

INVESTIGATION OF THE MECHANICAL PERFORMANCE OF CONCRETE INCLUSIVE WITH WASTE TIRE RUBBER

Md. Oahiduzzaman*¹ and Md. Robiul Awal²

¹ Undergraduate Student, Department of Civil Engineering, Rajshahi University of Engineering & Technology (RUET), Bangladesh, e-mail: mdoahiduzzamano@gmail.com

² Professor, Department of Civil Engineering, Rajshahi University of Engineering & Technology (RUET), Bangladesh, e-mail: robi95@ce.ruet.ac.bd

***Corresponding Author**

ABSTRACT

The waste tire rubber growing day in day out has become one of the key concerns in the ecological arena and has become a major pollutant. Rubber will take a long time to break down in the land and contaminate the soil and the surrounding environment. In order to examine a sustainable solution, the proposed study seeks to come up with a concrete that incorporates waste tire rubber and in this case rubber was added as a partial replacement (by volume) of fine aggregate. This experiment intends to employ rubber at 10%, 20%, and 30% proportions. Rubber has a comparable feature to fine aggregate. The physical properties of the raw materials were determined using standard testing procedures to ascertain the process of the casting. The concrete samples were cast as per the mix design and allowed to cure for 28 days. Mechanical properties were also measured using compressive strength test, split tensile strength test, flexural strength test, and drop weight impact resistance test as an evaluation of the energy absorption capacity of rubberized concrete compared to conventional concrete. As rubber is more elastic than concrete, it was expected that rubberized concrete would have increased energy absorption capacity. Other mechanical performances like compressive strength, tensile strength, and flexural strength were also tested by using the right testing techniques. The compressive strength went down with the increase in the rubber content in a progressive manner. The highest compressive strength was measured in the fresh control mix with 0% content of rubber. It also decreases the Flexural strength and tensile strength following the addition of rubber in the concrete. There was also an observed major change in impact resistance following the introduction of rubber in concrete. The first cracking and failure cracking blows were higher with more percentage of rubber in concrete. Moreover, it was found that after the addition of rubber to concrete, the concrete could be rubberized to allow more energy-absorbing capacity. This research aims to assess the performance of rubberized concrete with different proportions of rubber and compare with that of normal concrete, and encourage the use of waste tire rubber as a sustainable solution to reduce environmental pollution.

Keywords: *Rubberized Concrete, mechanical Properties, Energy Absorption Capacity*

1. INTRODUCTION

The rapid growth of the global automobile industry and the increasing dependence on personal vehicles have caused a rise in tire production. Consequently, an estimated 1,000 million tires are discarded globally each year (Eldin, N. N., & Senouci, A. B., 1994). Discarded rubber poses a significant waste management challenge worldwide. Tires, made mostly from natural and synthetic rubber, carbon black, steel, and textile fibers, are not easily degradable under normal environmental conditions (Laftah, W. A. et al., 2025). As a result, millions of end-of-life tires (ELTs) have accumulated globally, creating a need for eco-friendly disposal methods. However, conventional disposal methods lead to a massive accumulation that occupies valuable landfill space. Furthermore, due to their shape, tires can retain water for long periods and creates a breeding habitat for various types of pests (Thomas, B. S., Gupta, et al. 2015). Incineration, the cheapest disposal method also causes serious fire hazards (Gesoglu, M., & Günayisi, E., 2011). These issues led researchers to recognize the urgency of this problem. By the early 1990s, researchers began to explore ways to reuse scrap tires in construction projects (Ganjan, E., Khorami et al., 2009). Following these explorations, the use of waste tires significantly increased in various industries. Yet, large stockpiles remained in the United States during the mid-2000s, according to the estimation of the Rubber Manufacturers Association (Eldin, N. N., & Senouci, A. B., 1994) which indicates that the problem is far from solved. Among the various potential applications for ELTs, incorporating them into cement-based materials appears to be one of the most promising large-scale solutions. Using rubberized concrete not only helps tackle the tire disposal problem but can also improve certain performance characteristics of concrete (Siddique & Naik, 2004). Existing research has proven that rubber can successfully replace part of the aggregates in concrete. However, more comprehensive data are needed to understand both the mechanical and energy-absorbing behavior of modified concrete. In particular, a detailed comparison of static properties (compressive, tensile, and flexural strength) alongside dynamic properties such as impact resistance is necessary to fully evaluate rubberized concrete for real-world use. Therefore, the main goal of this study is to thoroughly examine the mechanical and energy-absorption behavior of concrete where part of the fine aggregates is replaced by processed tire rubber. The study focuses on evaluating how different volumetric rubber replacement percentages (10%, 20% and 30%) affect the compressive, tensile, and flexural strengths. Furthermore, the impact resistance of rubberized concrete is assessed under the standardized drop-weight test outlined in ACI 544.2R-89. By carefully analyzing these aspects, this research aims to determine its potential for use in structures and support the sustainable, practical use of scrap tire materials in advanced construction applications.

