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Original Article

Influence of Partial Replacement of Fine Aggregate with Varying Amounts of Different Particle Sizes of Treated Crumb Rubber on the Mechanical and Durability Properties of High-Strength Concrete

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Abstract *- Crumb rubber is formed when used tires from automobile industries and garages are recycled and crushed. As a result of increasing population growth, high-strength concrete usage for high-rise structures has increased. High-strength concrete comes at a high cost since the materials required are high quality. One such material is a fine aggregate (FA), consisting of natural sand or crushed rock dust, which are non-renewable natural resources. This study examined the effects of partially substituting fine aggregate with various particle sizes of crumb rubber pre-treated with sodium hydroxide (NaOH) on the characteristics of high-strength concrete. Workability, density, compressive, splitting tensile, flexural strength, and water absorption were the tests performed to understand the effects of the various particle sizes of CR on high-strength concrete. The researcher employed a lower water/binder ratio of 0.35 with a carboxylate-based superplasticizer to enhance workability. Crumb rubber concrete (CRC) showed a higher slump than the control concrete. The compressive strength for both particle sizes (0.18-1.25mm and 0.18-5mm) at 3, 7, 14, 28, and 56 days were lower than the control concrete. Crumb rubber concrete at 2.5% for the two particle sizes produced higher tensile and flexural strength than the control concrete at 28 days. At 28 days, CRC of particle size 0.18-1.25mm at a FA replacement of up to 5% had less water absorption than the control concrete. In all, CRC water absorption increased as the rubber content increased. Despite lower compressive strength than the control, replacing 2.5% FA with crumb rubber of particle size 0.18-1.25mm produced acceptable results for high-strength structural concrete. Additionally, it improved the workability, tensile and flexural strength, and decreased water absorption of hardened concrete. Hence, pre-treated crumb rubber can lessen the number of natural aggregates needed, and the pollution that damaged tires cause to the environment.*

Keywords *- High strength concrete, Crumb rubber, Workability, Density, Water absorption.*

1. Introduction

Concrete is amongst the most prevalent materials in the construction industry [45],[46]. It is only second to water as the most used matter worldwide [1],[2]. Due to the readily available materials that make up its components, it has the versatility to a wide range of dimensions and shapes, good toughness properties, strong endurance performance in adverse environments, and less maintenance cost during service life compared to other materials [3]-[5]. Conversely, concrete has low tensile strength and low ductility, and it is more weighted than other materials, leading to the use of many supplements and other materials to minimize these flaws [48]. Since the dawn of civilization, concrete has been a primary building material used to build various structures, from buildings to bridges, dams, and paved roads [6]. As a result of the prevailing quest for improved concrete properties, new varieties of concrete, such as high-strength and high-performance concrete, are being developed [2],[7]. Concrete with high strength offers high compression resistance compared to regular concrete. Almost identical to traditional concrete, high-strength concrete is produced from cement, fine and coarse aggregates, water, and chemical admixtures [6],[7]. Apart from its high compressive strength above 60 MPa, it also offers better durability in harsh environments and flowability in the fresh state for easy placement compared to conventional concrete [6],[52]. With population growth and rapid urbanization, the demand for concrete on a broad scale has increased, resulting in high energy consumption, production cost, pollution of the environment, and reduction of natural resources [1],[9]-[13]. Of the high volume of concrete materials produced worldwide, aggregates comprise around 70–80% of that volume, with fine aggregate making up 25–30% [1],[14]. The fine aggregate used in concrete comes primarily from natural sand and crushed stone dust. Using natural aggregates as primary constituent material in concrete has adversely affected production, especially with the high energy required to crush rock to obtain stone dust and the depletion of natural resources caused by rock quarrying and sand mining. For decades, several studies have been on materials suitable for fully or partially replacing natural aggregates in concrete to reduce cost, energy consumption, and natural resource depletion while promoting a clean and safe environment [15].

On the other hand, solving the issue of what to do with used car tires has generated much interest [16],[17]. Waste tires are non-degradable and contribute significantly to the pollution of the environment [9],[16]. Recent research has focused on using recycled tire rubber to replace part of the fine natural aggregates in concrete due to the limited availability of natural resources. Due to the scarcity of natural resources, recent research has concentrated on using recycled tire rubber in concrete as a replacement for natural aggregates; this has led to the development of a new type of concrete known as crumb rubber concrete (CRC) [16]-[20],[47]. Utilizing used tires in making concrete conserves natural resources, offers a method of disposal for the tires, and creates environmentally friendly concrete [21]. It is worth noting that significant works by past researchers were performed on CR; most were on conventional concrete with less focus on high strength. Researchers have found that CRC offers improved ductility, toughness, impact resistance, energy dissipation, and damping ratio of concrete in previous studies on CRC materials [22]–[25]. In contrast to normal concrete, it possessed a reduced elastic modulus, compressive strength, and tensile strength [26]–[30]. The flat surfaces of the rubber particles and low hydraulic conductivity make it more difficult for the rubber/cement contact to bond, two of the main causes of this strength loss. [30]-[32]. Zinc stearate, employed in tire composition during manufacturing, is another cause of this poor adherence [18]. When this substance diffuses and moves to the rubber surface, it creates a soapy layer that keeps water away [18],[49].

