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Effect of Waste Tire Rubber on The Mechanical Properties of Concrete

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Abstract

The increasing accumulation of waste tires creates significant environmental problems. Recycling waste tire rubber into concrete offers an eco-friendly disposal method, reduces the demand for natural aggregates, and may improve certain performance properties such as impact resistance and energy absorption. This study investigates the effect of replacing a portion of the fine aggregate, by volume, with waste tire rubber at levels of 5%, 10%, 15%, and 20% on the mechanical properties of concrete. Mechanical tests including compressive strength, tensile strength, flexural strength, and drop weight impact resistance (conducted following ACI 544.2R-89) were performed. Results indicated a gradual decrease in compressive, tensile, and flexural strengths with increasing rubber content, while impact energy absorption and ductility improved significantly. Conversely, the inclusion of rubber significantly enhanced the concrete's ability to absorb impact energy and improved its ductility. These improvements are particularly beneficial in applications subjected to dynamic or impact loads. Despite some strength loss, the enhanced ductility and impact resistance suggest that rubberized concrete is suitable for applications where energy absorption and durability under dynamic loads are critical, such as in pavements, sidewalks, and protective barriers. Additionally, the use of rubber aggregates contributes to circular economy principles and supports sustainable construction practices by integrating recycled materials into mainstream engineering applications.

Keywords: *Rubberized Concrete; Mechanical Properties; Impact Resistance; Drop-weight test; Energy Absorption Capacity.*

1. Introduction

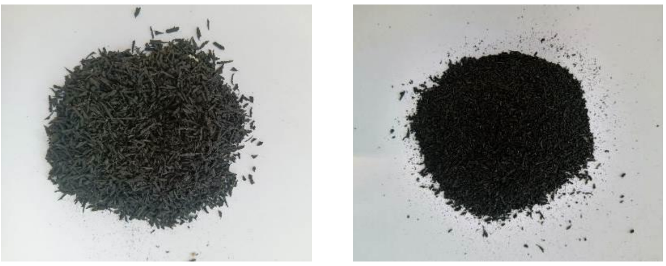
The disposal of end-of-life vehicle tires containing rubber presents a growing environmental challenge, as these materials constitute a substantial portion of global solid waste (Eldin, N. N., & Senouci, A. B.,1994). Landfilling and stockpiling of waste tires not only occupy valuable space but also pose significant health, ecological, and economic risks (Mohammed et al, 2012). Due to their impermeable nature and hollow shape, tires can retain stationary water for extended periods, creating favorable conditions for the proliferation of disease-carrying vectors such as mosquitoes (Thomas et al, 2015). Traditional disposal methods, particularly open burning, have been widely practiced due to their low cost (Gesolu, M., & Güneyisi, E., 2011). However, they are associated with severe fire hazards and persistent environmental contamination. Once ignited, tires are difficult to extinguish owing to their high void content, which facilitates oxygen retention and sustained combustion. The resultant by-products including toxic fumes, residual ash, and oil from melted rubber further pollute soil and water. Globally, approximately one billion tires reach the end of their functional lifespan each year, with current stockpiles estimated at over three billion in the European Union and one billion in the United States. Projections indicate that by 2030, annual tire disposal could exceed 1.2 billion units, intensifying the ecological burden (Thomas et al 2015). Tires landfilling contributes to biodiversity loss and the leaching of hazardous compounds, underscoring the urgent need for sustainable management strategies (Batayneh et al 2008). Recent research has explored the incorporation of waste tire rubber into concrete as a partial replacement for conventional aggregates (Li et al 2020). Rubberized concrete has shown promise in applications subjected to dynamic loads and seismic activity, such as railway sleepers and earthquake-resistant structures, as well as in non-structural elements like acoustic barriers. The mechanical performance of rubber-modified concrete is highly dependent on the type and gradation of rubber particles used. While the inclusion of crumb rubber tends to reduce compressive strength, it remains within acceptable limits for lightweight concrete (Siddique et al., 2019). Moreover, rubber aggregates contribute to lower unit weight and maintain adequate workability. Experimental findings reveal that substituting coarse aggregates with rubber results in more pronounced reductions in strength compared to fine aggregate replacement, yet it enhances post-cracking behavior, energy absorption, and ductility (Nadim et al., 2024). Based on these premises, the primary objective of this research is to evaluate the effect of partial volumetric substitution of fine aggregate on the key mechanical properties of concrete, including its compressive strengths, split tensile strengths, and flexural strengths. Furthermore, the impact resistance performance of this rubberized concrete is quantitatively evaluated under the standardized drop-weight test protocol outlined in ACI 544.2R-89.