2. MATERIALS AND METHODS

2.1 Cement

Cement is a basic component of concrete and works as a binder to form a composite compound known as concrete. It is a fine binding material containing lime, silica, and calcium silicate compounds, which are mainly responsible for strength. Tricalcium Silicate (C_3S), which is responsible for early strength, and Dicalcium Silicate (C_2S), which is responsible for long-term strength. There are many types of cement manufactured in the industry to serve various physical and chemical requirements of structures. In general, most of the construction work is done with ordinary Portland cement, where no physical and chemical issues arise. In this research, ordinary Portland cement was applied as a binding material to erect test specimens.

2.2 Fine Aggregate and Coarse Aggregate

Aggregates are the structural skeleton of concrete. Aggregates passing through a 4.75mm sieve and retained in a 0.075mm sieve are categorized as Fine aggregate. Aggregates retained in a 4.75mm sieve are defined as coarse aggregate. Aggregates are the primary load-bearing component in concrete and have a great influence on strength, durability, and workability. The gradation of coarse aggregate and fine aggregate is also a factor that affects the properties of concrete.



Figure 1: Coarse Aggregate Figure 2: Fine Aggregate

Figure 1 shows the coarse aggregates used in this study, while Figure 2 presents the fine aggregates.

Table 1: Physical properties of aggregates

Properties	Coarse Aggregates	Fine Aggregates
Apparent Specific Gravity	2.88g/cc	2.78 g/cc
Bulk Specific Gravity	2.81g/cc	2.62 g/cc
Bulk Specific Gravity (SSD)	2.84g/cc	2.68 g/cc
Unit Weight	1658kg/m ³	1634 Kg/m ³
Absorption Capacity	0.8%	1.6%
Maximum Aggregate Size	19mm	4.75mm

Table 1 represents physical properties of coarse aggregates and fine aggregates. Grain size distribution curve of coarse aggregates and fine aggregates are represented in figure 3 and figure 4 respectively.

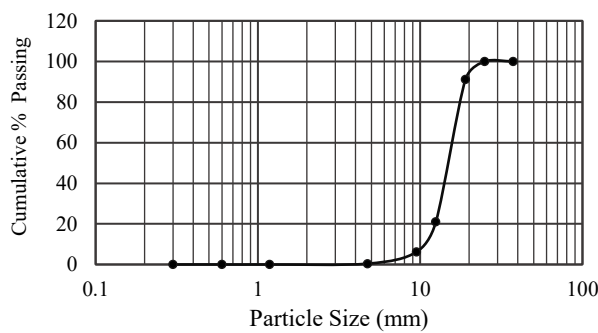


Figure 3: Grain Size Distribution Curve of Coarse Aggregate

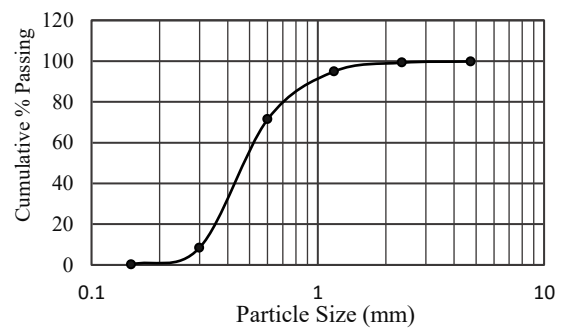


Figure 4: Particle Size Distribution Curve of Fine Aggregates

2.3 Waste Rubber

Waste rubber from discarded tires is now one of the growing concerns due to its harmful effects on the environment as a pollutant. The decomposition rate of rubber is very slow because it is physically and chemically inert. Waste rubber takes around 150 to 200 years to break down, depending on the category. Depending on the size, waste rubber is categorized into crumb rubber, chipped rubber, and powder rubber. Chipped rubber is in sizes of 13mm to 76mm, and powder rubber is 0.425mm to 4.75mm. Chipped rubber, crumb rubber, and powder rubber are generated from the mechanical grinding of junk tires at room temperature. Figure 5 and figure 6 shows crumb and powder rubber respectively.



