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OVERVIEW OF RECYCLING RUBBER TIRE AS AGGREGATES IN CONCRETE: AN APPROACH FOR SOLID WASTE MANAGEMENT

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Abstract: The difficulties related to non-biodegradable waste management raise the danger of environmental and health issues since millions of worn rubber tires are discarded yearly. Over the past several years, the building industry has been compelled to use this material combined with cement-based products due to the material's accessibility and vast manufacturing volume. Due to its promising properties, including enhanced ductility, damping ratio, and vibration resistance, recycling used tire rubber as a partial replacement of natural stones in concrete is a topic of intense research. Conversely, the rubber aggregator reduces the mechanical characteristics and workability of the resulting concrete mixtures. This study reviews the feasibility of using shredded rubber tire waste as a partial replacement for traditional aggregates in concrete. The properties of the rubberized concrete are discussed with respect to various ratios of rubber tire waste and traditional aggregates. The results of previous studies showed that using rubber tire waste as an aggregate in concrete significantly reduces the mechanical properties of the concrete, including its compressive strength, tensile strength, and flexural strength. On the other hand, using rubber tire waste as an aggregate reduces the weight of the concrete, which may have potential benefits for structural design. Overall, the study suggests that recycling rubber tire waste as an aggregate in concrete is a viable approach for solid waste management and can also provide environmental and economic benefits.

Keywords: Rubberized concrete; Concrete properties; Recycled aggregate; Dynamic properties.

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1. Introduction

With the increased likelihood of uncontrolled fires, other ecological risks, and health issues, improper tire disposal is regarded as a substantial environmental challenge that impacts people worldwide (Pelisser et al., 2011; Aslani, 2016; Hassanli et al., 2017). According to the World Business Council for Sustainable Development, approximately 1000 million tires worldwide reach the end of their life cycle each year (WBCSD, 2010). Furthermore, 128 million tires are discarded nationwide, although several measures for handling this waste material have already been implemented in the United States (Xue and Shinozuka, 2013). Moreover, recycled crumb rubber was utilized in concrete mixes as aggregates in various investigations (Thomas and Gupta, 2016). Additionally, from a sustainability standpoint, these plans are seen as a double-edged victory because they safeguard the environment from the hazards of discarding this material while preserving natural resources by using an alternative component of aggregates in cementitious mixtures to produce rubberized concrete (Siddique and Naik, 2004). In recent years, investigations have been conducted on the characteristics of rubberized concrete and the barriers impeding its effectiveness, and in order to resolve contemporary engineering problems, numerous studies have been performed. Since many studies were published in the literature, it is necessary to perform review to describe the findings and point out any challenges. Examples of these reviews can be seen in the literature (Najim and Hall, 2010; Alam et al., 2015; Li et al., 2016; Mushunje et al., 2018; Strukar et al., 2019; Moo-Young et al., 2003). Additionally, most reviewed articles concentrate on the material behavior characteristics of rubberized concrete without focusing on critical studies, especially those about structural performance or finite element modeling and rubberized concrete analysis. This study conducts a review of the feasibility of using shredded rubber tire waste as a partial replacement for traditional aggregates in concrete. The properties of rubberized concrete, including its strength, durability, water absorption, and permeability, are discussed in comparison to those of conventional concrete. Moreover, the effects of different ratios of rubber tire waste and traditional aggregates on the properties of the rubberized concrete are also highlighted. Within the study context, the research methodology includes identifying suitable papers from the literature, shortlisting them with respect to those contributing to structural rubberized concrete, and discussing their critical findings.

2. Recycled Rubber Aggregates

The irreparably damaged tires are shredded and made into rubber to be implemented with cement. Similar to natural aggregate, various rubber particle sizes can be found as shown in **Figure 1**, including coarse and fine particles (Najim and Hall, 2010; Habib et al., 2020). Rubber particles have low specific gravity, which makes them lightweight aggregates. Nevertheless, due to the significant water adsorption this material experiences, the water-to-cement ratio in concrete is altered (Eldin and Senouci, 1992).

