Rubberized Concrete and Strategies for Improving Its Durable Properties - A review

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Abstract

Globally, the disposal of used tires is a major environmental concern, creating difficulties such as mosquito breeding grounds, igniting uncontrolled fires, and poisoning soil and vegetation. Therefore, alternative outlets for these tires are urgently required, with a concentration on tire recycling. Concrete is an excellent building material that is believed essential for modern civilization and human society. The utilization of recycled tires in concrete is now technically feasible. However, substituting rubber for concrete will drastically alter its mechanical and durable properties. Even if there is a reduction in the mechanical properties and durability properties of rubber concrete, this may be overcome by increasing its adherence by treating the aggregates. To improve the adherence of rubber aggregates, with physical, mechanical, chemical, and thermal treatments may be utilized. Under the rubberized concrete, the majority of studies collected data on mechanical qualities. Regarding durable properties, data collection is fairly less. This analysis aims to accomplish that objective by examining the qualities of rubberized concrete and the strategies for overcoming the challenges associated with rubber concrete's durability attributes. This study reviews water absorption rate, water permeability, chloride penetration, carbonization, Alkali-Silica reaction, and freeze throw resistance, and how to overcome some negative results by various kinds of treatment methods. This paper is intended to stimulate the use of rubberized concrete in infrastructure development and serve as a foundation for future research on this material. The usage of rubber concrete will result in the sustainable utilization of waste material, protecting the environment and conserving sources of diminishing natural aggregates.

Keywords— *Rubberized concrete, Durability, Corrosion resistance, Chemical treating, Sustainable development*

Introduction

Based on variable mix design proportions, additives, and preparation techniques, concrete is produced in a variety of shapes. As concrete technology advances, additional opportunities are created for the use of cutting-edge, environmentally friendly solutions to both concrete designs and applications. Sustainability is a topic that interests a lot of building materials researchers.

To address environmental issues and save energy, recycled and waste materials are being used more and more in concrete. Further study into the creation of green concrete is encouraged by the improvements in the characteristics of concrete as well as the advantages to the environment from the utilization of waste materials. To improve the strength of mortar or concrete, number of alternative waste materials have been used, including fly ash, marble waste, silica fume (SF), natural pozzolan, Ground Granulated Blast Furnace Slag (GGBFS), paper industry sludge waste, silico-manganese fume, glass powder waste, nano-silica, cement kiln dust, electric arc furnace dust, granite residues, ornamental stone-processing waste, wind turbine blade waste and kaolinitic clay. Another waste that is currently being used as an alternative material for concrete composites is tire rubber waste (vulcanized rubber). Rubber is a crucial component found in many different industries.

One of these industries is the manufacture of automobiles, where the rubber is utilized in a variety of products, including rubber tires. According to Fan *et al.*[1] more than 15 million tons of natural rubber are used annually, and over 31 million tons of rubber products are produced globally. A sizable portion of this number is solely dumped untreated in landfills. The land is used up significantly when tires are disposed on landfills. Thus, there is an immediate need to dispose of waste tires in an environmentally friendly and beneficial manner.

One option for reducing tire waste in landfills is to use the rubber material in concrete mixes as a partial substitute for fine or coarse aggregate. Many studies have been conducted on this form of rubberized concrete, which is also known as Rubbercrete, Crumb Rubber Concrete (CRC), Rubber Included Concrete (RIC), and Tire Rubber Filled Concrete. Rubberized Concrete is created by incorporating rubber into concrete mixtures (RUC). Various research on the addition of rubber to the concrete mix has shown that it can improve several qualities of concrete such as ductility, energy dissipation, and sound absorption[2]. Rubberized concrete mixtures are inexpensive and

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simple to manufacture. They have strong acid resistance and greater ASR resistance. Because rubberized concrete has a lesser strength capacity than conventional concrete, it may be utilized in sectors where strength isn't as necessary to benefit from its added characteristics over ordinary concrete.

