Effect of Micro-silica and Crumb Rubber on Mechanical Properties of Concrete

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Abstract: *Several researches conducted on rubberized concrete in the past but very few researchers explained the bonding effect of the waste tire rubber particles with different cementitious materials. In this research the effect of the fineness of the micro silica and its bonding with the rubber particles is studied. To check the influence of fractional replacement of cement using micro silica and discarded tire rubber as limited substitution of sand with providing pre-treatment to rubber particles, this experimental investigation has been conducted on concrete with varying percentage switch of cement using micro silica (SF), especially micro-silica was used in this study to exchange with cement by its weight. SF exchanged cement from 0% to 12% with an incremental ratio of 3%. Along with this, the sand was fractionally replaced using pretreated crumb rubber (CR) particles derived from end-of-life tires. The replacement ratio changed by 5% by the volume of sand, ranging from 0% to 20%. The pre-treatment process for CR was done using Sodium Hydroxide (NaOH) of 1 Molarity, for achieving good bonding between cementitious material paste and rubber particles. Distinct fresh and hydrated concrete properties were assessed and compared with normal concrete (NC) having 0% SF and 0% CR. 17 concrete mixtures in all, together with the control mix, were assessed in this study with varying amounts of SF and CR. The bonding structure and impermeability were enhanced by using SF in concrete with promising enhancement in mechanical strengths. Based on the outcomes obtained from this research, the optimal proportion for partial substitution of cement and sand by SF and CR was fixed for the desired grade of concrete to provide an innovative form of concrete to the construction industry.*

Keywords:

micro silica, crumb rubber, pre-treatment of crumb rubber, rubberized concrete, cementitious materials

Abbreviations: Silica Fume (SF), Crumb Rubber (CR), Normal Concrete (NC), Rubberized Concrete (RC) Silica Fume-and Crumb Rubberized Concrete (SCRC), Crumb Rubberized Concrete (CRC), Carbon Dioxide (CO2), Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Discarded Tires (DT), Self-compacting concrete (SCC), Ordinary Portland Cement (OPC)

1. Introduction

Concrete is the utmost useful construction material in infrastructure and construction industries as it withstands against all aggressive environmental actions by providing a huge lifespan to the structure. Still, the performance of concrete needs to improve for all kinds of weathering actions and different loading conditions, Researchers are continuously pushing their limits to enhance the properties of concrete and to invent alternate options for ingredients of concrete as most of them belong to natural resources which are limited in measure and their extraction affects the ecosystem.

With the recent swift development of industrialization in the last four decades, this fastest-growing world is facing very severe problems like global warming and managing solid waste generated by industries [1], [2]. Focusing on the construction industry, each ton of cement production emits an equal amount of CO_2. Production of cement alone holds around 8% of total CO_2 emissions around the globe [3]–[6]. At the same time, industrial by-products like SF, FA, GGBS, etc. are rich in silica content and can be utilized as fractional/ complete substitution of cement in concrete as binder material [7], [8]. Such consumption of the by-products can be a viable solution to environmental hazards caused by the concrete industry and to develop sustainable construction materials.

Sand is another most used natural ingredient of concrete extracted from rivers triggering damage to the environment and aquatic presence. Stringent rules and regulations are set in several nations on the extraction of sand leading to a critical deficiency of it and ultimately resulting in a hike in construction costs. Some options like quarry dust, crushed sand, and artificial sand were invented by researchers but they are also not optimized in terms of the economy of the construction. On the other hand, the automobile industry has also grown very fast in the previous 40 years all around the world, leading to the generation of discarded tires (DT), which are stockpiled or used in pyrolysis neglecting the land and air pollution instigated by them. Many research studies have tried to inculcate the usage of CR particles in concrete. A common observation from this kind of experimental research was that the concrete's strength decreased. This study confirms the decrement in the reduction of strengths for concrete by utilizing SF and CR as a fractional exchange of cement and sand correspondingly at higher percentages.

