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Experimental Evaluation of Slurry Infiltrated Fibrous Concrete with Waste Tire Rubber Fine Aggregate

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ABSTRACT

Slurry-infiltrated fibres concrete (SIFCON) represents a specialized variant of high-performance steel fibres reinforced concrete (HPFRC), celebrated for its superior strength and ductility characteristics. In the ongoing quest for more sustainable construction materials, an opportunity arises to harness the massive quantities of waste tires generated globally by the burgeoning automotive industry. This study investigates the effects of replacing fine aggregate in SIFCON with treated waste tire rubber at various replacement rates (5%, 10%, and 15%) on the resultant compressive strength, flexural strength, and split tensile strength. This approach not only contributes to waste reduction but also aids in preserving natural aggregates. A novel method of introducing strong polarity groups to the rubber surface was employed in this study to foster robust chemical interactions between the rubber and the cement matrix, aiming to enhance the concrete's mechanical properties. Despite the observed deterioration in the mechanical characteristics of SIFCON as the rate of sand replacement with rubber powder increased, the incorporation of waste rubber demonstrated significant benefits in terms of reduced the density and cost. This research underscores the potential for treated recycled chopped rubber as a partial substitution for fine aggregate in SIFCON, simultaneously supporting sustainable construction practices and contributing to global waste management efforts.

1. INTRODUCTION

Slurry-infiltrated fibres concrete (SIFCON) is a specific type of fibre concrete that is recognized by its high fibre content. During the manufacturing process, fibres are first inserted into moulds, and then a cement slurry or mortar is introduced, which usually has a low ratio of water to cementitious material. The production process of SIFCON significantly deviates from the conventional manufacture of fiber reinforced concrete by pre-placing fibers, resulting in a major increase in fiber content [1-5].

SIFCON, which combines a high-strength cement-based matrix with a higher amount of fibres, has enhanced post cracking strength and toughness (energy absorption capacity), in comparison to traditional fibre reinforced concrete. However, the presence of a significant amount of fibre in SIFCON leads to a rather expensive price [1-5]. The promise of SIFCON is especially apparent in applications that need resistance to impact and improved ductility, such as seismic retrofit designs, constructions subject to impact or explosive impacts, and the restoration of reinforced concrete parts [6].

Unlike standard fibres-reinforced concrete (FRC) which normally has fibres in a volume of 1-3%, SIFCON has a higher fibre content ranging from 4-20%, with the most prevalent use lying between the 4-12% range [6]. The production process of SIFCON, which entails the penetration of a layer of pre-arranged fibres with cement slurry, is noticeably dissimilar from fibres-reinforced concrete (FRC), which is created by inserting fibres to the wet concrete [7, 8].

The exponential growth of the automotive sector, combined with a decrease in available space for trash disposal, has intensified the issue of managing and disposing of used tires. Approximately seventy-five to eighty percent of used tire debris is presently disposed of in landfills, highlighting the urgent need for alternate alternatives [9-12]. Furthermore, the disposal of discarded tires poses substantial environmental risks owing to the presence of non-biodegradable toxic compounds inside the tires [9-12].

An encouraging approach for using discarded tires is by including them as aggregates in concrete, which is mostly constituted of aggregate and cement. Approximately 60% of discarded tires are unlawfully disposed of, despite their significant potential [9-12]. Utilizing used tires in the production of concrete is an effective approach to save waste. Multiple researches have examined the concrete's mechanical characteristics that incorporates various types and quantities of waste chopped rubber [9-12].

The main objective of these experiments has been to substitute natural sand with chopped rubber in the concrete's manufacturing. Results from different levels of crumb rubber substitution have shown variability, with some studies suggesting that a 10% substitution rate of scrap rubber is optimal [13]. Introducing a 25% replacement of recycled rubber significantly enhances the concrete's ability to absorb energy, however, it does result in a substantial decline in the compressive strength [14]. The decline in compressive strength seems to be associated with the volume and dimensions of the chopped substitution particles. This can be attributed to a weak interfacial transition-zone (ITZ) between the chopped particles and the cement paste, in addition to the variations in the elastic modulus between the chopped particles and concrete [15].

