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Article

Regression Based Performance Analysis of Composite Light Weight Concrete

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Abstract. Low cost sustainable structural green concrete produced using lignocellulosic waste (coconut shell) and industrial waste (ground granulated blast furnace slag) was investigated in this study. Various cost effective pre-treatments were carried out on coconut shell such as cold water extraction, hot water extraction and lime water extraction to remove the extractives (hemicelluloses, phenols). This primarily enhances the interface bond strength leading to increased strength of concrete. Workability and compressive strength of the concrete incorporating untreated and pre-treated coconut shell was investigated systematically. Hot water extraction of coconut shell proved to be an effective method to improve the compressive strength of concrete when compared to other pre-treated coconut shell concrete mixes tested in this study. Among the various concrete mixes investigated a maximum compressive strength of 27.0 MPa was achieved using hot water extracted coconut shell incorporated concrete composites.

Keywords: Lignocellulosic waste, supplementary cementitious material, coconut shell, ground granulated blast furnace slag, m-sand, pre-treatment.

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1. Introduction

Sustainable alternative construction materials from waste, is gaining popularity in construction due to environmental issues posed by conventional concrete. Instead of dumping these industrial and agricultural waste as landfill, it can be used effectively as a substitute material in concrete production, thereby reducing the cost of construction [1]. The use of supplementary pozzolanic materials such as ground granulated blast furnace slag (GGBFS), silica fume, rice husk ash, coal ash, wood ash can reduce the use of Portland cement, as well as produce a durable concrete [2, 3]. GGBFS is a by-product obtained from iron processing industry and replacement of cement with GGBFS has proved to increase the resistance against carbonation, sulphate attack, alkali silica reaction and chloride penetration [4].

Next to Portland cement, production of coarse aggregate is the major source responsible for 13-20% of total CO_2 emission. Many efforts have been taken by researchers to promote the usage of waste materials in concrete and to reduce natural resource depletion [2]. In recent years coconut shell (CS) has been successfully used as coarse aggregate owing to its light weight and production of low cost concreting. These are primarily the waste material obtained from agricultural sector and around 15 billion nuts is produced annually in India. The discarded shells are used for handicraft making, in pharmaceuticals, as activated carbon and as fuel for boilers. Apart from this, vast amount of CS is yet to be utilized effectively. Coconut shell concrete (CSC) is classified under light weight concrete and has proven mechanical and durability properties in acceptable range on par with other light weight concrete [5, 6]. Since the composition of CS is comparable to hardwood and generally, hard wood is incompatible with cement. Pre-treatment is necessary to increase its compatibility. Wood materials generally contains soluble organic compounds such as hemicelluloses, starch and phenols known as extractives; insoluble compounds such as lignin, which retard the setting and strength development of cement and make the wood incompatible with cement [7]. It has been noted that cold water extraction dissolves tannins, gums, sugar and coloring matter whereas in addition, hot water extraction dissolves starch, increasing wood cement compatibility [8]. Analysis of CS showed: moisture 8%, ash 0.6%, ethanol extractive 4.2%, lignin 29.4%, hemicelluloses (pentosans) 27.7%, uronic anhydrides 3.5%, cellulose 26.6%, methoxyl 5.6%, nitrogen 0.11% and phenols 26.5% [9]. There was not much significant research carried out on pre-treatment of CS, but coconut coir was pre-treated by various methods like hot water extraction, alkali treatment, for making coir cement boards and to increase the compatibility with cement. Coconut coir possesses high lignin and low cellulose similar to coconut shell which makes them strong and durable. Also mechanical and durability properties of wood cement composites was improved by adding pozzolanic materials like fly ash, silica fume, GGBFS and metakaolin [10]. In addition pre-treatment was carried out by researchers on palm shell which is effectively used as light weight aggregate. Pre-treating palm shell with 20% poly vinyl alcohol (PVA) achieved a compressive strength of 32.84 MPa and with 5% slaked lime solution achieved a compressive strength of 17.87 MPa whereas untreated palm shell concrete achieved a compressive strength of 23.6 MPa [11]. Also replacing 30% of cement by GGBFS reduced the slump significantly in palm shell concrete. In contrast GGBFS increase the viscosity which resists the floating of light weight aggregate and also it prevented the bleeding in concrete [2].

Due to scarcity of river sand in recent years and its large scale usage poses threat to ground water protection, manufactured sand (M-sand) has been used successfully in construction as a suitable alternative, which is cost wise affordable than river sand. M-sand is produced by crushing rock for fine aggregate size in a well graded form. M-sand has angular and rough surface than compared to naturally weathered river sand. M-sand concrete has better mechanical and durability properties than river sand concrete [12].

2. Need for This Study

Even though, research has been done using the above said alternative aggregates (CS and M-sand) and supplementary cementitious material (GGBFS) separately, there was not much significant research has been carried out using all these sustainable waste into concrete. In this study, concrete mix was arrived using CS as coarse aggregate (C), GGBFS as pozzolan and M-sand as fine aggregate (F) to produce structural concrete thereby reducing the environmental consequence caused by conventional concrete materials. Since the composition of CS is similar to wood, various low cost pre-treatments like cold water extraction, hot water extraction and lime water extraction was carried out in this investigation. The compatibility with cement and the characteristics of untreated and pre-treated CSC was systematically analyzed.