Figure 1. Rubber particles with different sizes (Habib et al., 2020)

3. Properties of Fresh Concrete

Due to the rubber's different shape and texture from natural aggregates, it has been proven in earlier studies that rubberized concrete workability decreases as a proportion of rubber substitution increases, as shown in **Figure 2**. (Hernández-Olivares and Barluenga, 2004; Güneyisi et al., 2004). Additionally, it has been demonstrated that using rubber particles with a size distribution similar to sand may considerably increase the workability of concrete (Bisht and Ramana, 2017). Although the workability is still acceptable (Youssf et al., 2014), the handling procedure becomes increasingly tricky when tiny rubber particles are included in the concrete mixes (Hernández-Olivares and Barluenga, 2004). Furthermore, increasing the quantity of admixture used is necessary to maintain the feasibility of placing and finishing in concrete with a high rubber component (Güneyisi et al., 2004). Also, the density of concrete with rubber is considerably reduced compared to that of normal aggregates (Khatib and Bayomy, 1999). Contrarily, the connection between the air and rubber contents is linear and unaffected by the amount of compaction force applied (Zheng et al., 2008). Furthermore, rubber particles trap air in their rough surfaces because of their non-polar character (Najim and Hall, 2010).

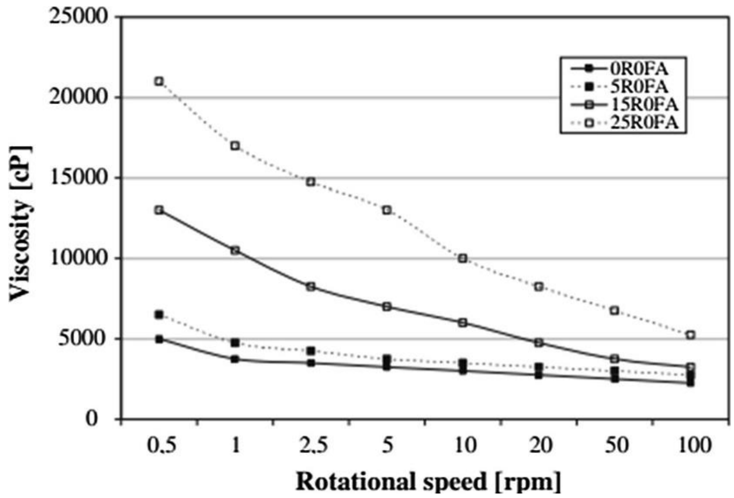
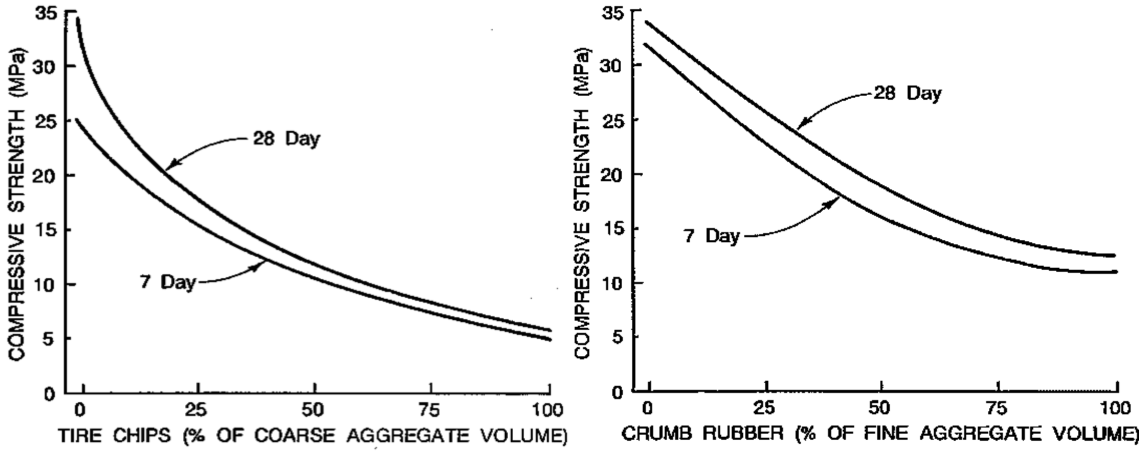


