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Comparative Performance Study of Rubberized Concrete and Conventional Concrete: Strength, Sustainability, and Innovation

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Abstract

The growing amount of car waste is a major problem around the world, and getting rid of old tires is especially important for the environment. Rubberized concrete (RC) uses broken tire rubber as a substitute for natural materials in concrete, which is a smart and new way to help build in a more sustainable way. This review paper compares how well RC works against conventional concrete (CC). The study looks at three main areas: strength (such as how well it can handle pressure, stretching, bending, and impacts), sustainability (how good it is for the environment, how long it lasts, and how it uses waste), and innovation (how the mix is made and how materials are improved). The results show that using waste tire rubber (WTR) usually makes the concrete somewhat weaker in some ways, but it makes it better at handling things like bending, breaking, and impact. This makes it good for certain uses. Also, using WTR helps to reduce a lot of waste that would otherwise end up in landfills. The review talks about new methods like treating the rubber surface and mixing it with other materials to make the concrete stronger and better at connecting with cement. Looking ahead, there is a need for clear rules on how to mix the concrete, more long-term studies on how it behaves over time, and more research into its good qualities, like how it handles heat and sound. This study shows that RC is an important new material that turns a waste problem into a useful construction material, helping create a more sustainable and environmentally friendly built environment.

Keywords: Comparative performance, crumb rubber, durability, mechanical properties, rubberized concrete

INTRODUCTION

The Environmental Impact of Regular Concrete

Concrete is the second most widely used material in the world after water. Making the main part of concrete, called Ordinary Portland Cement (OPC), causes about 5–8% of all man-made carbon dioxide emissions worldwide. Also, the high need for small and large stones leads to the quick use up of natural resources and causes a lot of quarrying and mining [1].

The construction and demolition industries generate a significant amount of waste. Because of these environmental challenges, there is a need to transition toward more sustainable building practices. Using materials manufactured from industrial waste and by-products, known as resource-efficient materials, is becoming necessary to reduce the environmental impact of buildings [2].

The Development of Rubberized Concrete

Another big environmental problem is the huge

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amount of old tires. It is estimated that over one billion tires are discarded each year worldwide, piling up into large, non-degradable piles that pose serious health and fire risks. The idea of rubberized concrete (RC) addresses both of these issues. RC is a type of material in which some of the conventional stones in concrete are replaced with finely processed rubber bits, often called crumb rubber (CR), sourced from used tires. The production of RC was initially challenging because rubber does not adhere well to cement mixtures; however, improvements in science and materials have led to effective methods for preparing rubber. This review compares RC with regular concrete in terms of strength, structure, and environmental impact to determine whether RC is a viable, eco-friendly option (Figure 1) [3].

METHODOLOGY: STRUCTURE OF THE REVIEW

To ensure a thorough analysis, this review used a systematic approach based on the following keywords: “rubberized concrete,” “crumb rubber,” “waste tire management,” “concrete mechanical properties,” and “sustainability.” The sources were mainly obtained from trusted databases such as Scopus, Web of Science, and Google Scholar, and focused on articles published between 2010 and 2024 in the databases [4, 5].