2. Literature Review

Mallick [9] explained in his studies that the inclusion of SF imparted more strength to concrete by making the dense structure of binder materials. Fine particles of SF reduced the capillary action and porosity of concrete. Similar observations were made in the study performed by Dash [10] that the splitting strength was enhanced by the incorporation of SF in concrete along with a lessening of about 40% in flexural strength for concrete having 30% SF as a replacement of cement. Acceleration in hydration of cement by the inclusion of SF was noticed by Khan, and Siddique [11], they also determined that the diffusion of chloride ions is decreased significantly with an upsurge in corrosion resistance and alkali-silica expansion. Carbonation depth was increased in this research. The hardened properties were enhanced with the use of SF as compressive, tensile splitting, and flexural strengths increased for final replacement up to 20% of cement [12]. Khan and Ali [13] commented that the improvement in strength was observed for concrete mixes with the inclusion of SF and FA and, this combination also improved the energy absorption and toughness index. Workability was found to be increased due to the application of SF in self-compacting concrete by Sasanipour et al. [14]. Onuaguluchi and Panesar [15] used precoated CR and SF in concrete and concluded the enhancement in compressive strength, electrical resistivity, and resistance to chloride permeability. They also stated that the combination of using SF and CR together as a substitution of cement and sand can be a viable solution to provide sustainable construction material with an environmental benefit. Elchalakani [16] researched the high-strength RC with the amalgamation of SF in form of micro silica and concluded that the amalgamation of rubber powder and crumb rubber along with SF provides desired workability and enhanced the axial compressive, flexural strengths, and elastic modulus of concrete. He also commented the reduction ratio for strength was lower for high-strength concrete of 100 MPa than normal strength concrete of 40 Mpa. The optimal replacement of sand by rubber particles was found to be up to 30% by weight by including SF for high-strength concrete and 17% for normal-strength concrete. Fakhri and Saberi realized [17] that the RC with and without SF improved the mechanical strengths of concrete at lower levels of swap of sand by rubber particles, in addition to this the improvement in strength was more for rubberized concrete with SF having 5% rubber particles. Water absorption for concrete with a combination of SF and CR was found to be reduced by up to 50% for 24 hours in the same experiment. Also, Gupta et al.[18] worked on the resistance to the impact of RC and discovered enrichment in impact resistance for RC with SF. Another study performed by Gupta et al. [19] on RC with and without SF at different water-cement (w/c) ratios indicated that the RC with the inclusion of SF as a fractional switch of cement showed the same workability with no effect and upgrading mechanical strengths and higher flexibility than the normal concrete. The concrete with 25% rubber fiber and 10% SF at 0.35 w/c ratio showed improvement in compressive strength by 33.3% related to the strength of RC without SF. They reasoned that the good adherence and void-filling property of SF improved the compressive strength. Mohammed et al. [20] explored the advantage of nano-silica on RC and found that the compressive strength was improved by approximately 2.44 times for the inclusion of 5% nano-silica in RC with 25% CR when compared to the RC exclusive of nano-silica. They recorded this increment in compressive strength due to densification in the microstructure of concrete by including nano-silica. Hilal's [21] study on rubberized SCC with class F-FA added as a 30% cement substitute produced unfavorable findings for the hardened properties of concrete, such as compressive, tensile strengths, and elastic modulus. He also stated the influence of rubber particles sizes on the decline of strength. Copetti et al. [22] stated that the increased porosity owed to the presence of CR particles in concrete is observed to be reduced by the utilization of SF as a fraction switch of cement up to 15%. The reduction in elastic modulus by nearly 50% was seen by replacing sand by 30% with CR, this reduction was also minimized by the incorporation of SF up to 30% for the same rubber content. Also, Onuaguluchi and Panesar [23] conducted a research study on utilizing limestone powder-coated CR as a limited substitution of sand from 0% to 15% by volume and 15% SF as an ancillary of cement and noted the significant improvement in compressive strength by 14% and split tensile strength around 15% at 10% sand replacement with 15% SF as an alternative for cement. Pelisser et al. [24] reflected on the effects of the pre-treatment of CR and utilization of SF as a substitution for cement and achieved satisfactory strength with an energy-efficient option for air conditioning energy consumption. Pre-treatment of CR and use of SF reduced the reduction in compressive strength from 67% to 14%. Xie et al. [25] researched the use of CR and SF with normal and reprocessed coarse aggregates and found that the physicomechanical properties have been improved. The compressive strength for 10% SF and 15% CR showed about a 22.9% increment in compressive strength.

