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Influence of biomass ash and coconut shell in scrap steel fiber reinforced concrete

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ABSTRACT

To develop a sustainable concrete solution, the aggregates and cement in the concrete mixture were partially replaced with Cocos nucifera endocarp (coconut shell) aggregate and biomass ash (sugarcane bagasse ash) respectively. The fresh and hardened properties were studied for three types of mixes (i) the concrete mix with 10-30% replacement of cement with bagasse ash (BA), (ii) Bagasse ash concrete mix with scrap steel fiber and (iii) Bagasse ash concrete with scrap fiber and 10 - 50% coconut shell aggregate. The fresh property of concrete is positively influenced by the addition of bagasse ash. With the addition of scrap fibers and coconut shell the workability reduces by 47% when compared to the control mix. The slump values recorded for all the mixes were within the permissible limit. The density of concrete decreases with the inclusion of bagasse ash and coconut shell which helps reduce the dead weight of structural elements. The mechanical property of concrete increased by 5%, 6% and 8% in compression, split and flexure modes respectively, for 10% bagasse ash steel fiber reinforced concrete. Replacement of gravel with coconut shell affects the strength properties, but all the values were within the permissible limit for structural concrete application. The SEM image analysis showed that the porosity increased with coconut shell content. From the fresh and hardened concrete test results, it was observed that the coconut shell, bagasse ash and scrap fiber can be effectively used as substitutes for concrete ingredients to develop a sustainable fiber reinforced concrete solution.

1 Introduction

Urbanization results in the rapid depletion of natural resources at high speed and leads to the large amounts of energy consumption. Concrete, being the important material in the construction industry, consumes tons of cement, sand, and gravel. Concrete production per person in developed countries ranges between 1.5 and 3 tonnes per year. At this rate of consumption, it is difficult to meet the resource requirements for our future generation [1]. Therefore, in order to maintain sustainability and reduce the consumption of natural resources at a faster rate, the major ingredients in concrete, namely cement and aggregate are replaced with new sustainable materials. The sustainable materials are either industrial waste byproducts or agricultural waste byproducts which reduce CO_2 emissions, and the dumping waste on open land, thereby reducing environmental pollution without compromising the strength of concrete and concrete composites [2]. Out of the total natural resource consumption, coarse aggregate contributes about 70-80% of the total amount; therefore, more focus is given to alternative aggregate materials such as copper slag, steel slags, sintered fly ash aggregate, and agricultural waste such as palm shell, coconut shell, kernel shell etc. These byproducts and waste materials are used as replacements for mineral gravel aggregate. Compared to high density industrial waste (slags), agricultural waste has a lesser density, better sound insulation, thermal resistance, cost-effective and is also easily renewable. Out of the different shells available as a substitute for gravel aggregate, coconut shell is the most preferred aggregate due to its hard texture and better volume stability [3]. In addition to natural aggregate replacement, much research is also being carried out to reduce the cement consumption in concrete, in which, cement is replaced with low carbon alternative materials with better pozzolanic property. Recently, the use of biomass ash such as corn cob ash, rice straw ash, bagasse ash, rice husk ash, palm oil fuel ash, etc. has increased because of its renewable nature. Compared to fly ash which has excellent pozzolanic properties and is obtained as the combustion residue of coal (non-renewable), biomass ash is preferred in the construction industry [4]. Using such agro-waste as cement and aggregate replacement in the concrete reduces the cost of construction and also reduces the environmental pollution caused by the disposal of those wastes in open land [5]. Aside from cement replacement and natural coarse aggregate replacement, several studies on the mechanical behaviour and durability characteristics of fiber-reinforced

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concrete have been conducted over the last two decades. A variety of synthetic fiber and plant fibers such as polyolefin, glass, carbon, polypropylene, banana fiber, sisal fiber, caryota fiber, roselle fiber, jute fiber, and coconut fiber are used as reinforcement in concrete nowadays to improve the mechanical strength and ductility characteristics of both normal and light weight aggregate concrete [6],[7],[8],[9],[10], [11]. Even though synthetic fibers have better thermal resistance, mechanical strength and durability, when compared to natural fibers, plant fibers are much preferred nowadays, due to their low cost and highly renewable nature[12],[13],[14],[15]. Using steel fibers of different aspect ratios and origins helps enhance the mechanical properties of concrete [16]. Recently much research has been carried out using steel fibers as reinforcement in both normal and light-weight concrete to reduce the brittleness of the material and improve its tensile properties [17],[18]. From the knowledge gained, this research paper will mainly focus on using coconut shell (CS) aggregate as the partial replacement for natural gravel aggregate, bagasse ash (BA) as a partial replacement of cement, and lathe industry scrap steel fibers (SrF) as fiber reinforcement.

2 Recent studies on light weight coconut shell concrete

Much research has been carried out using coconut shell as a partial or complete replacement for natural gravel aggregate. Gunasekaran et al. conducted extensive research on the strength properties, structural behaviour, bond characteristics, long-term compressive and bond strengths, plastic shrinkage, and deflection characteristics of coconut shell concrete, proving that the bond property of coconut shell concrete is higher than the values predicted by standard codes, and that the density and compressive strength of concrete increase as the percentage of coconut shell concrete decreases. The plastic shrinkage area decreases but the deflection increases with the amount of coconut shell replacement. Studies on Coconut Shell Concrete (CSC) pipes subjected to hydrostatic pressure showed that the coconut shell can be used as a partial replacement for aggregate in reinforced cement concrete pipes used for various hydrological applications in medium traffic locations. [19],[20],[21],[22],[23]. Results on the durability properties of CSC showed that the water absorption, permeable voids, chloride penetration, and temperature resistance are much more comparable to other light-weight aggregate concrete. The coconut shell aggregate absorbs water which helps in the hydration process and proper curing conditions are to be adopted to achieve better durability characteristics of coconut shell concrete [24]. In addition to the CS aggregate, coconut shell ash when added to concrete at 10 % cement replacement, has a negative effect on the workability of CS concrete. But the splitting and compressive strength of modified CSC with 10% ash and 5% aggregate subjected to elevated temperature showed better performance, when compared to concrete with only 5% coconut shell aggregate [25]. The coconut shell aggregate concrete with different percentage of replacement of fly ash showed higher deflection, which proves that the CS aggregate reduces the brittleness and improves the ductility of concrete [26]. Addition of different percentage of sisal fibers , steel fibers and polypropylene fibers along with coconut shell aggregate improves the mechanical property mainly the tensile strength of lightweight concrete [2]. In addition to coconut shell, the biochar obtained from the burnt coconut shell is used to reduce the plastic shrinkage cracks in silica fume cement binder concrete [27]. Addition of coconut fiber in CS aggregate concrete also help to improve the tensile strength of coconut shell concrete [28]. Different plant fibers, steel fibers and synthetic fibers are used as the fiber reinforcement in lightweight coconut shell concreteto improve the tensile and flexural strength properties of coconut shell concrete[29],[30]. To reduce cement consumption and carbon-dioxide emission different pozzolanic industrial and agricultural waste such as fly ash, bagasse ash, quarry dust, coconut char, Coconut Ash has been used as partial replacement for cement [31],[32],[33]. Research work carried out using crushed CS and synthetic biomass modified CS aggregate showed that modified biomass CS concrete has excellent thermal resistance, and can be used as an excellent energy saving building material. Recent research on fiber reinforced coconut shell concrete and its research significance is tabulated in Table 1.

3 Research significance

From the literature study, it can be seen that, many new lightweight aggregates are being identified and added to concrete as a substitute for gravel to produce lightweight concrete, and different strength properties are being studied. Coconut shell is used as a substitute for natural gravel aggregate because it is the hardest and most popular light weight aggregate available in most Asian countries. The mechanical properties, bond characteristics, durability properties, plastic shrinkage behaviour and beam deflection characteristics of CSC were studied in detail by many researchers. These properties were tested in different types of concrete mix either by using coconut shell as partial or complete replacement for gravel aggregate. Along with coconut shell aggregate, pozzolanic binder materials such as fly ash, silica fume and coconut char were used as partial replacements for binder. In addition, to the above-mentioned substitution in concrete, some metal fibers, synthetic fibers and natural fibers such as steel fibers, polypropylene fibers, sisal fibers, coconut fibers etc. were used in different percentages of the volume of concrete, to reduce the brittleness in concrete and impart ductility to lightweight fiber reinforced concrete. From the literature study it was identified that the study on bagasse ash and coconut shell aggregate concrete with scrap steel fibers as reinforcement had not been studied so far. Therefore, this research work focuses on the properties of scrap steel fiber reinforced coconut shell concrete with bagasse ash as a partial replacement for cement.