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3. Experimental Study

3.1. Materials Used

3.1.1. CS as coarse aggregate

CS is collected from local source and was well seasoned by drying in sunlight to increase its resistance against insect and fungal attack since; it is an organic material like wood and prone to decomposition. Since CS is flaky and irregular in shape it cannot be broken into particular shape; hence it was randomly broken into smaller pieces and two size of CS was selected. Shell size passing through 12.5mm and retained on 10 mm; passing through 10mm and retained on 4.75mm was used as shown in Fig. 1. A good gradation of CS was achieved by adjusting the proportion of two size of CS in such a way to achieve minimum voids by packing density method. The concept behind packing density is that the voids created by larger size particle would be occupied by smaller size particle. In packing density method the smaller and larger size CS were mixed in different proportions by mass in a container of known volume and the bulk density was found. Since CS is flaky and curvy in nature, voids are formed in between large particles. The bulk density increases as we increase the mass proportion of smaller size CS, as the smaller size CS tends to occupy the voids formed by larger shell and after a particular proportion the bulk density starts decreasing as it reaches the optimum packing as shown in Fig. 2. Also the percentage voids for maximum bulk density is minimum, since maximum packing is attained as shown in Fig. 2. Maximum Bulk density was achieved for 70% of 10mm – 4.75mm size and 30% for 12.5mm – 10mm size of CS with minimum percentage voids as shown in Fig. 2. The physical properties of CS and M-sand were given in Table 1.

Fig. 1. Processed coconut shell aggregates.

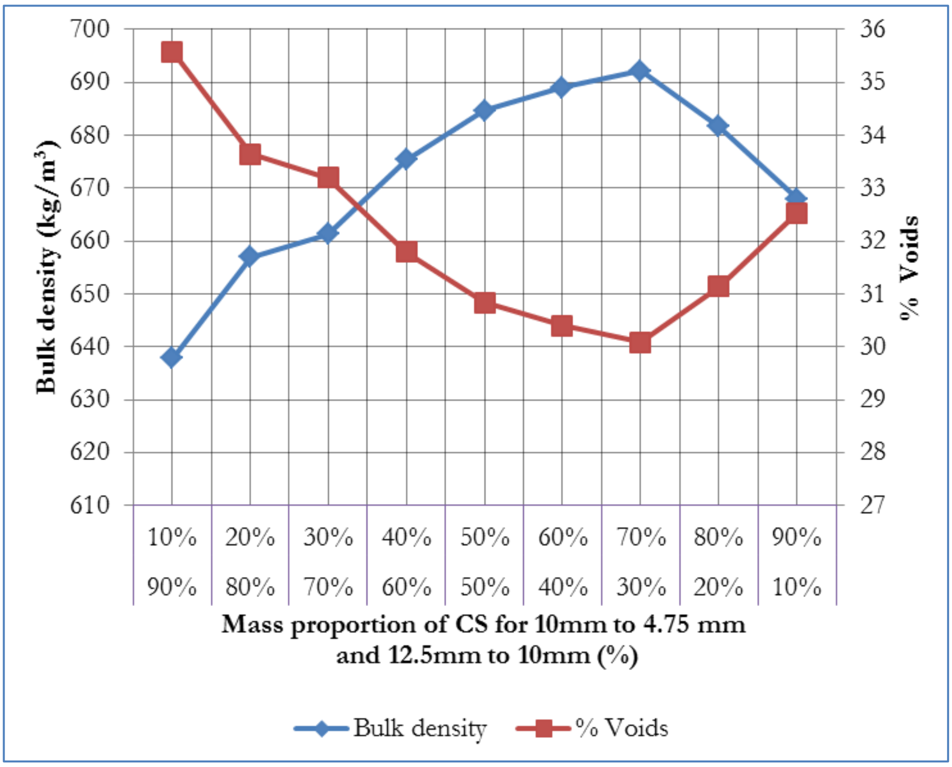

Fig. 2. Packing density for two sizes of air dried CS.

Table 2. Physical and mechanical properties of CS and M-sand.

Physical and mechanical properties	CS		M-sand	
Loose air dried bulk density	692	kg/m³	1599	kg/m³
Moisture content	10.33	%	-	
Specific gravity	0.99		2.541	
Water absorption (24 hours)	29.602	%	0.64	%
Aggregate crushing value	1.597	%	-	
Aggregate impact value	3.937	%	-	
Fineness modulus	6.3		2.91	
Bulking	-		44	%
Sieve analysis	-		Zone II	

3.1.2. M-sand as fine aggregate

M-sand was used as fine aggregate (F) and the sieve analysis results conforms to zone II as per IS 383-1970 [13]. Gradation curve for M-sand and CS was shown in Fig. 3.