Previous researchers have explored various techniques to eliminate or minimize these flaws in rubberized concrete. The most popular of these techniques is pre-treating rubber crumb rubber with NaOH or adding an additive, like silica fume, to CRC to improve their overall characteristics and interface connection with the cement matrix. The most popular of these techniques is pre-treating rubber crumb rubber with NaOH or adding an additive, like silica fume, to CRC to improve their overall characteristics and interface connection with the cement matrix [17]. However, contradictory and inconsistent experimental results have been recorded up to this point. The compressive strength of CRC increased when crumb rubber was pre-treated with different methods and external additives [33]-[37]. However, another researcher has found that using chemicals or rubber pre-treatment results in negligible augmentation strength losses [38]-[42]. [18] employed three different methods of enhancing the properties of CRC, namely, pre-treating the CR particle for up to two (2) hours with sodium hydroxide (NaOH), adding up to 15% of silica fume to the mix, and increasing the amount of cement from 300-400 kg/m3. The result proved that 30 minutes of treatment of CR with NaOH and 0% silica fume had a better effect than the other treatment methods. [16] Investigated the impact of using different concrete grades and particle sizes of CR on CRC's physical and mechanical properties. Their findings showed that (0.15-2.36 mm) was CR's best particle size range in reducing strength losses.

From the assessment above, it is clear that most earlier efforts were on enhancing CR's qualities to increase its applicability in standard concrete, with just a small amount of crumb rubber effect on high-strength concrete. Secondly, only a tiny fraction of researchers experimented with Portland Pozzolana Cement (PPC); most employed OPC as the binder ingredient. Also, the effect of crumb rubber with variable particle size on high-strength concrete properties was not studied. This research uses different particle size distributions of CR treated with sodium hydroxide to replace a portion of the fine natural aggregate in high-strength crumb rubber concrete (HSCRC) production. This study also investigates the fresh and hardened properties of high-strength concrete made when CR is added. Finally, the researcher will assess the effects of varying percentages of CR replacement of fine aggregate on HSCRC. In addition to reducing the considerable environmental impact of waste tires, the success of this research will offer information on the practical application of CR in the manufacture of HSCRC.

2. Materials and Methods

2.1. Materials

All materials utilized in this investigation were readily available in Kenya on the local market. Portland Pozzolana Cement (CEM II 42.5) was used as a binder material. Crumb rubber was purchased from Athi River and was sieved to obtain the two-particle size distribution (0.18-1.25mm) and (0.18-5mm). Meru supplied the fine aggregate that was used for this study. The coarse aggregate was purchased and sieved to achieve the maximum aggregate size of 12.5mm. The Sika Viscoflow-615KE superplasticizer enhanced the workability of the concrete. Sodium hydroxide (NaOH) pellets of 97 percent purity were used to pre-treat crumb rubber in a 10 percent solution. Lastly, the concrete was mixed using tap water.

2.2. Materials Preparation

The coarse aggregate for this study was first washed and air-dried to remove debris and impurities that adversely affect the properties of concrete. The fine aggregate was also washed with tap water to reduce the silt content. CR was first sieved to obtain two particle size ranges and then pre-treated with 10% NaOH for 0.5hr. The crumb rubber was then rinsed with clean water to reduce the pH, adversely affecting the concrete's hardening properties [18].

2.3. Characterization of Materials

The physical and chemical properties of PPC were obtained as per EN 197. The specific gravity (SG) and absorption for natural (WA) aggregates and CR were obtained per ASTM C128-01. Aggregate impact and crushing values followed ASTM D5874-16 and ASTM C131. The standards used in performing the various tests are shown in Table 1.