There have been several studies and review papers addressing the mechanical characteristics of rubberized concrete[3, 4]. However, reports on its long-term durability are scarce in the study sector. This review provides a cutting-edge evaluation of the long-term durability of concrete by combining untreated and treated tire rubber waste. The effective treatment strategies have been classified. It is intended that this analysis would increase the use of rubber concrete in infrastructure development and serve as a foundation for future research on this material. When it comes to the long-term properties of concrete, water absorption, water permeability, chloride penetration, carbonization, Alkali Silica Reaction (ASR), and freeze throw resistance are the most important. Some of these features provide favorable consequences, while others produce negative results. However, treating the rubber particles can increase the attributes of long-term performance. The next paragraphs and discussions will provide further information about the long-term durability of rubberized concrete.

Durable properties of rubberized concrete

Water absorption rate

Water absorption in concrete is correlated with permeability, which represents the material's resistance to water penetration and, ultimately, ions such as alkali ions, sulphate ions, chloride ions, and any other potentially hazardous compounds. When the rubber component of rubberized concrete was increased, its water absorption capacity improved. More water was absorbed by rubberized concrete than by conventional concrete[5].

The water absorption of lightweight concretes was governed by the heterogeneity of hardened rubber mixes (random positioning of rubber aggregates) and the air content introduced into these lightweight concretes, as a result of the nature of these aggregates trapping this air with their rough surfaces and making them more permeable[6]. This characteristic will also affect other types of rubberized concrete.

According to Onuaguluchi and Panesar,[7] the water absorption capacity of rubberized concrete decreases when silica fumes are added. Concrete with silica fume exhibited lower water absorption compared to concrete without it. But Guneyisi *et al.*[8] researched that as the rubber content increased, the difference in water absorption values of concrete with and without silica fume decreased until almost same as 6.03% and 6.06% were observed at the 25% rubber content level.

Azevedo *et al.*[9] researched that adding more rubber to the mix enhanced water absorption, whereas partially replacing fly ash and metakaolin for cement lowered it. According to Gesoglu and Guneyisi[10] the water absorption of self-compacting concrete decreased as the rubber component increased. After 90 days of testing, using fly ash as a 40% substitution decreased water absorption furthermore. The samples with NaOH treated rubber absorbed less water compared to those with untreated rubber particles. That means rubber treated with NaOH has less porosity and generates stronger rubber-cement adhesion than rubber that has not been treated.[11]

Grinys *et al.*[12] noticed a decrease in the rate of water absorption in a rubber concrete mix containing glass trash due to decreased open porosity. Water absorption is about 3.27% and 3.26% for fine aggregate replaced with glass waste from 10% and 20% crumb rubber, respectively, whereas water absorption is approximately 3.72% and 4.11% for 10% and 20% crumb rubber without glass waste. They discovered that glass powder rubberized concrete absorbed the least amount of water when compared to the other batches. According to Elaqra *et al.*[13] the pozzolanic reaction of glass, effect on the rate of water absorption in concrete. According to above analysis when increasing the amount of rubber in the concrete mixture it increasing the water absorption rate of the concrete. However, those effects can be minimized by adding silica fume, fly ash, metakaolin and glass waste to the concrete mixture or by treating rubber particles with NaOH solutions.

Water permeability

During water permeability testing, water penetrates concrete under high pressure, neutralizing the rubber's initial resistance to water. The larger concrete's porosity, the wider its water permeability. According to the findings of Bjegovi *et al.*[14], if rubber content as a percentage of aggregate volume is raised, water permeability depth will likewise rise. The addition of 10% rubber particles by aggregate volume results in an average increase of 100% in water permeability depth; however according to the Table 1, the use of granulated rubber results in lower water permeability depths when compared to shredded rubber, likely due to their superior setting in the mixture.

The water permeability of rubberized concrete at 25% rubber content reached 150 mm, in concrete with and without silica fume. However, silica fume

Table 1: *Water permeability ratio for shredded and granulated rubber mixtures for various rubber percentages.[14]*

Rubber content (%)	Water permeability ratio	
	Shredded rubber	Granulate rubber
0	1.00	1.0
5	1.90	1.4
10	1.75	2.2
15	1.00	1.4

had a distinct impact on the water permeability of concrete having less than 25% rubber[8]. Likewise, Gupta *et al.*[15] reported that the permeability of rubberized concrete may be decreased by substituting silica fume for cement. On replacing 10% of the cement with silica fume, the water penetration depth of crumb rubber concrete containing 25% crumb rubber reduces by 14%, 11%, and 11% for w/c ratios of 0.35, 0.45, and 0.55, respectively. The reduction in water penetration depth caused by silica fume due to the result of strong adhesion between the rubber and cement matrix.