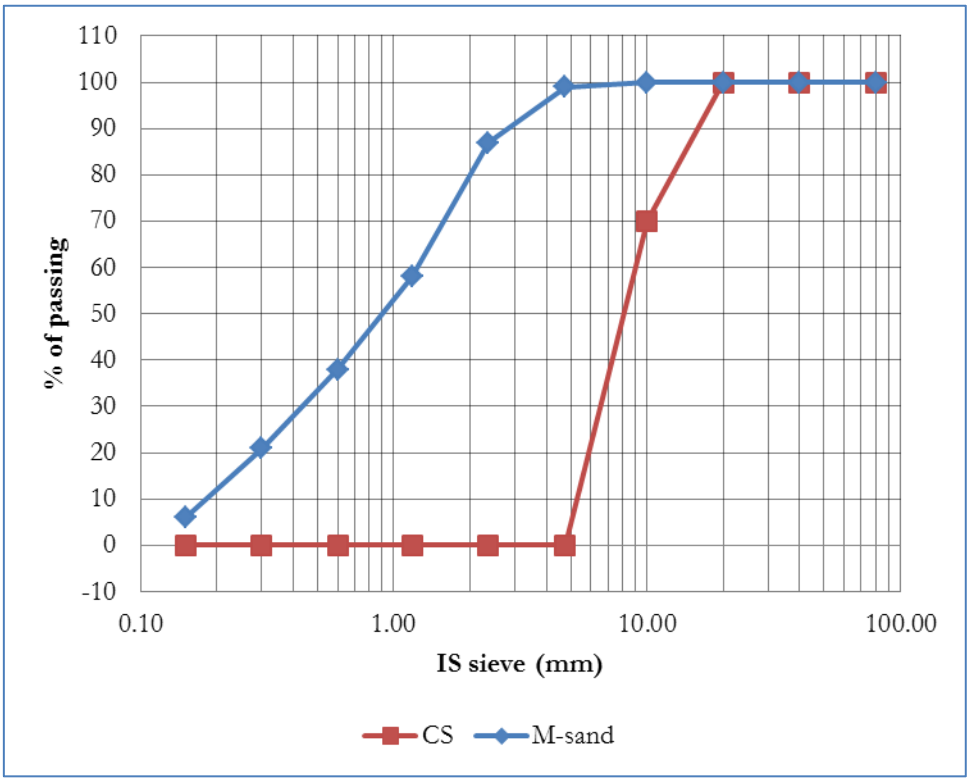

Fig. 3. Gradation curve for CS and M-sand.

3.1.3. GGBFS as mineral admixture

GGBFS with specific gravity of 2.9 was replaced by 0%, 25% and 50% by mass of binder.

3.1.4. Ordinary Portland cement

OPC of grade 53 with specific gravity of 3.15 was used throughout this experiment conforming to IS 12269-1987 [14].

3.1.5. Hyper plasticizer

Carboxylic ether plasticizer of specific gravity 1.15 was used by 1% mass of binder (B) i.e cement and GGBFS throughout the test in order to facilitate workability of fresh concrete mixes with water binder ratio of 0.35.

3.1.6. Water

Potable water (W) free from any contaminants was used in this study.

3.2. Mix Design and Experimental Methodology

Mix design was carried out using ACI 211.2-98 [15] specifications primarily used for light weight concrete. Various trial mixes were carried out by varying W/B, C/F ratios and percentage replacement of GGBFS by using air dried CS (untreated CS). Trial mixes were casted with three cubes for each mix and its workability and compressive strength was determined. Nine mixes which has shown better compressive strength has been selected (see Table 2), and further studies were done on those mixes by doing various pre-treatment on CS.

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Table 2. Mix proportions used.

W/B	CA / FA	% of GGBFS	Cement (kg/m^3)	GGBFS (kg/m^3)	M-sand (kg/m^3)	CS (kg/m^3)	Super plasticizer (kg/m^3)	Water (kg/m^3)
0.35	0.28	0	540.54	0.00	938.10	262.67	5.41	189.19
0.35	0.28	25	401.35	133.78	938.10	262.67	5.35	187.30
0.35	0.28	50	264.91	264.91	938.10	262.67	5.30	185.44
0.35	0.33	0	540.54	0.00	872.92	288.06	5.41	189.19
0.35	0.33	25	401.35	133.78	872.92	288.06	5.35	187.30
0.35	0.33	50	264.91	264.91	872.92	288.06	5.30	185.44
0.35	0.38	0	540.54	0.00	816.21	310.16	5.41	189.19
0.35	0.38	25	401.35	133.78	816.21	310.16	5.35	187.30
0.35	0.38	50	264.91	264.91	816.21	310.16	5.30	185.44

3.2.1. Pre-treatment on CS

Various cost effective pre-treatment like cold water extraction, hot water extraction and lime water extraction was done on CS and was used for the selected mix. The physical appearance of the untreated and pre-treated CS was shown in Fig. 4.

Fig. 4. Physical appearance of untreated and pre-treated CS.

3.2.2. Cold water extraction

The CS was soaked in potable water for 24 hours, washed thoroughly and surface dried. Soaking in cold water for 24 hours dissolves the soluble extractives from CS.

3.2.3. Hot water extraction

The CS was kept in boiling water (100 degree Celsius) for 15 minutes and then extracted for air drying.

3.2.4. Lime water extraction

CS is soaked in 10% lime solution for 24 hours and then washed thoroughly to remove the excess lime and then surface dried since; excess lime causes unsoundness of concrete. Lime reacts with lignin, outer harder layer present in the CS and hydrolyze it thus making it non-reactive.

3.2.5. Casting and testing methodology

CSC cubes were casted of 100 mm x 100 mm x 100 mm size. Three cubes were casted for each mix using untreated and pre-treated CS. After casting, the cubes were covered with polythene sheet to prevent moisture evaporation. The cubes were de-moulded after 24 hours and then cured in potable water at room temperature. The compressive strength of cubes were tested using Digital compression testing machine of

2000 kN capacity operated at a pace rate of 2.3 kN/sec as per IS 516-1959 [16]. The average compressive strength of three cubes was taken.