Although several studies have been conducted on RC, very few researchers determined the consequence of cementitious materials on the bonding of rubber particles and cementitious paste. In this experimental study, the influence of SF and CR on the hardened qualities of concrete was investigated. The CR of size 1.18 mm was utilized with an incremental ratio of 5% to reach up to 20% replacement of sand and SF passing from size 45 microns (μ) was taken as substitution of cement. Using NaOH, CR has been pretreated before its inclusion in concrete. The slump of all mixes was kept fixed with the aid of plasticizers.

3. Materials & Methodology

3.1 Materials

The research work was done using OPC cement having a specific gravity of 3.15 following IS12269 [26], zone II graded sand following the norms of IS 2386- Part 3 [27] with 2.65 specific gravity extending from 4.75 mm to 150 microns, and angular coarse aggregates conforming IS 383 and IS 2386 Part1 [28], [29] of size 10 and 20 mm with 2.84 specific gravity. Freshwater is used for concrete mixing along with a Polycarboxylate ester polymer base super-plasticizer referring to IS 9103 [30] to maintain the required slump. The superplasticizer can reduce water content by up to 20%. Micro silica fume (SF) passing from 45μ with a specific gravity of 2.2 determined using a gravity bottle and conforming to IS 15388-2003 [31] was used. CR with a size of 1.18 mm and a specific gravity of 0.92 was utilized as a partial switch of sand. The CR particles underwent treatment using NaOH, they were kept in 1 molarity NaOH solution for 24 hours and then rinsed with water and dried before being included in the concrete mix. Fig. 1 demonstrates the pre-treatment process for CR.

3.2 Material Properties

The properties of various ingredients of concrete were investigated before its use for the casting of concrete. The crushing strength of coarse aggregates was determined and it was around 18.11%, which is less than the permissible limit suggested by IS 383[32]. Following IS 383 [32] the impact value was found to be 4.30% and water absorption for coarse aggregates was 0.5%. The water absorption for sand was calculated as 1% along with its fineness modulus as 2.405 in accordance with IS 2386 part II [27]. The sieve analysis is shown in Fig. 2 for crumb rubber and sand. The chemical properties of CR were determined and explained in Table 1.

Fig. 1 Pre-treatment Process for CR by NaOH

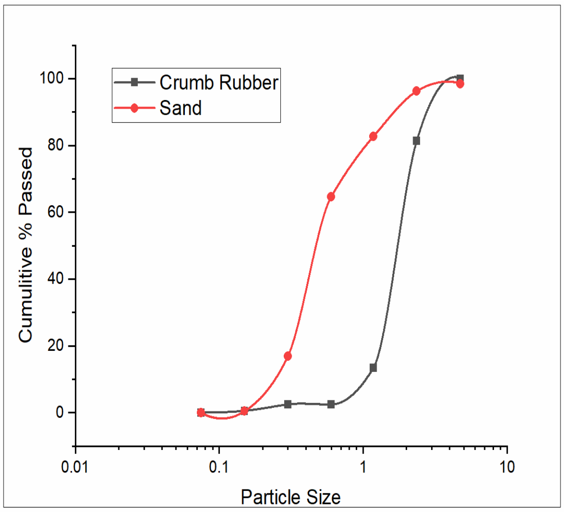

Fig. 2 Sieve Analysis for Sand and CR

Table 1 Chemical Composition of Crumb Rubber

Elements Present in Crumb Rubber	Amount Observed in %
Carbon-(C)	81.69
Oxygen-(O)	13.62
Zinc-(Zn)	2.76
Sulfur-(S)	1.10
Silicon-(Si)	0.30
Magnesium-(Mg)	0.24
Aluminum-(Al)	0.14