2. Materials and Experimental Methods

2.1 Materials

The concrete mixtures were prepared with standard materials: Ordinary Portland cement (ASTM compliant), natural river sand as fine aggregate, and crushed stone as coarse aggregate. In this study, a 50/50 blend of crumb rubber and powdered rubber replaced part of the fine aggregate. Based on research, including the findings of (Siddika et al, 2019), powdered rubber severely reduces workability due to its high surface area and hydrophobic nature, while larger crumb rubber can significantly compromise compressive strength by creating voids. The blend provides a strategic compromise. The crumb rubber helps maintain more manageable workability, while the finer powdered rubber improves packing density.

(a) Cement (b) Coarse Aggregates (c) Sand

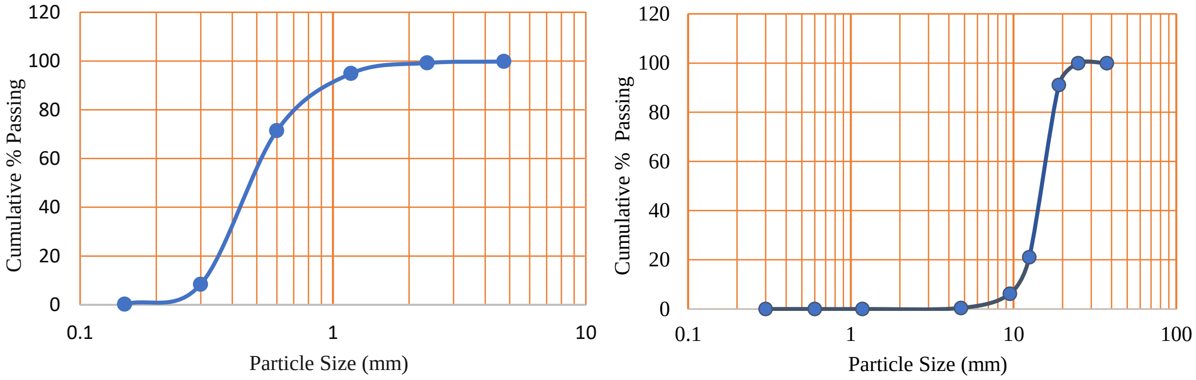


(d) Crumb Rubber (e) Powdered Rubber

Figure 1. Raw Materials

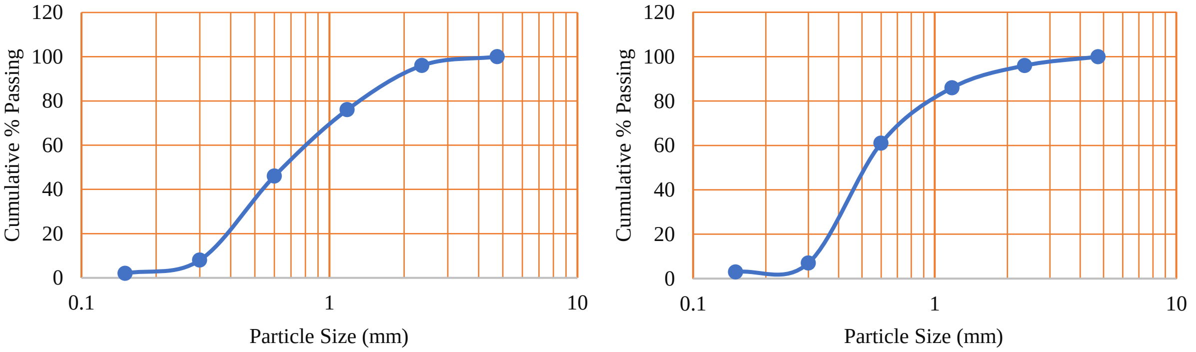
Table 1. Property of Materials

Materials	Specific Gravity	Unit Weight (kg/m^3)	Fineness Modulus
Fine aggregates	2.62	1634	2.03
Coarse aggregates	2.84	1658	6.81
Crumb rubber	1.07	597.97	2.72
Powdered rubber	1.14	509.387	2.47



(a) Fine Aggregates

(b) Coarse Aggregates



(c) Crumb Rubber

(d) Powdered Rubber

Figure 2. Particle Size Distribution of Raw Materials

2.2 Mix Design and Specimen Preparation

This study works with five different mix series that were designed and produced in laboratory. The target compressive strength was 20 MPa. The control mixture contained cement, fine aggregate, coarse aggregate, waste rubber, and water. Rubber was mixed in partial replacement of fine sand by volume. Rubber content in the mix was 0%, 5%, 10%, 15%, 20% corresponding mixed ID RC0, RC5, RC10, RC15 and RC20. The Table 2. shows the ingredients of each mix (Kg/m^3).