Bisht and Ramana [16] conducted a study to examine the mechanical and durability characteristics of concrete containing chopped rubber at different weight percentages: 0%, 4%, 4.5%, 5%, and 5.5%. It was discovered that the workability of rubcrete diminishes as the amount of used chopped rubber rises. A marginal decline in both flexural and compressive strength was seen when natural aggregates were substituted with waste-chopped rubber at a rate of 4%. Furthermore, the replacement amount had little impact on both water absorption and abrasion resistance. According to the research, as the levels of replacement rose, the unit-weight of rubcrete dropped. This occurred because of the lower specific gravity and the high porosity of chopped tire in comparison to natural sand [16].

Ganjian et al. performed study to evaluate the performance of concrete mixtures with waste chopped tire at different percentages (5%, 7.5%, and 10%) as substitutes for cement and natural aggregate. The concrete's compressive strength decreased substantially as the quantity of rubber used as a substitute increased. When cement or natural aggregate was substituted with 5% waste chopped tires, the compressive strength reduction was minimal (below 5%), but the other concrete parameters remained mostly unchanged. The splitting tensile strength of concrete containing recycled chopped tires as a substitute for aggregate was seen to be inferior to that of concrete with rubber powder as a partial substitution for cement. When five to ten percent of the natural aggregate was substituted with chopped rubber, the tensile strength decreased by 30-60%. An inverse correlation was established, wherein the use of rubber material instead of 5-10% of the cement resulted in a decrease of 15-30%. Furthermore, the surface of chopped tire was modified by introducing a multitude of hydroxyl, carbonyl, and sulfonate groups by sulphonation and oxidation [17].

In an independent investigation, Zheng et al. illustrated that the hydrophilic group's addition to the surfaces of rubber particles using polyethylene glycol (PEG) and acrylic acid (ACA) greatly improved the air entrainment, slump, flexural strength, impact resistance and compressive strength of the treated rubcrete. This research also emphasized the efficacy of a two-step approach that incorporates the application of silica fume (SF) and limestone powder (LP) as pre-coatings on Waste Tire Rubber, resulting in enhanced performance of rubberized cement mortar. Significantly, blends including silica fume and a maximum of 10% limestone powder with pre-coated chopped tires exhibited exceptional flexural strength [18].

Expanding upon the aforementioned discoveries, Mohammadi et al. investigated the performance of rubcrete that has been altered using solution of sodium hydroxide NaOH treated rubber. Although there was a significant enhancement in the compressive strength and a minor improvement in the modulus of rupture, this treatment approach did not lead to enhanced adhesion qualities. The treated rubbers' rougher surfaces were identified as the cause of this result. Segre et al. proposed that the primary function of NaOH solution is to diminish the additives in the chopped tire composition. However, they also observed that immersing the rubber in a NaOH solution for 24 hours did not affect its hydrophobicity, as indicated by the water contact angle on the surface of rubber remaining above 90 degrees [19].

In addition, Issa and Salem utilized discarded crumb tires as a partial replacement for fine aggregate in concrete, varying the replacement rate of crushed sand from 0% to 100%. The results indicated that replacing 25% of the sand with crushed sand produces a satisfactory level of compressive strength. Significantly, including crumb rubber at a maximum of 25% decreased the density of concrete by 8%, resulting in enhanced ductility. This makes it well-suited for shock-resistant components and highway barriers. The damping properties were improved as well [20].

The objective of this study is to examine the impact of waste powder rubber on the compressive strength, modulus of rupture, and split tensile strength of SIFCON. The test findings provided here give first insights into the mechanical characteristics of SIFCON after substituting fine aggregate with waste powder rubber. Therefore, the results of this research provide the foundation for further research on SIFCON using waste rubber and its potential applications.

2. OBJECTIVES OF THE STUDY

Despite its high cost, SIFCON (slurry infiltrated fiber concrete) is progressively gaining global acceptance, particularly in structures subject to explosive and impact influence. This preference is largely attributable to the superior durability and mechanical characteristics of SIFCON compared to conventional fibres reinforced concrete (FRC) [8]. As SIFCON is a relatively novel construction material, the existing body of knowledge on its characteristics remains limited, drawn primarily from the few published studies.