2.3.1. Sodium Hydroxide (NaOH) Treatment Crumb Rubber

CR particles were pre-treated for 0.5hr with a 10% sodium hydroxide solution. The process began with preparing the two grades of crumb rubber (0.18-1.25mm) & (0.18-5mm). Measured amounts of water and NaOH were mixed in a container until the NaOH pallets were dissolved, rubber particles were added, and the mixture was vigorously agitated until all the particles were soaked. The mix was left for 0.5h and then washed for one hour with tap water to reduce the pH of the CR particles. After that, CR Particles were placed on a clean plastic sheet and allowed to air dry. Fig.1 shows the treatment process of crumb rubber.

Table 1. Tests for physical preparties of materials

Material properties	Standards	Tests on concrete	Standards
Sieve analysis (SA.)	ASTM C33/C33M-18	Slump	ASTM C143-10
Specific gravity (SG.)	ASTM C128-01	Compressive Strength	BS EN 12390-03
Water absorption (WA.)	ASTM C128-01	Tensile Strength	ASTM C496/C496
Bulk density (BD.)	ASTM C29/C29M	Flexural Strength	ASTM C78-02
Density	ASTM C29-97	Water absorption	BS 181-122 (2011)
AIV	ASTMD 5874-16		
ACV	ASTM C131S		

Stage 1. Sieving of CR

Stage 2. Preparation of NaOH solution

Stage 3. Treatment of CRwith NaOH

Stage 4. Washing CR

Stage 5. Air drying of CR

Fig. 1 Preparation and pre-treatment of crumb rubber

Table 2. Concrete mix proportion (kg/m3)

CR percentage (%)	Coarse Aggregate	Fine Aggregate	Crumb Rubber	Cement	Water	Superplasticizer
0	1026	489.00	0.00	500	171.5	3.5
2.5	1026	476.78	12.23	500	171.5	3.5
5	1026	464.55	24.45	500	171.5	3.5
7.5	1026	452.33	36.68	500	171.5	3.5
10	1026	440.10	48.90	500	171.5	3.5
12.5	1026	427.88	61.13	500	171.5	3.5
15	1026	415.65	73.35	500	71.5	3.5

2.4. Mixed Design

ACI 211.4R-08 was used as a design guide for all mixes with a 0.35 water/binder ratio. The constituent materials' properties obtained from characterization were used in designing the concrete. Superplasticizer was added to all mixes at 0.7 percent of cement weight. Table 2 shows the proportion of each material for control concrete and CRC mixes.

2.5. Preparation of Test Sample

The initial set of samples comprised only the control concrete (CC) mix. A total of 18 cubes were prepared to be tested at 3, 7, 14, 28, and 56 days, and for water absorption at 28 days, 3 cubes were tested for each record. 3 cylinders, each measuring 200 (mm) long and 100 (mm) in diameter, were cast for split cylinder test at 28 days, and 3 beams of 100 x 100 x 350 (mm) were also made to be tested in flexure at 28 days.

For the CR of particle size (0.18-1.25mm), a total of 108 cubes of size 100 mm were concreted and tested at the same ages as the control concrete while varying the fine aggregate replacement with CR at 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%, and also testing for water absorption at 28 days for each CR content. Similarly, 18 beams 100 x 100 x 350 (mm) and 18 cylinders 100 (mm) diameter 200 (mm) long were cast to test for split tensile strength and flexural strength, respectively, at 28 days.

Similar samples for the CR of particle size (0.18-1.25mm) were made for the CR of (0.18-5 mm). All test samples were taken from the mold after 24 hours and moist cured at average temperature until the time of testing.

2.6. Tests on Fresh and Hardened Properties of Concrete

2.6.1. Workability

The slump test of freshly mixed concrete for all mixes was used to measure workability according to ASTM C143/C143M-10. The concrete samples were placed in three layers in the cone and tamped 25 times at each layer for compaction. Finally, the cone was removed, and slump values were recorded. Fig. 2(a) illustrates the slump test.

2.6.2. Compressive Strength

The samples were tested on a 1500 KN load capability UTM compression machine. The concrete specimens were removed from the curing tank once they had achieved the requisite age, dried with an absorbent material, and left for an hour to allow natural drying. Then, each sample was positioned in the middle of the testing equipment's battens. The loading was carried out constantly to each sample until it was crushed, and the results for maximum load and strength were recorded as per BS EN 12390- 03. For each record, three cubes were tested; the average was then calculated. Fig. 2(b) shows the west up for the test.