Figure 2. Viscosity of rubberized concrete (Güneyisi et al., 2004)

4. Mechanical Properties of Rubberized Concrete

Studies on the mechanical properties of concrete have shown that adding rubber particles in place of standard aggregate changes the features of the material. The compressive strength of rubberized concrete is negatively affected when the rubber component of the mixture is increased (Habib et al., 2020). Concrete elasticity modules are positioned in a similar manner (Khatib and Bayomy, 1999). Furthermore, replacing coarse aggregate with sand significantly affects the pressure and flexural strength of concrete under compression (Topçu, 1995). **Figure 3** illustrates the relationship between the change in mechanical characteristics and the increase in rubber aggregates used. This decline is attributed to many factors, including using an aggregate with lower strength and load-carrying capacity (Xue and Shinozuka, 2013), weaker contact between rubber granules and cement paste, which makes concrete break easier (Güneyisi et al., 2004), and interfering with the water transfer process, which causes flaws in the hydration process around rubber particles and a general decline in concrete compressive strength capacity (Mendis et al., 2017). For concrete mixes with equivalent strengths, the rubber component does not affect the rate of strength increase, splitting tensile strength, modulus of elasticity and rupture, or stress-strain behavior (Noaman et al., 2016). Thomas and Gupta (2016) built a more robust version, finding that limiting the fine rubber content to 12.5% might help create high-strength rubberized concrete with ductile failure, whereas 20% fine rubber content caused a more than 50% loss in compressive strength. Su et al. (2015) tests on rubberized concrete mixes that include fine rubber particles with various size distributions revealed that the size distribution of microscopic rubber particles did not affect concrete's flexural and compressive strengths. Noaman et al. (2016) adding more fine rubber aggregate to concrete increases strain capacities and changes the material's brittleness to ductility. Additionally, it enhances the absorption energy and expands the region beneath the pressure curve. Several methods have already been introduced into the literature for improving the engineering properties of rubberized concrete, including pretreating the rubber with a NaOH solution (Youssf et al., 2016; Wang et al., 2018), adding materials like silica fume and steel fiber (Onuaguluchi and Panesar, 2014), and pre-coating with limestone powder (Segre et al., 2002). Increased surface roughness of rubber aggregates is the main objective of using NaOH, which also aims to lessen the severe negative effects of the insufficient bonding between rubber particles and cement paste. Additionally, the predicted zinc stearate on tire rubber particle surfaces declined when it was submerged in NaOH solution, leading to a noticeable change in the treated rubber's surface area and enhanced adhesion between recycled materials and cement paste (Xie et al., 2019). Moreover, by impeding water transport, modifying rubber's surface regions with a 10% NaOH solution lessens its detrimental impact on the hydration process and helps restore the strength of drop-in concrete (Mendis et al., 2017). In contrast to non-treated specimens, it increases the concrete's compressive strength by 6% and 15% at seven and twenty-eight days, respectively (Su et al., 2015). Also, the prolonged duration would harm concrete properties because of the massive absorption of NaOH solution into the rubber. According to an earlier study, treating rubber with NaOH solution for 30 minutes is the best strategy to increase concrete strength (Wang et al., 2018). On the other hand, silica fume treatment encourages strong backing and filling cement aggregate voids in concrete mixes (Thomas and Gupta, 2016). Xie et al. (2019) showed that the concrete strength significantly improves when 10% of silica fume is added to the solution.