While previous research has explored the incorporation of waste fibers in SIFCON, the utilization of recycled chopped tires in SIFCON production is a novel approach, marking this study as a unique endeavor. The primary objective of this experimental investigation centers on the evaluation of the impact of varying percentages of natural aggregate substituted with recycled chopped tire (5%, 10%, and 15%) on the compressive strength, modulus of rupture, and splitting tensile strength of SIFCON. The details and outcomes of this experimental investigation are presented herein.

The primary obstacle related to the use of scrap chopped tires in concrete is the resulting drop in both compressive and tensile strength, along with the intricacy of estimating the load-bearing capacity of 'rubcrete' components. If the negative impacts on the concrete can be efficiently controlled, it may be possible to achieve a new structural cement-based material that has enhanced ductility and reduced density.

3. METHODOLOGY

3.1 Mix proportions and materials used

Currently, there is no established standard definition for the composition of SIFCON mixes. The results of the literature research dictated the design of SIFCON's mixes. The prior studies suggest that the standard weight ratio of fine aggregate to cementitious materials is 1:1. Therefore, this ratio was used in the current experiment. Several studies [21-24] used cement quantities ranging from 800 to 1000 kg/m^3 and a water-to-cement ratio of below 0.4 while making the SIFCON matrix. Multiple research [21, 23, 25-28] used natural sand that has undergone a 4.75 mm screening process as the natural sand component in the production of SIFCON mortar. However, several studies contended that the dimensions of this naturally occurring sand were too substantial to efficiently create SIFCON samples. It is advised to only use fine with maximum size of 1.18 mm screen [29, 30] or passing through 1mm, 600 micron, or 500 micron sieve [2, 24, 31, 32]. This will guarantee the complete infiltration of the steel fiber network, with no blockages or voids formed. Several experimental mixtures were tested to determine the slurry mixture that has the most favorable viscosity, fluidity, and filling capacity during its first stage, without any segregation, bleeding, or creation of air voids in the fibre network. As a result, there was a substantial drop in the mechanical characterstics of SIFCON. Table 1 is an accumulation of several qualities. The mini-slump test, according to ASTM C1437 [33], was used to assess the workability of the mixtures, especially by measuring a distance of 255 mm. The mini-V-funnel test was performed as an additional technique for measuring the viscosity of slurry. The flow rate of the mix was measured at 10 seconds.

Table 1. Mix design of SIFCON matrix

Constituent	Mix Proportion
Cement (kg/m^3)	872.4
Natural aggregate (kg/m^3)	969
Micro Silica (kg/m^3)	96.9
Hooked Steel Fibre (kg/m^3)	312
Super Plasticizer (%)	2.7
V-funnel time (s)	10
Water/binding	0.26
Mini-slump (millimetre)	255

The study used Ordinary Portland cement (OPC) Type I, which followed the ASTM C150-18 [34] Standards. The specific gravity of cement is 3.14. With 97 minutes initial setting time, and 178 minutes final setting time. Table 2 presents a comprehensive summary of the chemical, physical, and mechanical characteristics of typical Portland cement. The composition of natural river sand consists of particles passing through 600 micron sieve. The fine aggregate was determined to have a free surface moisture content of 1.1%, a 1.6% water absorption value, and a 2.67 specific gravity of fine aggregate. Furthermore, the fineness modulus is 2.83. The size must be sufficiently small to fully permeate the compact steel fibers without encountering any obstructions.