Khern *et al.*[16] researched the water permeability of rubberized concrete which was chemically treated with NaOH and $Ca(OCl)_2$. In comparison to untreated rubber aggregates, the water penetration depth of treated rubber aggregates has been considerably reduced. In addition, a few of the treatments reduced the water penetration depth relative to the control concrete. Results indicate that $Ca(OCl)_2$ treatment of rubber aggregates is the most effective method for decreasing the permeability of concrete mixes. In addition, they were treated with periods of 2 h, 24 h, and 72 h. The longest treatment duration (72 h) showed the best results.

The above results clearly show that when increasing the rubber percentage in the concrete mixture tend to increase the water permeability of the concrete. According to the past researches and similar to the water absorption rate; permeability can reduced by adding silica fume to the concrete mixture or treating the rubber particles with NaOH and $Ca(OCl)_2$.

Alkali Silica Reaction (ASR)

Due to the growth of Alkali-Silicate gels, Alkali-Silicate Reaction (ASR) can degrade concrete under internal pressure. Afshinnia and Poursass[17] discovered that adding rubber aggregate to concrete can lower the ASR expansion of concrete. Since rubber has a lower stiffness and greater deformability than stone aggregate, it will allow Alkali-silicate gels to swell, hence reducing the hydraulic pressure that caused the concrete to expand. During the testing period, a visual inspection of the mortar bars confirmed these results. As seen in Figure 1 (a, b), a large number of cracks were found on the surface of the control mortar bar, but the mortar bars containing 16% and 24% crumb rubber (Figure 1 (c) and (d), respectively) exhibited no evident surface degradation. ASR expansion of mortar samples with 16% and 24% substituted crumb rubber decreased by 43% and 39%, respectively. [17]

According to Abbas *et al.*[18], control specimens without rubber waste exhibited expansions of 0.232% and 0.284% at 14 days and 28 days, respectively, meeting the ASTM C1260 standard for reactive ASR nature. The expansion of specimens containing rubber waste was reduced. For instance, mortar bars containing 5% rubber waste expanded by 0.20% at 14 days and 0.26% at 28 days, respectively. At 28 days, the combination containing 20% and 25% rubber waste by aggregate volume exhibited expansion values less than 0.2%, meeting the ASTM C1260 standard for non-reactive ASR nature. The microstructural study of specimens containing rubber waste revealed no surface cracking, despite the production of ASR gel.Nonetheless, specimens lacking rubber waste exhibited significant microcracks as a result of ASR. Authors summarized that the elastic nature of rubber, which guarantees the dissipation of expansion pressures caused by the production of ASR gel, was primarily responsible for the reduction in ASR expansion in combinations including rubber waste. Due to the low transport characteristics and higher rubber-cement bonding strength of samples with NaOH-treated rubber, the NaOH-treated samples have the potential to further reduce expansion[11].

Wang *et al.*[19] determined the specimens with additional rubber particles had a length change rate

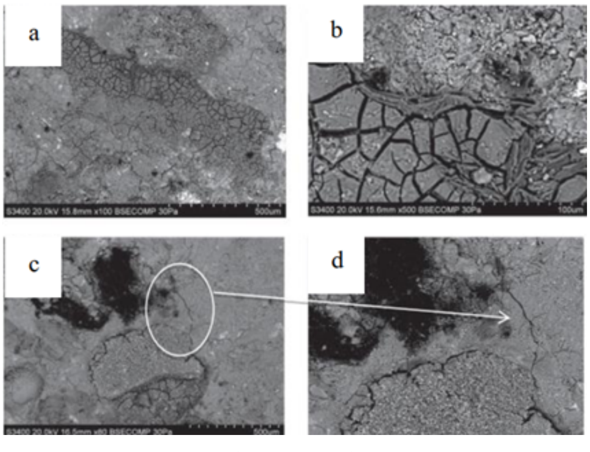

Figure 1: *(a), (b) Crack formation of specimen without rubber. (c), (d) crack formation of specimen with 16% and 24% crumb rubber.[17]*

of 0.063%, however the length expansion was still less than that of the control samples (0.08%). The addition of polyvinyl alcohol fibbers to specimens lowered the percentage of length expansion from 0.08% to 0.0372% as compared to the control specimens. They concluded that the soft rubber particles alleviated the strain caused by the expansion of the ASR gel and reduced structural damage.

