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Waste Rubber Pre-treatments and Their Effects on Compressive and Flexural Strength of Modified SIFCON

Ali M. Hashim*, **Basil S. Al-Shathr**

Civil Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: bce.20.02@grad.uotechnology.edu.iq

HIGHLIGHTS

- Possibility of using waste rubber tires in the production of SIFCON.
- Different pre-treatment methods were used to improve the bonding between the cement paste and rubber particles.
- Waste chopped rubber has caused a decline in the flexural strength of modified SIFCON.
- Pre-treatment of chopped rubber with NaOH solution produced the highest compressive and flexural strength values.

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ABSTRACT

Slurry-infiltrated fiber concrete (SIFCON) is a comparatively new and unique steel fiber-reinforced concrete (FRC) form. SIFCON possesses many desirable characteristics, including high strength and ductility. Sustainable concrete is one of the most critical types of concrete for the current environment. An enormous volume of waste rubber tires is produced globally due to the expansion of the automobile industry. This study's primary purpose is to assess the impact of employing pre-treated waste rubber tires in slurry-infiltrated fiber concrete on its flexural and compressive strengths. Based on flexural and compressive strengths, an experimental program was conducted to evaluate the flexural and compressive strengths of SIFCON containing 4% steel fiber and 6%, 8%, and 10% waste rubber. Different pre-treatment methods were used to improve the bonding between the cement paste and rubber particles, including Na(OH) solution, $Ca(OH)_2$ solution, and pre-treatment using Cempatch AB solution. Compressive and flexural strength decreased with increasing waste rubber content, up to 43% and 37% for a 10% waste rubber content, respectively. Moreover, The test results showed that the pre-treatment of chopped rubber with NaOH solution produced the highest values for compressive and flexural strength, giving strong polarity groups to the surface of the rubber and generating a strong chemical interaction between the rubber and the cement matrix.

1. Introduction

Slurry Infiltrated Fiber Concrete (SIFCON) is a high-performance cementitious material that falls under the category of fiber-reinforced concrete [1-6]. In SIFCON production, the fibers are first incorporated into the molds and then infiltrated with cement slurry, which typically has a low water/binder ratio. This method of production is distinct from the production of normal fiber-reinforced concrete. As a result of the prepackaging of the fibers in SIFCON, the fiber content can be significantly increased. Due to the high fiber content and high-strength cement-based matrix, SIFCON's energy absorption capacity and post-cracking strength, or toughness, can be considerably higher than those of conventional steel-fiber reinforced concrete. The high fiber content contributes to their comparatively expensive cost.

Using the estimation that there are 1.3 billion vehicles worldwide, it is possible to compute that 5.2 billion tires are now in use. Even though worn-out tires can be used again after being rethreaded or regrooved, they are still considered trash and are hard to eliminate [7].

Each year, more than 20 billion vehicle tires are rendered obsolete [8,9]. Disposing of worn-out tires in a sanitary manner is one of the industry's most significant obstacles. Because there are so many tires, burying them is impractical and expensive. As a result, it is prohibited to keep tires outdoors, which presents environmental risks, including massive fires and an increase in insects and rodents [10,11]. End-of-life tires are used in other industries, such as the concrete industry since reusing and recycling old tires to make new ones is costly. Depending on their size, the residual rubber fragments may be utilized in concrete as tire chips, powder, or crumb rubber. The first two types of rubber are widely used in concrete as partial substitutes for natural aggregates, while the third kind of rubber is utilized as a partial substitute for fine sand, filler, or binder.

