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A Study on the Mechanical Properties of Concrete using Crumb Rubber in Replacement of Fine Aggregate

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Abstract. One of the most popular building materials, concrete is always being researched to improve its mechanical qualities and sustainability. This study looks at whether it's possible to substitute some of the fine aggregate used in the manufacturing of concrete with crumb rubber, a recycled material made from used tyres. The objective is to evaluate how the addition of crumb rubber affects the mechanical characteristics of concrete, including its tensile, flexural, and compressive strengths. This research explores using crumb rubber from discarded tires as a sustainable alternative to fine aggregate in concrete production. The project systematically investigates various crumb rubber sizes and concentrations, comparing them with control mixtures. Testing includes material characterization, mechanical assessments, and durability evaluations under different conditions. The study aims to provide valuable insights into crumb rubber's potential to enhance concrete's mechanical properties while reducing environmental impact. The investigation's results provide significant insights into the field of sustainable building materials. While concurrently addressing the environmental issues related to the disposal of scrap tyres knowledge of crumb rubber's capacity to improve or modify the mechanical qualities of concrete might result in creative uses in the building industry. The findings are expected to benefit construction professionals, researchers, and policymakers seeking eco-friendly solutions in the construction industry, promoting a greener future for concrete production.

Keywords: Crumb Rubber, Concrete, Compressive Strength, Splitting Tensile Strength, Energy Absorption, and Environmental Benefits.

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1. Introduction

Extensive quantities of solid waste are produced globally as a consequence of widespread industrialization and technological advancements. Ineffective recycling of waste tires results in the disposal of approximately 1.5 billion tires annually, contributing to environmental pollution. Numerous research studies have explored the possibility of utilizing waste tire rubber as a partial substitute for aggregate in concrete. The inherent durability and elasticity of the rubber material have the potential to address the inherent limitations of concrete, particularly in terms of elasticity and energy absorption capacity (Wang et al., 2000). As per the recent study titled "Circulating Tires in the Economy" conducted by the NGO Chintan and reported in The Times of India, around 60% of end-of-life tires (ELTs) could potentially be disposed of in landfills or incinerated. In the fiscal year 2016-17, India manufactured 127.34 million tires, with 60% of the resulting scrap tires ending up in landfills or being burned. This improper disposal of waste tires poses health risks to the public and has adverse effects on the environment.

Several researchers have directed their attention toward utilizing waste tire rubber as a substitute for both fine and coarse aggregates in concrete blends. The incorporation of waste rubber in concrete not only contributes to sustainability but also improves various properties such as ductility, toughness behavior, thermal insulation, and impact resistance. However, there is a crucial requirement to bolster the strength of rubberized concrete. In recent times, the application of nanotechnology in the concrete industry has garnered significant interest due to the nanoparticle size, offering a means to augment the mechanical properties of concrete.

The objective of this study is to investigate how different concentrations of Nano-silica and elastomeric polymer impact the mechanical, thermal, and vibroacoustic properties of rubberized concrete. This research encompasses a comprehensive experimental program designed to advance our understanding of the behavior and characteristics of rubberized concrete incorporating Nano-sized particles. The scientific importance of this research lies in its contribution to expanding knowledge and comprehension of the properties of rubberized concrete with nanosilica.

The primary drawback associated with incorporating rubber into concrete is a significant decline in concrete strength, as reported in various studies (Bewick et al., 2010). Research indicates that a substantial amount of rubber can reduce the compressive strength of rubberized concrete by up to 90% compared to control samples without rubber (Youssf & Elgawady, 2012). Therefore, a thorough investigation into optimizing the crumb rubber content in the concrete mix becomes essential to attain a balance that enhances positive effects while minimizing the adverse impact of adding crumb rubber.

It can be stated that the incorporation of rubber has two major opposite effects regarding the mechanical characteristics of concrete. The negative impact is associated with the reduction of mechanical strengths. In contrast, the positive effect can be an increase in ductility and deformation capability. However, the extent of positive and negative effects are not similar for the different rubber contents (Kang & Jiang, 2008). According to the literature, the size of rubber particles significantly affects the properties of rubberized concrete (Sukontasukkul et al., 2012). Additionally, the systematic reduction in the ultimate strength of crumb rubber concrete (CRC) may constrain its application in concrete structures (Bravo & Brito, 2012). Consequently, these negative effects have prompted the exploration of various treatment methods to counteract the detrimental impact of rubber addition to concrete. Therefore, based on the mechanical properties of concrete, this study discusses techniques for rubber treatment and rubber content optimization.