In conclusion, incorporating rubber waste as a partial replacement for reactive aggregates in the construction industry, mainly in concrete pavements, bridges, Dams, tunnels, and airport runways offers a promising solution to mitigate the destructive effects of Alkali-Silica Reaction (ASR) in concrete infrastructure.

Freeze throw resistance

Freeze-thaw cycling may induce internal frost damage and surface damage in concrete, which influences the durability performance of concrete in cold countries and is one of the primary causes of the degradation of aged infrastructure. The change in water volume inside the pores of concrete causes a change in internal stress. The concrete structure deteriorates due to the rising internal stress[11].

Crumb rubber with a particle size between 1 to 4 mm can increase the freeze-thaw resistance of concrete when the rubber content is limited to 10% by volume[20]. Rubber aggregate increases the freeze-thaw resistance of concrete after 246 freeze-thaw cycles, mass loss and dynamic modulus decrease in rubberized concrete. The impact was more noticeable in samples of rubber treated with NaOH. NaOH treated 15% crumb rubber concrete had the best resistance to freezing and thawing of all the samples. Particularly, the freeze-thaw degradation of NaOH treated 50% rubberized concrete increased dramatically when compared to other NaOH-treated rubberized concrete due to the substantial reduction in stiffness of concrete containing a high proportion of rubber aggregate[11]

According to research by Gesoglu *et al.*[20], the freeze-thaw resistance of rubberized pervious concrete and ordinary concrete with a lesser number of cycles is the same. In addition, the initial freeze-thaw resistance of the reference and rubberized mixes did not differ significantly up to 240 cycles. All mixes lost less than 4% of their bulk. When the number of cycles exceeded 300, the behaviour of the standard concrete mixture changed dramatically. The mass loss of traditional concrete mixture reached 34%, but the mass loss of rubberized mixes remained unchanged (mass loss of 4.2%). This might be considered a significant increase in freeze-thaw resistance, since it saves 30% of the mass loss that can only be obtained by adding $10 - 20\%$crumb rubber.

Pham *et al.*[5] examined the impact of an enhanced rubber-cement matrix bond on the freeze-thaw resistance of Crumb rubber concrete. The untreated and copolymer-coated crumb rubber was utilized as a 30% volume substitute for fine aggregate. Following 200 freeze-thaw cycles, the mass loss of control concrete without crumb rubber, Crumb rubber concrete covered with a copolymer and untreated crumb rubber was 4.1%, 1.5% and 0.5%, respectively. This shows that untreated crumb rubber had superior freeze-thaw performance.

The above experimental results clearly show that when replacing rubber aggregates in the concrete it will increase the freeze throw resistance of the concrete. Furthermore, when treat the rubber particles with NaOH it increased furthermore. But if increased the rubber content in the concrete more and more it tends to reduce the freeze throw resistance of the concrete due to substantial reduction in stiffness of concrete.

Chloride penetration

Corrosion of reinforcing steel in concrete is a crucial issue affecting the performance of a reinforced concrete structure. Chloride ion penetration is a critical mechanism via which this occurs[5]. Corrosion of reinforcing steel occurs as a result of chloride ions infiltrating the pore network inside the concrete, neutralizing the alkaline environment around the embedded steel. As a result of that corrosion of the implanted steel occurs due to the oxidation of ferrous atoms.

According to Thomas *et al.*[21], mixtures containing up to 10% crumb rubber have almost comparable or lower penetration depths than the control mixture, but the penetration depth rose steadily as the crumb rubber content increased. A small reduction in penetration depth of Chloride ions in mixtures containing more than 7.5% crumb rubber. However, increasing the quantity of crumb rubber by 20% increased the porosity of the concrete, resulting in a greater depth of chloride penetration. Figure 2 illustrates the depth of chloride penetration in 56 and 90 days for each combination as determined by the experiment. The decrease in chloride ion penetration was also related to the impermeable nature of crumb rubber particles, which impedes the passage of chloride ions[21].