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

Liu and Zhang [12] investigated the influence of recycled rubber particles (WRP) on the mechanical characteristics of concrete. According to the results, the concrete mix specimens' average flexural and compressive strengths dropped by 15%. This decrease resulted from the rubber chips in the concrete mixture being incredibly "soft." Mehrani [13] studied the effect of rubber granules on the mechanical characteristics of lightweight concrete in a separate investigation. The results showed that up to 5% rubber powder replacement had a positive effect. The mechanical characteristics of concrete were investigated experimentally by Al-Tayeb et al., [14]. Fine aggregate replacements of 5%, 10%, and 20% by volume, and cement replacements of 2.5%, 5%, and 10% by volume were used to produce the mixtures. The compressive strength was reduced by 19%, 32%, and 53%, respectively, when waste rubber powder substituted cement at 2.5%, 5%, and 10% of the volume. In a series of studies, Gupta et al. [15] discovered that adding rubber fibers and rubber granules to concrete decreased its compressive strength and density but increased its fatigue life, impact resistance, and flexural load-carrying capacity. Adding fibers and rubber granules to concrete enhanced its water carbonation depth and permeability.

Bisht and Ramana [11] assessed the durability and mechanical properties of concrete containing 0%, 4%, 4.5%, 5%, and 5.5% by weight of recycled tire rubber. The workability of concrete has been seen to decrease when recycled rubber tire content increases. Flexural and compressive strength test results indicate a slight reduction with a 4% substitution of sand for crumb tire rubber. Abrasion resistance and water absorption were also slightly influenced by the identical substitution ratio of crumb tire rubber in concrete. Furthermore, as the replacement level increases, the density of rubberized concrete decreases. This could be due to the increased porosity of the concrete and the lower specific gravity of waste tire rubber compared to fine aggregates. Ganjian et al. [16] examined the efficacy of concrete mix containing (5%, 7%, and 10%) waste rubber tires as cement and aggregate substitutes. The study's findings were as follows: With rising percentages of waste rubber substitution in concrete, compressive strength declined; nevertheless, the reduction in compressive strength at 5% substitution of cement or aggregate with waste rubber was minimal (below 5%), and other concrete parameters were unaffected. Concrete containing rubber chips as aggregate replacement has a lower tensile strength than concrete with rubber powder (for cement replacement). The tensile strength decreased by 30–60% when 5 to 10% of aggregate was replaced by chopped tire rubber, whereas the drop for 5 to 10% cement substituted by waste powder rubber was 15-30%. Numerous hydroxyl, carbonyl, and sulfonate groups were introduced by oxidation and sulphonation during the surface modification of recycled tire rubber.

The physical characteristics of the fibers and matrix and the bond's strength are the key determinants of the composite material's theoretical performance. Bond strength varies depending on a large number of factors, including time. The material's strength decreased in the compressive, flexural, and tensile directions, which was one of the typical results from several studies. Prior surface treatment of the waste tire has been suggested in several papers as a potential way to minimize strength loss [17]. Segre and Joekes [18] carried out research in which the powdered rubber surface was altered using a range of treatments, such as sodium hydroxide NaOH. Their goal was to improve the surface hydrophilicity of rubber. It was thought that by applying that, the NaOH would hydrolyze the carboxyl and/or acidic groups on the rubber surface. Using samples of rubber that had been treated with 10% sodium hydroxide, tests on flexural strength, elastic modulus, compressive strength, and abrasion resistance were conducted. They discovered that the specimen containing rubber treated with NaOH displayed greater values for flexural strength than the control specimen. Mohammadi et al. [19] assessed the characteristics of rubberized concrete made with rubber that had been treated with sodium hydroxide NaOH, and they found that this treatment process led to a substantial improvement in compressive strength and a small increase in flexural strength. However, due to the modified crumb rubber's coarser surfaces, it did not result in improved adhesive properties for the rubberized concrete.

In order to create sustainable concrete, Rajan, et al. [20] investigate the use of recycled tire rubber material as a partial replacement for fine aggregates in M30 grade of concrete mix at varied percentages. In order to create a good chemical interaction between the cement matrix and the rubber surface, a method of surface modification was suggested. Prior to being washed with clean water, waste tire rubber was first immersed in a 5 percent sodium hydroxide (NaOH) solution for 24 hours. Second, waste tire rubber was added to a solution of 5 percent potassium permanganate ($KMnO_4$), whose pH was corrected to 2-3 using sulphuric acid, and the solution was heated to 60°C while being agitated for around two hours to facilitate the oxidation reaction. The recycled tire rubber is washed in clear water before submerging in a 5 percent saturated sodium bisulfite ($NaHSO_3$) solution at 60℃ for 0.5 to 1 hour. They discovered that, compared to conventional concrete, in 5% and 7.5% by weight, the compressive strength exceeds 100% of the replacement of treated recycled tire rubber. Additionally, the flexural strength reaches (100% and 90%) of the replacement of treated recycled tire rubber in (2.5% and 5%) by weight as compared to normal concrete [20].