3.3 Concrete Mix Proportion

With the varying percentages of SF and CR, 17 concrete mixes are prepared including NC with no utilization of SF and CR. Quantities of each mix proportion were stated in Table 2. The nomenclatures of different mixes are denoted as Percentage of Silica Fume and percentage of Crumb Rubber, i.e. S0R0 stands for Control mix having 0% silica fume and 0% Crumb Rubber.

Table 2 *Mix Proportions for Concrete Mixes for concrete in kg/m3*

SN	Mix	Cement	Silica Fume	Water	Coarse Aggregate	Sand	Crumb Rubber	Super-plasticizer	W/C Ratio	Slump (mm)
1	S0R0	443.00	0.00	155.00	1200.00	682.00	0.00	4.43	0.35	120
2	S3R5	429.71	13.29	155.00	1196.00	646.00	12.00	4.87	0.35	120
3	S3R10	429.71	13.29	155.00	1196.00	611.00	24.00	5.32	0.35	120
4	S3R15	429.71	13.29	155.00	1195.00	577.00	35.00	5.76	0.35	120
5	S3R20	429.71	13.29	155.00	1194.00	543.00	47.00	6.20	0.35	120
6	S6R5	416.42	26.58	155.00	1193.00	644.00	12.00	4.87	0.35	120
7	S6R10	416.42	26.58	155.00	1193.00	610.00	24.00	5.32	0.35	120
8	S6R15	416.42	26.58	155.00	1192.00	575.00	35.00	5.76	0.35	120
9	S6R20	416.42	26.58	155.00	1191.00	541.00	47.00	6.20	0.35	120
10	S9R5	403.13	39.87	155.00	1190.00	642.00	12.00	4.87	0.35	120
11	S9R10	403.13	39.87	155.00	1189.00	608.00	23.00	5.32	0.35	120
12	S9R15	403.13	39.87	155.00	1189.00	574.00	35.00	5.76	0.35	120
13	S9R20	403.13	39.87	155.00	1188.00	540.00	47.00	6.20	0.35	120
14	S12R5	389.84	53.16	155.00	1187.00	640.00	12.00	4.87	0.35	120
15	S12R10	389.84	53.16	155.00	1186.00	606.00	23.00	5.32	0.35	120
16	S12R15	389.84	53.16	155.00	1186.00	572.00	35.00	5.76	0.35	120
17	S12R20	389.84	53.16	155.00	1185.00	538.00	47.00	6.20	0.35	120

3.4 Test Methods

The slump of each set of the concrete mix was kept constant at 120 mm. As a substitute for sand, the superplasticizer dosages were adjusted by 0.1% for every 5% increase in CR because of its water absorption capability. For control mix S0R0, 1% superplasticizer is added. After specimens were allowed to cure for 28 days at room temperature, the mechanical properties of concrete were ascertained.

Density of Concrete

The inclusion of CR and SF with specific gravities of 0.92 and 2.2 respectively, affected the density of concrete as sand and cement were replaced by these industrial byproducts, this material exchange, in turn, influenced the density. The density of concrete was determined by following ASTM C138 and IS 1199 Part 3 [33], [34]. Casting and testing for the density of concrete are explained in Fig. 3.

3.5 Compressive Strength

Concrete cubes with a size of 0.15m on each side with an area of 0.0225 m^2 were prepared in accordance with IS 516 and IS 1199 [35], [36]. Samples were assessed on a 2000 kN capacity compression testing machine of standard make. Fig. 3 illustrates the process to calculate the compressive strength.