4 Experimental methodology

4.1 Material characterization

The materials used for the preparation of concrete mix include cement, gravel aggregate, coconut shell aggregate, M – Sand, Bagasse Ash (BA), water reducing admixture and portable water. The sugarcane bagasse ash was received from a sugarcane mill located at virudhachalam district, Tamilnadu, India. To obtain the BA, sugarcane fiber was heated in a muffle furnace at 10°C /min. The burnt ash was subjected to a high temperature of 900°C for 2 hours and then the ash trays were allowed to cooled in the open air. After proper cooling, each sample was ground in a ball mill at 66 rpm, until the fineness of the BA sample was within the

Table 1. Recent study on sustainable coconut shell aggregate concrete

Reference	Year	Aggregate replacement	Cement replacement	Fibers	Properties	Parameters	Conclusion
[17]	2022	Coconut shell	Flyash-10%	Steel fiber	Mechanical properties and Flexural strength of beams	Fiber content varied from 0.25-1% volume of concrete	Both flexural toughness and beam ultimate capacity increased with the fiber content
[34]	2022	Coconut shell-5% replacement	Coconut shell ash-10%	-	Cracking pattern, flexural and shear behaviour of beams	Influence of coconut shell particle on the flexure, shear and cracking pattern of the beams	Combination of coconut shell aggregate and coconut shell particle increase the ductility by 8%.
[30]	2022	Coconut shell partial	Bagasse ash 25%	-	Mechanical property, drying shrinkage and structural performance.	Influence of 25% bagasse ash and combination of CS and gravel aggregate in concrete	concrete with 25% ash and 50% CS showed better performance in shrinkage behaviour which is about 18% less than normal concrete.
[1]	2022	Coconut shell & Synthetic bio mass aggregate	-	-	Microstructure of biomass recycled aggregate coconut shells concrete Mechanical strength, shrinkage and thermal conductivity.	Comparative study on the effect of crushed coconut shell and biomass recycled aggregate in concrete	Energy saving potential and thermal resistance was better in coconut shell and synthetic biomass aggregate concrete compared to normal concrete.
[35]	2021	Coconut shell	Fly ash-10%	Sisal fiber	Mechanical strength and impact resistance	sisal fiber percentage varied from 1-4%	With 3% fiber addition the mechanical strength of concrete increased.
[27]	2020	Gravel	Biochar from coconut	-	Mechanical property and permeability characteristics of biochar replaced cement mortar.	5% wt. of cement and 33 % wt. of silica fumes replaced with biochar. Influence of biochar on the strength and durability properties of mortar.	Autogenous and drying shrinkage reduced by 61% and 23% for the addition of biochar and silica fume in cement mortar.
[36]	2020	Coconut shell	Flyash-10%	Steel fiber	Fresh properties and mechanical property of CS concrete	Fiber content varied from 0.25-1% volume of concrete.	39% increase in compressive strength and 17% increase in MOE were observed.
[37]	2019	Coconut shell	Flyash-10%	Polypropylene fiber	Fresh properties and mechanical property of CS concrete	The volume fractions of polypropylene fibres were 0.25%, 0.5%, 0.75% and 1.0%.	Increased volume fractions of polypropylene fibres reduce the compressive strength
[28]	2019	Coconut shell	-	Coconut fiber	Water absorption, sorptivity, void characteristics, rapid chloride penetration and temperature resistance	Fiber Volume fraction of 3%; Three different curing conditions.	Durability properties were better in full water immersion condition for CS concrete.

range of cement (2750 cm^2/g). The pictures of sugarcane crushed fibers, burnt fiber and sieved bagasse ash is shown in Figure 1(a-c). The elemental composition of cement and bagasse ash showed silica contents of 23.86% and 56.37%, respectively. The calcium oxide of the cement binder is about 50.76%, while the Loss on Ignition (LOI) for cement and bagasse ash is around 6-10%. The elemental composition of bagasse ash is within the limit specified by ASTM standards for pozzolana. The detailed chemical composition of cement and BA is listed in Table 2. The XRD of BA ash showed a high range of reactive silicas and oxides, as shown in Figure 2. The coconut shells were procured from the coconut mandi located at Thiruporur, Kanchipuram district, Tamilnadu. The dry coconut shell was crushed using a crusher in such a way that the gradation of the broken coconut shell ranges from 4.75 mm to 12 mm aggregate size to achieve high packing density. The coconut shells collected from the coconut mandi and the broken coconut shell of size 4.75 mm to 12 mm are shown in Figure 3. To improve the strength of CSC, scrap steel fiber (Figure 4), stored as waste in the manufacturing laboratory was collected and used as fiber reinforcement. The length of the fibers was cut to 20-40 mm and the diameter of the scrap steel fibers varies from 0.5 -0.7 mm. The physical properties of coconut shell gravel and scrap steel fiber are listed in Table 3. The Scanning Electron Microscope (SEM) image showing the uniform crystalline structure of cement particles and image of bagasse ash with spherical, cuboidal and polygonal particles along with porous structure of coconut shell are shown in Figure 5 (a-c).

Figure 1.(a) Sugarcane fiber (b) burnt bagasse ash (c) sieved bagasse ash

Table 2. Chemical properties of cement and bagasse ash

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	P_2O_5	Na_2O	K_2O	MgO	LOI
Cement	23.86	5.77	2.19	50.76	0.12	0.91	0.92	1.36	6.97
Bagasse Ash (BA)	56.37	14.61	5.04	2.36	0.85	1.57	3.29	1.43	10.53

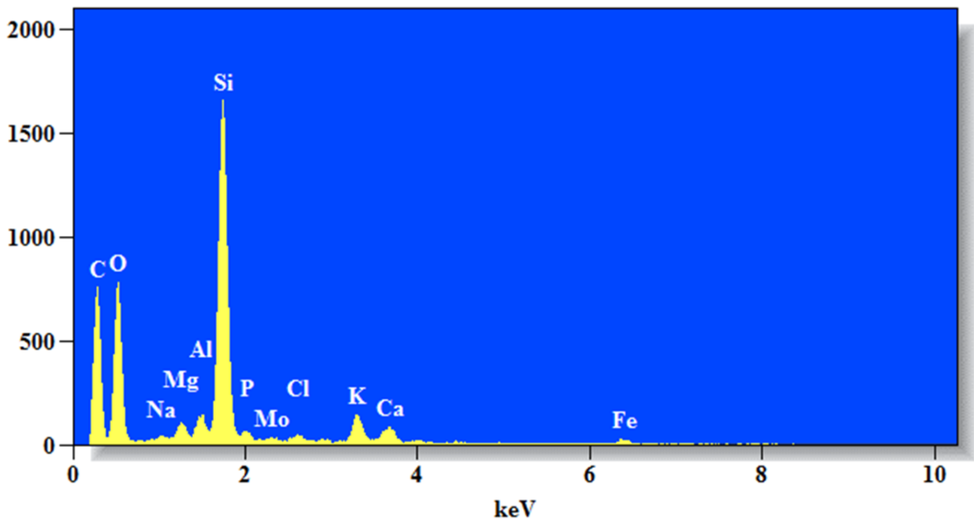

Figure 2. Elemental composition of bagasse ash

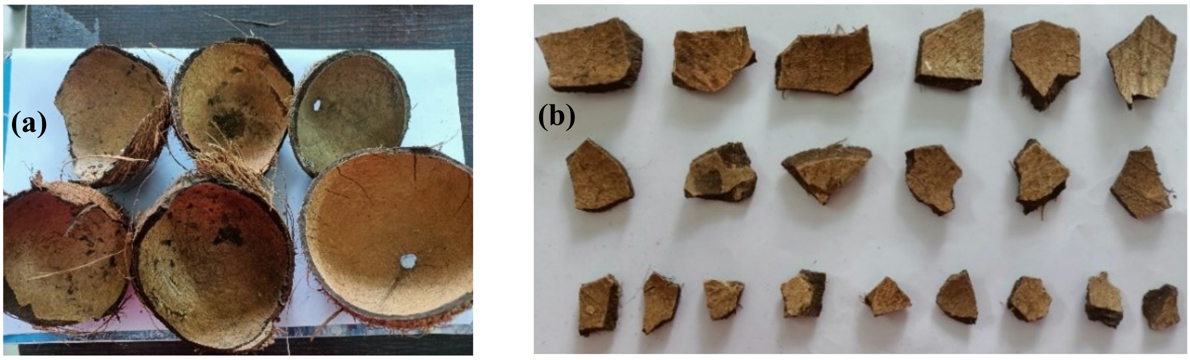

Figure 3.(a) Coconut shells (b) broken shells of 4.75-12 mm sizes

Figure 4. Scrap steel fiber

Table 3. Physical property of coconut shell and scrap steel fiber

Physical Properties	Specific Gravity	Crushing Value (%)	Impact Value (%)	Water Absorption (%)	Fineness Modulus	Bulk Density (kg/m^3)	Abrasion value (%)	Crushing value (%)
Gravel	2.85	20.2	18.6	0.66	6.79	1.68	10.5	20.5
Coconut shell	1.20	2.58	8.15	24	6.26	550	1.8	2.67
Physical Properties of scrap steel fiber	Cross-section	Diameter (mm)	Length (mm)	Unit Weight (kg/m^3)	Elasticity modulus (N/mm^2)	Tensile strength (N/mm^2)	Aspect ratio (%)	Elongation (%)
	deformed and straight	0.3 – 0.75	5 – 20	7850	2x10^5	500 – 3000	45 – 100	5 – 35