The primary objective of studies relating to waste rubber has been the substitution of fine aggregate in concrete with chopped rubber. Different percentages of crumb rubber replacement in concrete produced variable results, and researchers determined that 10% crumb rubber substitution is optimal [21]. With a 25% waste rubber substitution, the energy absorption of the resultant concrete dramatically increases, but the compressive strength decreases [22]. The compressive strength decreases in proportion to the size and percentage of rubber replacement particles. The compressive strength decrease can be attributable to a weakened bond between rubber particle crumbs and cement material in the interfacial transition zone (ITZ) or to elastic modulus variations between rubber and cement [23].

Despite the fact that there are investigations regarding waste fibers in SIFCON in the literature, this research is the first to use waste chopped rubber tires to produce SIFCON. This experimental study's primary goal was to look at the compressive and flexural strengths of SIFCON made with waste rubber from used tires. This article presents the details and results of the experimental investigation. The reduction in flexural and compressive strength, choosing the suitable method for rubber pre-treatment, and the difficulty in predicting the load capacity of rubberized concrete members represent the greatest challenges for using recycled tire rubber in concrete. If these undesirable influences of concrete can be reduced, a new cement-based structural material with improved ductility and low weight will be developed.

2. Experimental Work

2.1 Materials Used and Mix Proportions

Because there is currently no standard specification for SIFCON mixture design. The findings of the literature review aided in the design of SIFCON mixtures. According to these studies, the ratio of sand to cementitious materials by weight in the majority of cases is 1:1, so this value was used in the present study. For the production of the SIFCON matrix, numerous researchers [24-27] recommended using a W/C ratio of less than 0.4 (by weight) and a cement content ranging from 800 to 1000 kg/m3. Some researchers [24,26,28-31] used natural sand passing through a 4.75 mm sieve as a fine aggregate in preparing SIFCON mortar. While other researchers considered this size of fine aggregate to be too coarse to be used successfully in making SIFCON specimens, and they recommended using only fine sand with a small size, either passing through a 1.18 mm sieve [32,33] or with a maximum size of (1,0.6,0.5 mm) [2,27,34,35] in order to ensure complete penetration through the network of steel fiber without honeycombing or clogging.

Many trial slurry mixes were made to find a mixture with the best fluidity, viscosity, and filling abilities in its fresh state without bleeding, segregation, or pore pockets in the fiber network and a significant reduction in the mechanical properties of SIFCON. The properties of mixtures are listed in Table 1. The Mini-slump flow test, in accordance with ASTM C1437 [36], was used to determine the workability of the mixes, which was found to be 255 millimeters. The mini-V-funnel test was another method used to measure the viscosity of slurry. The flow rate of the mixture was 11 seconds.

Table 2 illustrates the physical, mechanical, and chemical composition of ordinary Portland cement (OPC) Type I according to the ASTM C150-18 [37] standard used in this work. As shown in Table 2, micro-silica (MS) complies chemically with ASTM C1240-15 [38] criteria. Sand with a maximum particle size of 0.60 mm and a specific gravity of 2.65 was utilized as fine aggregate for SIFCON. It must be small enough to ensure total penetration without blocking the thick steel fiber.