A superplasticizer (SP) based on polycarboxylate, which adheres to the ASTMC494/C494M-17 [35] standard, was used. This is essential to ensure that the slurry can flow smoothly through the dense fiber bed without creating honeycombs. The experiment used 35mm hooked-end steel fibers with a diameter of 0.5mm. The fibres had a length-to-diameter ratio (aspect ratio) of 70 and had 1100 MPa tensile strength. The experiment used a steel fibre volume percentage of four percent. The fibre volume was obtained by computing the volume of the mold for each sample. Figure 1 demonstrates the hooked steel fibres utilized in this study. The steel fibers were incorporated into the SIFCON matrix via a multi-layer technique, after many attempts at laboratory casting techniques. After inserting and compacting the randomly aligned fibers to a certain degree in the mold, the mortar was then poured into the mold to achieve the same level. The mortar must have enough fluidity to allow it to penetrate the fiber, as shown in Figure 2.

The local industry, namely the Al-Diwaniya tire plant in Iraq, gathered waste rubber. The waste rubber was pulverized into a fine powder and then sifted using a 600 micron screen after extracting steel and textile fibres. The replacement method considered the change in specific gravity between waste rubber and fine aggregate. The substitution mass of sand was determined by multiplying the ratio of the specific gravity of fine aggregate to that of rubber. The powder rubber's specific gravity is 1.04. This work focuses on the particulate rubbers shown in Figure 3. Powdered rubber was used as a replacement for natural aggregate at various weight ratios (5%, 10%, and 15%). Only powder rubber was used as a replacement for the fine aggregate, but all other factors remained the same. To improve the bonding in the interfacial transition zone, 10% micro-silica was added to the SIFCON with the weight of cement [36]. By incorporating micro-silica into concrete, its strength may be improved by promoting dense packing and sealing the pores in the cement paste. Micro silica demonstrates greater reactivity in the presence of moisture and normal temperatures compared to fly ash. Table 2 demonstrates that the chemical characteristics of silica fume (SF) comply with the standards outlined in the ASTM C1240-15 [37] standard.

Table 2. Mechanical, physical and chemical characteristics of cement and micro-silica

Chemical Composition	Cement (%)	SF (%)	Physical Characteristics	
SiO_2	64.2	89.43	**Cement**	
Al_2O_3	21.8	0.64	Specific surface (m^2/kg)	326
Fe_2O_3	3.6	0.45	Specific gravity	3.15
SO_3	2.6	0.85	**SF**	
CaO	3.6	0.81	Specific surface (m^2/kg)	21000
L.O.I	3.4	4.11	Specific gravity	2.2
CaO (free)	1.33	2.15		

Figure 1. Steel-fibres that were used

Figure 2. The SIFCON specimens pouring procedures

Figure 3. The powder waste rubber tires used

The compressive strength testing was performed on 100×100×100 mm cubic samples, in accordance with the parameters provided in ASTM C 109/C 109M [38]. The flexural strength was determined by performing tests on prisms of (100×100×400) mm using the third-point loading technique outlined in ASTM C78 [39]. The tensile strength test was carried out according to the ASTM C496-04 standard [40]. The experiment included cylindrical samples measuring 100mm in diameter and 200mm in height. Following the casting process, the samples were extracted from the moulds after being stored in a controlled atmosphere with high humidity for 24 hours at a temperature of 20±2℃. The specimens were subjected to a 28-day immersion in water for curing. The water temperature used for the process of curing was consistently maintained at a controlled range of 20±2℃. Table 3 displays the codes for all the mixes investigated in this research, which are also used in the tables and figures that illustrate the findings of the study.

Table 3. SIFCON's samples codes.

Code of Sample	Steel Fiber %	Rubber Content %	Rubber Pre-Treatment
NS0	4	0	-
NS5	4	5	-
NS10	4	10	-
NS15	4	15	-
MNS5	4	5	NaOH
MNS10	4	10	NaOH
MNS15	4	15	NaOH

3.2 Treatment of waste tires rubber

The rubber particles were immersed in the solution of Sodium hydroxide (NaOH) with a concentration of five percent (%) for a duration of 24 hours. Prior to use, the chopped particles were removed after the specified duration period, purified using distilled water, and then dried under conventional laboratory conditions. To minimize the potential chemical influence of the solution of Sodium hydroxide on the bonding between the chopped particles and cement paste, the chopped particles underwent a water purification process. This procedure was implemented because of the well acknowledged fact that chopped particles have a reduced water absorption rate [41-43].