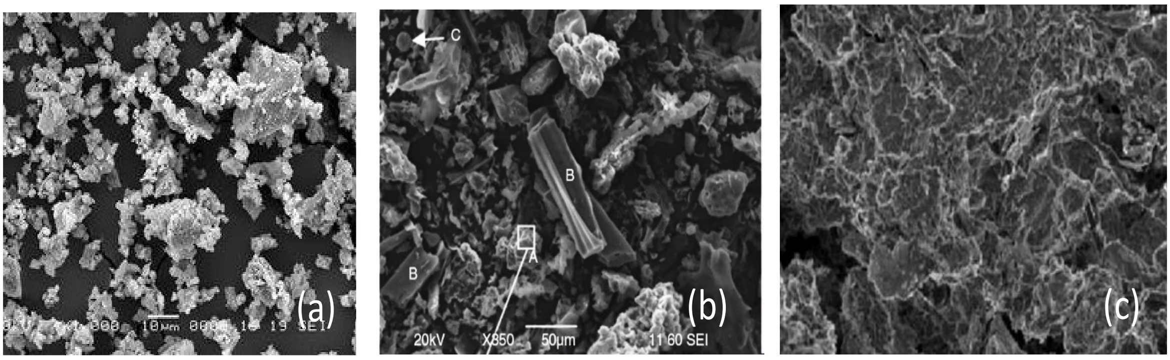

Figure 5. SEM image of (a) cement; (b) bagasse Ash with polygonal (A), cuboidal (B) and spherical (C) shaped particles; (c) coconut shell

4.2 Mix proportions and specimen ID

Before the preparation of the concrete mix, the broken shell was immersed in a water tub for 48 hours, to prevent the absorption of water by coconut shell from the wet concrete mix. The control mix's ingredients, namely cement, sand, coarse aggregate, water, and plasticizer, were mixed in the following proportions: 1:1.64:1.72: 0.32: 0.01. River sand of specific gravity of 2.37 and a fine modulus of 2.9 was used as fine aggregate. Totally, ten mixes were prepared, the first mix is the control mix without any mineral admixtures and 100% cement (CM). The second set of mixes was the bagasse ash replaced concrete mix, in which the bagasse ash was replaced at 10-30 % by weight of cement and designated as CM-10BA, CM-20BA, CM-30BA for 10%, 20 % and 30% of replacement of cement respectively. From the second set of mix the optimum percentage of BA replacement was determined and the same percentage of replacement of BA was maintained for the third set of concrete mixes. For the third set, a total of six mixes were prepared, starting with a concrete mix with 10% BA, 3% scrap steel fiber and 100% gravel aggregate (CM-BA-SrF). In the remaining mixes, the coarse aggregate was replaced at a percentage of 10-50% with coconut shells. Along with the coconut shell addition, 10% of BA and 3% steel fiber were maintained constant throughout all the mixes. The mixes were identified as CS1-BA-SrF for 10 % coconut shell replacement, 10% BA and 3% scrap fiber. Similarly, the other mixes were identified accordingly. The mix proportions are listed in Table 4.

4.3 Testing of specimens

The workability of control and coconut shell concrete was determined by conducting a slump cone test. The slump values were noted for each mix and only one trial was done for the slump cone test. The fresh density and hardened density of each mix were calculated by measuring the weight of the specimen in the fresh state, hardened state and after oven drying. The strength properties of concrete specimens were assessed by conducting compressive strength tests on a cube of 150 mm size, splitting tensile strength test on cylinder specimens of dimensions 150 mm × 300 mm, flexural strength tests on a 100 mm ×100 mm × 500 mm beam, and modulus of elasticity tests on a 150 mm × 300 mm cylinder. The test set used to measure the strength properties is shown in Figure 6 (a-e). For the hardened concrete test, three specimen readings were noted and the average value of the strength properties were calculated and tabulated in Table 5.

Table 4. Mix proportions

Specimen ID	Cement (kg/m^3)	Bagasse Ash (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Coconut shell (kg/m^3)	Scrap steel fiber (kg/m^3)	Water content (kg/m^3)	Super plasticizer (kg/m^3)
CM-1	500	-	970	1010	-	-	160	5
CM -10 BA	450	50	970	1010	-	-	160	5
CM -20 BA	400	100	970	1010	-	-	160	5
CM -30 BA	350	150	970	1010	-	-	160	5
CM-BA-SrF	450	50	970	1010	-	15	160	5
CS1-BA- SrF	450	50	970	924	37	15	160	5
CS2-BA- SrF	450	50	970	838	74	15	160	5
CS3-BA- SrF	450	50	970	752	111	15	160	5
CS4-BA- SrF	450	50	970	666	148	15	160	5
CS5-BA- SrF	450	50	970	580	185	15	160	5

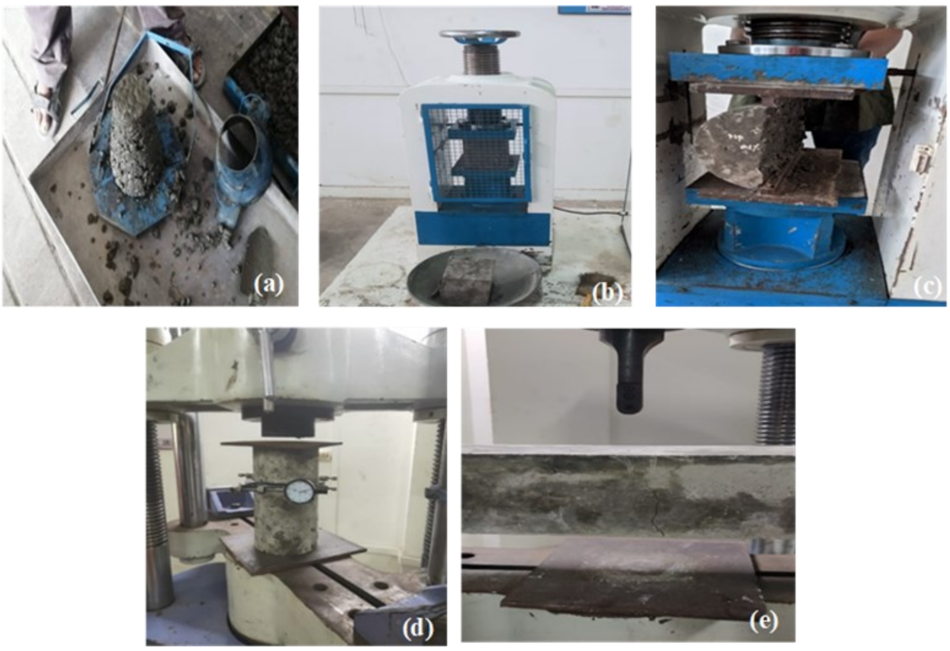

Figure 6. Fresh and hardened concrete test setup

Table 5. Density and workability properties of control and coconut shell concrete

Specimen ID	Wet density (kg/m^3)	Demolded density (kg/m^3)	Air dried density (kg/m^3)	Oven dried density (kg/m^3)	Slump
CM	2708	2631	2625	2560	85
CM -10 BA	2645	2504	2489	2433	78
CM -20 BA	2610	2480	2425	2390	76
CM -30 BA	2590	2455	2394	2350	75
CM-BA-SrF	2693	2593	2581	2530	73
CS1-BA-SrF	2563	2323	2311	2255	65
CS2-BA-SrF	2347	2299	2290	2228	61
CS3-BA-SrF	2240	2246	2222	2160	56
CS4-BA-SrF	2169	2169	2160	2100	52
CS5-BA-SrF	2010	2107	2077	1995	45

5 Results and Discussion

An experimental study was done to understand the fresh and hardened properties of coconut shell scrap steel fiber reinforced concrete. The fresh density, hardened density and slump values were measure for all the mixes and tabulated. Similarly, the hardened concrete test such as compressive, split, modulus of elasticity and flexural properties were measured and tabulated.