(a) (b)

Figure 3. Effect of rubber particle on compressive strength of concrete (a) coarse rubber aggregate, (b) fine rubber aggregate (Eldin and Senouci, 1992)

5. Durability Properties of Rubberized Concrete

The resistance to water permeability often falls dramatically when recycled rubber is added to the concrete mixture (**Figure 4**). It is affected by the increased porosity of rubberized concrete, and it is generated by the elastic behavior of the rubber particles under compaction pressure and the floating of lightweight rubber particles over the wet mixture. However, the drop could be partially recoverable if graded rubber particles are added accurately (Bisht and Ramana, 2017). The non-polarity effect traps water drops at the interfaces, leading to a significant reduction in water absorption (Siddique and Naik, 2004). According to past research on regular and high concrete strength, the abrasion resistance is higher when rubber is included in the concrete mixture (Thomas and Gupta, 2016). Also, it has been reported the addition of rubber to concrete improves the concrete's ability to withstand abrasion. As a result, it is especially crucial in cases where environmental influences impose degradation on the surface to use rubberized concrete in structures and pavements since it enhances resistance to deterioration compared to ordinary concrete. The resistance of concrete to freeze-thaw is generally improved by adding fine rubber particles to the concrete mixture by roughly 25% (Bravo and de Brito, 2012). Although it is more prone to shrinkage than conventional concrete, the concrete with rubber particles fell within the allowable bounds (Yung et al., 2013). According to Thomas and Gupta (2015), rubberized concrete offers good carbonation resistance when 12.5% of the natural aggregates are changed with finely graded rubber particles. However, employing big rubber particles alters the concrete carbonation behavior.

Finally, the use of rubber particles in concrete was discovered to increase electrical resistance (Thomas and Gupta, 2015).

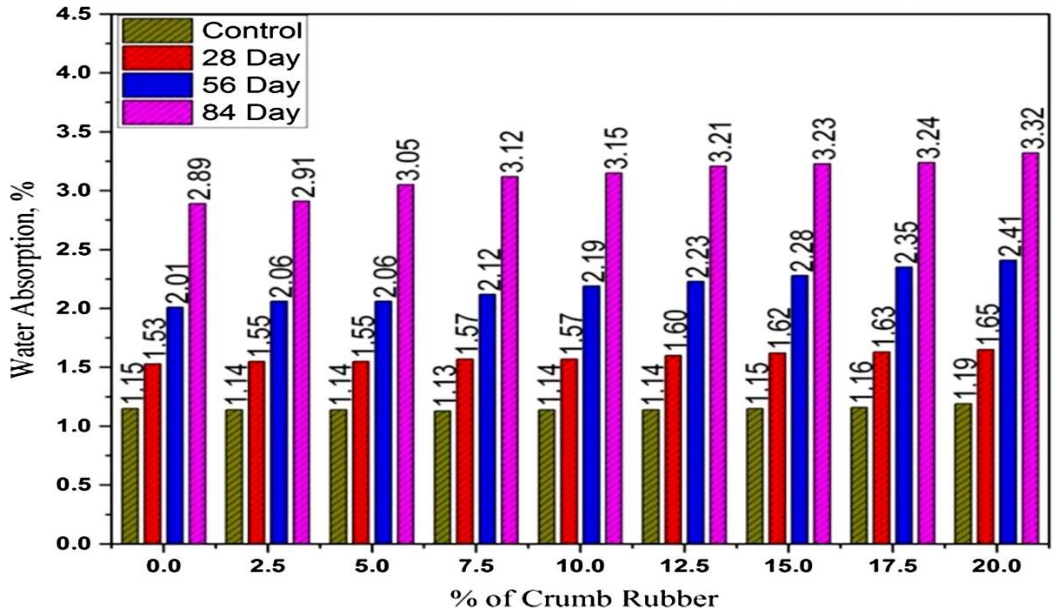


Figure 4. Water absorption of rubberized concrete (Thomas and Gupta, 2016)

6. Applications of Rubberized Concrete

In order to guarantee the security and comfort of occupants within their homes, structures that are vulnerable to vibration waves must have enough mitigation capability. Buildings built to endure earth movement excitations and floors where there is a possibility the neighbors might make noise that could employ this material. According to a recent study, the damping ratio was increased by 62% in concrete mixtures when 15% of the coarse aggregate was replaced with 6 mm rubber particles (Xue and Shinozuka, 2013). The damping decrement of concrete was increased by 37.5% by substituting 20% of the fine aggregate with individually graded rubber particles allowing the material to be used for noise insulation of buildings, foundations, and industrial floors (Skripkiūnas et al., 2009). Additionally, the experimental findings of earlier investigations provide strong proof of the positive association between the rubber content and improving damping ratio.