4. Results and Discussion

4.1. Effect of GGBFS on Workability

The workability of CS incorporated concrete mixes with various percentage (0%, 25% and 50%) replacements of GGBFS was measured using slump cone test. A typical graph showing percentage replacement of GGBFS versus slump was plotted in Fig. 5 for C/F ratio of 0.28, which shows the reduction in workability as the percentage replacement of GGBFS increases. GGBFS being finer than cement requires more water for surface wetting and this may be the reason for reduction in slump which can be observed in Fig. 5. Also, it is inferred from the results provided in Table 3 that workability of cold water extracted and hot water extracted CS was more or less similar. Workability of air dried untreated CSC is slightly lower than cold water extracted CSC. Since untreated CS tends to absorb moisture from concrete which reduces the slump and also there is no availability of free moisture because of less water content, hence only marginal difference in workability was noticed. Also with the increase in C/F ratio the total surface area decreases with the increase in CS and workability increases because of less binder content occupied. The flaky particles of CS were also a factor leading to good workability. The workability of lime water treated CS in concrete was lesser than untreated CS and this may be due to the hydration of residual lime on CS and also the surface roughness caused by the leaching of CS by lime. Even then, the addition of GGBFS caused a reduction in workability a subsequent increase in the viscosity of the matrix leads to homogeneous distribution of CS in the concrete.

4.2. Compressive Strength of Untreated and Pre-Treated CSC

The selected mixes were tested as per IS516-1959 [15] and the compression test results were given in Table 3. It can be noted that the compressive strength of CSC exhibited an increase in strength with an increase in density of concrete as noted in Figs. 6 and 7. There exists a good linear correlation between 7 day strength and 28 day strength as shown in Fig. 8 by which the 28 day strength can be interpreted from the 7 day strength. Apparently, the corresponding increase in strength was higher in hot water extracted CS incorporated concrete due to the effective extrication of hemicelluloses and phenol content on the surface of the CS, which can affect the inter-bonding of matrix and aggregates. Also, a compromising strength enhancement was anticipated in the case of cold water extracted CSC. In the case of lime water extracted CSC a marginal increase in compressive strength was observed. A similar trend was noted at 28 days testing in which case the hot water extracted CS had shown a relatively higher increase on the compressive strength compared to other pre-treated CSC. The failure process initiated with the spalling of concrete surface and a gradual crushing was observed. This also exhibited a controlled failure due to de-bonding of aggregates from the matrix and the concrete had shown pseudo ductile failure behavior. Though the CS is pre-treated it was observed that the failure of CSC cube was due to the poor interface bond between CS and mortar. This may be due to the organic property and smoothness of CS in the concave side. Similar failure pattern in palm shell concrete due to weak interface bonding was observed [10]. As the target was to achieve a low cost concrete, low cost pre-treatment techniques like cold water extraction, hot water extraction and lime water extraction was carried out and its characteristics was studied. Control concrete mix with 100% cement (CCM12) achieved higher compressive strength for untreated and pre-treated CSC when compared to other mix. Whereas mix M1 with 25% replacement of cement by GGBFS achieved compressive strength next to the control concrete CCM12. The compressive strength decreases as the C/F ratio increases (see Fig. 9), which show that the compressive strength depends on the volume of the CS used. Also from Fig. 9 it can be seen that there is not much improvement in 7 days and 28 days strength for untreated CSC for all the C/F ratios, this may be due to the retarders like hemicelluloses and phenols on the surface of the CS. As the C/F ratio increases there was not much significant difference between compressive strength for 7 days and 28 days this may be due to the presence of more extractives in CS for higher C/F ratio.

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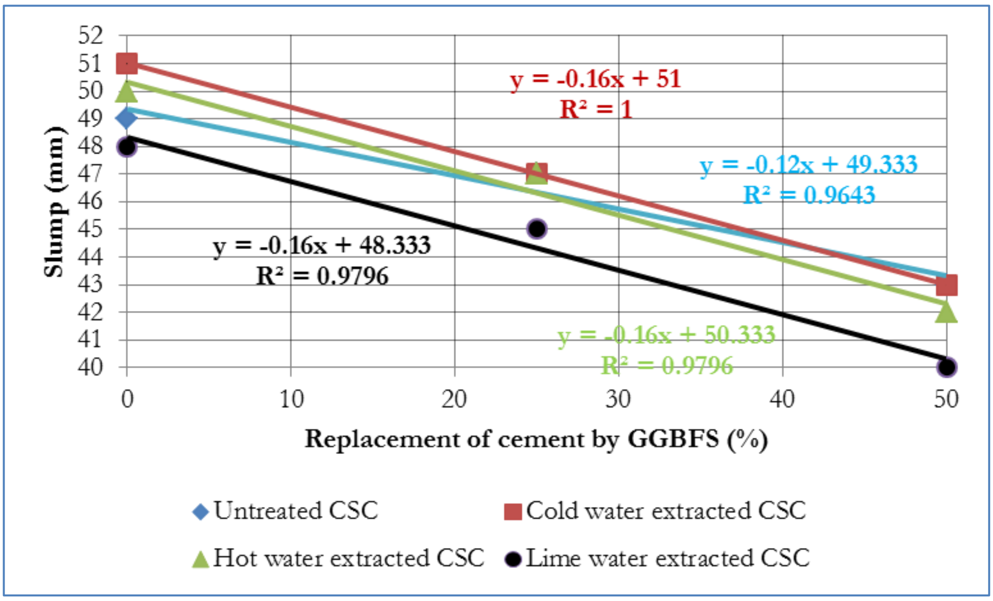

Fig. 5. Relationship between slump and % replacement of GGBFS for C/F-0.28.