2.6.3. Tensile Strength

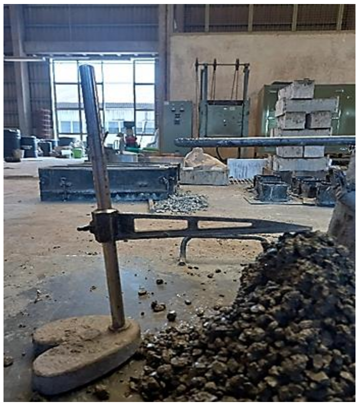
The split tensile test on three samples was conducted using a compression testing device for CC and CRC mixes. The results were averaged with the mean load and strength recorded. ASTM C 496/C 496M – 04 methods were used for testing after 28 days. Fig. 2(c) shows how the test was set up.

2.6.4. Flexural Strength

Three samples of CC and CRC mixes underwent the flexural strength test using a Universal Testing Machine (UTM), and the results were averaged with the mean load and strength noted. ASTM C78 – 02 was used as a test guide after 28 days of curing. Fig. 2(d) shows the setup for the test.

2.6.5. Water Absorption

A 28-day water absorption test was performed following BS 1881-122. (2011). A total of 3 cylinders were tested for CC and CRC mixes, and the average value was noted. Fig. 2(e) shows some of the cubes immersed in water.



(a) Slump test

(b) Compressive strength test

(c) Split tensile strength test

(d) Flexural strength test

(e) Concrete water absorption test

Fig. 2 Tests on fresh and hardened properties of concrete

Table 3. Test results for aggregates and crumb rubber (CR.)

Type of aggregates	Fineness modulus	Specific gravity	Water absorption (%)	Density (kg/m^3)	Voids ratio (%)	ACV (%)	AIV (%)
Fine Aggregate	2.88	2.35	3.89	2350	29	-	-
Coarse Aggregate	-	2.66	3.50	2660	42	17.6	6.2
Crumb Rubber (0.18-1.25)	2.15	1.11	39.12	1110	53	-	-
Crumb Rubber (0.18-5.0)	2.74	1.11	39.12	1110	77	-	-

3. Results and Discussion

3.1. Physical and Mechanical Properties of Constituent Materials

Table 3 displays the materials' physical and mechanical properties. Fig. 3 also depicts the outcomes of the sieve analysis and particle size distribution. The results show that the fine aggregate met ASTM C33 requirements with a fineness modulus (FM) of 2.88, within the (2.3-3.1) range as per ASTM Standards. The test results for specific gravity (SG) of fine aggregate was 2.35, and water absorption (WA) was 3.89%, less than 4% which conformed to ASTM C128-01. The specific gravity of CR is 1.11, less than the FA, making it a lightweight aggregate with water absorption of 39.12% higher than FA for untreated CR. The silt content for FA was 4.63%, less than 5%, according to ASTM C33/C33M-18. The maximum aggregate size of Coarse aggregate was 12.5mm, with 90% of the particle between 5-12.5mm, with most of the aggregate passing a 10mm sieve. The curve for the particle grading falls within the lower and upper limits of ASTM C33/C33M-18. FA and CA had bulk densities of 1650kg/m3 and 1468kg/m3, respectively, which fall between 1200-1750kg/m3. CA's aggregate impact and crushing values were 6.3% and 17.6%, less than 10% and 30%, respectively, conformed to ASTM 5874-16 and ASTM C131, respectively. The results of the chemical analysis for untreated and treated CR are shown in Table 4. The results show that the CR contains adequate SiO2, Al2O3, and CaO to react with mixing water to create cementitious hydrated calcium silicates and aluminates, improving the concrete strength [3]. Additionally, it was noted that untreated rubber had a higher SiO2 content than treated rubber, but as the rubber was treated, the CaO level rose and contributed to improving pozzolana activity.

Table 4. Chemical composition of untreated and treated CR

Element/ Compound	Untreated (%)	Treated (%)
Al_2O_3	1.955	2.733
SiO_2	51.35	40.703
S	25.841	26.748
Cl	0.279	0.416
K_2O	0.958	0.633
CaO	5.287	12.877
Ti	0.257	0.319
Cr	0.025	0.25
Mn	0.354	0.079
Fe	1.945	1.964
Zn	11.648	13.366
Sr	0.006	0.013
Zr	0.005	0.00
W	0.077	0.103
Ta	0.013	0.004

Table 5. Workability of control concrete and crumb rubber concrete slump value (mm)

Control	110	
Percent replacement	**Slump (0.18-5mm)**	**Slump (0.18-1.25mm)**
2.5%	120	150
5.0%	110	145
7.5%	105	135
10.0%	100	130
12.5%	95	120
15.0%	85	110