Figure 5: Crumb Rubber Figure 6: Powder Rubber

The properties of processed waste rubber, shown in table 2 and fine aggregates are likely to be similar. In this study, chipped rubber and powder rubber were used as a partial replacement (by volume) of fine aggregate.

Table 2: Physical Properties of Waste Rubber

Properties	Crumb rubber	Powder rubber
Color	Black	Black
Particle size	0.5-4.75mm	0.40-0.0425mm
Surface	Moderately rough	Moderately rough
Unit weight	597.97kg/m ³	509.387kg/m ³
Fineness modulus (FM)	2.72	2.47

Figure 7 and figure 8 depicts the particle size distribution curve of crumb and powdered rubber respectively.

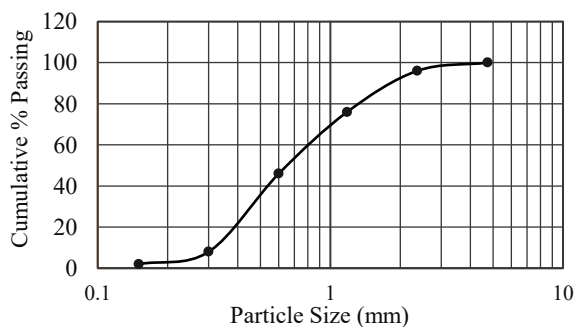


Figure 7. Particle Size Distribution Curve of Crumb rubber

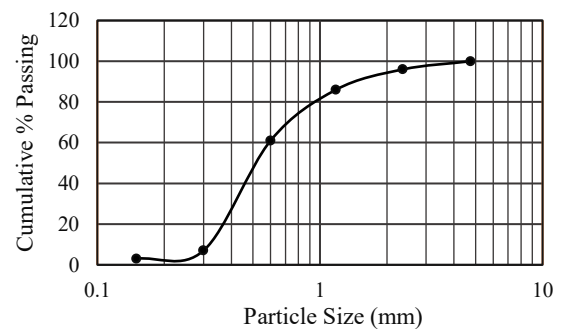


Figure 8. Particle Size Distribution Curve of powdered rubber

2.4 Mixed Design of Concrete

This research involves four distinct concrete mix series that were proportioned and prepared in the laboratory. The fundamental ingredients for all mixes were cement, water, fine aggregate, and coarse aggregate. The primary variable was the amount of waste rubber used to replace fine aggregate by volume. The series included a control mix (WRC0) with 0% rubber, and three experimental mixes with 10% (WRC10), 20% (WRC20), and 30% (WRC30) rubber content. The table 3 shows the ingredients of each mix (Kg/m³).

Table 3: Concrete mix proportions

Mix ID	Cement	Fine Aggregate	Coarse Aggregate	Rubber	Water	Cost (Fine aggregate+ Rubber), BDT
WRC0	512	768.0	1536	0.0	230.4	1331+0=1331
WRC10	512	691.2	1536	26.2	230.4	1198+665=1863
WRC20	512	614.4	1536	52.4	230.4	1065+1310=2375
WRC30	512	537.6	1536	78.6	230.4	932+1965=2897

2.5 Strength Testing

An experimental program was implemented to assess the strength characteristics of the designed rubberized concrete mixtures. This program encompassed four distinct standardized tests: the compressive strength test, the flexural strength test, the split tensile strength test, and the drop weight impact resistance test. To determine the compressive strength, cylindrical specimens with a diameter of 100 mm and a height of 200 mm were cast. For the tensile strength test, cylindrical specimens with a diameter of 150 mm and a height of 250 mm were prepared. To evaluate the flexural strength, concrete beams measuring 100 mm × 100 mm × 500 mm were prepared. Impact resistance was assessed using discs with a diameter of 152 mm and a height of 63.5 mm, manufactured in accordance with the ACI 544.2R-89 standard. Each specimen underwent a curing process for 28 days before testing.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength test