4. RESULTS AND DISCUSSION

4.1 Compressive strength

Table 4 illustrates the compressive strength and the percentage of strength reduction of slurry-infiltrated fibre concrete including treated and prepared chopped rubber. To minimize the expected range of error for each recorded outcome, the values in this table were computed by taking the average of the results obtained from three separate cube tests.

Figure 4 illustrates the variations in compressive strength of SIFCON specimens after 28 days, as influenced by the proportion of sand replaced with powdered rubber [23]. With the increase in the quantity of powdered rubber, there was a progressive decline in compressive strength. The compressive strength of the mix containing 15% powdered rubber decreased by about 50% in comparison to the reference mixture. The control mixture with 0% powdered rubber exhibited the maximum compressive strength, measuring 85.52 MPa. Conversely, the mixture with 15% sand replacement using powdered rubber had the lowest compressive strength, measuring 44.01 MPa.

For SIFCON specimens with pre-treatment powder rubber with NaOH solution, the percentage of strength loss is less than that of untreated specimens at the identical percentage of sand replacement with powder rubber. With 5% sand replacement MNS5 the compressive strength at 28 days reduces to 76.43 MPa that is a reduction of 10.6%. While with 10% sand replacement MNS10, compressive strength is 64.14 MPa that is a reduction of 25.0% from the control value. For the sand replacement of 15% MNS15 the compressive strength reduces to 46.35 MPa that is a reduction of 45.8 % from the control mix. All SIFCON specimens did not exhibit brittle failure under compressive load and horizontal fractures were seen.

Previous studies on rubberized concrete have provided evidence for the decline in mechanical properties of SIFCON resulting from the replacement of sand with powdered rubber [44]. The decline in the compressive strength and modulus of rupture of rubcrete may be attributed to (a) the insufficient adhesion between chopped particles and cement paste, in contrast to the adhesion between cement paste and normal sand. Fractures may arise as a result of the uneven distribution of forces. (b) The compressive strength is effected by the physical and mechanical characteristics of the component materials. The addition of rubber to replace a part of the material will result in a drop in strength. (c) Chopped rubber particles tend to rise in the vibration process, resulting in a higher concentration of chopped particles in the surface. This is due to the rubber's limited bonding with other SIFCON elements and its low specific gravity. The presence of several components in this concrete sample lowers its strength [17].

4.2 Flexural strength (modulus of rupture)

The flexural strength of slurry-infiltrated fiber concrete containing waste chopped that has been untreated and pre-treatment is shown in Table 5. Moreover, a proportionate percentage of strength decrease was determined when compared to the control mixes.

Figure 5 demonstrates that the pre-treated mixes (MNS6, MNS8, and MNS10) exhibit a smaller decrease in comparison to the original reference mix NS0. This is due to the NaOH solution pre-treatment, which enhances the adhesion between the cement mortar and the rubber surface. The modulus of rupture at 28 days decreases to 19.11 MPa with the addition of MNS5, which replaces 5% of the rubber content. This is a decrease of 7.4%. The flexural strength of MNS10, with a 10% rubber substitution, is 17.08 MPa. The decrease from the control mix amounts to 17.2%. The rubber percentage of MNS15, which is 15%, results in a flexural strength of 15.01 MPa, representing a decrease of 27.3% in comparison to the reference mix.

Figure 6 shows the results of the flexural strength measurements. The substitution of powdered rubber results in a predictable decrease in flexural strength. Table 5 shows that the untreated rubber mixes resulted in reduction in flexural strength when rubber was used. Specifically, there was a reduction of 9.5% at NS5, 21.2% at NS10, and a significant loss of 40% at NS15 compared to the control mix NS0.