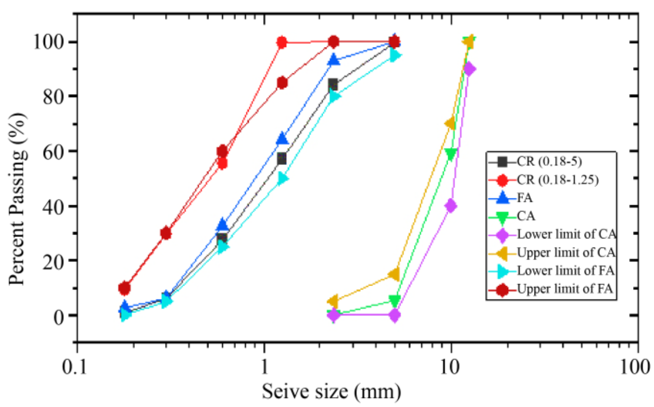


Fig. 3 Materials sieve analysis graphs

3.2. Workability

Findings from previous research prove that the workability is improved when CR is pre-treated in NaOH solution [18],[19]. [19], demonstrated that the slump increased as pre-treated CR increased in the concrete; this can be attributed to free water left on the rubber surface not exposed to air drying. In this study, the slump values for six (6) replacement levels of CR were evaluated; the results are displayed in Table 5. 2.5% replacement of the fine natural aggregate by weight with CR for both particle size distributions (0.18-5mm) & (0.18-1.25mm) enhanced the slump by 9% and 36% compared to Control Concrete. The reduction in a slump for (0.18-5mm) particle size is due to a bigger rough surface area caused by removing acidic content during NaOH treatment. Overall, treating CR with NaOH improved the slump compared to Control Concrete. The slump values for both particle sizes decreased when CR content increased in the concrete.

3.3. Compressive Strength

The results for compressive strength for CC and CRC mixes at six (6) replacement levels were obtained at 3, 7, 14, 28, and 56 days as shown in Fig. 4(a) & Fig. 4(b). The results showed higher compressive Strength for Control Concrete (CC) values than CRC mixes at all ages. There was a compressive strength reduction of 16%, 24.2%, 21.4%, 16.4%, and 18.2% of (0.18-1.25mm) at 2.5% replacement at all ages when compared to CC with an increased 35.5%, 4.4%, 19.6%, 24.5%, and 23.5% at 2.5% compared to (0.18-5mm). Although the results obtained for CRC mixes were lower than that of CC, it is worth noting that CRC with (0.18-1.25mm) at 2.5% replacement produced the best results compared to all other CRC mixes. The improvement in CR's strength of (0.18-1.25mm) particle size at 2.5% replacement could be due to the finer CR size, disseminated throughout the concrete mix and enhancing the packing density [51]. Samples used during the test for CRC remained intact, while those of CC failed in a scattering fashion. This result could be caused by the high ductility index of rubber, which makes it very suitable for seismic regions [44]. Also, the less rough surface area of finer CR particles caused slower movement in concrete than larger particle sizes, leaving voids in the concrete. This finding could also cause strength reduction for (0.18-5mm) particle size distribution. For all mixes, the compressive strength increased as per curing days. It was also observed that as CR percentages increased, the compressive strength decreased in the concrete for both particle size distributions. The reduced stiffness of the rubber particles compared to the fine aggregate, which led to the formation of a significant stress concentration when loads were applied, is what led to this, consistent with findings from other earlier researchers [19],[51].

3.4. Split Tensile Strength

The Universal Testing Machine (UTM) performed the split tensile test. The tests were conducted on CC and CRC mixes. Fig. 5(a) & 5(b) display the test result for tensile strength. At 28 days, the tensile strength for all mixes was tested. At 2.5% replacement of CR replacement of FA by weight for both particle sizes, the tensile strength was higher than that of CC by 2.6% and 13%, respectively. This may be due to the high ductility properties of rubber.

Additionally, CR's finer (0.18-1.25mm) particle size distribution has a lower rough surface area and requires less water, making it easier to compact and enhance the strength. On the other hand, the replacement of CR by weight could also be a reason why the strength is enhanced because CR has less specific gravity compared to fine aggregate, which implies that more of the material was incorporated in the concrete to equal the deducted mass of FA, taking up more space in the concrete and enhancing the stress capacity. Furthermore, it was noted that as rubber percentages rose, the tensile strength of the concrete decreased because the rubber's lower stiffness resulted in a loss of toughness, which was also noted by [19].