Cyclic load test of reinforced concrete columns using 20% fine rubber granules was conducted by Youssf et al. (2015). The rubberized concrete column could sustain roughly 98.6% of the lateral force in the regular column, despite the fact that the recorded compressive strength decreased by 28% in the case of rubberized concrete. The reinforced rubberized concrete column with fiber reinforced polymer (FRP) confinement was subjected to a seismic load test by Youssf et al. (2016), who noticed a minor difference in the specimen's performance compared to the control. Pham et al. (2018) applied load scenario impact to a rubberized concrete column enclosed in FRP and discovered that the peak forces of the rubberized concrete case were down by up to 40% compared to the control case. According to Mendis et al. (2017), the beams built with rubberized concrete will have a close ultimate flexural strength and load-deflection curve regardless of how much rubber is added to the concrete mixture. According to Ismail and Hassan (2017), a rubberized concrete beam containing 0.35% steel fibers has a comparable shear failure mode to a beam without rubber aggregates but has a lower fracture width. Li et al. (2018) examined the behavior of slabs made of rubberized concrete using both computational and experimental methods. It was concluded that both ordinary and rubberized concrete specimens could attain a similar bending moment capability. At short shear spans, rubberized concrete ultimate failure loads are very similar to those of standard concrete slabs, but at large spans, the failure load of the reference specimen was significantly better, according to Mohammed (2010), who investigated the influence of slabs using steel sheets and rubberized concrete. Habib et al. (2021) examined the effectiveness of reinforced concrete frames covered in rubberized concrete. Therefore, rubberized concrete provides superior damping energy and a lower hysteretic than normal concrete.

7. Modeling of Rubberized Concrete Properties

The capacity of several machine learning algorithms to forecast rubberized concrete properties has been examined in the literature. The fresh density and flow table values were estimated by Topçu and Saridemir (2008) using a feed-forward back-propagation neural network and an adaptive neuro-fuzzy inference system. The compressive strength and splitting tensile strength of rubberized concrete were predicted by Cheng and Cao (2016) using a radial basis function neural network, genetic programming, multivariate adaptive regression splines, and evolutionary multivariate adaptive regression splines. In a study conducted by Hadzima-Nyarko et al. (2020), regression trees, multi-layer perceptron neural networks, and random forests were utilized to forecast the compressive strength of rubberized concrete. In order to estimate the damping ratio, dynamic modulus of elasticity, and natural frequency of rubberized concrete components, Habib and Yildirim (2021) used a feed-forward back-propagation neural network and multivariable linear regression.

8. Conclusion

In conclusion, this paper sought to synthesize findings from prior studies and produce some statistical support using experimental data gathered from the literature. Within this context, given their considerably low specific gravity, rubber aggregates could be considered lightweight particles. The findings from the literature sources and this paper show a negative association between the rubber aggregates and the compressive strength, flexural strength, and elastic modulus of concrete. In addition, rubber aggregates are added to the concrete mixture, which decreases the endurance characteristics of the concrete. In contrast to regular concrete, rubberized concrete has significantly superior energy dissipation, ductility, and vibration resistance. The strength properties of using fine rubber aggregates are better than those of coarse ones. Concrete's characteristics are greatly improved when rubber particles are pretreated with NaOH solution for 30 minutes. The lateral load-carrying capability of reinforced concrete columns subject to seismic stress and the flexural behavior of reinforced concrete beams are little affected by the addition of rubber to concrete. Finally, there are still many gaps in the literature that need to be addressed in future research. These gaps incorporate the experimental performance of reinforced concrete columns and beam jacketed with a rubberized concrete mixture, various codes' capability in reliably designing reinforced rubberized concrete elements, and applying rubberized concrete to solid slabs.

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