Tensile Strength

The tensile properties of concrete were determined and linked to the tensile properties of the control mix. The splitting tensile strength was performed on 0.3 m long cylindrical specimens with a diameter of 0.15 m, referring to IS 516 and IS 5816 [35], [37]. Flexural properties were evaluated using concrete beams of size 0.1 x 0.1 x 0.5 m at 28 days using a two-point loading flexural testing machine. Fig. 4 explains the setup for determining the flexural and split tensile strength.

Capillary Absorption Test

The Capillary water absorption test was conducted on cubes cured for 28 days and oven-dried at 105^0 C and then kept for cooling at room temperature for 6 hours. The cubes were kept in a tray around 5 mm above the surface and the water level in the tray was upheld at 5 mm. Readings were noted after every 30 minutes for 3 hours. The coefficient of capillary absorption was calculated by a formula derived in the research study by A. K. Dash [10]. The capillary absorption test setup is shown in Fig. 5.

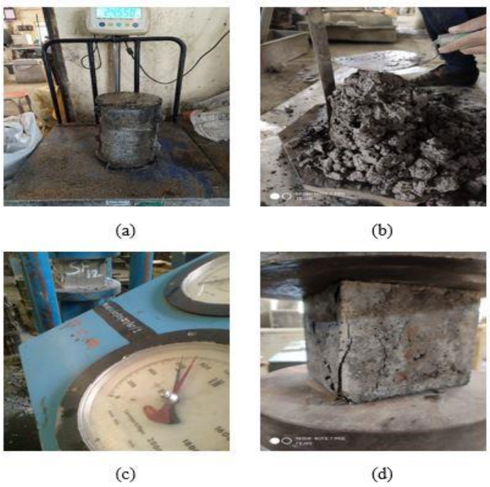

Fig. 3 (a) Fresh Density of Concrete, (b) Slump of Concrete, (c) and (d) Compressive Strength for concrete

Fig. 4 (a) and (b) Flexural Tensile Strength, (c) and (d) Split Tensile Strength

Fig. 5 Test Setup for Capillary Absorption Test

4. Results and Discussions

After completion of casting and curing, specimens were tested using various Indian Standards, and results were interpreted.

The cylindrical vessel of 0.3 m and 0.15 m in length and diameter respectively was deployed to assess the fresh density of concrete by following IS 1199 Part 3 [34]. The empty weight cylinder is determined and noted as M_1, then the fresh concrete is placed in a cylinder in three layers and compacted using a needle vibrator. The weight of the cylinder filled with concrete was noted as M_2, using the difference in weights M_2 and M_1 and the cylinder's volume V the density of fresh concrete is assessed.

Fig. 7 represents the density of fresh concrete for different mixes. It is observed that the density of concrete specimens was decreased with an increase in the percentage replacement of SF and CR. CR played a crucial role in the reduction of density owing to its low specific gravity. The minimal reduction in density was observed for S3R5 at 5.32% and the maximum reduction was noted for S12R20 at 25.21%.