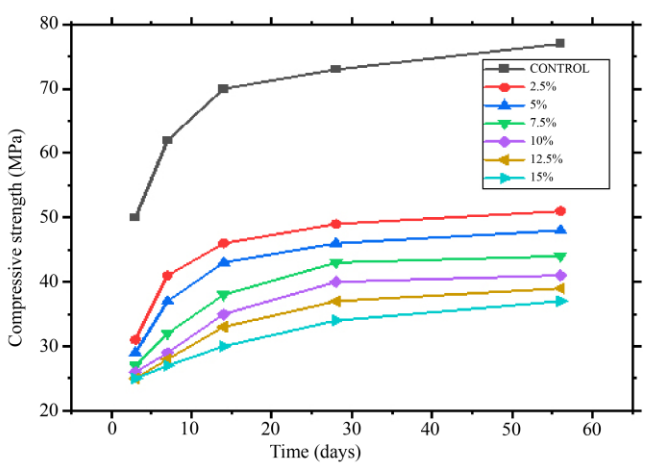


Fig. 4(a) The impact of CR particle size (0.18-5mm) on the compressive strength of concrete

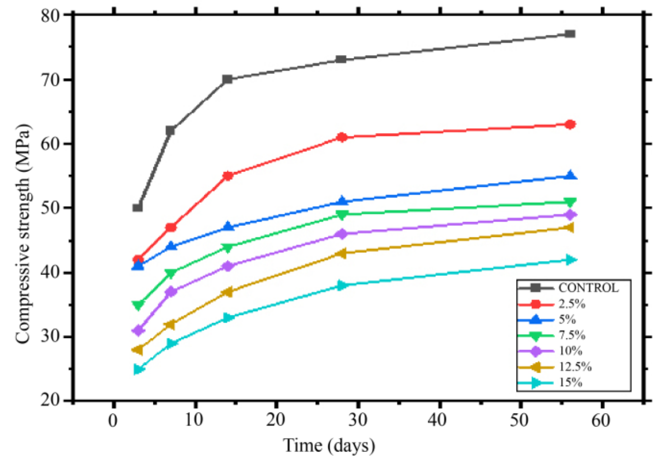


Fig. 4(b) The impact of CR particle size (0.18-1.25mm) on the compressive strength of concrete

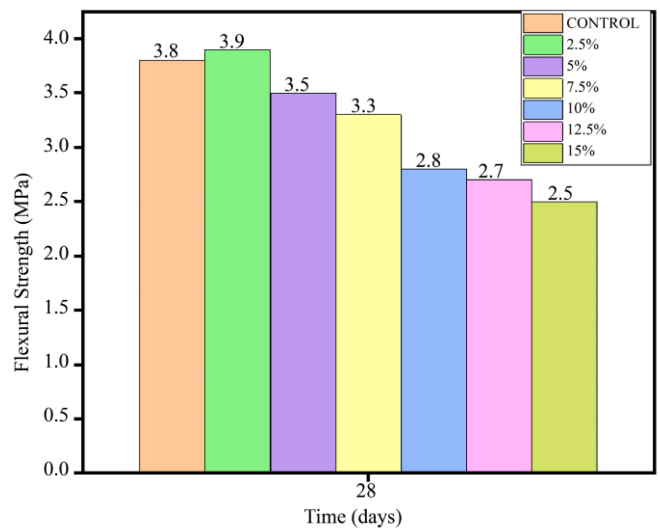


Fig. 5(a) The impact of CR particle size (0.18-5mm) on the tensile strength of concrete

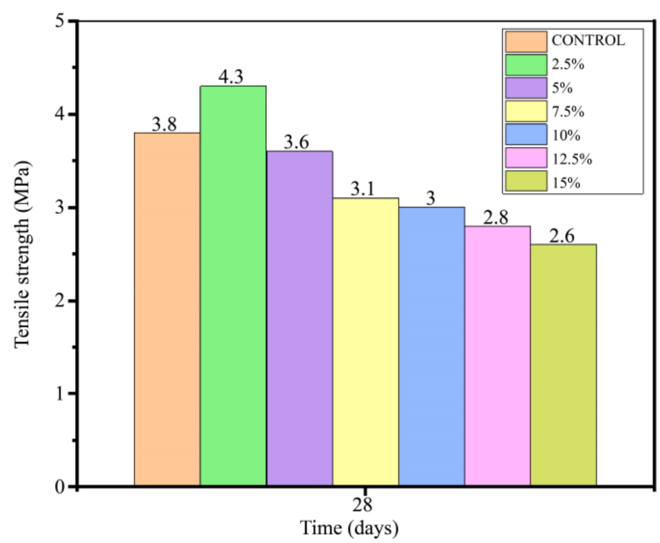


Fig. 5(b) The impact of CR particle size (0.18-1.25mm) on the tensile strength of concrete