According to Gesoglu and Guneyisi's[10] investigation, chipped and crumbed rubber was used to replace coarse and fine aggregates in volumetric proportions of 15%, and 25%. The experiment discovered an increase in chloride ion permeability for mixes with increasing rubber content, i.e. the mix with 25% rubber aggregates replacement shows a 57% increase

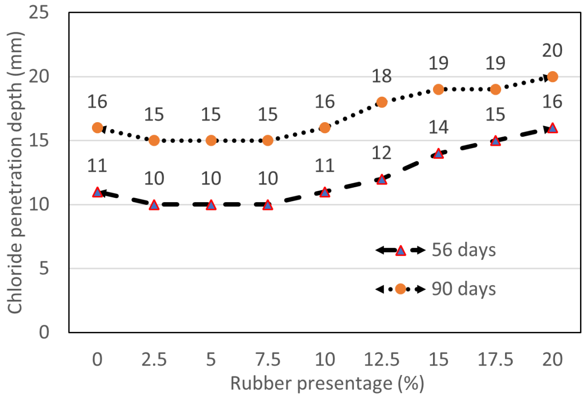

Figure 2: *Depth of chloride penetration in each combination for 56, 90 days[21]*

in chloride ion permeability.

Increasing the particle size of rubberized concrete improves its resistance to chloride penetration. They observed that rubber particles created cryogenically were less resistant to chloride penetration than rubber particles crushed manually in rubberized concrete[22].

According to Oikonomou and Mavridou[23], increasing the rubber component in rubberized concrete results in a reduction in chloride ion penetration. They used two different proportions of rubber: 2.5% and 15%. This resulted in a 14.22% and 35.85% reduction in chloride ion penetration, respectively, when compared to a conventional concrete mix. The coefficient of chloride ion diffusion decreased as the amount of crumb rubber increased. In comparison to normal concrete, the coefficient of chloride ion diffusion in rubber powder concrete containing 20% crumb rubber powder and hybrid rubber concrete containing 10% crumb rubber powder and 25% crumb rubber fiber decreased by 24.5 and 21.81%, respectively[24].

Gesoglu and Guneyisi[25] researched self-compact rubberized concrete. They observed that increasing the quantity of rubber in concrete decreased its resistance to chloride, but adding fly ash to rubberized concrete boosted its chloride resistance. The chloride permeability of the rubberized concrete decreased from 67% to 79% after curing for 90 days. Existing variations regarding the chloride ion penetration of rubberized concrete are indicative of an insufficient focus on the material's durability. This is made worse by variations in specimen preparation, mixture design, and experimental procedure. The increase in chloride ion ingress is also attributable to the use of crumb rubber aggregates, as advocated by Alsaif *et al.*[26]. These aggregates increase the number of pervious voids and absorptivity.

The overhead results clearly show that the diffusion of chloride ions in concrete can be significantly reduced with proper treatment and the appropriate amount and grade of rubber aggregates.

Carbonization

Carbonation is another main technique related to steel reinforcement corrosion. The process of carbonation describes the interaction between atmospheric CO_2 and the alkaline constituents of concrete[27]. Typically, reinforcing steel within concrete is shielded from corrosive environments. The alkaline environment within the matrix (pH 12–14) enables the formation and maintenance of a passivation layer surrounding the embedded steel. However, with continuous contact with CO_2, the alkaline environment is neutralized. This technique lowers the pH level below the passivation level of steel, allowing water to come into direct contact with steel rebars, resulting in their ultimate degradation.

The rise in crumb rubber led to an increase in carbonation depth[22]. Yu and Wang[28] observed that rubber integration first decreases the anti-carbonation of concrete, but later increases it, indicating that rubber will enhance the anti-carbonation of concrete. The best content is 10%, the others are not noticeable. And smaller particle sizes are superior for enhancing the anti-carbonation properties of concrete. Furthermore, Thomas *et al.*[21] observed that when the carbonation depth dropped, crumb rubber replacement increased up to 10%. This may be because the fine aggregates and the substituted crumb rubber were almost the same sizes, and the tightly packed rubber particles and natural aggregates in the concrete may prevent the passage of CO_2 gas. Rubber powder may have acted as a filler in the concrete. Incorporating fine rubber powder into crumb rubber concrete improved the pore structure, especially at lower water-cement ratios, resulting in enchanted carbonation resistance. Conversely, concrete containing crumb rubber in a fine powder form exhibited higher carbonation resistance[29].