4.1 Compressive Strength

Referring to IS 516 [35] concrete cubes were tested after curing for 28 days. Before testing concrete samples were dried and then loading was applied on one face of the cube till the development of cracks. The average of three cubes of each set of the concrete mix was considered as the compressive strength of a particular set. All test results were compared with the compressive strength obtained for the control mix and necessary observations were recorded. The compressive strength for all mixes was found to be fluctuating due to the incorporation of SF and CR. The least compressive strength was recorded for mix S3R20 as 29.30 MPa with a reduction of 29.62% when linked to the strength of the control mix. Maximum strength was noted for mix S12R5 as 43.08 MPa with an increase of 3.48% strength in parallel to the strength of the control mix. From the study of Fig. 6, it is observed that the inclusion of CR decreases the compressive strength while the fractional substitution of cement by SF has shown promising results for enhancing the compressive strength. The best strength results were obtained for mixes S3R5, S6R5, S9R5, S9R10, and S12R5 as they have given strength more than the required characteristic compressive strength. The strengths are 40.36, 42.08, 42.26, 40.10, and 43.08 MPa. Mohammed B.S. et al. [20] have commented on the same results of an enhance in compressive strength with a reason for the insertion of SF as it made concrete denser and boosted the pore refining process. The use of SF has also overcome the weak bonding of cementitious material paste and rubber particles, as it is the root cause for the decline in compressive strength. Obinna Onuaguluchi and Daman K. Panesar also concluded the improvement in compressive strength due to the pretreatment of rubber particles and utilization of SF.

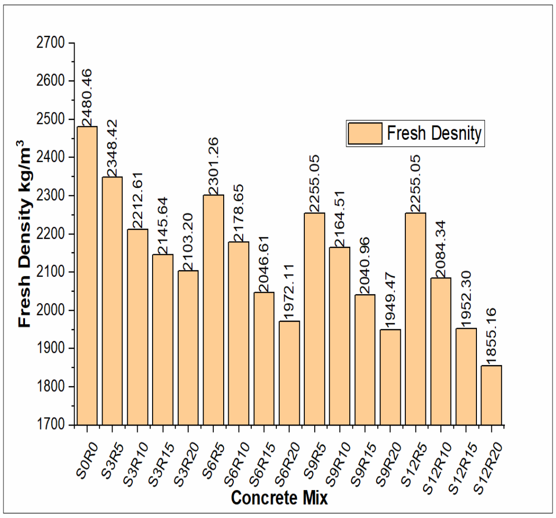

Fig. 6 Comparison for density of concrete mixes

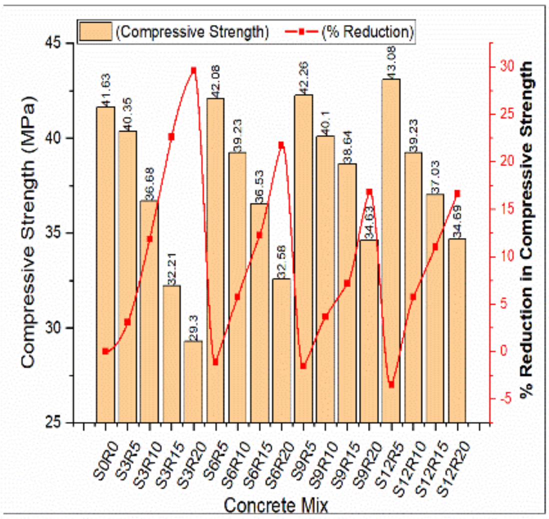

Fig. 7 Compressive Strength of concrete mixes

4.2 Splitting Tensile Strength

Concrete cylinders cast by following the dimensions mentioned in IS 516 and IS 5816 [35], [37] and cured for 28 days were tested on a compression testing machine. The cylinders were kept between two plates and loading was applied until the development of cracks in the sample. The strength for the control mix was observed to be 4.62 MPa, and the splitting tensile strength for concrete with SF and CR is found to be increased with a promising amount till 10% swap of sand by CR, further upsurge in partial switch of sand by CR shown a declining nature for split tensile strength. Referring to Fig. 8, for S3R15, S3R20, S6R20, S9R15, S9R20, and S12R20 the strengths were 4.34, 3.87, 4.08, 4.36, 4.10, and 4.24 Mpa respectively, which were lower than 4.62 MPa obtained for the control mix. Fig. 8 demonstrates the variation in split tensile strength at a constant percentage replacement of cement by SF and varying percentage of CR as exchange of sand. The maximum reduction was noted for S3R20 as 16.33% in correlation to strength for the control mix, while the maximum gain was detected for S12R5 by 19.39%. Fig. 8 (a), (b), (c), and (d) shows a loss in tensile strength owing to variation in the amount of CR but up to 10% CR as the replacement of sand showed improvement in splitting Tensile strength. Mohamed Elchalakani [16] also commented on the same decrement in tensile strength for a greater proportion of rubber particles in concrete.