Table 2. Concrete mix proportions

Mix ID	**Cement (Kg)**	**Fine Aggregate (Kg)**	**Coarse Aggregate (Kg)**	**Rubber (Kg)**	**Water (Kg)**
RC0	512	768	1536	0	230.4
RC5	512	729.6	1536	13.1	230.4
RC10	512	691.2	1536	26.2	230.4
RC15	512	652.8	1536	39.3	230.4
RC20	512	614.4	1536	52.4	230.4

2.3 Strength Testing

To evaluate the strength characteristics of rubberized concrete prepared in the laboratory according to the specified mix design, four distinct tests were conducted. For the compressive strength test, cylindrical specimens measuring 100 mm in diameter and 200 mm in height were cast. To determine tensile strength, larger cylindrical specimens of 150 mm diameter and 250 mm height were prepared. For the flexural strength test, concrete beams with dimensions of 100 mm × 100 mm × 500 mm were fabricated. Furthermore, impact resistance was analyzed through cylindrical specimens of 150 mm diameter and 63.5 mm height, prepared in compliance with the standards outlined in ACI 544.2R-89. All the cast specimens were subjected to 28 days of curing before testing.

3. Results and Discussion

3.1 Compressive Strength

The correlation between compressive strength and the mix proportions employed in this study was demonstrated in Figure 4. A consistent decline in strength was observed as the rubber percentage increased in the concrete. At 28 days, the control mix (0% rubber) achieved the highest strength of 23.065 MPa, while the 20% rubber mix dropped to 13.995 MPa. It was evident that there was a marked reduction in the compressive strength of concretes with increasing rubber content. The reduction in mechanical properties aligns with findings from previous studies (Fauzan, Putri et al., 2023). The strength reduction due to the addition of rubber was because of the poor adhesion between the cement paste and rubber particles, which resulted in crack formation and propagation in the interfacial zone.

3.2 Flexural Strength

Figure 5 represents the flexural strength of rubberized concrete mixes RC0 to RC20 with varying waste rubber content. The control mix (RC0) achieved the highest strength of approximately 3.20 MPa. As rubber content increased, a gradual reduction in flexural strength was observed. RC5, RC10, RC15, and RC20 recorded strengths of 3.08 MPa, 2.73 MPa, 2.27 MPa, and 2.03 MPa, respectively. This trend highlights the impact of rubber inclusion on tensile performance under flexural loading. The decline was primarily due to poor interfacial bonding between rubber particles and the cement matrix. Rubber and cement paste had weak adhesion, which counteracted effective stress transfer. These factors contribute to early crack initiation and reduced mechanical integrity. Smaller rubber particles slightly mitigated strength loss due to their filler effect.

3.3 Tensile Strength

The results of the split tensile strength test are presented in Figure 6. The control mixture exhibited the highest strength at 3.0 MPa. In contrast, replacing 10% of the fine aggregate with rubber reduced the strength to 2.58 MPa, while a 20% replacement further decreased it to 2.23 MPa. The strength consistently declined as the volume of rubber increased in the concrete. This reduction is primarily attributed to the weak interfacial bonding between the cement paste and rubber particles. As the rubber content increased, the integrity of the aggregate framework was compromised, impairing its ability to effectively transfer tensile loads and thereby diminishing the split tensile strength of the rubberized concrete.

3.4 Drop Weight Impact Resistance Test

The impact resistance performance of the concrete infused with waste rubber is summarized in Figure 7. The impact resistance was measured using a drop weight impact test according to ACI 544.2R-89 at a curing age of 28 days. A 4.5 kg hammer was vertically dropped from a height of 457 mm, impacting the center of a concrete disc specimen measuring 150 mm in diameter and 63.5 mm in thickness. The number of blows required for the initial crack and the number for the final crack represent the impact resistance of rubberized concrete. Figure 7 clearly shows that increasing the rubber content from 0% to 20% significantly enhanced the impact resistance of the concrete specimens. Specifically, the number of blows needed to initiate the first crack increased from 27 to 97, while the blows required to reach complete failure went from 28 to 106. The increase in impact resistance was attributed to the ability of rubber particles to absorb impact energy because of their ductility. With an increase in rubber content, the overall failure mode of the concrete specimens during impact resistance testing changed noticeably from brittle to ductile, as shown in Figure 3. The reduction in air voids with increasing rubber content also contributed to the increase in impact resistance. It is clear that adding rubber successfully improved the material’s deformability and its capacity to withstand impact loading.