Table 4. Compressive strength of SIFCON with sand replaced by powder rubber

Age Days	Compressive Strength fcu (MPa)						
	NS0	Untreated Rubber %			Modified Rubber %		
		NS5	NS10	NS15	MNS5	MNS10	MNS15
28	85.52	70.5	61.3	44.0	76.4	64.1	46.3
Residual Strength %	100	82.5	71.7	51.4	89.4	75.0	54.2
Strength Loss %	0	**-17.5**	**-28.3**	**- 48.6**	**- 10.6**	**- 25.0**	**- 45.8**

Table 5. Flexural strength of SIFCON with sand replaced by powder rubber

Age Days	Flexural Strength fcu (MPa)						
	NS0	Untreated Rubber %			Modified Rubber %		
		NS5	NS10	NS15	MNS5	MNS10	MNS15
28	20.6	18.6	16.2	12.3	19.1	17.1	15.0
Residual Strength %	100	90.5	78.8	60.0	92.6	82.8	72.7
Strength Loss %	0	**-9.5**	**-21.2**	**-40.0**	**-7.4**	**-17.2**	**-27.2**

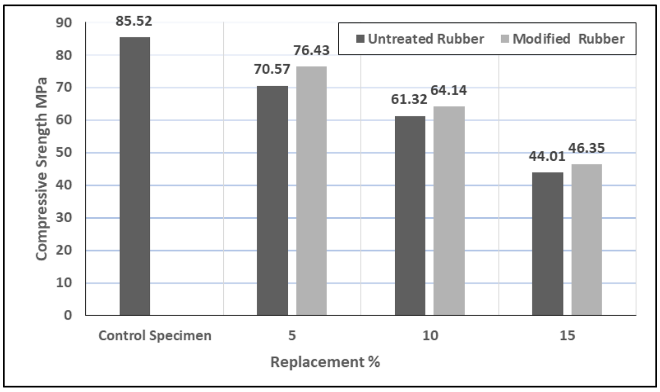

Figure 4. Compressive strength of varying powder rubber replacement (%)

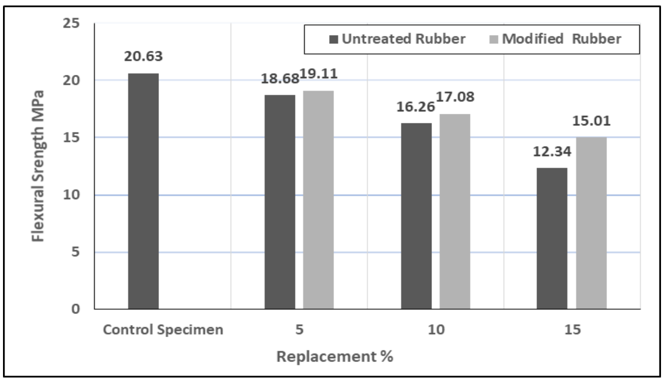

Figure 5. Flexural strength of varying powder rubber replacement (%)

Every SIFCON sample exhibited deformation without total disintegration, as seen in Figure 6. The use of silica fume and a lower water to cement ratio have improved the modulus of rupture of rubberized concrete. The inclusion of micro-silica in high-strength rubcrete led to a diminished strength loss in comparison to normal-strength concrete. This might be attributed to the influence of silica fume on the bonding of the interfacial transition zone [45]. The primary cause for the reduction in modulus of rupture and compressive strength is attributed to inadequate adhesion between the rubber surfaces and cement mortar. Moreover, the experimental findings clearly indicate that substituting sand with powdered rubber in SIFCON samples has a more pronounced impact on their compressive strength values compared to their flexural strength. This phenomenon may be attributed to the elastic qualities of rubber, which allow it to effectively absorb a significant amount of energy and demonstrate exceptional resistance to bending.

Figure 6. Flexural failure mode of SIFCON samples

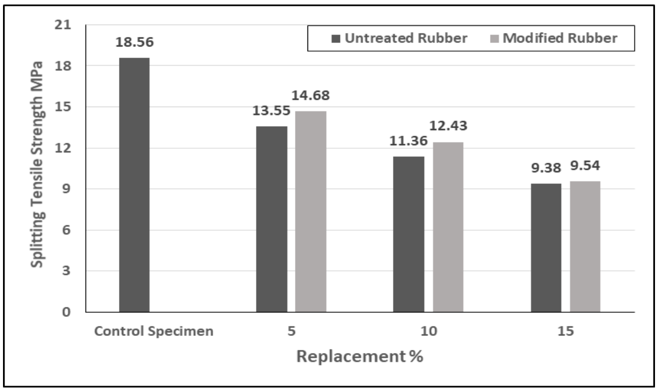

Figure 7. Splitting tensile strength of varying powder rubber replacement (%)