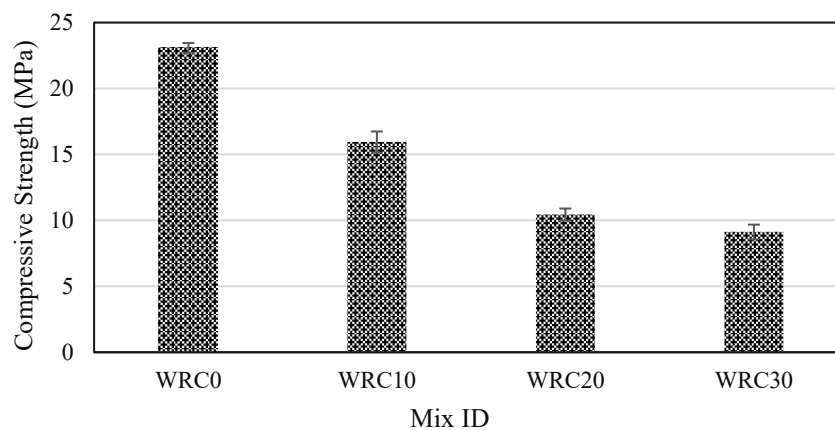


Figure 9: Compressive strength with different mix proportions

Figure 9 shows how the compressive strength of concrete with various percentage content of waste rubber changes with time (28 days) of drying. A strong negative trend was recorded thus showing that compressive strength reduces with the percentage of rubber. The maximum compressive strength of 23.08 MPa had been obtained in the control mix WRC0 has 0% waste rubber. On the other hand, the lowest compressive strength of 9.12 MPa was in the WRC30 mixture, which has 30 percent rubber to replace fine aggregates. The other two mixes of WRC10 and WRC20 with 10% and 20% rubber, respectively, had compressive strengths of 15.94 MPa and 10.44 MPa, respectively. Thus, compressive strength decreases with an increase in the rubber content. This observation is consistent with the past studies (Ganjian, E., et al., 2009). This makes the cement paste loosen strength due to the loose connection between cement paste and rubber particles as a result of cracks that develop and spread across the interfacial zone

3.2 Flexural Strength test

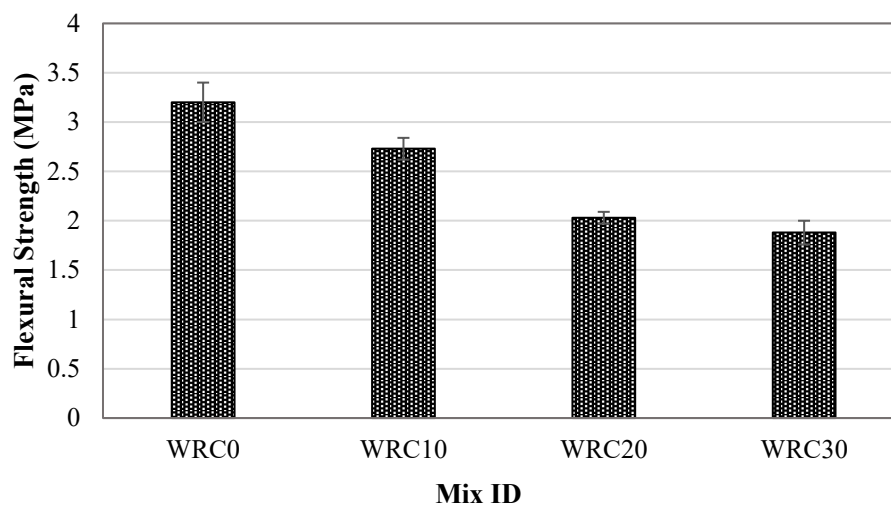


Figure 10: Flexural strength with different mix proportions

Figure 10 shows the relationship between mix proportions and flexural strength. The findings show a steady decrease in flexural strength as the content of rubber is raised. The flexural strength of the control mix with 0% rubber (WRC0) was the highest (3.2 MPa). Conversely, the mixture that had the highest concentration of rubber (WRC30, 30%) produced the least strength of 1.88 MPa. Intermediate mixes, WRC10 and WRC20 with 10% and 20% content of rubber as a replacement of fine aggregates had flexural strengths of 2.73 MPa and 2.03 MPa, respectively. The standard deviation is low in all the specimens that are tested which confirms the reliability of these findings. This inverse relationship between flexural strength and content of rubber is in line with the results found in the literature (Sofi, A., 2018). The major process of strength degradation is the poor bond at the rubber-cement junction, which undermines the transfer of stress and encourages premature cracking. The smaller particles of rubber were found to reduce this loss of strength slightly, probably because of their filler action in stiffening the concrete matrix.