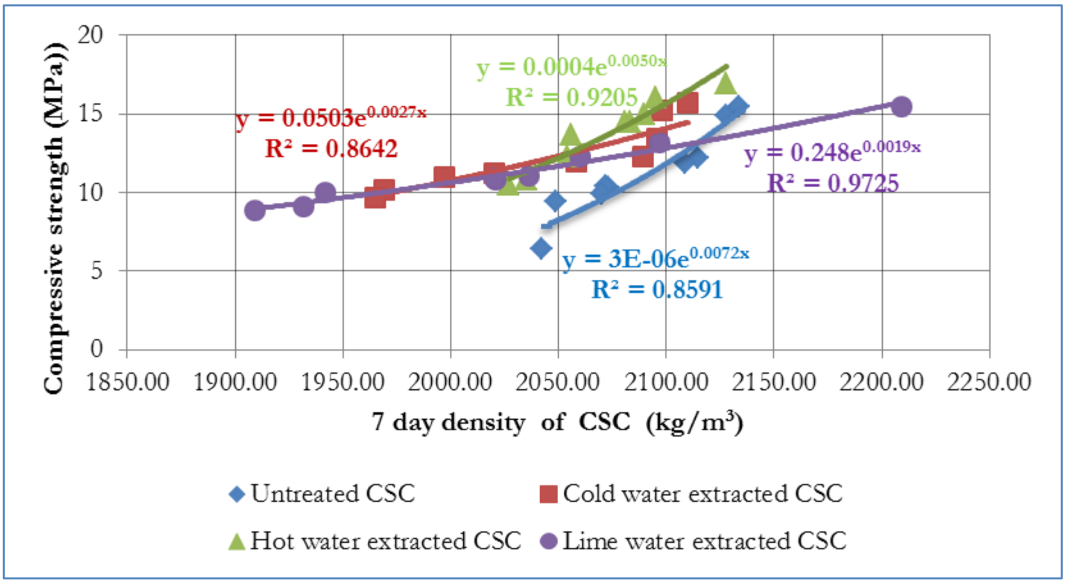

Fig. 6. Relationship between 7 day density versus compressive strength of concrete mixes.

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Table 3. Compressive strength and slump for untreated and pre-treated CSC.

Mix ID	Untreated CSC					Cold water extracted CSC					Hot water extracted CSC					Lime water extracted CSC				
	Density (kg/m^3)		Compressive strength (MPa)		Slump (mm)	Density (kg/m^3)		Compressive strength (MPa)		Slump (mm)	Density (kg/m^3)		Compressive strength (MPa)		Slump (mm)	Density (kg/m^3)		Compressive strength (MPa)		Slump (mm)
	7 days	28 days	7 days	28 days		7 days	28 days	7 days	28 days		7 days	28 days	7 days	28 days		7 days	28 days	7 days	28 days	
CCM12	2134	2180	15.5	20.4	49	2110	2123	15.7	25.3	51	2128	2138	16.9	27.0	50	2209	2075	15.5	21.0	48
M1	2128	2167	14.9	19.1	47	2098	2119	15.2	25.0	47	2095	2119	16.0	25.7	47	2097	2071	13.2	20.2	45
M2	2115	2144	12.2	16.1	43	2096	2114	13.4	21.9	43	2090	2095	15.0	23.8	42	2060	2056	12.3	19.5	40
CCM34	2109	2130	11.9	15.9	54	2089	2107	12.3	21.7	55	2083	2089	14.5	23.2	54	2036	2043	11.1	19.2	49
M3	2073	2122	10.3	14.7	52	2058	2071	12.0	21.5	53	2081	2082	14.5	22.6	53	2021	2033	10.8	17.0	47
M4	2072	2113	10.4	14.5	49	2020	2035	11.2	21.4	50	2056	2081	13.7	22.5	50	2020	2018	10.9	16.3	45
CCM56	2070	2081	9.9	12.5	56	1997	1996	11.0	21.3	56	2054	2069	12.3	22.3	56	1942	2009	10.0	16.0	50
M5	2049	2069	9.4	10.6	54	1969	1966	10.2	16.4	55	2035	2061	10.8	18.1	54	1932	1988	9.1	15.4	48
M6	2042	2051	6.4	7.1	51	1965	1958	9.7	15.8	52	2027	2055	10.5	17.2	51	1909	1983	8.9	14.3	46

Note: CCM refers to control concrete mix; M refers to coconut shell replaced concrete mixes.