5.1 Density of scrap steel fiber reinforced CS concrete

For each mix, the fresh weight of the concrete specimen, the weight of the demolded specimen, weight of the specimen following 24 hours of air drying, and the final weight of the specimen following 24 hours of oven drying at 120°C were measured. The fresh density, air-dried density, and oven-dried density were determined and summarised in Table 5. Normally the density of light weight aggregate concrete varies between the range of 1600-2000kg/m^3, but in the present study the gravel aggregate was partially replaced with CS, and therefore the oven dry density of coconut shell concrete varied from 2255-1995kg/m^3, in which, the CS5-BA-SrF mix with 50% replacement of CS falls under the category of light weight concrete. For the control mix (CM) the density of concrete was around 2560 kg/m^3, as the cement content was partially replaced with 10-30% BA, the dry density decreased from 2433kg/m^3 to 2350kg/m^3. This is because, specific gravity of BA ranges is lesser when compared to cement. Therefore when cement is replaced with BA, a higher volume of concrete will result in a lesser density [38]. For 10%, 20% and 30% replacement of cement with BA, the density reduction is approximately around 5%, 7% and 8% respectively. The addition of SrF to BA replaced concrete (CM-BA-SrF) slightly increased the density from 2433 kg/m^3 to 2530 kg/m^3, due to the addition of steel fiber. For the third set of mixes namely the coconut shell concrete, the density decreases with the increased percentage of CS. For 10% replacement of CS the wet density and dry density were around 2563 kg/m^3 and 2255 kg/m^3 respectively. As the replacement percentage increases to 50%, the wet density and dry density decrease to 2010 kg/m^3 and 1995 kg/m^3. The variation of density for the control mix (CM) and BA concrete mix with BA(CM-BA) and coconut shell BA concrete with scrap steel fiber (CS-BA-SrF)) is shown in Figure 7.

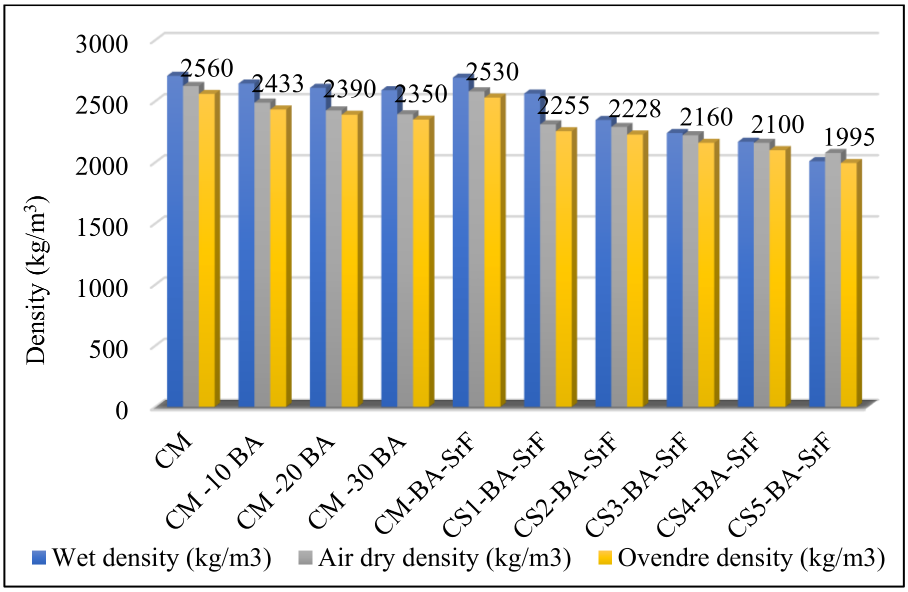

Figure 7. Wet density, air dried density and oven dried density of CS-SrF reinforced concrete

The linear empirical equations that relate the percentage of coconut shell content to the density of concrete are given by equation (1). It can be observed that a very high coefficient of determination (0.96) was obtained. The linear regression plot to correlate density with the compressive strength is shown in Figure 8 and the developed equation with a high regression value ($R^2 = 0.91$) is given by equation (2).

$$D = -64.8\ CS\% + 2342 \tag{1}$$

$$D = 298.59\sqrt{fc'} + 549.47 \tag{2}$$

5.2 Workability of scrap steel fiber reinforced CS concrete

The slump test is very frequently used to measure the flowability of concrete. The slump values determine the ease with which the concrete flows and is placed in the mould. The slump value recorded for the present work is listed in Table 5. The variation of slump for the control mix, concrete mix with BA and coconut shell concrete mix with scrap steel fiber is shown in Figure 9. Previous research work suggested that the slump of conventional concrete varies from 100-125 mm, while that of lightweight aggregate concrete ranges from 50 mm to 75 mm [40]. In the present study, the slump value of coconut shell concrete ranged between 65 mm and 45 mm. The slump value recorded for the control mix was 85 mm, which increased with the amount of bagasse ash in concrete. With the addition of 10%, 20% and 30% of BA the slump value increases to 89 mm, 90 mm, 92 mm respectively. The reason for this increase in the workability is that, the bulk density of BA which is less than cement, fills small pores in the cement matrix, occupies more volume in the concrete mix making it less permeable and more flowable. Therefore, the addition of mineral admixtures up to 5-20% increases the workability of concrete [38]. The addition of steel fibers hinders the movement of aggregate and thereby reduces the workability of fresh concrete. The workability of CM-BA-SrF concrete reduces from 89 mm to 73 mm with the addition of 3% of scrap steel fiber. The workability of coconut shell scrap steel fibre reinforced concrete is further reduced to 65 mm, 61 mm, 56 mm, 52 mm, and 45 mm for 10%, 20%, 30%, 40%, and 50% coarse aggregate replacement, respectively. The irregular shape of coconut shell and the flaky nature of coconut shell tend to reduce the workability of concrete. The correlation between the slump and CS percentage for all the concrete mixes is shown in Figure 10. The correlation equation relating the slump (S) with the percentage of replacement of coconut shell (CS%) is given by equation (3). The correlation equation predicted by other researchers, for CS concrete with steel fiber [36]; CS concrete with sisal fiber [2] is given by equations (4) and (5) respectively.