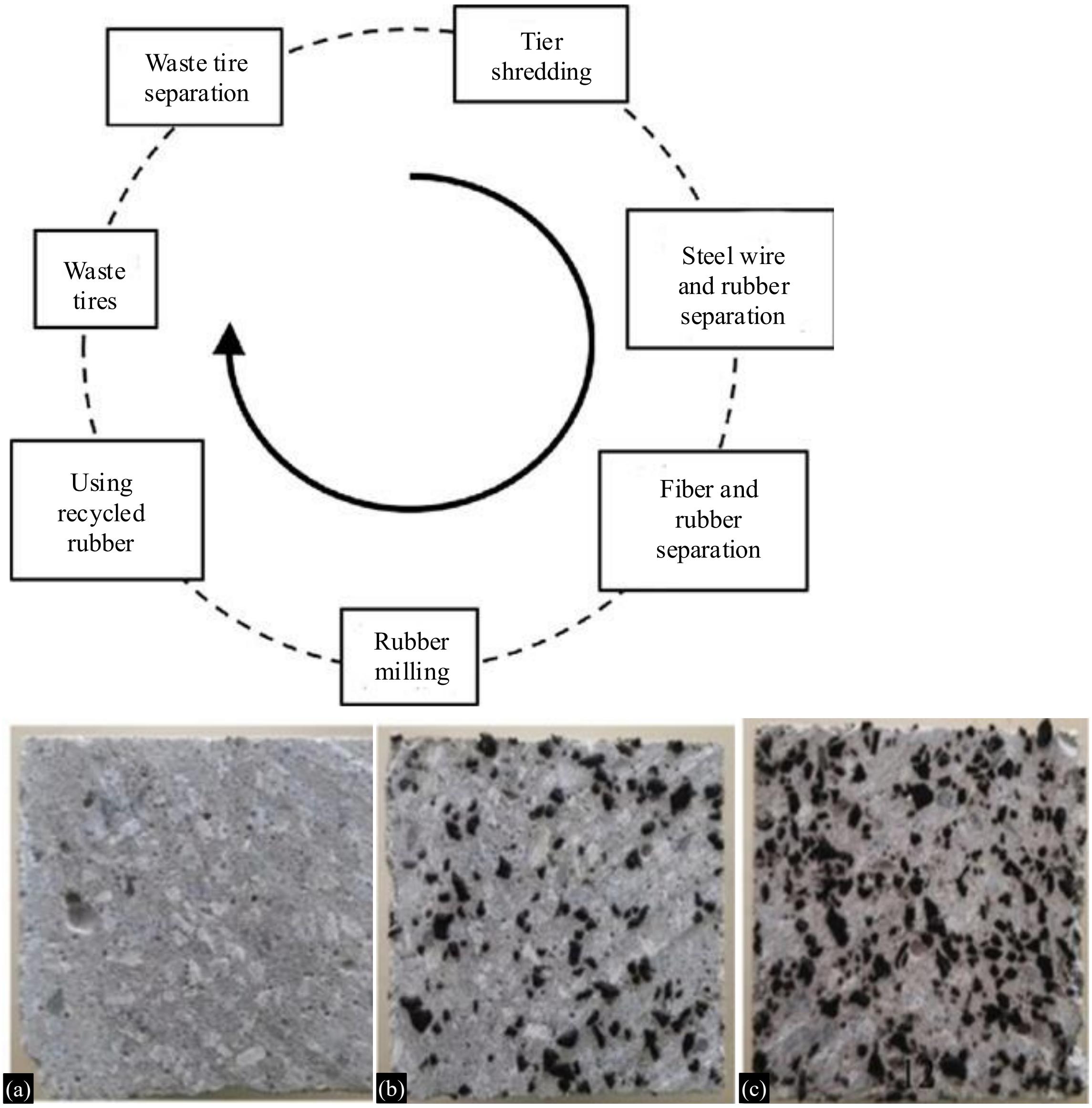

Figure 1. Internal visual inspection of the rubberized. Concrete cubes with cut-outs of 100 mm × 100 mm from the test specimens containing (a) 0%, (b) 15%, and (c) 30% rubber content.

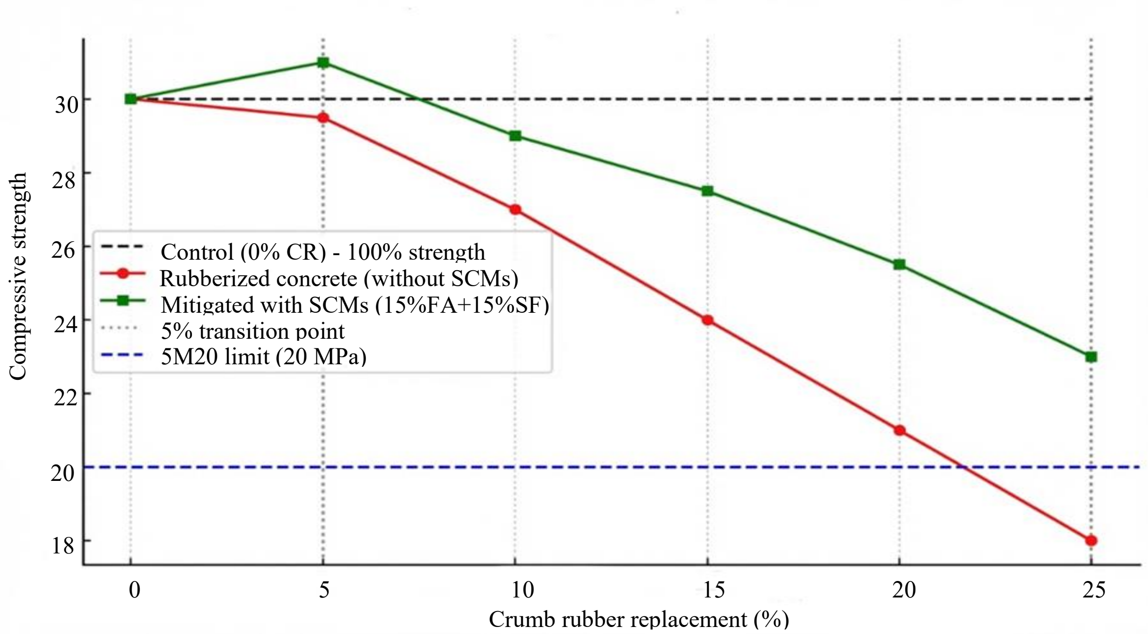

Figure 2. Effect of crumb rubber on compressive strength.