Table 1: SIFCON matrix mix design

Constituent	Mix Proportion
Cement (kg/m^3)	872.4
SF (kg/m^3)	96.9
Sand (kg/m^3)	969
Super Plasticizer by Wt. of Cementitious (%)	2.7
Hooked-end Steel Fiber (Kg/m$^{3)}$	312
Water/binding	0.26
V-funnel time (s)	11
Mini-slump flow (mm)	255

A polycarboxylate-based superplasticizer (SP) that complies with ASTMC494/C494M-17 [39] was used in order to produce the requisite workability of the slurry, which should be fluid enough to pass through the thick fiber bed without leaving honeycombs. Furthermore, hooked-end steel fiber with a length of 35 mm, a diameter of 0.5mm, and an aspect ratio of 70 with a tensile strength of more than 1100 MPa was utilized in this study. The steel fiber volume fraction employed in this investigation was 4%. The fiber volume was determined according to the volume of each specimen's mold. Figure 1 illustrates the hooked-end steel fiber used in this research, and Table 3 indicates the technical properties of steel fiber used according to the manufacturer Company. After several casting technique trials in the laboratory, the hooked end fiber was incorporated into the SIFCON matrix using a multi-layer method. Initial placement and packing of randomly oriented fibers in the mold to a specified level was followed by filling the mold with mortar to the same level. As demonstrated in Figure 2, the mortar must be sufficiently flowable to achieve infiltration into the fiber.

The waste tire rubber, with a specific gravity of 1.1 and a particle size ranging from 3 - 5 mm used in this study, was collected from the Al-Diwaniya tire factory in Iraq as waste car tires. They were cleaned with tap water to eliminate anything that may affect the characteristics of crumb rubber. The rubber fibers are shown in Figure 3. Using 100×100×100 mm cubes, the compressive strength testing was conducted in accordance with ASTM C 109/C 109M [40]. Whereas prisms with (100×100×400) mm were tested for flexural strength according to ASTM C78 (third-point loading) [41]. After being cast, samples were kept for 24 hours in saturated humid air at 20 ± 2°C before being demolded. The specimens were cured for 28 days in water. The temperature of the curing water was set to 20 ± 2°C.

Table 2: Cement and micro-silica's physical, mechanical, and chemical composition

Chemical composition (%)	Cement	Micro Silica	Physical characteristics	
SiO_2	64.1	88.43	**Cement**	
Fe_2O_3	3.7	0.45	Specific gravity	3.15
Al_2O_3	20.8	0.64	Specific surface (m^2/kg)	327
CaO	3.6	0.81	**Micro-Silica**	
CaO (free)	1.33	2.15	Specific gravity	2.2
SO_3	2.6	0.85	Specific surface (m^2/kg)	21000
Loss on Ignition (L.O.I.)	3.4	4.11		
Main Compounds (Bogue's Equation)				
Tricalcium Silicate (C3S)	55.11			
Dicalcium Silicate (C2S)	19.01			
Tricalcium Aluminate (C3A)	9.29			
Tetracalcium Aluminoferrite (C4AF)	7.98			

Table 3: Material and geometrical data of the steel fibers*.

Property	Results of hooked-end steel fiber	ASTM A820-04
Description	Deformed shape hooked end	
Appearance	Bright and clean wire	
Length (l),mm	35	
Diameter(d),mm	0.5	
Aspect ratio(l/d)	70	
Density (kg/m^3)	7800	
Tensile strength (MPa)	1100	Min. 345

*According to the manufacturer

Figure 1: The steel fibers used

Figure 2: Casting processes of SIFCON specimens

Figure 3: The waste rubber tires used

2.2 Treatment of Waste Tires Rubber

In order to produce stronger rubber concrete, it will be crucial to strengthen the bond between rubber aggregate and cement paste. Several methods of rubber pre-treatment, including NaOH solution, $Ca(OH)_2$ solution, and Cempatch AB bonding agent pre-coating, were investigated in the present study. These methods are described in more detail below.

2.2.1 Pre-treatment by using NaOH solution

Rubber particles were immersed for 60 minutes in a saturated NaOH solution. The rubber particles were removed after the allotted time, washed with clean water, and then air-dried under laboratory conditions. See Figure 4A. The rubber particles were water-washed to eliminate any potential chemical effect of NaOH on the adhesion between the rubber particles and cement paste, as it is well-known that rubber particles have negligible water absorption [18,42,43].