$$S = -0.6971CS\% + 78.095 \tag{3}$$

$$S = -48\ SF + 74 \tag{4}$$

$$S = -8.5\ SiF + 72 \tag{5}$$

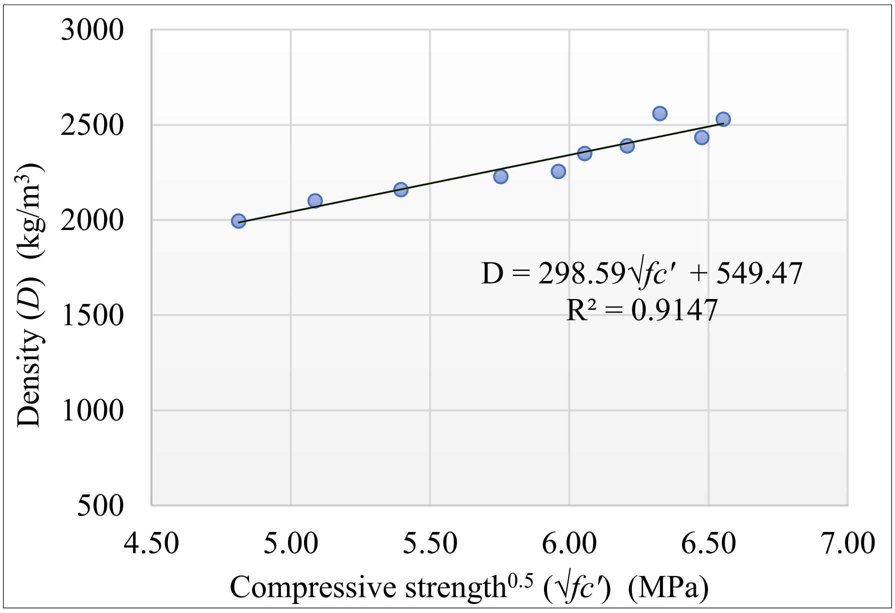

Figure 8. Correlation of density with compressive strength$^{0.5}$

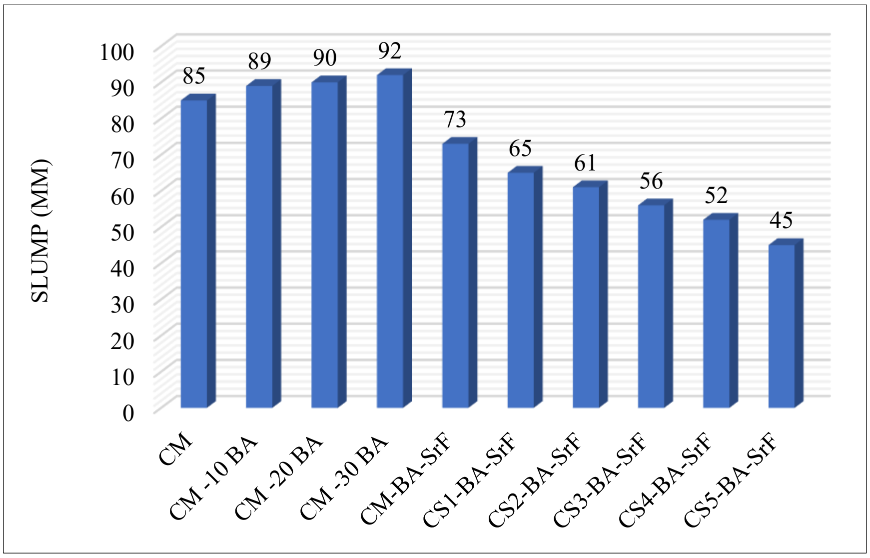

Figure 9. Variation of slump for control and coconut shell concrete

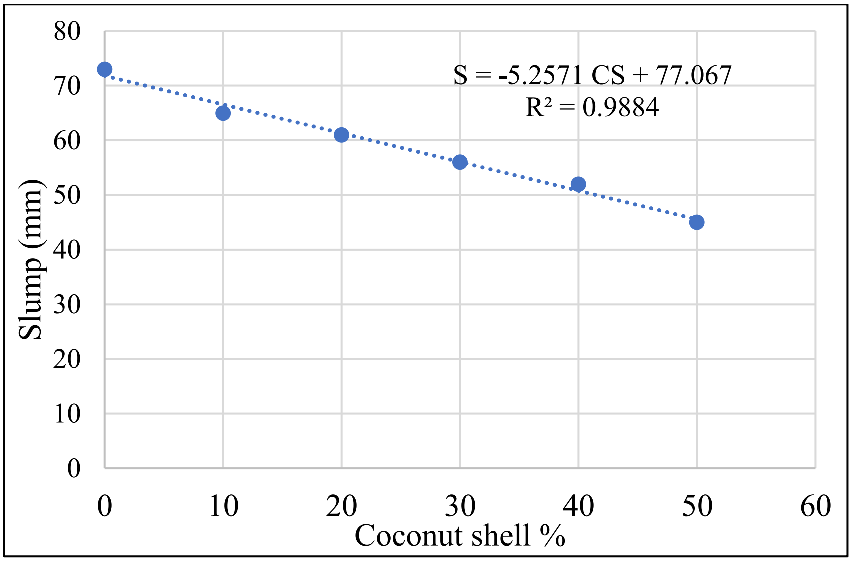

Figure 10. Correlation relation of slump with the percentage replacement of CS

5.3 Compressive Strength

The hardened concrete test was done after 28 days of water curing, and the values are listed in Table 6. The variation of compressive strength of concrete for control mix, bagasse ash concrete mix and fiber reinforced coconut shell concrete mix is shown in Figure 11. In the current study, 10% cement replacement with BA increases compressive strength from 40.01 MPa to 41.94 MPa, which is about 4% higher than the control mix. Previous research on bagasse ash concrete, proved that the strength of concrete, increased with a 5-10% substitution of cement with BA. Beyond 10% the strength is slightly affected [38]. The increase in strength properties is due to the high silica content of BA which is obtained during the burning process of sugarcane fiber at 800°C in control chamber. The silica content in BA has excellent pozzolanic property which helps to improve the strength of concrete [30]. Also the lower bulk density of BA occupies small pores in the concrete mix which reduces the permeability and also increases the compressive strength [4]. From the tabulated values it can be concluded that, out of three types of cement replaced bagasse ash concrete mix, the concrete mix with 10% BA showed increase in compressive strength. Our present result matches well with the previous research findings on BA replaced concrete. Therefore, 10% replacement of cement with BA was adopted as standard for other mixes with coconut shell and scrap steel fibers. The fibre in the fiber-reinforced BA concrete mix holds the aggregates and cement matrix together and effectively distributes the crack, delaying the formation of a major crack plane and increasing load carrying capacity. The compressive strength of fiber reinforced BA concrete (CM-BA-SrF) showed up to 2% increase in strength compared to unreinforced mix (CM-10BA). It was proven from the authors previous research work that, up to3% of fiber addition will help to improve the strength of fiber reinforced concrete [8]. Therefore 3% of steel fibers added were maintained for the remaining concrete mixes with coconut shell.The Scanning Electron Microscope (SEM) image of 20% and 30% CS concrete along with the failed specimen is shown in Figure 12 (a-d).

Table 6. Strength properties of control and coconut shell steel fiber reinforced concrete

Specimen ID	Compressive Strength (N/mm^2)	Splitting Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)	Modulus of Elasticity (GPa)
CM	40.01	3.76	4.43	27.39
CM -10 BA	41.94	3.89	4.62	28.04
CM -20 BA	38.54	3.65	4.35	26.88
CM -30 BA	36.67	3.54	4.29	26.22
CM-BA-SrF	42.95	3.98	4.78	29.23
CS1-BA-SrF	35.54	3.56	4.47	27.10
CS2-BA- SrF	33.11	3.31	4.23	25.40
CS3-BA- SrF	29.11	3.11	4.18	24.23
CS4-BA- SrF	25.88	2.97	4.01	23.11
CS5-BA- SrF	23.17	2.87	3.91	21.20

For the coconut shell fiber reinforced concrete, the compressive strength decreases with the increase in coconut shell percentage. When coarse aggregate is replaced with coconut shell, the strength decreases from 42.95 MPa to 35.54 MPa, 33.11 MPa to 29.11 MPa, and 25.88 MPa to 23.17 MPa. According to previous research findings, the compressive strength of steel fibre coconut shell concrete was approximately 35.6 MPa [36], and the compressive strength of polypropylene fibre reinforced coconut shell concrete was approximately 36.8 MPa [37]. Without fiber reinforcement, Gunasekaran et al [19] were able to achieve a compressive strength of 26.7 MPa. Therefore, the present research finding is well within the acceptable range of previous research findings. The compressive strength values of all the CS-BA-SrF reinforced concrete satisfied the minimum requirement of structural lightweight concrete (20MPa) for all percentages of replacement of CS.

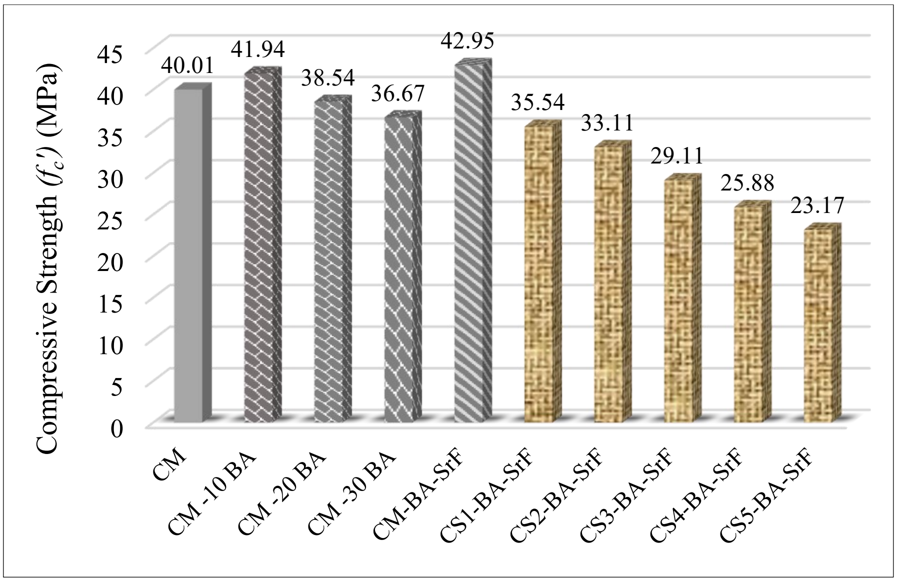

Figure 11. Compressive strength of control, BA concrete and coconut shell scrap steel fiber concrete

