Experimental Study on Sustainable Mortar Using Recycled Tyre Rubber Aggregates

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Abstract: **The characteristics of cement mortar are investigated experimentally in this study by substituting discarded tyre rubber crumb for some of the fine aggregate. The primary objective is to address environmental concerns related to tyre disposal while promoting sustainable construction practices. Mortar mixes were prepared with varying percentages of rubber crumb (0%, 3%, 6%, 9%, and 12%) as a substitute for sand. Efficiency, strength of compression, and water absorption properties were tested at various curing times. Results demonstrated that the inclusion of rubber crumb reduces the density and enhances ductility of the mortar. However, a gradual decrease in compressive strength was observed with increasing rubber content. An optimum replacement level was identified around 6%, where acceptable strength and improved durability properties were achieved. Additionally, rubberized mortar showed variations in water absorption behavior compared to conventional mortar. The study concludes that waste tyre rubber can be effectively utilized in non-structural applications. This approach contributes to waste management and supports eco-friendly construction materials.**

Keywords: Rubberized mortar; Waste tyre recycling; Compressive strength; Partial sand replacement; Sustainable construction; Water absorption.

I. INTRODUCTION

The rapid growth of urbanization and industrialization has led to a significant increase in waste generation across the world. Among various types of waste, discarded tyres pose a serious environmental challenge due to their non-biodegradable nature and large volume. Globally, approximately one billion waste tyres are generated every year, and this number is expected to rise drastically in the coming decades. Improper disposal methods such as landfilling and open burning lead to severe environmental issues including soil and water contamination, air pollution, fire hazards, and health risks. In countries like India, where infrastructure development is rapidly expanding, the consumption of natural resources such as river sand is increasing significantly. Excessive extraction of sand results in environmental degradation, riverbank erosion, and ecological imbalance. Therefore, there is an urgent need to identify sustainable alternatives to conventional construction materials.

One promising solution is the utilization of waste tyre rubber in cement-based materials. Incorporating rubber crumb as a partial replacement for fine aggregate (sand) in cement mortar not only helps in waste management and additionally assists to sustainable construction practices. Rubberized mortar exhibits unique properties such as improved ductility, energy absorption, impact resistance, and reduced density. These characteristics make it suitable for various non-structural and semi-structural applications. However, the addition of rubber particles in mortar also affects its mechanical properties, particularly compressive strength, due to weak bonding between rubber and cement paste. To overcome this limitation, techniques such as reducing particle size and chemical pre-treatment of rubber (e.g., NaOH treatment) are adopted to enhance interfacial bonding.

This study focuses on the experimental investigation of cement mortar by partially replacing sand with fine-grinded waste tyre rubber crumb. Various percentages of rubber replacement are considered to evaluate their effect on properties such as workability, compressive strength, and water absorption. The aim is to calculate the ideal rubber replacement percentage that ensures adequate strength while improving sustainability and reducing environmental impact.

Early studies by Goulias et al. (1998) demonstrated that the inclusion of crumb rubber improves the ductility & energy absorption capacity of concrete, although it leads to significant deformation before failure. Similarly, Biel and Lee (1996) reported that rubberized concrete using magnesium oxychloride cement showed better bonding characteristics compared to conventional mixes. Khatib et al. (1999) observed that increasing rubber content results in a reduction in compressive with flexural strength. They proposed that rubber replacement should be limited to about 20% to maintain acceptable strength levels. Malek K. Batayneh et al. (2008) also confirmed that higher percentages of crumb rubber reduce compressive, tensile, and flexural strengths, although the material remains workable and suitable for non-structural applications such as pavements and barriers.

Sara Sgobba et al. (2010) examined the impact of rubber aggregates on concrete properties and found that while compressive strength decreases, the material becomes lightweight and exhibits improved toughness. Similarly, El-Gammal et al. (2010) reported a significant reduction in density and strength when rubber replaces aggregates, but noted enhanced ductility. Hernandez-Olivares et al. (2002) concluded that small amounts of rubber (up to 5%) do not significantly affect mechanical properties, while higher percentages improve energy dissipation under dynamic loading. This makes rubberized concrete suitable for applications requiring vibration resistance and impact absorption.

Recent studies have focused on improving the performance of rubberized concrete. Fengming Ren et al. (2022) highlighted that poor bonding at the interfacial transition zone (ITZ) is the main reason for strength reduction. They suggested that chemical treatment of rubber particles can significantly enhance bonding and improve overall performance. Yang Li et al. (2019) reported that low percentages of crumb rubber (up to 10%) can slightly improve compressive and flexural strength, while higher percentages reduce strength but enhance durability properties such as resistance to chloride penetration, abrasion, and freeze-thaw cycles.