The review is organized as follows:

- To measure the effect of adding rubber on the main mechanical properties of concrete (strength).
- To determine the basic reasons for changes in performance (interfacial transition zone (ITZ) and air voids).
- To summarize the ways used to reduce the negative effects (treatment methods).
- To examine the changes in performance (durability and resilience).
- To assess the wider impacts (sustainability and application).

LITERATURE REVIEW AND PERFORMANCE CHARACTERISTICS

Research on rubberized concrete has shown that its performance has complex trade-offs, which are mainly influenced by the amount of aggregate replaced, the size and texture of the crumb rubber, and any pretreatment of the rubber particles [6].

Mechanical Strength (Compressive, Tensile, and Flexural)

Many studies have shown that replacing mineral aggregates with crumb rubber leads to a decrease in the main mechanical strengths of concrete. This decrease is mainly because rubber has lower stiffness and elasticity than traditional aggregates [7].

Compressive Strength

A decrease in compressive strength is usually proportional to the amount of rubber used. For example, replacing up to 15% of the aggregate with crumb rubber can reduce the 28-day compressive strength by 10%–30%, and higher replacement rates result in a more significant loss. This relationship is often shown as a curve, in which the strength decreases with increasing rubber volume. Quantitatively, using crumb rubber as a fine aggregate replacement is less detrimental to strength than using it as a coarse aggregate replacement, often allowing for higher inclusion levels before the strength goals are missed. However, the use of special additives or pretreatment methods can help reduce this loss, especially in studies on high-strength concrete made with waste tire rubber (Figure 2) [8].

Tensile and Flexural Strength

The effect on the tensile and flexural properties is often similar to that on the compressive strength. Notably, the inclusion of rubber increases the ductility and strain capacity of the concrete matrix. This allows concrete to handle more deformation before it fails completely, thereby preventing the sudden failure that is common in regular concrete [9].

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Stress–Strain Behavior and Density

In contrast to regular concrete, which has a sudden failure curve, rubberized concrete shows a smoother, more gradual decline in the stress–strain curve. This demonstrates the ability to fail without being brittle and to absorb a significant amount of energy after the peak load. Additionally, because rubber has a lower density than natural aggregate, rubberized concrete usually has a lower weight, typically reducing the concrete unit weight by 5%–15%. This makes it attractive for applications in which reducing the weight is important [10].

Mechanisms of Strength Reduction

The decrease in mechanical performance is due to three main microstructural issues:

- *Low modulus of elasticity of rubber:* Soft and flexible rubber particles act as stress points and small voids within the rigid cement matrix when the concrete is under load.
- *Weak interfacial transition zone:* The main challenge in manufacturing high-performance rubberized concrete is the weak bond between the non-polar (hydrophobic) rubber surface and the highly polar (hydrophilic) cement paste. This weak ITZ is porous and weak, acting as the main path for microcracks to spread, speeding up failure under compression.
- *Increased air voids:* The rubber particle surface often traps air bubbles during mixing, resulting in more air voids in the final structure than in regular concrete, which weakens the density and strength.

The Interfacial Transition Zone Optimization and Treatment Methods

The success of rubberized concrete depends largely on optimizing the ITZ to establish a strong chemical or mechanical bond between the rubber and cement matrix. Pretreatment of rubber is a key step in the production process. The process typically follows a clear sequence: (1) shredding of waste tires, (2) grinding or crumbling, (3) treatment, and (4) mixing (Figure 3).

Chemical Treatment (e.g., NaOH)

This involves soaking crumb rubber in solutions such as sodium hydroxide (NaOH) or silane coupling agents. NaOH treatment alters the rubber surface by breaking down the polymer chain ends and removing organic impurities. This process increases the roughness of the surface and creates more hydrophilic sites, enhancing mechanical interlocking and potentially improving the chemical bond with cement paste [6]. Typical NaOH concentrations range from 6% to 10% of the total content, and studies have shown strength recovery of up to 15% compared to untreated rubberized concrete mixes.