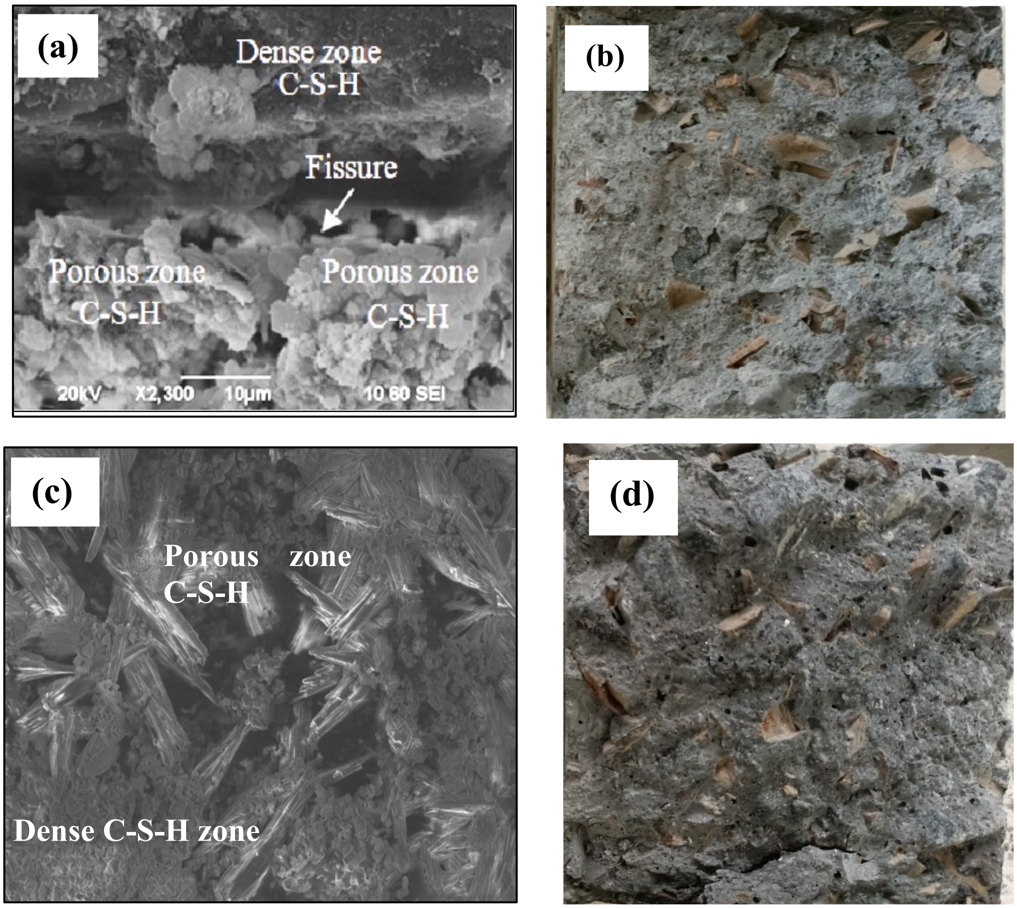

Figure 12. (a &c) SEM image of CS concrete showing the dense and porous Calcium-Silicat-Hydrate (C-S-H) region; (b &d) tested CS cube specimen

5.4 Split tensile strength

The splitting tensile strength values of all the concrete mixes are listed in Table 6. The variation of splitting tensile strength for all the mixes is shown in Figure 13. The splitting tensile strength of the control mix was 3.76 Mpa, which increased by 3.5% with the addition of 10% BA. Similar to compressive strength, the tensile strength also showed an increase in the splitting tensile strength for 10% of BA, beyond which the splitting tensile strength decreases. For the fiber reinforced mix, the addition of 3% scrap steel fiber increases the tensile strength from 3.89 to 3.98 MPa. As the steel fibers have a higher tensile strength, the fiber binds the aggregate and the cement matrix together, preventing propagation of cracks and helping to improve the tensile strength. For fiber reinforced coconut shell concrete, the tensile strength decreases with an increase in the percentage of coconut shell. The density of CS aggregate, the orientation of the aggregate, the bond between the aggregate and the cement matrix, or the thin shape of coconut shell aggregate all contribute to a reduction in strength properties [30]. Fracture of CS aggregate was not identified in any of the tested specimens, which proves that the brittle nature of CS does not affect the strength of concrete when used as replacement for conventional aggregate [19]. Figure 14(a-f) depicts the tested specimen with the irregular orientation of CS aggregate and uncrushed CS aggregate after loading. For 10%, 20%, 30%, 40% and 50% CS aggregate scrap steel fiber reinforced concrete the splitting strength was 3.56 MPa, 3.31 MPa, 3.11 MPa, 2.97 MPa and 2.87 MPa. Despite the fact that the strength decreases as the percentage of CS replaced increases, the splitting tensile strength recorded for all of the coconut shell scrap fibre mixes was well within the minimum splitting tensile strength requirement (2 MPa) for structural light weight concrete. In the previous research work, the Splitting tensile strength values of coconut shell brick aggregate concrete with 0%, 5%, 10% and 15% of CSwere about 2.75, 2.87, 2.25 and 2.09 MPa, respectively[41]. Prakash et al [37] reported that inclusion of polypropylene fibres showed a split tensile strength 0f 3.12 Mpa and 3.65 MPa for full and partial replacement of coconut shell. The addition of steel fibers showed improved splitting tensile strength of 4.25 Mpa for partially replaced coconut shell concrete [36].

Figure 15 depicts the linear regression plot used to develop a correlation between compressive strength and splitting tensile strength. The empirical equation developed, to correlate splitting tensile strength with compressive strength with a high regression value (R^2 = 0.98) is given by equation (6). The previous research equations correlating splitting tensile strength with the compressive strength of coconut shell concrete with sisal fiber, polypropylene fiber and steel fiber reinforcement are given by equations (7), (8) and (9) respectively. The developed relation matches well with the previous researchers' equations.

$$f_{t(SrF)} = 0.65\sqrt{f_c} \quad (6)$$

$$f_{t(SiF)} = 0.531\sqrt{f_c} \quad (7)$$

$$f_{t(PPF)} = 0.66\sqrt{f_c} \quad (8)$$

$$f_{t(SF)} = 0.82\sqrt{f_c} \quad (9)$$

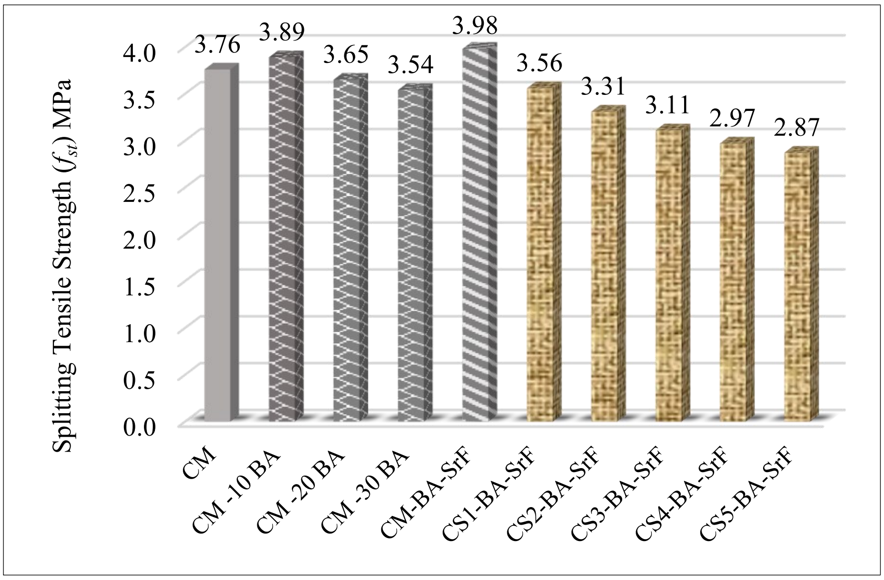

Figure 13. Splitting tensile strength of control, BA concrete and fiber reinforced coconut shell concrete