Abbas Mohajerani et al. (2020) emphasized the environmental benefits of using waste tyre rubber in construction, noting improvements in ductility, thermal insulation, and vibration damping. However, they also pointed out concerns related to potential leaching of harmful substances, indicating the need for further research. Recent advancements by Kamrul Hasan et al. (2024) confirmed that although rubberized concrete shows reduced strength, its durability properties such as resistance to acid, sulphate attack, and permeability can be improved with proper treatment and mix design.

The goals of the study are

- To improve various properties of motor with fine grind Rubber crumb as a sand replacement.
- To investigate the strength at compression of concrete mortar by substituting different percentages of rubber crumb for fine aggregate.
- To study the water absorbing capacity of mortar using rubber crumb to be used as waterproof material.
- To study the cost effectiveness with optimum material utilization by reducing weight of motor.

Fig. 1. Rubber Crump

II. EXPERIMENTAL INVESTIGATION AND PROCEDURE

A. *Experimental Investigation*

The present study focuses on investigating the mechanical and durability properties of cement mortar by partially replacing natural fine aggregate with waste tyre rubber crumb. The primary objective is to evaluate how varying percentages of rubber crumb influence properties such as compressive strength, workability, and water absorption. The experimental program was designed to address environmental concerns related to waste tyre disposal while promoting sustainable construction materials.

Ordinary Portland cement (OPC 43 grade), natural river sand, potable water, and finely processed rubber crumb obtained from waste tyres were used in this investigation. The rubber crumb was sieved to ensure uniform particle size comparable to fine aggregate. Different mortar mixes were prepared by using rubber crumb in place of sand at varying percentages such as 0%, 3%, 6%, 9%, and 12%. The control mix (0% replacement) functioned as a basis to compare the performance of rubberized mortar.

The experimental investigation included both fresh and hardened state tests. Fresh properties were evaluated through workability and consistency observations, while hardened properties were determined through compressive strength and water absorption tests. Additionally, basic material characterization tests such as specific gravity, fineness, and sieve analysis were conducted to understand the physical properties of the materials used.

With the help of a compression testing apparatus, the compressive property of mortar cubes was assessed at curing ages of seven and twenty-eight days. The results indicated that the inclusion of rubber crumb generally leads to a reduced compressive strength due to weak bond of rubber particles with cement paste. However, an optimum replacement level (around 6%) showed comparable or slightly improved strength owing to better particle packing and stress distribution.

Water absorption tests were performed to assess the durability of mortar mixes. It was observed that lower percentages of rubber crumb reduced water absorption due to improved pore structure, while higher percentages increased porosity, leading to higher absorption. The experimental findings highlight that rubberized mortar can be effectively used in non-structural applications where lightweight and durability are more important than high strength.

B. *Experimental Procedure*

The experimental procedure was carried out systematically to ensure accuracy and consistency in results. The methodology involved material preparation, mix design, casting, curing, and testing of specimens.

Initially, all raw materials like cement, sand and rubber crumb were collected and tested for physical properties. The fine aggregate and rubber crumb were subjected to sieve analysis to determine their grading. The specific gravity of cement, sand and rubber crumb was determined using standard methods. The normal consistency and setting time of cement were also evaluated using the Vicat apparatus. For the preparation of mortar mixes, the required quantities of cement, sand, and rubber crumb were weighed as per the mix proportions. Firstly, the dry materials were mixed thoroughly to achieve uniform distribution of rubber particles. Water was then added gradually, and mixing was continued until a homogeneous and workable mix was obtained.

The prepared mortar was then poured into standard cube moulds of size 70.7 mm × 70.7 mm × 70.7 mm. The moulds were properly cleaned and oiled before casting. The mortar was placed in layers and compacted either manually or using a vibrating table to remove air voids. The top surface was leveled using a trowel to ensure a smooth finish.

The specimens were kept at room temperature for an entire day after casting. The cubes were then demoulded and transferred to a curing tank. To ensure that the cement was properly hydrated, curing was done for seven and twenty-eight days. After the curing period, the specimens were taken out and tested for compressive strength using a compression testing machine. The highest load was noted when the load was introduced progressively until it failed. The compressive strength was calculated by dividing the load by the c/s area of the specimen. Water absorption tests were conducted by oven drying the specimens, immersing them in water, and measuring the weight difference. This helped in determining the porosity and durability characteristics of the mortar. The experimental procedure ensured that all tests were conducted as per standard guidelines, and results were recorded systematically for analysis and comparison.

Fig. 2. Casting of specimens

Fig. 3. Curing of specimens

III. RESULTS AND DISCUSSIONS

A. Water Absorption

TABLE I. WATER ABSORPTION TEST RESULTS

% Replacement of crumb rubber	Avg water absorption %	Water cement ratio
0	8.66	0.5
3	6.93	0.5
6	5.78	0.5
9	8.37	0.5
12	9.34	0.5

B. Compressive strength

Compressive strength of mortar blocks with various percent of fine aggregate (sand) replacement by rubber crumb at 0%, 3%, 6%, 9%and 12% is carried out.

