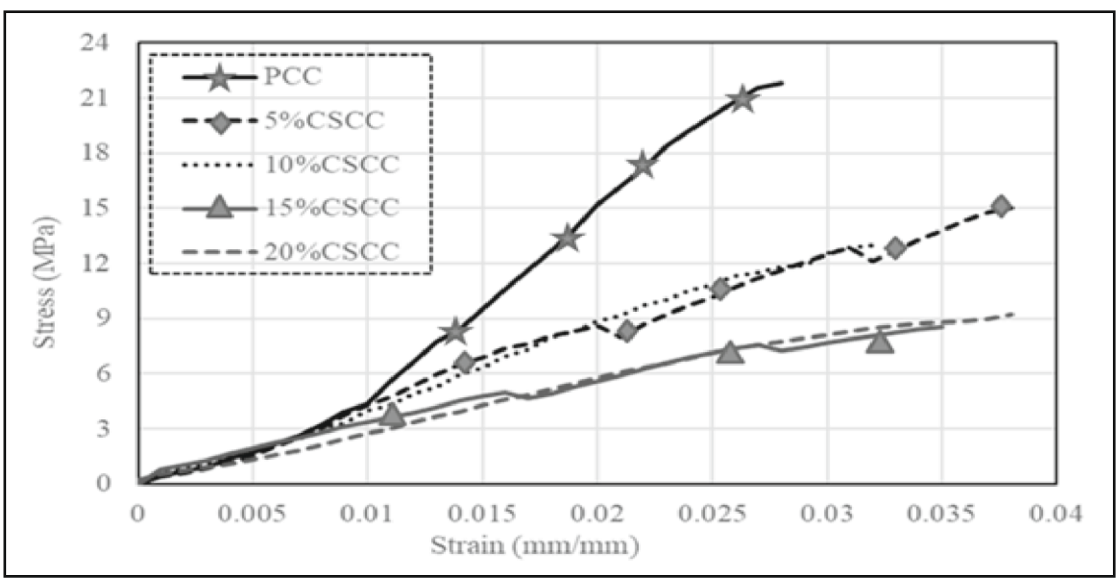

Fig. 6. Stress-Strain Variation (Average)

TABLE II.

COMPRESSIVE STRENGTH OF SAMPLES ON 14TH DAY AND ON 28TH DAY

Sample	PCC	5% CSCC	10% CSCC	15% CSCC	20% CSCC
14^{th} day (MPa)	21.8	15.0	13.4	8.9	9.2
28^{th} day (MPa)	29.0	25.8	23.6	21.4	20.2

crushing of CS results in an overall decrease in the compressive strength of 5% CSCC. It is expected from the result of 5% CSCC that the samples with 10% CS may show a further decrease in compressive strength. For the 10% CSCC samples, the decrease in compressive strength is 38.59%, which is due to more localized crushing sites in samples. Similarly, the compressive strength of samples (15% CSCC and 20% CSCC) when compared with PCC shows reduction by 59.04% and 58.03% respectively. This reduction in compressive strength is not advisable. However, the reduction in compressive strength of 20% CSCC is less than 15% CSCC. A similar observation of comparison was found for samples tested on 28^{th} day. However, in general, it can be concluded that the appreciable improvement in compressive strength is observed in the samples tested on 28^{th} day as compared with the samples tested on 14^{th} day.

The compressive strengths of PCC tested on 14^{th} day and 28^{th} day are 21.8 MPa and 29.0 MPa respectively. This clearly shows a significant increment in compressive strength. The comparison of PCC and all CSCCs on 28^{th} day reveals reduction in compressive strength as expected.

However, in detail, the compressive strength of 5% CSCC reduced by 11.03% in reference to the PCC. This reveals that the strength achieved by the concrete on 28^{th} day is significant to withstand the applied compressive load. Analogous observations were obtained on comparing the compressive strength of PCC with 10% CSCC, 15% CSCC, and 20% CSCC, specifically. The reduction in compressive strength is by 18.62%, 26.21%, and 30.34% respectively with reference to PCC. The improvement of the compressive strength of all samples on 28^{th} day and 14^{th} day clearly shows the significance of the curing of concrete. As stated earlier, the effect of the number of days of sample curing on compressive strength can be investigated in detail. One can observe that the compressive strength of PCC on 28^{th} day increased by 33.03% on comparing the same values on 14^{th} day. For M25 concrete, PCC compressive strength 29.0 MPa is acceptable. Similar results for 5% CSCC shows compressive strength increment by 72.00% and compressive strength of 25.8 MPa for M25 concrete. The rest of the three samples (10% CSCC, 15% CSCC, and 20% CSCC) could not cross the desired value of 25 MPa for M25 concrete. However, if their compressive strength is compared on 28^{th} day and 14^{th} day, one can observe the enhancement of compressive strength by 76.29%, 139.64%, and 120.77% respectively.

Comparing the compressive strength of all lightweight GC samples developed in this work, the 5% CSCC qualifies the requirement of concrete (M25). Therefore, it can be successfully used for primary construction components. However, the rest of the CSCC samples can satisfy the requirement of the secondary construction component. The primary construction components are those responsible for direct load-bearing, viz. columns, beams, slabs, braces, etc. On the contrary, secondary construction components are those interchangeable parts such as walls (external, internal, and boundary), partitions, posts, beams, railings, stairs, parapets, lintels etc. These support primary construction components and serve some other useful functions that are not related to the strength or stability of the structure. Additionally, secondary components can be removed if required. Thus, they do not affect the overall stability and integrity of the structure. Hence, the CSCC developed in this work even with reduced compressive strength can be sufficiently and successfully used for secondary structural components without any adverse effect on the structural and overall performance of the system under consideration. Moreover, the addition of CS in the concrete shall reduces the use of natural resources and helps in the overall reduction of structural weight.

IV. CONCLUSION

It is concluded from this study that the CSCC developed by 5%, 10%, 15%, and 20% CS shows all acceptable slump displacement (26-43 mm) showing proper workability of CSCC. Density computation shows reduction in density by 3.03%, 4.56%, 8.05%, and 8.87% for 5%, 10%, 15%, and 20% CSCC when compared with PCC. The compressive strength measurement shows that PCC is better than all others, which is obvious. The compressive strength gained by all CSCC samples at 28 days is appreciably high when compared with the strength at 14 days. The average compressive behaviors of all samples indicate that PCC appears the best performing and all CSCC sample show reduced behavior. It is also observed that the reduction in compressive strength increases with an increase in the percentage of CS. Comparing the compressive strength, 5% CSCC qualifies the requirement of concrete (M25) for primary construction components. However, the rest of the CSCC samples can satisfy the need for secondary construction components. The CSCC prepared during the current research shall be satisfactorily and adequately used for secondary structural components without any adverse effect even at the comparatively reduced compressive strength in comparison with PCC.

AUTHORS' CONTRIBUTION

Deepak Kumar completed his Master's Thesis under the supervision of Prof. S. J. Pawar. Both the authors identified the problem. Deepak Kumar did all preparation, testing, and report writing. Prof. S. J. Pawar guided him as per requirement, did the preparation and worked on the manuscript.

CONFLICT OF INTEREST

The authors certify that they have no conflict of interest. They have no involvement in any organization or entity with any financial interest, non-financial interest in the subject matter, or materials discussed in the manuscript.

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