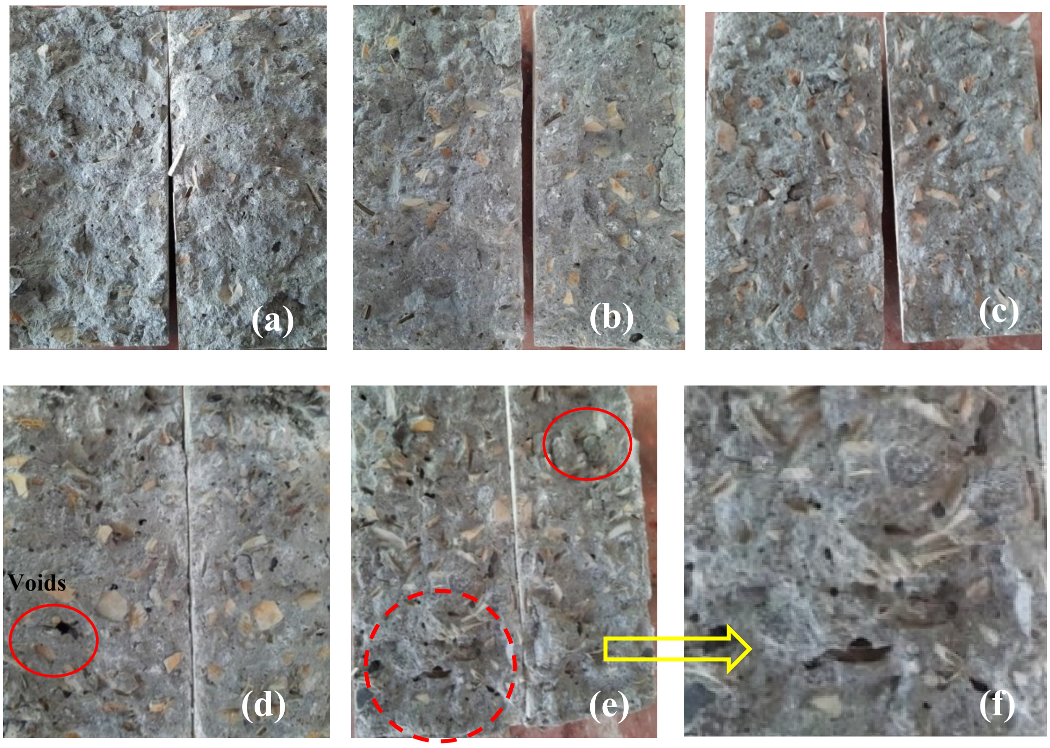

Figure 14. (a-e) Failed specimen of 10%,20%,30%,40% and 50 % CS concrete; (f) increase in voids with CS%

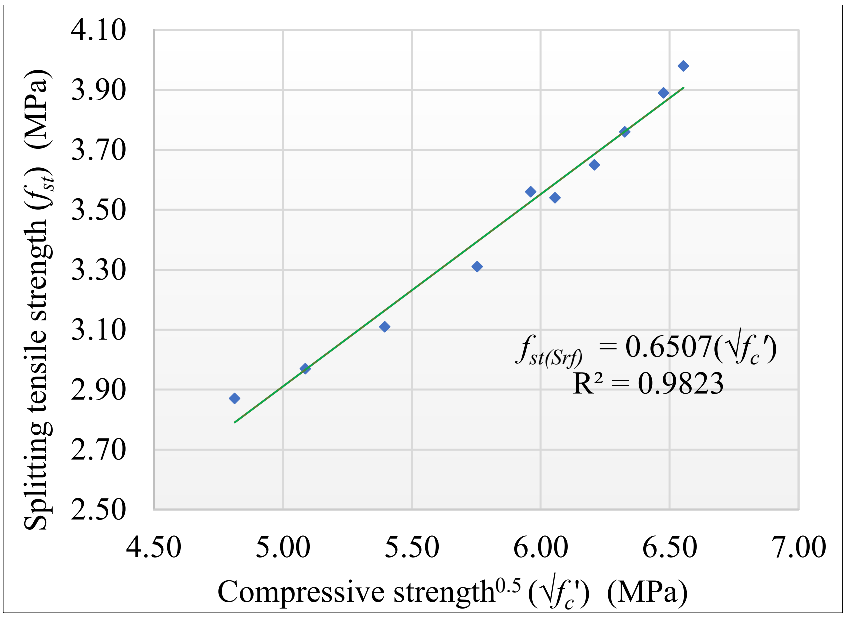

Figure 15. Regression plot of splitting tensile strength and compressive strength

5.5 Flexural Strength

The flexural strengths of normal and coconut shell fiber reinforced concrete are given in Table 5. The flexural strength of control specimen was 4.9 MPa which increased by 8.5% for a 10% replacement of cement with BA. Similar to compression and splitting tensile strength, the flexural strength also increases with the addition of 10% of BA, beyond which the strength reduces. For the fiber reinforced mix the strength increased by 16 % with the addition of 3% scrap steel fiber when compared to control mix (CM). The post-peak toughness of the beam under flexural load is increased by the addition of fiber. All the fibers embedded in the concrete matrix are involved in the stress transfer, which continues until the failure of the specimen, which occurs after the ultimate capacity of the fibers is reached. The failure pattern of the beam and the fiber involved in the bridging of cracks is shown in Figure 16. For the coconut shell fiber reinforced mix, the flexural strength values vary from 5.32 MPa, 5.21 MPa, 5.11 MPa, 4.98 MPa and4.78 MPa for 10%, 20%, 30%, 40% and 50% CS fiber reinforced concrete respectively. The variation of flexural strength is shown in Figure 17. In the previous work, the addition of sisal fiber showed a flexural strength of 5.7 MPa, which corresponds to22% increase in the flexural strength for a 4% addition of sisal fiber [43]. Similarly, Gunasekaran et al reported a flexural strength of 4.78 Mpa without any fiber reinforcement [19]. The present flexural strength values agree well with the previous research findings. The linear regression plot to develop a correlation between the compressive strength and flexural strength with a high regression value (R^2 = 0.91) is shown in Figure 18. The developed equation relating flexural and compressive strengths is given by equation (10). The previous research equation correlating flexural strength with the compressive strength of coconut shell concrete with sisal fiber, polypropylene fiber and steel fiber reinforcement are given by equations (11), (12), and (13), respectively. The developed relation matches well with the previous researchers' equations.

$$f_{r(SrF)} = 0.416\sqrt{f_c} \quad (10)$$

$$f_{r(SiF)} = 0.495 f_c^{2/3} \quad (11)$$

$$f_{r(PPF)} = 0.562 f_c^{2/3} \quad (12)$$

$$f_{r(SF)} = 0.58 f_c^{2/3} \quad (13)$$

Figure 16. Fibers involved in the crack arresting process

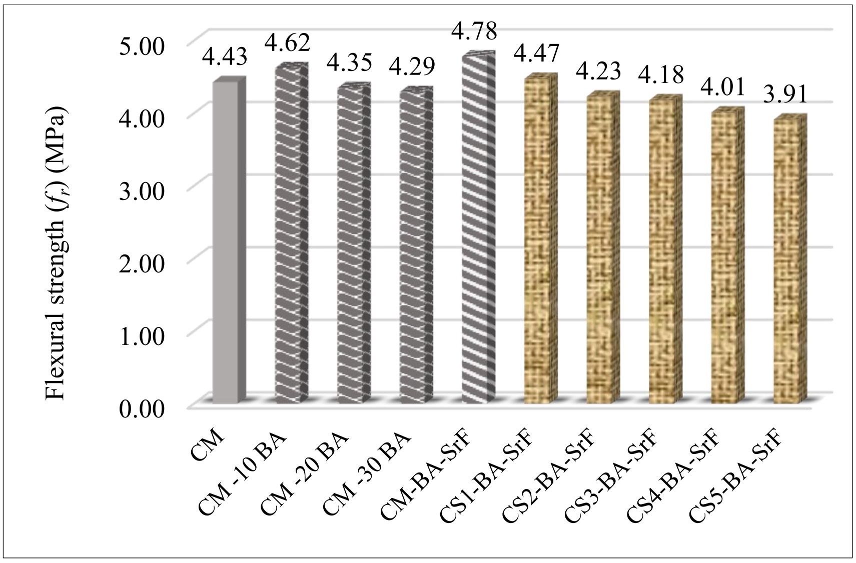

Figure 17. Flexural strength of control, BA concrete and coconut shell scrap steel fiber concrete