TABLE II. COMPRESSIVE STRENGTH TEST RESULTS

% of Replacement Rubber crumb	7 Days Compressive Strength (MPa)	28 Days Compressive Strength (MPa)
Normal (0%)	7.33	11.43
3% Replacement	6.8	10.61
6% Replacement	7.1	11.84
9% Replacement	6.61	11.02
12% Replacement	6.24	10.41

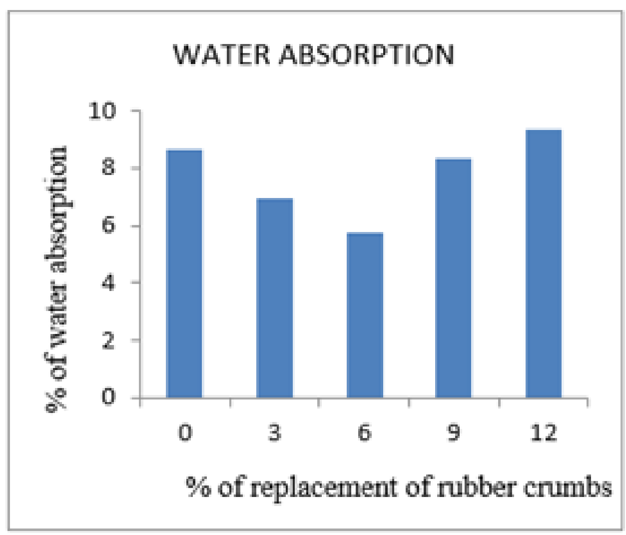

Fig. 4. Water Absorption test results

The experimental investigation on cement mortar with partial replacement of fine aggregate using waste tyre rubber crumb revealed significant changes in both mechanical and durability properties. The results indicate that the inclusion of rubber crumb affects compressive strength, water absorption, and overall behavior of mortar depending on the percentage of replacement.

Control mix (0% rubber) demonstrated strengths of 7.33 MPa at 7 days with 11.43 MPa at 28 days, according to the compressive strength data. With the insertion of rubber crumb, there is a general trend of strength reduction; however, an exception is noted at 6% replacement, where the compressive strength slightly increased to 7.1 MPa (7 days) and 11.84 MPa (28 days). This indicates that a small

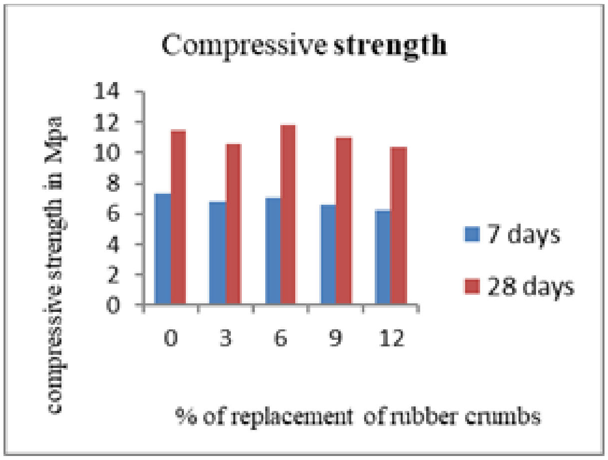

Fig. 5. Compression strength test results

percentage of rubber can contribute positively due to better particle packing and stress distribution. Beyond this optimum level, the strength decreases significantly, reaching 6.24 MPa (7 days) and 10.41 MPa (28 days) at 12% replacement.

Water absorption results show an initial decrease from 8.66% (0%) to 5.78% (6%), followed by an increase at higher replacement levels. This suggests that limited rubber content helps in reducing pore connectivity, while excess rubber increases voids due to poor bonding.

- *Weak Interfacial Transition Zone (ITZ):* Rubber particles are hydrophobic and do not bond well with cement paste. This creates a weak interface between rubber and cement matrix, leading to reduced load transfer and lower compressive strength at higher replacement levels.
- *Elastic Nature of Rubber:* Rubber has low stiffness and high deformability compared to sand. Below the compressive load, the rubber particles deform instead of resisting stress, resulting in reduced strength but increased ductility and energy absorption.
- *Void Formation and Porosity:* At higher percentages, rubber particles create micro-voids and increase porosity due to improper packing and weak adhesion. This leads to higher water absorption and reduced durability.
- *Improved Packing at Optimum Content:* At lower replacement levels (around 6%), fine rubber particles fill micro-voids within the mortar matrix, improving density and slightly enhancing strength and durability.
- *Reduced Density:* Since rubber has lower specific gravity compared to sand, the overall density of mortar decreases, making it lightweight but also contributing to reduced strength at higher dosages.

Thus study concludes that an optimum replacement level of around 6% rubber crumb provides a balance between strength and durability. Beyond this limit, the negative effects such as weak bonding, increased porosity, and reduced stiffness dominate the behavior. Therefore, rubberized mortar is more suitable for non-structural applications such as pavements, partition walls, and lightweight construction where ductility and sustainability are prioritized over high strength.

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