3.3 Split tensile strength

Figure 11 shows split tensile strength of the concrete mixture with different content of waste rubber as a fine aggregate replacement. The outcomes show that there is an apparent inverse relationship, the higher the content of rubber in the concrete the lower the tensile strength. The highest tensile strength of 3.0 MPa was obtained when the control mixture (WRC0) was used and it had no rubber particles. Conversely, the minimum strength of 2.04 MPa was obtained on the specimen that contained 30 percent of rubber under WRC30. The intermediate mixtures WRC10 (10% rubber) and WRC20 (20% rubber)

had tensile strength of 2.58 MPa and 2.23 MPa respectively. Tensile strength decreases with the weight of rubber used, which is in line with the results of past research (Khaloo, A. R., et al, 2008). This can be explained by the fact that the addition of rubber disturbs the aggregate skeleton and disrupts the overall integrity of the matrix, and thus loss of its effectiveness in the transfer of tensile stresses, culminating in lower split tensile strength in rubberized concrete.

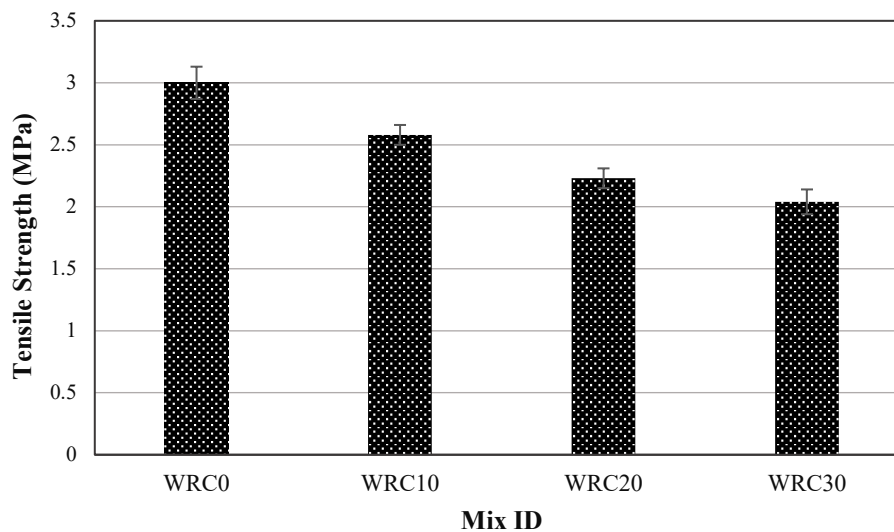


Figure 11: Tensile strength with different mix proportions

3.4 Drop Weight Impact-resistant test

Figure 12 shows the layout of the setup suggested in ACI 544.2R-89, Figure 13 illustrates the test setup with steel ball and a 4.5 kg hammer, and Figure 14 represents the hammering action on the specimen. Figure 15 demonstrates the sample of impact resistance test after failure. The effect of resistance on the incorporation of waste rubber as a partial replacement of fine aggregate into concrete was determined and the findings depicted in Figure 16. The test protocol was based on ACI 544.2R-89 protocol, and a drop impact test was carried out on specimens that had been cured after 28 days was used. The experiment apparatus entailed a weight of 4.5 kg, which was thrown vertically out of a distance of 457 mm and onto the centre of a concrete disc sample (152 mm diameter × 63.5 mm thickness). The effect performance was measured by documenting the quantity of blows needed to begin to noticeably fracture (N1) and the quantity of blows required to accomplish total damage (N2). A sign of a substantial and steady enhancement in impact resistance as the rubber content increases is indicated in Figure 16. Both the starting and ending crack failure criterion depicted a significant increasing trend.

The control mix WRC0 showed the least impact resistance with the first crack and the last failure being 27 and 29 blows respectively. Incorporation of 10% rubber (WRC10) led to significant improvement in performance, and the blows were 57 and 62 for the first and last crack respectively. This was the case as the WRC20 mix (20% rubber) survived 97 blows to crack and 106 to fail. The highest impact resistant was recorded in WRC 30 mix (30% rubber) that took 103 and 109 blows to initiate and final failure respectively.