(a) Mix ID: RC0

(b) Mix ID: RC20

Figure 3. Failure pattern of Impact Resistance Test

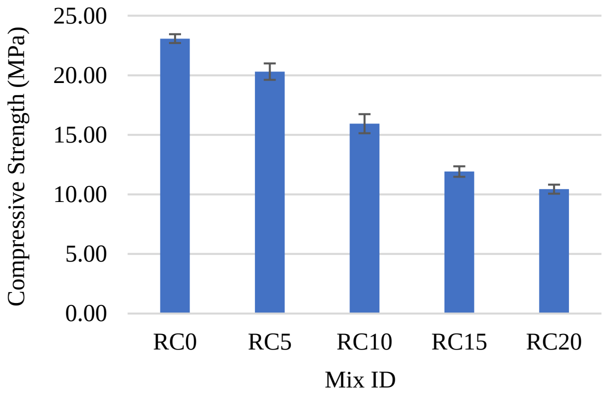


Figure 4. Compressive strength for various mix ID

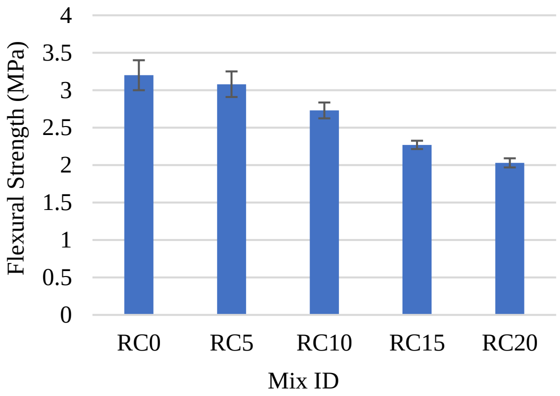


Figure 5. Flexural strength for various mix ID

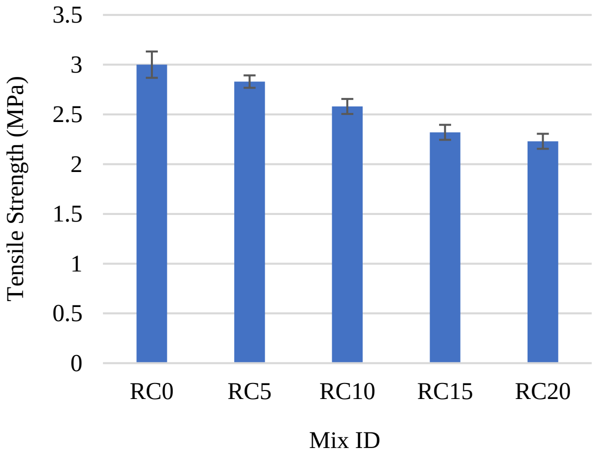


Figure 6. Tensile Strength for various mix ID

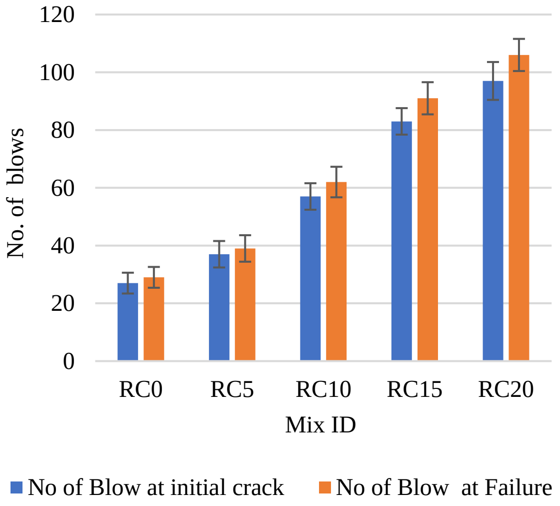


Figure 7. No. of blow required for initial crack and final crack in replacement of fine aggregates

4. Conclusion

The test results of this study demonstrated significant potential for incorporating waste tire rubber into concrete mixtures, highlighting their effectiveness in enhancing performance characteristics and promoting sustainable construction practices. The incorporation of waste rubber particles into concrete mixtures significantly influences their mechanical properties. As the rubber content increases, a consistent decline in compressive strength is observed, primarily due to the inherent flexibility of rubber and its poor adhesion with the cement paste. Similarly, split tensile strength exhibited a downward trend, with the highest values recorded at the lowest rubber inclusion level. An inverse correlation was observed between the rubber content and the flexural strength of the concrete. The flexural strength of the concrete decreases with an increase in rubber content. In contrast to the reductions in strength parameters, impact resistance improved significantly with an increase in rubber content. The test results discovered that rubberized concrete exhibits enhanced energy dissipation capabilities, resisting brittle fracture when subjected to compressive and split tensile loads. These findings suggest that while rubberized concrete may not be ideal for high-strength structural elements, it offers considerable advantages in applications requiring enhanced impact resistance and sustainable material. Its exceptional energy absorption capacity makes it ideal for impact-resistant structures such as bridge crash barriers, road safety barriers, and protective pavements, as well as non-structural elements like sidewalks or partitions where high compressive strength is not critical.

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