4.3 Flexural Strength

Rectangular concrete beams of length 0.5 m were tested under a two-point loading flexural testing machine after 28 days of curing. The distance between two roller shafts supporting the beam was kept at 0.4 m. Standards specified in IS 516 [35] were used to perform the test. The maximum decrement was recorded for the mix S3R20 and S6R20 as 14.40% and 12.70% respectively, in contrast, the supreme gain was witnessed for the S12R5 mix as 12.83% in reference to the flexural strength of the control mix as 4.88 MPa. Fig. 9 illustrates the alteration in flexural strength. Up to 10% replacement of sand by CR and at all variations of SF the flexural strength of concrete mixes was enhanced, further increment in substitution of sand showed the reduction in strength. The cause of the increase in strength was similar to that of compressive strength, that the microstructure of concrete was improved by the inclusion of SF. Also, similar observations were recorded by Jiahne Xie et al. [25] that the inclusion of SF in concrete increases the flexural strength, and the addition of CR decreases the strength.

4.4 Capillary Absorption Test

This test was supervised on concrete cubes cured for 28 days. Oven-dried cubes of similar weights were considered and they were kept in a tray having a water level of around 5 mm from the bottom, the cubes were placed in such a manner that the unidirectional flow must be maintained. By determining the coefficient of capillary absorption indirectly the durability of the concrete is predicted. The coefficient of capillary absorption for concrete was recorded lowest for the concrete mix S12R5 as 0.68x10^-3 and highest for the mix S3R20 as 1.73x10^-3. The findings suggested that the increased amount of SF in concrete showed less capillary absorption and increment in CR as the substitution of sand increases the capillary absorption. Fig. 10 demonstrates the variation in capillary absorption coefficient for varying rates of SF and CR. For the inclusion of SF, similar results were obtained by A. K. Dash and Jagdish Mallick [9], [10].

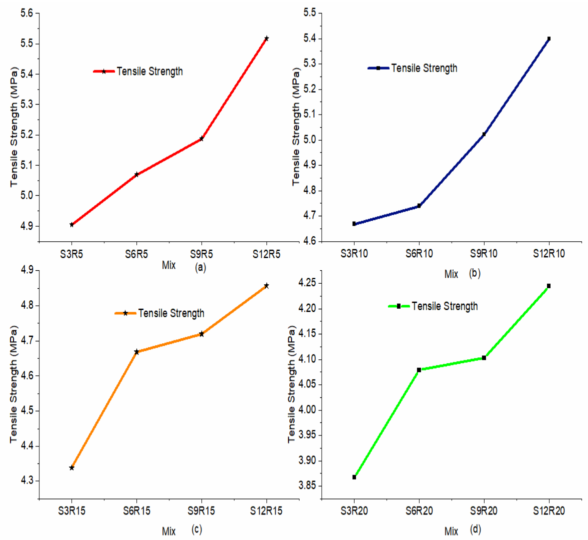

Fig. 8 Split Tensile strength for varying SF with (a) 5% CR, (b) 10% CR, (c) 15% CR, (d) 20% CR