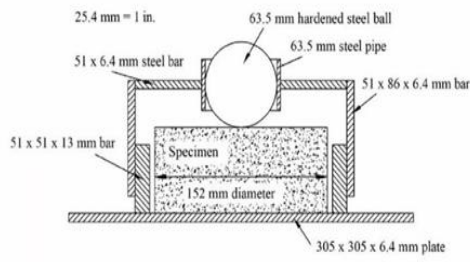


Figure 12: Drop-weight test apparatus (ACI 544.2R-89)



Figure13: Test Setup with Steel Ball and 4.5 kg Hammer



Figure 14: Hammering Action



Figure 15: Failure plane of impact resistance test

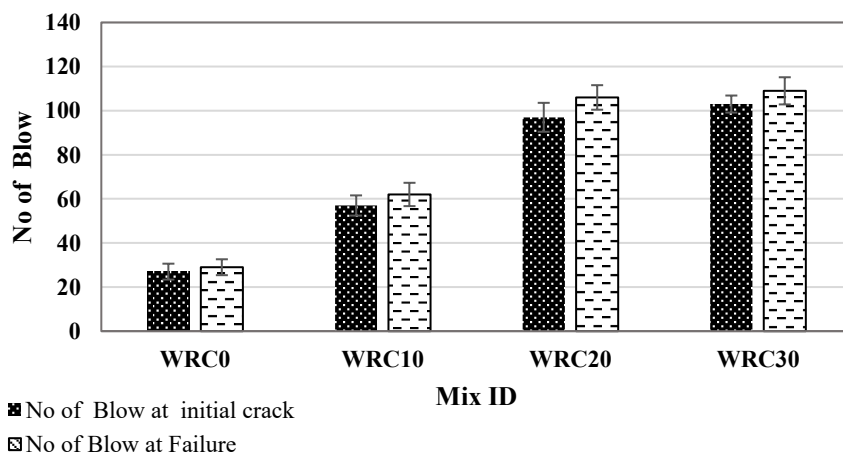


Figure 16: No. of Blow required for the initial crack and the Final crack in replacement of fine aggregates

3.5 Impact Energy at failure

Figure 17 shows the relation of rubber content of concrete and the impact energy to failure. The findings prove that there is a strong positive relationship, with the effect energy surging with the increased percentage of rubber replacement of fine aggregate. The energy was calculated by the formula:

Impact Energy (J) = Mass of Hammer (kg) × Number of Blows (N₂) × Drop Height (m) × Gravitational Acceleration (m/s²)

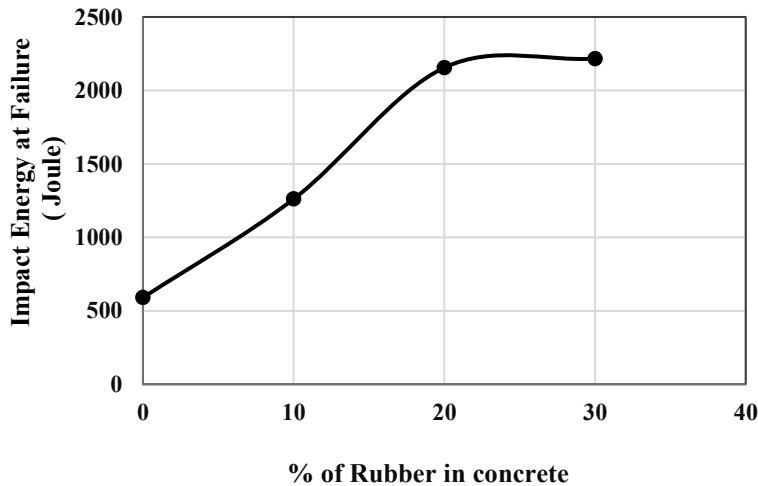


Figure 17: Impact Energy at failure (Joules) in different rubber content

Having the mass of 4.54 kg, the drop height of 0.457 m, and the acceleration due to gravity of 9.81 m/s². Quantitative analysis shows that the control mix (0% rubber) had the least impact energy of 589.65 J. Conversely, the highest impact energy of 2216.28 J was realized in the mix containing 30 percent of rubber (WRC30), and impact energies of 1260.64 J and 2155.28 J were obtained in the mixes containing 10 percent (WRC10) and 20 percent (WRC20) of rubber, respectively. This tendency correlates with the conclusions of the earlier research in the field (Gupta, T., et al 2015.) The main factor of such improvement is ascribed to the nature of rubber. The rubber particles have a high elasticity and excellent shock-absorbing behavior that enables them to absorb relatively large constituent of impact energy by undergoing elastic deformation, which in turn enhances the total impact and fracture resistance of the rubberized concrete.