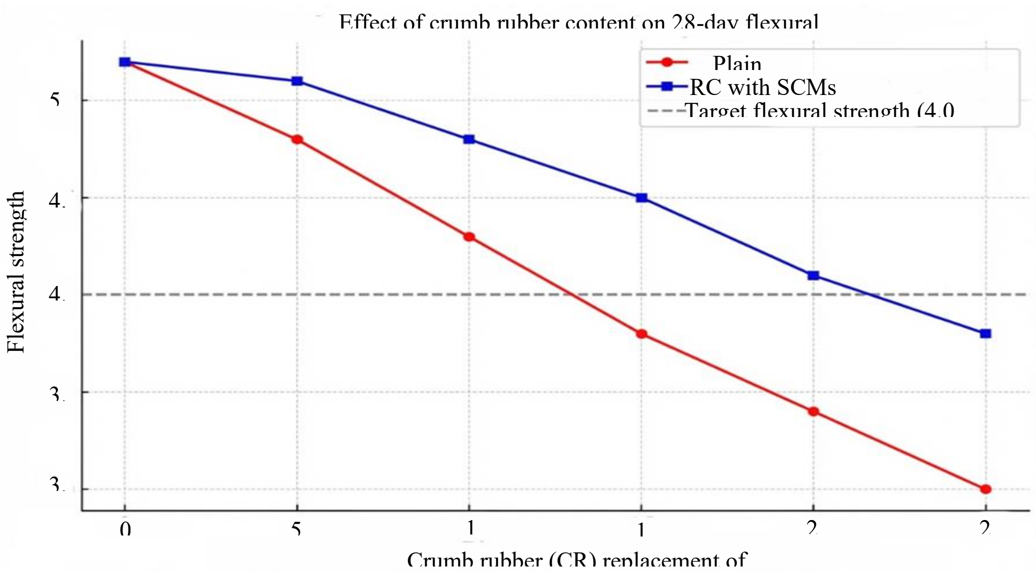

Figure 3. Effect of crumb rubber on flexural strength.

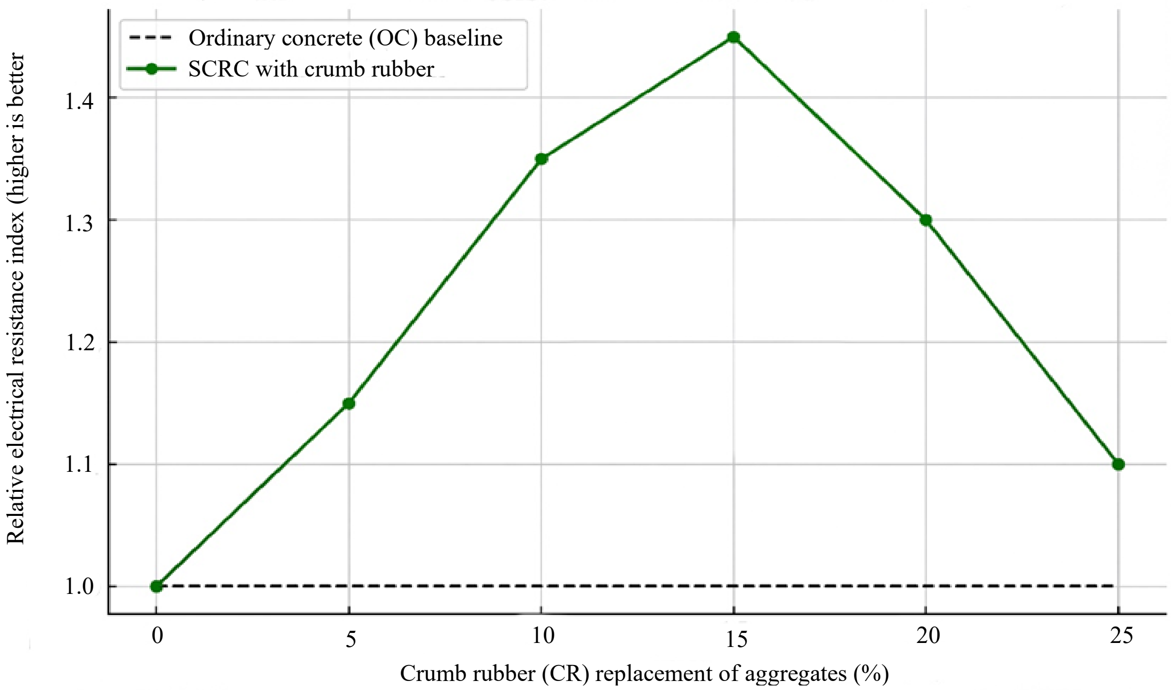

Figure 4. Effect of crumb rubber on relative electrical resistance.