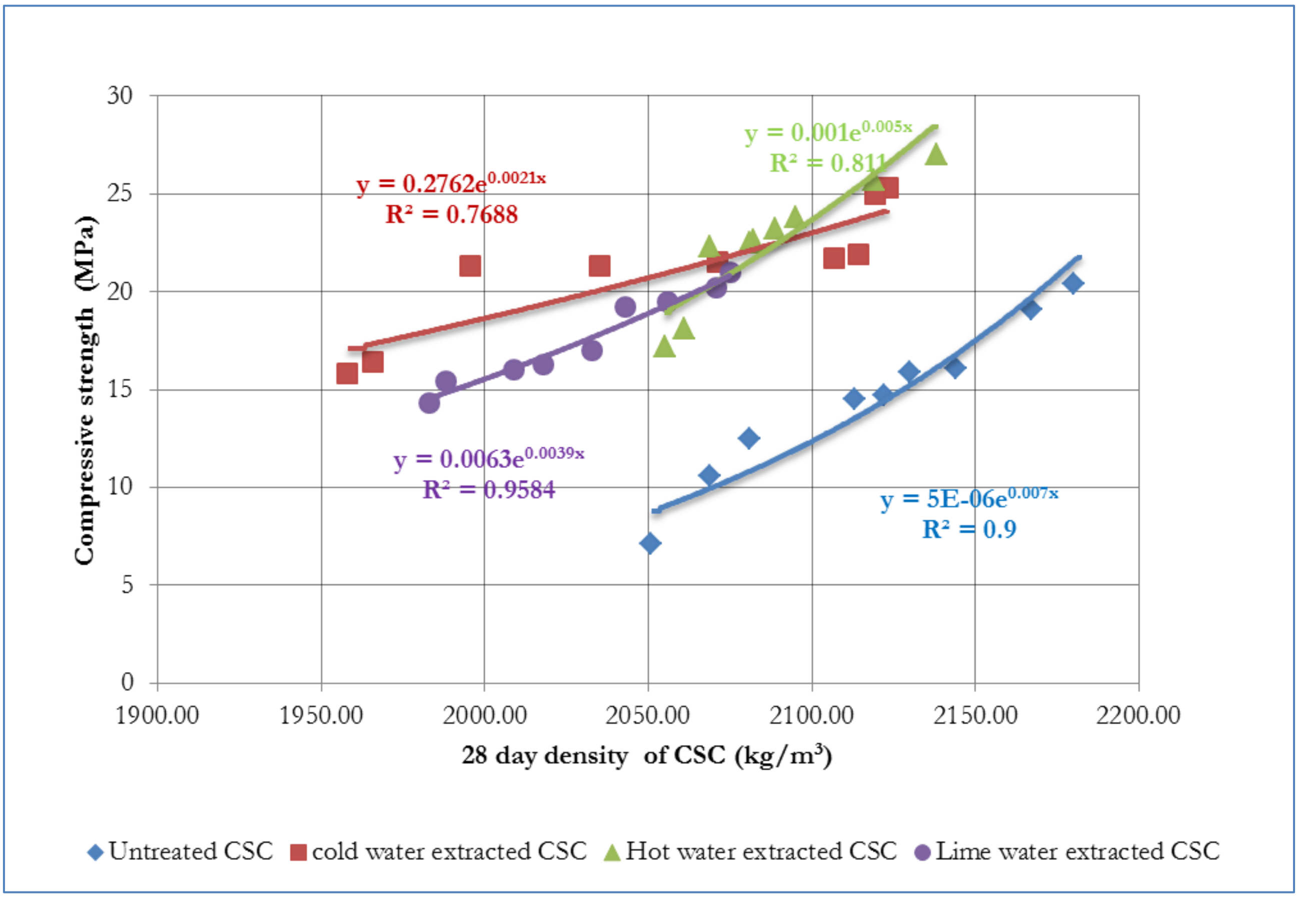

Fig. 7. Relationship between 28 day density versus compressive strength.

Replacement of cement with GGBFS in concrete showed an initial reduction; however marginal strength reduction was noticed at higher substitution of slag. With increase in curing period the reduction in compressive strength was slightly lower as noticed in Fig. 9. It can be drawn from the experimental results that there was not much difference observed for 25% GGBFS substituted concrete as compared to 50% GGBFS incorporated concrete mixes. This may be due to the faster hydration of GGBFS with Portland cement and thus higher addition can potentially leads to higher formation of calcium silicate hydrate gel.

4.3. Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity measurement was used to predict the homogeneity and quality of concrete produced with the incorporation of CS. The UPV values for all the untreated and pre-treated CSC does not show any significant difference, which emphasize that there is not any change in the internal voids structure due to the addition of untreated and pre-treated CS incorporated concrete. A typical graphical representation of the UPV values, compressive strength and C/F ratio for untreated CSC was shown in Fig. 10. From Fig. 10 it can be observed that a good exponential correlation of regression factor of 0.841 was obtained. Also the UPV varied between 3900 - 4600 m/sec which shows that the quality of concrete is in the acceptable range according to IS 13311-part 1-1992 [17]. This proves that the matrix and CS are in intact in concrete and only at the time of failure it is seen that the interface bond is poor and which shows that the UPV values would not have much impact on the different types of pre-treatment conducted on CS. Similarly, the UPV values of palm shell concrete for various heat treated palm shell does not showed much difference [18].