Gupta *et al.*[30] manipulated the replacement amount of crumb rubber and found that when crumb rubber concentration increased, so did carbonation depth. In addition, their data suggested that the depth of carbonation increased as the length of exposure to CO_2 increased, independent of the quantity of crumb rubber present.

Pham *et al.*[5] observed that pre-treating Crumb rubber with a NaOH solution enhanced the carbonation resistance of crumb rubber concrete compared to the water-treatment approach. Therefore, it was determined that the NaOH pre-treated specimens were more resistant to carbonation than the water pre-treated rubber specimens. This behaviour can be explained by the chemical interaction between leftover CO_2 and NaOH as shown in Equations 1 and 2:

$$\mathrm{NaOH} + \mathrm{CO_2} \rightarrow \mathrm{NaHCO_3} \quad (1)$$

The remaining NaOH interacts further with CO_2 gas to generate Na_2CO_3;

$$2\,\mathrm{NaOH} + \mathrm{CO_2} \longrightarrow \mathrm{Na_2CO_3}^{+}\mathrm{H_2O} \quad (2)$$

These activities demonstrate that CO_2 accessing the pore structure interacts with the leftover NaOH and is successfully utilized. This procedure prevents CO_2 from penetrating farther into the concrete, which may explain the difference in carbonation depths between the NaOH and water-pre-treated specimens.

From above reviewing process found that when the rubber content increased in the mixture so does the carbonation depth. However, when reduce the size of the particle size of rubber it shows positive results. Same as can further decrease the carbonation depth by treat the rubber with NaOH solutions.

Conclusions

By addressing the issue of waste tire transportation and disposal, the integration of rubber waste in concrete may considerably contribute to environmental conservation. The introduction of a less amount of tire rubber increased the durability of concrete by mitigating alkali silica reaction and freeze throw resistance. Other durable qualities, such as water permeability, water absorption, and chloride penetration, showed a marginal regression. The use of an excessive amount of crumb rubber might result in a significant loss in the durability of rubberized concrete. However, by treating the crumb rubber, the retrogression in these qualities can be reduced.

As the rubber component of the rubberized concrete mix increased, so did its water absorption capability[5, 6, 9].However, it can be reduced by treating it with NaOH and mixing it with silica fume, fly ash, metakaolin and crushed glass waste[7, 11, 9, 12, 13].

The water permeability of the concrete increases as the rubber percentage of the concrete mixture increases[14]. The main cause of this scenario was that rubber particles reduced adhesion between the aggregates and the cement paste. However, it can be reduced by treating it with NaOH, $Ca(OCl)_2$ and mixing it with silica fume[8, 15, 16].

When considering chloride ion penetration, the results are contentious. Some of studies discovered that the chloride ion penetration rises as the rubber content increases, whereas others discovered that it decreases as the rubber content grows. Chloride ion penetration mainly depends on the particle size[8, 15, 16] but this effect may reduce by adding Fly ash to the concrete[25].

The depth of carbonization increased as the rubber component increased[19, 22, 30]. But the effect was high when using crumb rubber compared to rubber powder as the rubber aggregate replacement[21, 29]. However, when rubber is treated with NaOH, carbonization can be reduced, because NaOH raises the pH and reacts with CO_2 that enters the concrete[5].

It was discovered that adding rubber aggregate to concrete can reduce the growth of alkali silica reaction, because rubber has less rigidity and more deformability than metal, it allows Alkali-silicate gels to swell, lowering the hydraulic pressure that caused the concrete to expand[17, 18, 19].

Freeze throw resistance of the concrete was increased with the rubber content increase[5, 10, 20]. When treat the rubber particles with NaOH, freeze throw resistance increased furthermore.[11].

Conflicts of interest

The authors declare that there are no financial interests or non-financial conflicts or conflicts of interest related to this research that could have influenced this research.

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