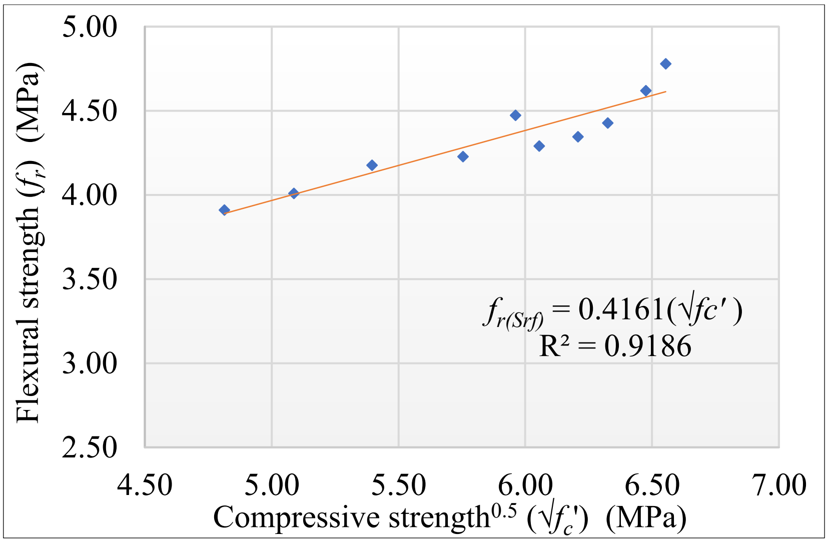

Figure 18. Regression plot of flexural strength Vs compressive strength

5.6 Modulus of Elasticity

Within the elastic region, the ratio of stress and corresponding strain measures the value of the modulus of elasticity (MoE) of concrete. Since concrete is a brittle material, the addition of steel fibers helps to improve the strength properties, mainly the compression, tension, and flexural strengths, thereby increasing the modulus of elasticity value. The variation of MoE for coconut shell BA fiber reinforced concrete is shown in Figure 19. For the control specimen the MoEwas 27.3 GPa which slightly increased to 28.04 GPa with the addition of 10% BA. The silica content in BA helps to improve the paste's strength by forming a dense Calcium -Silicate-Hydrate (C-S-H) region. For the increase in BA content beyond the MoE decreases, which is similar to the compression, tension and flexural strength value. For the addition of fibers, the MoE increase to 29.23 GPa which is about a 7% increase when compared to control mix. The MOE decreased with increasing percentage of gravel replacement with coconut shell for the third series of specimens, namely the fiber-reinforced CS concrete specimens. For the third series of specimen namely the, fiber reinforced CS concrete specimens, the MoE decrease with the increase in the percentage of replacement of gravel with coconut shell. For 10%, 20%, 30%, 40% and 50% CS fiber reinforced concrete the MoE value was 27.1GPa, 25.4 GPa, 24.2 GPa, 23.1 GPa and 21.2 GPa respectively. The voids in the concrete mix increase with the amount of CS, which also reduces the strength of the concrete and thereby the MoE value. The previous research on coconut shell concrete with polypropylene fibers reported anincrease in MoE of 8% for 50% addition of fiber volume. Which matched well with the present result. Coconut shell concrete with GGBS slag as cement replacement reached a MoE of 8 GPa [44], low value of MoE was due to the absence of fiber reinforcement. Similarly CS concrete with sisal fiber showed a MoE of 16 GPa for 3% addition of sisal fiber [45]. Therefore, it can be concluded that, addition of BA and scrap steel fibers helps to reduce the strain in the concrete for the applied compression load, thereby increasing the Modulus of

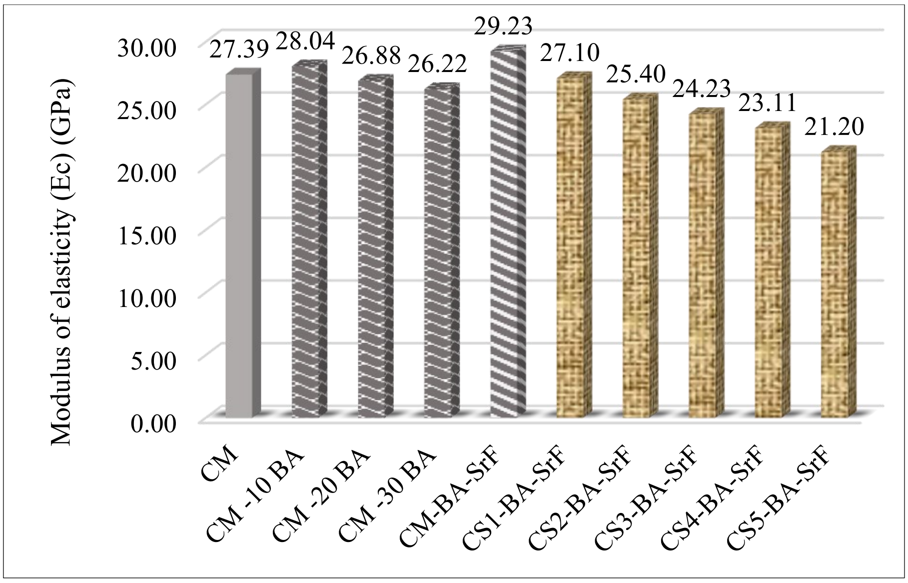

Figure 19. Modulus of elasticity of control, BA concrete and coconut shell scrap steel fiber concrete

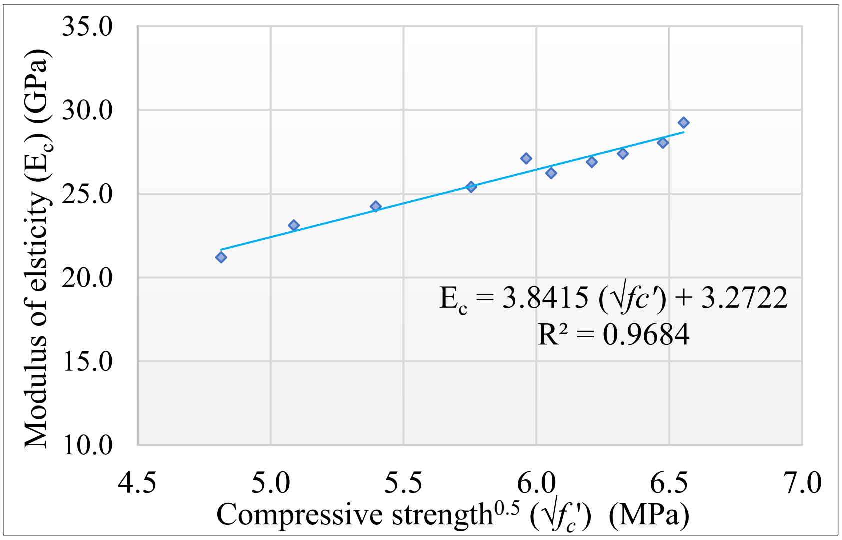

Figure 20. Regression plot of Modulus of elasticity Vs compressive strength

Elasticity. The linear regression plot to develop a correlation between the compressive strength and modulus of elasticity with high regression value (R^2 = 0.96) is shown in Figure 20. The developed equation relating modulus of elasticity and compressive strength is given by equation (14). The previous research equation correlating modulus of elasticity with the compressive strength of sisal fiber reinforced coconut shell concrete[43] is given by equation (15) and the equation predicted by Concrete Structural Design Standard Specification (CSDS) is given by equation (16) respectively. The established relationship corresponds well to the previous researchers' and standard specifications.

$$E_{c(SrF)} = 0.3.84 f_c{}^{0.5} \quad (14)$$

$$E_{c(SiF)} = 0.0307 w^{1.5} f_c{}^{0.5} \quad (15)$$

$$E_{c(CSDS)} = 0.77 w^{1.5} f_c{}^{1/3} \quad (16)$$

6 Conclusion

The following conclusions can be drawn from the experimental investigation into the fresh and mechanical properties of coconut shell bagasse ash scrap steel fibre reinforced concrete:

- The density of concrete in the control mix (CM) was around 2560 kg/m3, which decreases by 5%, 7%, and 8% for 10%, 20%, and 30% replacement of cement with BA, respectively. Therefore, bagasse ash concrete mix helps to reduce the self-weight of structural concrete. The oven-dry density of coconut shell concrete mixes ranged from 2255 to 1995 kg/m3, with the CS5-BA-SrF mix with 50% CS replacement falling under the category of light weight concrete.
- The slump value recorded for the control mix was 85 mm, which increased with the increase in the percentage of bagasse ash. With the replacement of 10%, 20% and 30% of BA the slump value increases to 89 mm, 90 mm, 92 mm

respectively. The slump value of coconut shell concrete ranged between 73 mm and 45 mm which is due to the irregular shape of CS aggregate.

• The compressive strength of scrap fiber reinforced BA concrete (CM-BA-SrF) showed up to a 2% increase in strength compared to unreinforced mix (CM-10BA). For the coconut shell fiber reinforced concrete, the compressive strength decreases with the increase in coconut shell percentage.

• The splitting tensile strength, flexural strength, and modulus of elasticity values increase with the addition of 10% BA and scrap fiber. For fiber reinforced coconut shell concrete, the strength properties decrease with an increase in the percentage of coconut shell. The reduction in strength properties with the increase in the percentage of coconut shell is due to the density of CS aggregate, the orientation of the aggregate, bond between the aggregate and cement matrix or the thin shape of coconut shell aggregate.

• Fracture of coconut shell aggregate was not identified in any of the tested specimens, which proves that brittle CS aggregate when used as a replacement for conventional aggregate does not have any limitations. Therefore, it can be concluded that, bagasse ash, scrap fiber and coconut shell can be effectively used as replacement materials in concrete to produce a sustainable concrete solution.

• The control mix with up to 10% replacement of cement with bagasse ash helps to develop sustainable concrete with a minor loss in strength. Similarly, coconut shell concrete with up to 30% aggregate replacement can be used effectively for structural applications. Beyond 30% replacement, the strength criteria fall below the minimum strength requirement for structural concrete, and such light-weight concrete can be used for non-load-bearing structural applications.

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