3.5. Flexural Strength

The results for flexural strength were obtained after 28 days of moist curing, as displayed in Fig. 6(a) & Fig. 6(b). The flexural strength of the CC was compared to those of CRC of variable particle size distribution. All mixes containing CR had higher flexural strength than control concrete for particle sizes (0.18-5mm) and (0.18-1.25). On the other hand, at 2.5% replacement of CR, both mixes had improved strengths of 21% and 27%, respectively. This finding is because 10% of NaOH pre-treatment gives the optimal rough surface area, which provides a better bond between CR and the cement matrix, thereby limiting crack propagation when loads are applied. This is highly useful when designing and building structures in earthquake-prone areas. The flexural strength dropped as the proportion of CR in the concrete rose, echoing the results for the compressive strength of CRC, which were previously noted by other researchers [18],[19],[51].

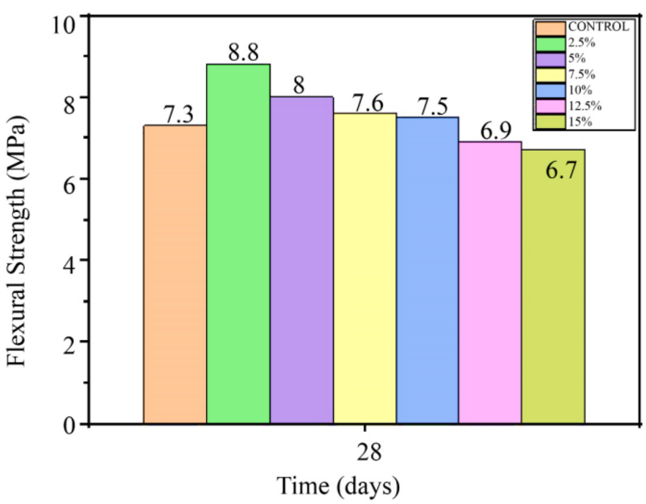


Fig. 6(a) The impact of CR particle size (0.18-5mm) on the flexural strength of concrete

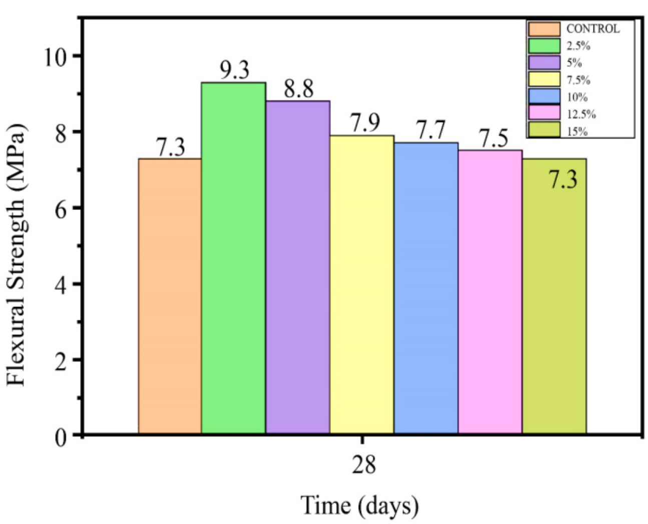


Fig. 6(b) The impact of CR particle size (0.18-1.25mm) on the flexural strength of concrete

3.6. Density

Control and CRC concrete densities were compared before cubes were tested for compressive strength after 28 days of curing. The densities of CRC mixes were lower than control concrete due to a lesser specific gravity (SG) of CR (1.11) compared to fine aggregate (2.35). CR, a lightweight material replacing natural aggregate, contributed to the reduction in densities. The densities decreased as the rubber quantity increased in the concrete. Other researchers also noted a similar observation [51].

Although the densities for CRC mixes were lower than that of the control concrete, they still offered acceptable values higher than (2000kg/m3) as per standards. This low density is beneficial in constructing tall structures since the dead load will be reduced. The test results are displayed in Fig. 7(a) & Fig. 7(b).