4.3 Tensile strength (Splitting test)

Figure 7 and Table 6 illustrate the results of the splitting tensile strength test. The tensile strength of SIFCON samples exhibited a reduction as the proportion of sand replaced with powder rubber increased, regardless of whether the mixes were treated or not. At a replacement percentage of 5%, the untreated mix resulted in a decrease in tensile strength of 27%, while the changed mixture experienced a decrease of 20.9%. The tensile strength decreased by 38.8% for the untreated combination and by 33.1% for the modified mixture when 10% replacement was done, as compared to the control mixture. At a replacement rate of 15%, the untreated mix had a drop in tensile strength of 49.5%, while the changed mixture experienced a reduction of 48.6%. Tire rubber, being a pliable substance, may serve as a protective barrier to prevent the formation of fractures in concrete. Hence, the utilization of chopped rubber in concrete should result in a higher tensile strength compared to the standard combination. Nevertheless, the findings refuted this idea. Possible causes for this behaviour may include the following factors: The insufficient adhesion between chopped rubber and cement results in the formation of a microfracture in the interface zone, which in turn hastens the deterioration of the concrete.

Table 6. Splitting tensile strength of SIFCON with sand replaced by powder rubber

Age Days	Splitting Tensile Strength fcu (MPa)						
	NS0	Untreated Rubber %			Modified Rubber %		
		NS5	NS10	NS15	MNS5	MNS10	MNS15
28	18.5	13.5	11.3	9.4	14.7	12.4	9.6
Residual Strength %	100	73.0	61.2	50.5	79.1	66.9	51.4
Strength Loss %	0	**-27.0**	**-38.8**	**-49.5**	**-20.9**	**-33.1**	**-48.6**

5. CONCLUSION

This study examines the practical use of powdered chopped rubber as a substitute for normal sand in various proportions for the manufacturing of SIFCON, as determined by experimental methods. The findings reported in this research utilizing experimental data for SIFCON samples with waste rubber provide the following conclusions:

- The findings show that the compressive strength reduced when waste rubber powder was used as a partial substitution for natural sand. The decrease in compressive strength may be ascribed to the variance in softness between the waste rubber particles and the natural sand particles next to the cementitious materials. When rubber particles are exposed to a compressive force, they break quickly, leading to a reduction in their ability to withstand compression.
- The splitting tensile strength exhibited a drop in proportion to the rise in powder rubber levels, similar to the compressive strength. The loss in tensile strength seen in concrete containing waste rubber may be attributed to the isolation of other solid elements of the mix by the presence of small rubber particles. These rubber particles function as voids, leading to stress concentration and ultimately causing a quick breakdown in tension. The main cause of the separation between cement pastes and waste rubber aggregate during crack formation is the weak link between them. This separation occurs specifically at the contact surfaces of the waste rubber particles when they are subjected to tensile stresses.
- The flexural strength declines with an increase in the proportion of powdered rubber material. This occurs due to the existence of fractures, which diminishes the strength of the connection between the component elements. When the sand is replaced with powdered rubber at the same proportion, the decrease in compressive strength is more pronounced compared to the decrease in flexural strength.
- Utilization of NaOH solution as a pre-treatment for rubber particles may improve the compressive, tensile, and flexural strength of SIFCON samples compared to untreated ones.

6. FUTURE SCOPE

Mechanical qualities were seen to decrease at replacement levels (5%, 10%, and 15%), mostly due to void generation caused by waste rubber's fineness. This negative impact might be mitigated by varying the grades of scrap rubber used in the SIFCON mixture. To assist reverse this performance deterioration, other alkaline chemical compounds may also be used to crumb rubber. The mechanical and durability features of the mixture might be improved by using the above-mentioned ways to strengthen the link between waste rubber and cement paste.

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