2.2.2 Pre-treatment by using $Ca(OH)_2$ solution

Treatment is performed on waste rubber to make their surfaces rough and improve their bonding with the mortar. This was achieved by immersion of waste rubber in a solution of calcium hydroxide $Ca(OH)_2$ for 60 minutes. After that, waste rubber was drained and washed with clean water to eliminate residual solutions. Then, the waste rubber was diffused on mesh sheets and allowed to dry in the air for 48 hours. As shown in Figure 4B.

2.2.3 Pre-treatment by using bonding agent (Cempatch AB)

Cempatch AB is a one-component modified acrylic liquid polymer from (DCP) company specially formulated as a bonding agent and curing aid for cementitious concrete systems. Rubber particles were immersed for 10 minutes in the Cempatch AB solution, as shown in Figure 4C. Table 4 represents the codes of all the mixes examined in this study, which appear in the figures and tables of the study's results.

(A) (B) (C)

Figure 4: Treatment of rubber tires using: (A) NaOH solution, (B) $Ca(OH)_2$ solution, and (C) Cempatch AB bonding agent.

Table 4: Codes of the samples

Sample Code	Steel Fiber %	Rubber content %	Rubber Pre-treatment
NS0	4	0	-
NS6	4	6	-
NS8	4	8	-
NS10	4	10	-
M1NS6	4	6	NaOH
M1NS8	4	8	NaOH
M1NS10	4	10	NaOH
M2NS6	4	6	$Ca(OH)_2$
M2NS8	4	8	$Ca(OH)_2$
M2NS10	4	10	$Ca(OH)_2$
M3NS6	4	6	Cempatch AB
M3NS8	4	8	Cempatch AB
M3NS10	4	10	Cempatch AB

3. Results and Discussion

3.1 Compressive Strength

Compressive strength is a well-known significant factor in determining the quality of concrete. Figure 5 and Table 5 illustrate the results of the compressive strength test conducted on the modified SIFCON specimens. Each value in this table was determined by averaging the results of testing three cubes in order to minimize the predicted error of each measured result. As seen from Table 5 and Figure 5, waste-chopped rubber has caused a decline in the compressive strength of modified SIFCON, which is directly proportional to the ratio of waste-chopped rubber. In addition, it is evident that independent of the treatment given to the particles, a more significant chopped rubber content reduces the compressive strength compared to the reference SIFCON sample. According to the findings, the control reference mixture NS0's compressive strength value was 85.52 MPa. While the three untreated mix designs with 6, 8, and 10% waste rubber content, NS6, NS8, and NS10, were 64.67, 59.9, and 48.64 MPa, respectively.

The test results showed that the pre-treatment of chopped rubber with NaOH solution produced the highest compressive strength compared to pre-treatments with $Ca(OH)_2$ solution and cempatch AB solution (see Figure 5). For SIFCON specimens pre-treated with NaOH solution, compressive strength at 28 days improved by 7.5, 10.1, and 11.6% for 6, 8, and 10% rubber content, respectively, compared to SIFCON specimens without treatment of chopped rubber.

This behavior could be attributed to the improvement in bonding (adhesion) between the rubber and the cement paste and/or an increase in the mechanical interaction (packing ability) due to the rough surface morphology of mortar-coated rubber particles [44]. Tire rubber is a complex mixture of different components, and more than one modification can occur simultaneously on the surface with the NaOH treatment. The experimental results from previously published infrared analysis and potentiometric titrations indicate that zinc stearate is removed from the rubber surface after the NaOH treatment. This removal causes significant changes in the surface chemistry of the treated rubber and may explain the improved adhesion between the treated rubber and the cement matrix. This observation can lead to further research on the best treatment to eliminate zinc stearate from the rubber surface in order to optimize the incorporation of tires into cementitious materials [18].

According to Albano et al. [45], 10% of untreated rubber had a compressive strength of 61.7% less than reference concrete; The decrease was 59.8% compared to rubber concrete that had been NaOH-treated. According to the authors, treated rubber concrete experienced 4.5% more damage than untreated rubber concrete.