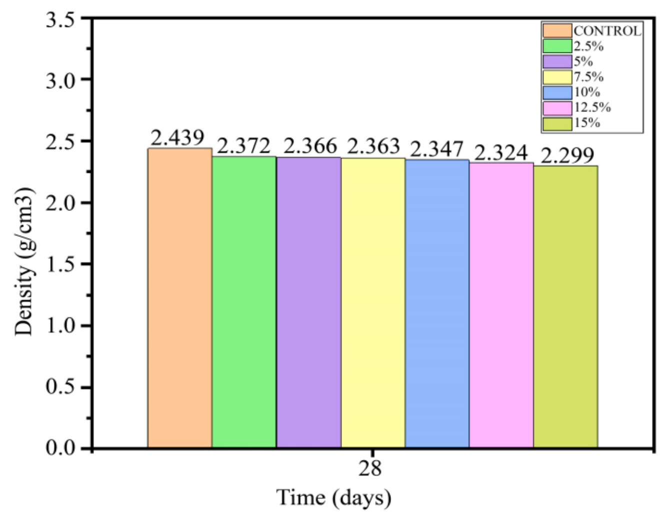


Fig. 7(a) The impact of CR particle size (0.18-5mm) on the density of concrete

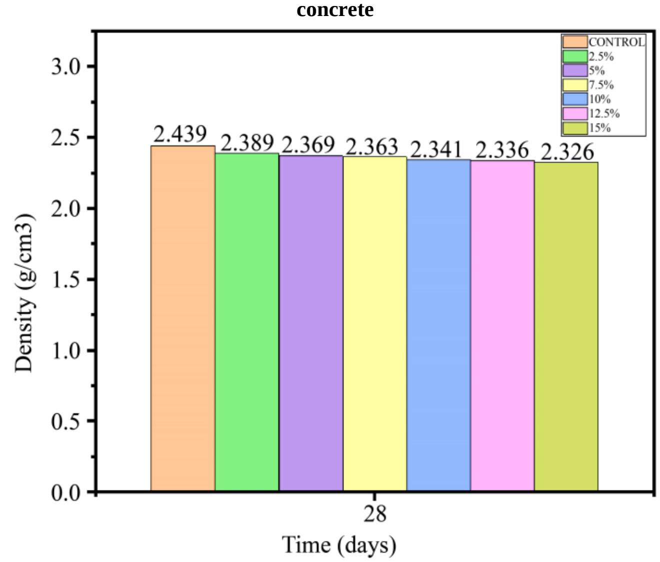


Fig. 7(b) The impact of CR particle size (0.18-1.25mm) on the density of concrete

Table 6(a). Water absorption for control concrete and CR (0.18-5mm)

% Replacement	weight of the dry sample (g)	Weight of wet sample (g)	Water absorption (%)
0	2295	2340	1.96
2.5	2250	2295	1.97
5	2247	2292	1.99
7.5	2236	2281	2.01
10	2211	2256	2.02
12.5	2192	2237	2.08
15	2191	2237	2.10

Table 6(b). Water absorption for control concrete and CR (0.18-1.25mm)

% Replacement	Weight of dry sample (g)	Weight of wet sample (g)	Water absorption (%)
0	2295	2340	1.96
2.5	2254	2296	1.85
5	2232	2275	1.94
7.5	2245	2289	1.96
10	2235	2279	1.98
12.5	2191	2235	1.99
15	2184	2228	2.01

3.7. Water Absorption

Tables 6(a) & 6(b) show the water absorption findings for CRC and control concrete mixes after 28 days of moist curing. The result showed that 2.5% replacement of the fine aggregate with (0.18-1.25mm) absorbed less water than control concrete and (0.18-5mm) particle size distribution for FA replacement up to 5%. The finding might be because of the dense packing of the finer CR particles, resulting in fewer voids in the concrete and less water absorption. The percentages of water absorption in all CRC mixes increased in the concrete as the rubber content rose, which was also reported by another researcher [51].

4. Conclusion

This paper experimentally examined the impact of using variable particle size distribution of CR pre-treated in a sodium hydroxide (NaOH) and utilized as a material to partially replaced fine natural aggregate in high-strength concrete with PPC as a binder material. This study utilized six replacement levels of 2.5%, 5%, 7.5%, 10%, 12.5%, and 15% of (0.18-5mm) and (0.18-1.25mm) CR for fine nature aggregate. The effects of six replacement levels on Portland Pozzolana Cement (PPC)-based high-strength concrete's slump, compressive strength, tensile strength, flexural strength, density, and water absorption characteristics. It was observed that 2.5% of (0.18-1.25mm) particle size was most suited for replacing the fine natural aggregate in terms of compressive strength with 61MPa at 28 days. The compressive strength for CRC was lower than that of the control mix, but it was still sufficient for high-strength concrete (>60MPa).

Besides having high strength, CRC incorporating 2.5% CR of particle size 0.18-1.25mm had several additional advantages: improved workability at fresh state, improved tensile and flexural strength, and reduced density and water absorption. All these factors show that treated CR can be incorporated in high-strength concrete with some reduction in compressive strength but with other enhanced performance parameters. In addition, an avenue for the disposal of waste tire rubber will be provided, and the use of natural non-renewable fine aggregate will be reduced.

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