Physical Treatment

Methods included surface grinding or plasma treatment (corona discharge) to modify the rubber surface energy by increasing surface roughness and polarity without the need for chemical immersion.

Encapsulation/Filler Methods

The use of supplementary cementitious materials (SCMs), such as fly ash, silica fume, or nano-silica, to coat or cover rubber particles can physically reinforce the ITZ and partially restore lost strength by acting as a strong filler around the rubber.

Durability and Resilience: The Key Advantages

The softness and flexibility of rubber aggregates offer benefits in situations where energy absorption and durability are important, highlighting the suitability of rubberized concrete for certain innovative uses (Figure 4).

Impact Resistance and Toughness

This is likely to be the most significant performance benefit. The elastic nature of the rubber particles allows concrete to absorb more impact energy by delaying and distributing crack formation under dynamic loading. This improved toughness makes rubberized concrete highly suitable for applications requiring resistance to blasts, abrasion, and repeated impacts.

Structural Behavior and Seismic Performance

Studies focusing on structural elements have shown that rubberized concrete components exhibit better energy dissipation under repeated loading (seismic events). Rubber acts as a shock absorber, thereby reducing the transfer of vibrational energy, which is an important performance indicator in earthquake-prone areas.

Water Permeability and Chloride Ion Penetration

Although adding more trapped air bubbles can increase the porosity of reinforced concrete, research on treated rubber and supplementary cementing materials has shown that they can resist chloride ion penetration as well as or slightly better than normal concrete. The ability of concrete to allow water to

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pass through depends largely on the quality of the interface between the cement paste and aggregates, as well as the overall mix design. This highlights the importance of using high-performance binding materials.

Freeze–Thaw Resistance

The elastic nature of rubber particles acts as internal spaces that help reduce the stress caused by water freezing and expanding inside the concrete. This often results in better or equal freeze–thaw performance compared to normal concrete, especially when the rubber content is low.

Fire Resistance and Spalling

Ordinary concrete can violently crack and spall when exposed to high heat because of the buildup of steam pressure. Rubberized concrete, however, performs better in fire conditions. The rubber particles begin to break down at approximately 200°C, forming small, connected paths (microchannels) that allow steam to escape, thereby lowering the risk of violent spalling and improving the strength of the remaining structure.

CONCLUSION

Rubberized concrete is a promising and sustainable alternative to conventional concrete. Although the inclusion of rubber particles can lead to a reduction in compressive strength, this can be mitigated through an optimized mix design and appropriate surface treatment of rubber aggregates. The resulting material exhibits superior flexibility, resilience, and energy absorption properties, making it particularly suitable for applications requiring enhanced durability and impact resistance. Furthermore, its environmental benefits, such as reducing waste from end-of-life tires and conserving natural aggregates, align with global sustainability goals. Consequently, rubberized concrete is a viable material for advancing eco-efficient and resilient urban infrastructure.

Future Scope

The future of research on rubberized concrete can be grouped into four main categories:

Improved Material Processing and Treatment

- *New surface treatments*: Although the use of sodium hydroxide is effective, future studies should focus on creating affordable, energy-saving, and eco-friendly methods to prepare the surface. Techniques, such as plasma treatment, ozonation, or natural treatments, can help improve the bond between rubber and cement without the use of strong chemicals.
- *Setting standard rubber sizes*: Currently, there is significant variation in performance depending on the type of rubber used (such as different tires) and how it is processed (such as room temperature grinding versus freezing). The next big step is to create clear guidelines for the best size, shape, and quality of rubber bits for different building uses.

Structural and Design Code Inclusion

- *Going beyond non-load-bearing uses:* Most current uses are for things that do not hold weight, such as noise walls. Future work needs large-scale testing and computer modeling to prove rubberized concrete can be used in important building parts, such as beams and columns. This is especially important in areas with lots of earthquakes, where rubberized concrete's ability to absorb energy is a big advantage.
- *Creating design codes*: The biggest problem stopping the industry from using rubberized concrete is the lack of official rules. Research needs to collect sufficient, reliable data to help regulatory groups establish specific standards that consider the behavior of rubberized concrete under stress and its effectiveness in reducing vibrations.

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