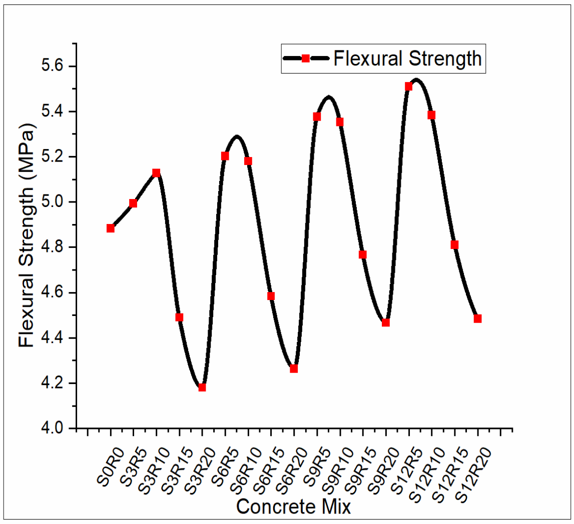

Fig. 9 Variation of flexural strength for concrete mixes

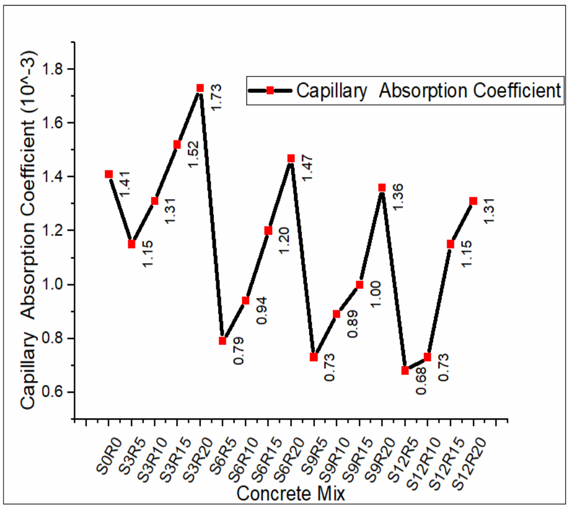

Fig. 10 Variation of Capillary Absorption Coefficient for concrete mixes

5. Conclusions

The purpose of the experiment was to determine how best to use pretreated CR as a partial substitute for fine aggregate in concrete and how utilizing SF in place of some cement could make the concrete denser and more favorable in terms of strength considerations. The conclusion of the entire experimental work was as follows.

The density of concrete was reduced with the incorporation of CR and SF in concrete. The cause for the reduction in density is the low specific gravity of these industrial wastes in comparison to the constituents of concrete to be replaced. For the highest substitution of sand and cement by CR and SF the least density was obtained, and it can be a positive sign to develop lightweight concrete. Similar observations were observed by the researchers in the past studies conducted on the RC [1], [38], [39].

The mixing of CR in concrete showed a decrement in compressive strength at higher replacement ratios, owing to its weak bonding with cement paste. While the merger of SF as a substitute for cement disclosed the decrease in the rate of reduction of compressive strength. combination of SF and CR in concrete contributed to the required compressive strength. The optimum replacement of SF and CR to achieve the required characteristic compressive strength was 9% for SF and 10% for CR.

The splitting tensile strength was initially enhanced and reduced after further replacement of sand and cement beyond 10% for CR. The inclusion of SF improved the splitting tensile strength by densifying the structure of the concrete mix.

The flexural strength of concrete was increased due to the mixing of SF and CR in concrete, at a lower percentage of SF and higher levels of replacement of sand by CR the flexural strength was declined. Promising results were obtained for SF replacement at 9% and more than 9%, and inclusion CR up to 15%. The same reason for weak bonding between cement and CR can be concluded for the decrement in strength.

Due to the microstructure of SF, the capillary absorption was minimized with an increase in SF as the dense structure of concrete was obtained. The CR particles have water absorption ability which in turn increases the capillary absorption but from the results, it can be concluded that the 10% optimum switch of sand by CR can be the viable solution for achieving the coefficient of capillary absorption less than the coefficient for the normal mix.

The study indicates that the utilization of industrial wastes like discarded tires from automobile industries and silica fume can be the eco-friendly and practicable option for replacing sand and cement by making lightweight concrete with the required qualities as it overcomes environmental hazards raised by the generation of the end of life tires, carbon-di-oxide emission owing to the making of cement, and can minimize the scarcity of sand.

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