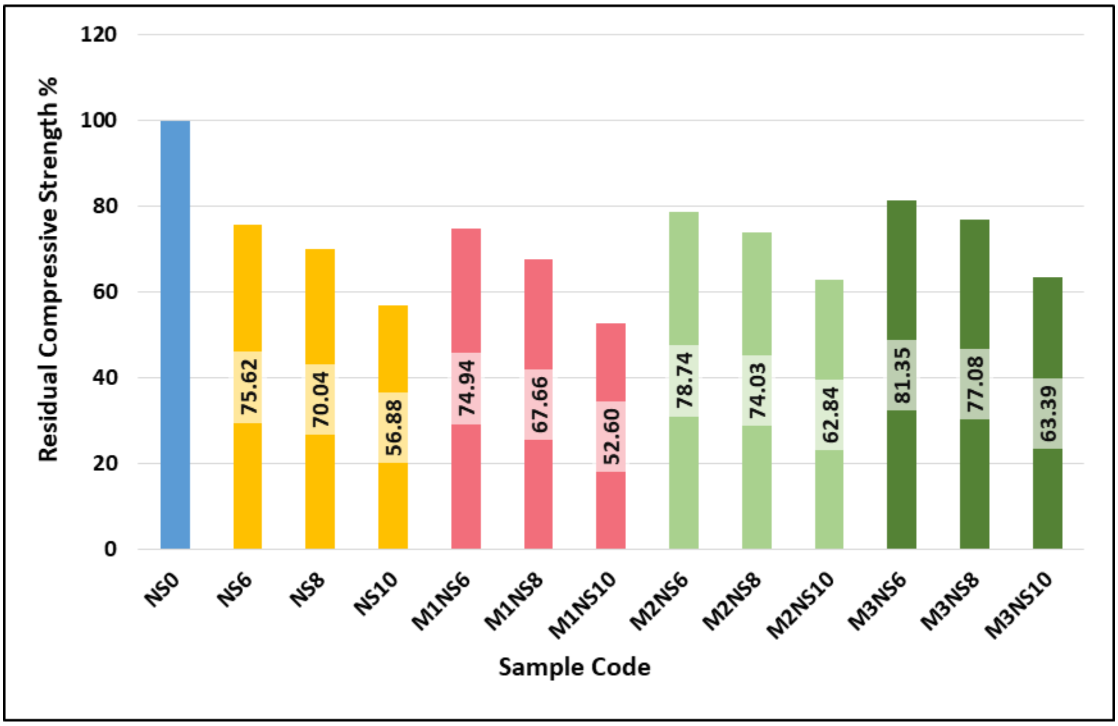

Figure 5: Effect of pre-treating methods on compressive strength

In the literature, the outcomes that were achieved are debatable. Some researchers claim that the treatment has little to no impact on concrete's mechanical and physical characteristics. Li et al. [46] noted that bigger-sized tire chips do not respond to NaOH treatment. According to Tian et al. [47], using acidic or alkaline solutions has no discernible effect on the performance of rubberized concrete for roadways. A study by Balaha et al. [48] found that concrete treated with polyvinyl acetate (PVA), silica fume, and NaOH solution showed an average reduction in compressive strength of 16%, which was lower than that of concretes with untreated rubber, which showed a decrease of 27% when compared to a reference concrete with w/c = 0.4 and cement content equal to 400 kg/m^3. Other studies have shown that the treatment improves these properties. According to Mohammadi et al. [49], concrete was made using 20% and 30% rubber that had been treated with NaOH throughout various treatment times (20 min, 24 h, and 7 d) and at various water/binder ratios (0.40 and 0.45). The authors found that for all w/b ratios, 24 h treated concrete produced the best results. Compared to rubber concrete that had not been treated, the concrete showed an average compressive strength of around 25% greater. According to Deshpande et al. [50], when a load is applied, the rubber's greater tenacity compared to natural aggregates causes a discontinuity in the matrix, reducing the matrix's resistance. In the study by He et al. [51], zinc-stearate spreads to the surface of rubber, leaving it with little free energy and causing poor bonding to the paste.