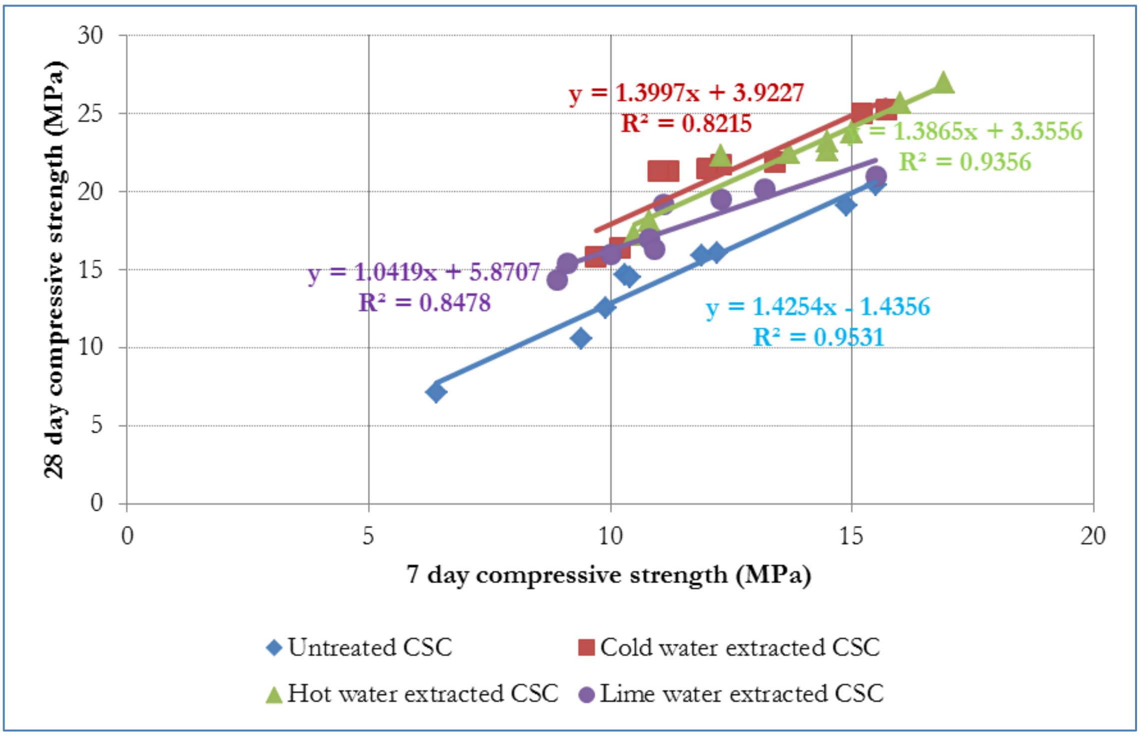

Fig. 8. Relationship between 7 day compressive strength versus 28 day compressive strength.

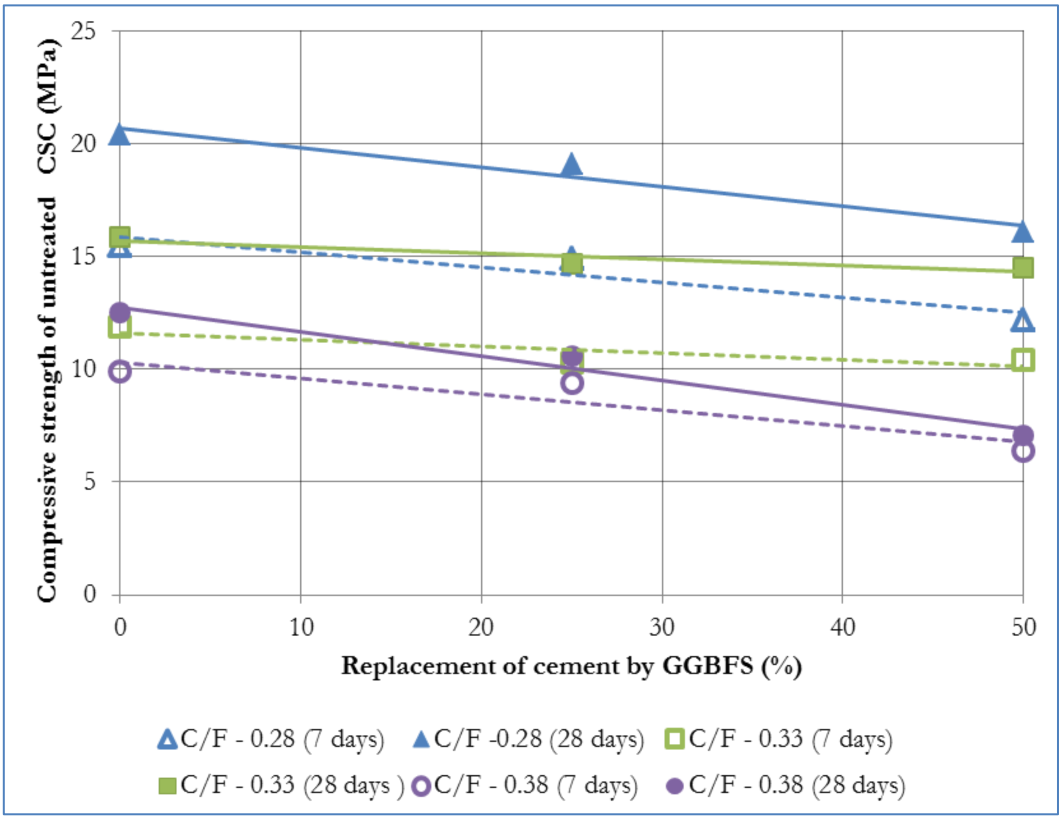

Fig. 9. Relationship between % of GGBFS versus compressive strength for untreated CSC.