4. CONCLUSION

The research demonstrated significant potential for incorporating waste tire rubber into concrete, highlighting its capacity to improve material performance and support eco-friendly building practices. The integration of waste rubber particles in concrete mixes substantially changes their mechanical properties. A steady fall in compressive strength occurs with higher rubber percentages, mainly because of rubber's natural elasticity and its weak bond with the surrounding cement matrix. Split tensile strength also decreased, with the most favourable results found at the minimal rubber percentage. A reverse relationship was noted between the quantity of waste rubber and the concrete's flexural strength, which declined as more rubber was added. Conversely, and unlike the diminishing strength properties, the resistance to impact improved markedly as the rubber content rose. Also, as the rubber percentages increase, the impact energy absorbent capacity rises. The investigation revealed that rubber-modified concrete possesses a greater ability to dissipate energy, preventing sudden, brittle failure under compressive and split tensile forces. These outcomes imply that although rubberized concrete might not

be suitable for primary structural members demanding high strength, it holds significant benefits for uses that need superior impact resistance and sustainable materials. The outstanding capacity of rubberized concrete to absorb impact energy positions it as a perfect material for structures designed to withstand collisions, such as bridge parapets, crash barriers, driveways, sidewalks, and special types of road way construction applications.

5. AI DECLARATION

This study did not use any AI tools to make any corrections.

REFERENCES

- Eldin, N. N., & Senouci, A. B. (1994). Measurement and prediction of the strength of rubberized concrete. *Cement and Concrete Composites*, 16(4), 287–298. [https://doi.org/10.1016/0958-9465\(94\)90041-8](https://doi.org/10.1016/0958-9465(94)90041-8)
- Ganjian E., Khorami, M., & Maghsoudi, A. A. (2009). Scrap-tyre-rubber replacement for aggregate and filler in concrete. *Construction and Building Materials*, 23(5), 1828–1836. <https://doi.org/10.1016/j.conbuildmat.2008.09.020>
- Gesoğlu, M., & Günayisi, E. (2011). Permeability properties of self-compacting rubberized concretes. *Construction and Building Materials*, 25, 3319–3326. <https://doi.org/10.1016/j.conbuildmat.2011.03.021>
- Gupta, T., Sharma, R. K., & Chaudhary, S. (2015). Impact resistance of concrete containing waste rubber fiber and silica fume. *International Journal of Impact Engineering*, 83, 76–87. <https://doi.org/10.1016/j.ijimpeng.2015.05.002>
- Khaloo, A. R., Dehestani, M., & Rahmatabadi, P. (2008). Mechanical properties of concrete containing a high volume of tire-rubber particles. *Waste Management*, 28(12), 2472–2482. <https://doi.org/10.1016/j.wasman.2008.01.015>
- Laftah, W. A., & Wan Abdul Rahman, W. A. (2025). A comprehensive review of tire recycling technologies and applications. *Materials Advances*, 6, 4992–5010. <https://doi.org/10.1039/D5MA00463B>
- Siddique, R., & Naik, T. R. (2004). Properties of concrete containing scrap-tire rubber—An overview. *Waste Management*, 24(6), 563–569. <https://doi.org/10.1016/j.wasman.2004.01.006>
- Sofi, A. (2018). Effect of waste tyre rubber on mechanical and durability properties of concrete – A review. In *Ain Shams Engineering Journal* (Vol. 9, Issue 4, pp. 2691–2700). Ain Shams University. <https://doi.org/10.1016/j.asej.2017.08.007>
- Thomas, B. S., Gupta, R. C., Mehra, P., & Kumar, S. (2015). Performance of high strength rubberized concrete in aggressive environment. *Construction and Building Materials*, 83, 320–326. <https://doi.org/10.1016/j.conbuildmat.2015.03.012>