Table 5: Effects of pre-treatment on compressive strength and flexural test of SIFCON specimens at the age of 28 days

Sample Code	Rubber Content %	Rubber Pre-treatment	Flexural Strength (MPa)	Compressive Strength (MPa)
NS0	0	-	20.63	85.52
NS6	6	-	16.87	64.67
NS8	8	-	14.26	59.9
NS10	10	-	12.08	48.64
M1NS6	6	NaOH	18.68	69.57
M1NS8	8	NaOH	16.35	65.92
M1NS10	10	NaOH	14.34	54.21
M2NS6	6	$Ca(OH)_2$	18.11	67.34
M2NS8	8	$Ca(OH)_2$	16.08	63.31
M2NS10	10	$Ca(OH)_2$	14.01	53.74
M3NS6	6	Cempatch AB	16.09	64.09
M3NS8	8	Cempatch AB	14.10	57.86
M3NS10	10	Cempatch AB	10.03	44.98

3.2 Flexural Strength

Table 5 and Figure 6 show the flexural strength of slurry-infiltrated fiber concrete with untreated and pre-treated waste rubber. The flexural strength of modified SIFCON decreases when chopped rubber is incorporated. In contrast to the effect on compressive strength, the efficacy of treated rubber samples was higher than that of untreated rubber concrete. However, It can be seen that the results of flexural strength are consistent with those of compressive strength in terms of chopped rubbers pre-treatment. The pre-treatment of chopped rubber with NaOH solution produced the highest values for compressive strength compared to pre-treatments with $Ca(OH)_2$ solution and cempatch AB solution. Figure 6 shows that the largest increment in flexural strength at 28 days (compared to untreated samples) was 10.7, 14.6, and 18.7% for 6, 8, and 10% rubber content, respectively, in the case of rubber pre-treated with NaOH solution, compared to pre-treatments with $Ca(OH)_2$ solution and Cempatch AB solution.