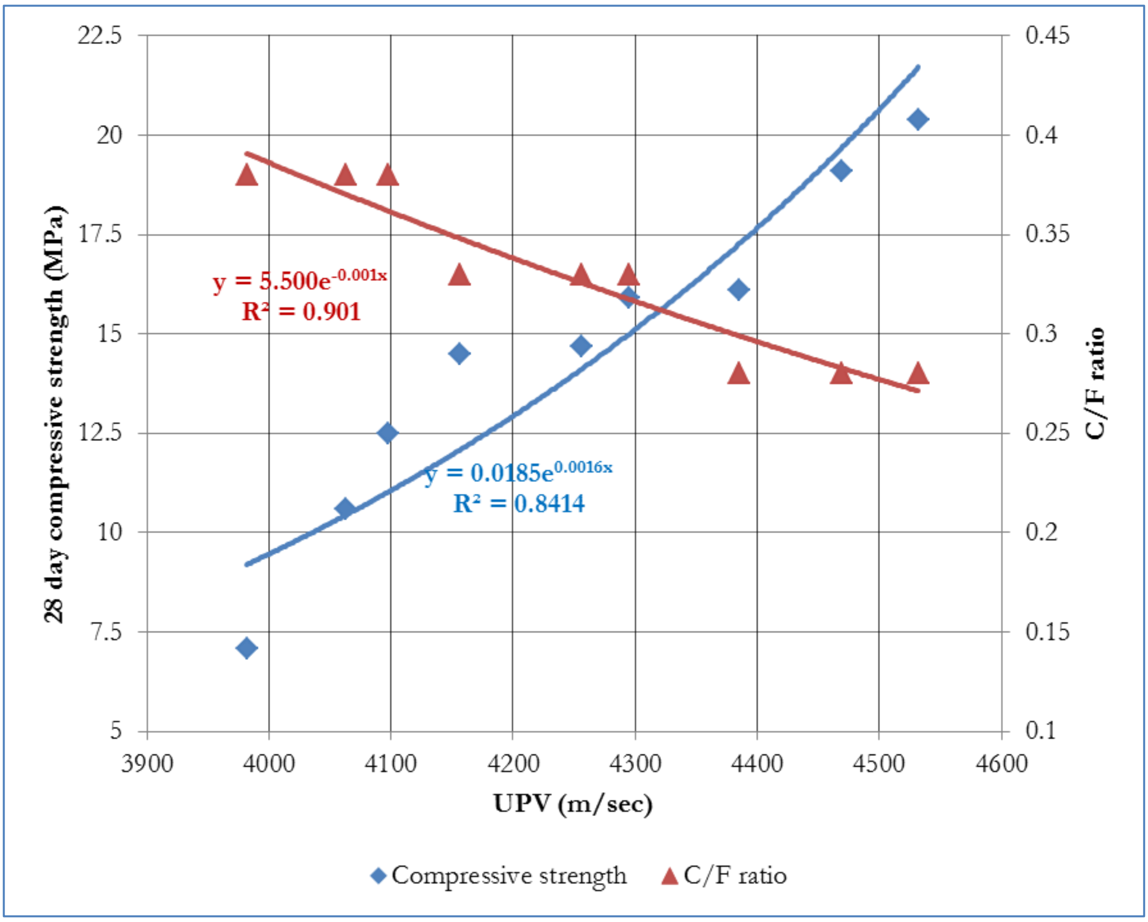

Fig. 10. Relationship between UPV versus compressive strength and C/F ratio of untreated CSC.

4.4. Empirical Relationship

From the test results, a linear empirical relationship were computed between slump and percentage of GGBFS addition for C/F ratio of 0.28 (see Fig. 5). A regression coefficient of more than 0.8 was obtained for all the mix. An exponential relationship between density and compressive strength at 7 and 28 days was obtained and shown in Figs. 6 and 7. This evidently shows the correlation existing between the physical and mechanical characteristics of CSC. Also it can be noted from Figs. 6 and 7 that the empirical relationship obtained for various C/F ratios at 7 and 28 days does not show any significant difference and it can be concluded that it follows a similar trend till 28 days. Empirical relationship was drawn at 28 day compressive strength (f'cr) for untreated, cold water extracted, hot water extracted and lime water extracted CSC with an acceptable regression coefficient of 0.859, 0.768, 0.810 and 0.958 as given below:

Untreated CSC for various mixes at 28th day,

$$f'_{cr} = 5 \times 10^{-06} e^{0.007\rho} \quad (1)$$

Cold water extracted CSC for various mixes at 28th day,

$$f'_{cr} = 0.276 e^{0.002\rho} \quad (2)$$

Hot water extracted CSC for various mixes at 28th day,

$$f'_{cr} = 0.001 e^{0.0049\rho} \quad (3)$$

Lime water extracted CSC for various mixes at 28th day,

$$f'_{cr} = 0.006 e^{0.003\rho} \quad (4)$$

where, 'ρ' is the density of concrete at 28th day in kg/m3.

From the above equation it is clear that the mean compressive strength (f'_{cr}) of untreated CSC yields a lower value than compared to other pre-treated CSC.

5. Conclusions

From the experimental studies conducted, the following conclusions are drawn which exhibits the characteristics of CS replaced concrete composites.

- Low cost structural light weight concrete was produced using agricultural waste CS; industrial waste GGBFS and M-sand.
- Workability of the CSC decreases as GGBFS was replaced by 0%, 25% and 50% by mass of binder.
- Of the various cost effective pre-treatment techniques like, cold water extraction, hot water extraction and lime water extraction performed on CS, hot water extraction was effective and a higher compressive strength of 27.0 MPa at 28 days was achieved.
- Compressive strength properties were greatly affected by the decrease in density and increase in C/F ratio resulting in loss of strength.
- Pre-treatment of CS showed convincingly improved strength properties due to the removal of organic retarders which affects the setting and hardening of cement.
- Addition of GGBFS reduces the compressive strength. The compressive strength of CSC for mix M1 produced by replacing 25% of binder by GGBFS was in close vicinity to control concrete (CCM12) produced using 100% cement. Hence concrete with 25% replacement of GGBFS can be used successfully.
- Since, CS has good impact and crushing strength, various other pretreatment methods can be used to increase its compatibility with mortar for enhancing interface bond strength.

Test results evidently exhibited CS as one promising material that can be used to substitute aggregates in concrete. Also the sustainability of the material in the long run is another compromising solution for alternative construction materials that can be a substitute for conventional materials used in concreting.

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