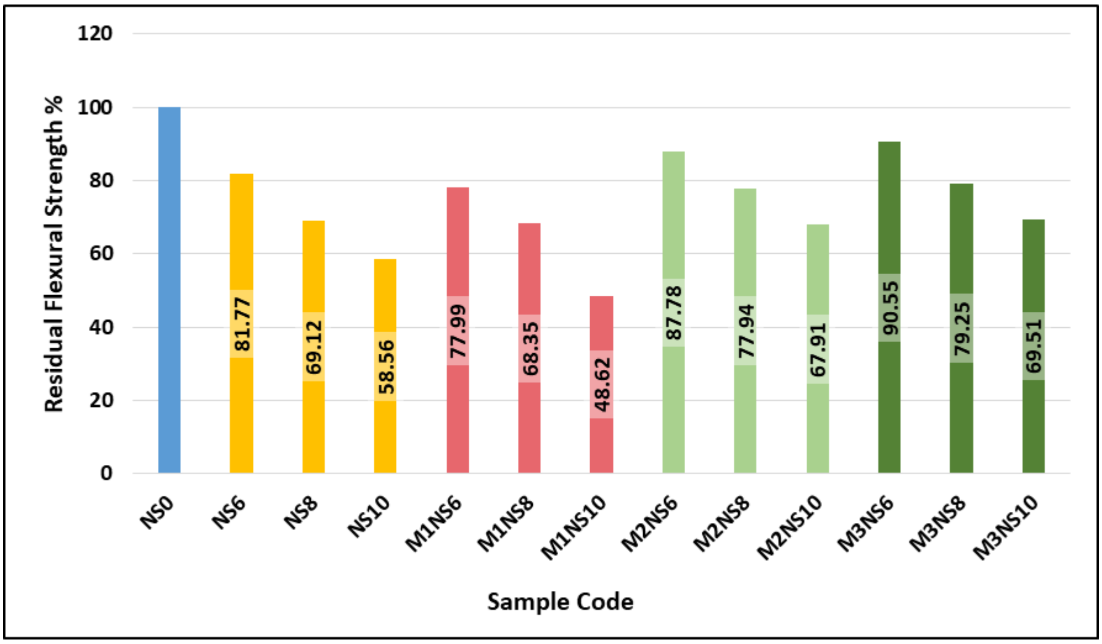

Figure 6: Effect of pre-treating methods on flexural strength

That behavior aligns with what Youssf et al. [52] observed. Concrete mixed with untreated rubber was compared to the reference concrete. The flexural strength was down 65.85%, according to the authors. After the rubber particles were treated, it was discovered that the resistance had partly returned as a result of the rubber particles' comparatively slower passage through the acidic solution's eroding impact on the surface. According to Onuaguluchi and Panesar [53], similar variables that impact compressive strength are also responsible for the decline in flexural strength. These elements include porosity, which rises as the amount of rubber particles increases, and the poor bonding between the rubber and the cement paste. Consequently, when loads are applied, the concrete begins to crack.

The loss of mechanical properties of modified SIFCON with waste-chopped rubber was supported by the findings of other studies dealing with rubberized concrete [54]. The decline in rubberized concrete's compressive and flexural strengths may be attributed to:

a) Compared to natural aggregate and cement paste, rubber particles, and cement paste would not properly bond. This might result in cracks because of the stresses non-uniform distribution.
b) The compressive strength depends on the components' mechanical and physical characteristics. The strength will decrease if a portion of the material is substituted with rubber.
c) Rubber tends to rise during vibration due to its low specific gravity and the lack of bonding between rubber and other SIFCON elements, resulting in a greater rubber concentration in the upper stratum. This form of heterogeneous concrete reduces the sample's strength [16].

All modified SIFCON samples exhibited deformation without total disintegration in the flexural test, as illustrated in Figure 7. The inclusion of micro-silica and a decrease in the water-to-cement ratio have increased rubberized concrete flexural strength. Due to the impact of silica fume on the interfacial transition zone bonding, the loss of strength of high-strength rubberized concrete was less in comparison to normal-strength concrete [55]. The main reason for decreased flexural and compressive strength is poor bonding between the rubber surface and cement mortar. Additionally, it is clear from the experimental results that adding waste rubber to SIFCON samples reduces their compressive strength values more significantly than it affects their flexural strength. This may be explained by the elastic properties of rubber, which enable it to absorb considerable energy and exhibit excellent bending toughness.

Figure 7: The flexural failure mode of SIFCON samples.

4. Conclusion

This study examined experimentally the effects of waste tire rubber pretreatment on the compressive and flexural strength of modified SIFCON. The following considerations may be made based on the results:

- Regardless of the treatment's application, including waste chopped rubber particles reduces the compressive and flexural strength of SIFCON.
- Compressive strength decreases as the percent of waste chopped tire increases for all SIFCON mixes of pre-treated and untreated rubber. This reduction may be attributed to the fact that the waste rubber particles are significantly softer than the natural sand particles adjacent to the cementitious materials; fracture begins rapidly around the rubber particles during compressive loading, reducing compressive strength.
- Pre-treatment of rubber particles with NaOH solution can enhance the inter-phase (aggregate-matrix) interfacial adhesion and, consequently, stress transformation. As a result, compared to untreated rubber, the compressive/flexural strength can be improved.
- Due to the various raw materials and additives, the divergence of effective rubber performance described in the literature must be connected to the various tire production methods worldwide. It is still necessary to have a deeper knowledge of the chemistry, surface morphology, and interactions between the treated particles and cement paste.

At waste rubber content of (6%, 8%, and 10%), compressive and flexural strength were found to be reduced, mostly as a result of void creation brought on by the fineness of waste rubber. Using different grades of waste rubber in the SIFCON mix might lessen this unfavorable effect. Waste rubber can also be treated with different alkaline chemical compounds to help overcome this performance decline. The techniques mentioned above may increase the bonding between cement paste and waste rubber, leading to an improvement in mechanical and durability properties.

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Author contributions

Conceptualization, A. Hashim and B. Al-Shathr; methodology, A. Hashim and B. Al-Shathr; validation, A. Hashim and B. Al-Shathr; investigation, A. Hashim; resources, A. Hashim.; writing-original draft preparation, A. Hashim; writing-review and editing, A. Hashim and B. Al-Shathr;. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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