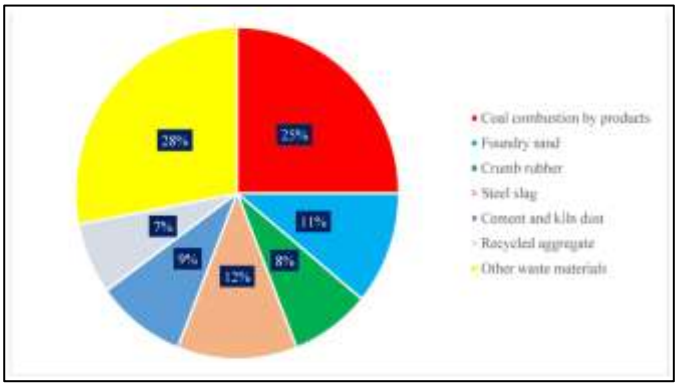

Figure 1. Overview of Concrete Performance

Concrete is a popular building material because it is strong and durable. However, it has low bending strength and splits easily under some conditions. One technique of enhancing its mechanical properties involves incorporation of crumb rubber in the mixture. Crumb rubber comes from recycled tires that have been shredded into small pieces. By doing this, concrete can become more ductile, fatigue-resistant, as well as impact-resilient. It can also decrease shrinkage and enhance flexural strength. Moreover, the addition of crumb rubber would improve thermal properties and sound insulation of concrete wall panels since rubber is a good insulator for both heat and sound (Sadek & El-Attar, 2015). Concrete with crumb rubber refers to a type of concrete that employs recycled rubber granules commonly in form of crumb rubber sourced from waste tires (Thomas et al., 2016). This innovation is one aspect of sustainable construction that aims at reducing environmental impacts through recycling waste materials (Mohammed et al., 2012; Yung et al., 2013). In short, disposing these used up tires poses grave environmental implications since most are made from rubber which does not decompose readily. Averagely about more than 303 million tires per year are disposed in the country leading to cumulative stockpile problem (Su et al., 2015).Using rubber particles can also provide an eco-friendly alternative to the disposal of worn-out tires in landfills (Pelisser et al., 2011). Several studies have investigated the effect of CR on the properties of concrete in small-scale testing (such as cylinders, prisms, and cubes). These studies indicate that the inclusion of CR particles appears to enhance the strain capacity, and damping ratio, and reduce the self-weight (Najim et al., 2012). The resistance of concrete to abrasion, freezing-thawing action, and acid attack was also found to increase with the inclusion of rubber (Gesoğlu et al., 2014). Reutilization of CR in concrete mixtures also plays an important role in enhancing the impact resistance of concrete. Gupta et al., (2015) investigated the replacement of fine aggregate with waste rubber up to 25% by volume in mixtures with different water-to-cement ratios. They found that the inclusion of rubber greatly improved the impact absorption energy of VRC by an average of three times compared to concrete without rubber. Taha et al., (2008) reported similar results in small prism VRC samples, in which the CR was used as a replacement for fine aggregate with percentages varied from 0% to 100% in increments of 25% (by volume). This investigation indicated that despite the reduction in the compressive strength, using a 50% CR replacement could achieve the maximum impact energy, while the beams with 75% CR exhibited impact energy mostly equal to the control mixture (CR = 0%). Furthermore, in large-scale testing, a limited number of studies have investigated the effect of CR on the structural performance of large-scale reinforced concrete elements. For example, Yousef et al., (2015) studied the effect of using 20% CR on the seismic performance of column-base connections. Their results indicated that using CR enhanced the hysteretic damping ratio and energy dissipation of column-base connections. A similar effect of CR was observed by Sadek and El-Attar (2015) in which the rubber-cement bricks showed high toughness and deformation capacity compared to their counterparts made with conventional concrete. Ismail and Hassan (2016) studied the flexural behavior of reinforced concrete beams incorporating CR up to a 50% replacement (by fine aggregate volume). They observed that adding up to 20% CR showed an improvement in the ductility and energy absorption capacity of tested beams, while further increasing the CR content led to a general decay in the behavior of tested beams. The use of rubber particles in concrete can also help to enhance the ductility and reduce the brittle failure. This can be attributed to the elastic nature of rubber particles that can present large elastic deformations before failure (Ganesan et al., 2013).

Here are some key points about concrete with crumb rubber: The rubber used in concrete is usually derived from recycled tires, which are processed into small, granular particles known as crumb rubber. Crumb rubber is added to the concrete mix, replacing a portion of the traditional aggregates. The inclusion of rubber particles imparts flexibility and resilience to the concrete, making it more resistant to cracking and impact. Concrete’s capacity to withstand heat and sound can be improved by using crumb rubber. Recycled rubber is used to reduce environmental concerns related to tyre disposal by diverting waste from landfills. For the construction of pavements, pavements and other outdoor surfaces, concrete containing crumb rubber is frequently utilized.

Several Sustainable Development Goals (SDGs) align with the use of crumb rubber in concrete as a replacement for fine aggregate. Below are some possible connections: SDG 9 – Industry, Innovation and Infrastructure: Crumb rubber in concrete is an innovative approach that helps to improve construction materials and practices. SDG 11 – Sustainable Cities and Communities: This can enhance sustainability of building within urban areas by recycling waste rubber through inclusion of crumb rubber into concrete thus relieving environmental stressors on cities. SDG 12 – Responsible Consumption and Production: Substituting traditional fine aggregate with crumb rubber is a sustainable practice which involves reuse of waste materials towards eco-friendly construction materials thereby reducing its impact on nature. . SDG 13 – Climate Action: The inclusion of crumb rubber in concrete could help to reduce the carbon footprint of construction materials. Moreover, if the tires were used as sources for the rubbers, it would be part of managing waste and addressing climate change

Water can seep through permeable concrete, causing leaks. This may result in water loss, lowering the tank's capacity and possibly causing nearby regions to become moist or flooded. (Dashtibadafridi et al., 2017) stated that concrete become weakened by water seepage. Since, water has the ability to dissolve minerals and release calcium hydroxide, which is essential to the strength of concrete, as it permeates. This may cause the tank's structural integrity to be compromised and result in cracking and flaking. Corrosion may result from water seeping through the concrete and reaching the steel reinforcement bars inside. This may lead to structural failure by weakening the reinforcement. There low permeability concrete should be preferred for water tanks. According to Dashtibadfarid et al., (2017) Low-Permeability Concrete reduces water seepage and guarantees the tank retains water efficiently. Where, the building water tanks that waterproof requires an in depth understanding of the concrete permeability.

Numerous studies in this field have shown that industrial wastes can function as efficient substitutes for conventional cementitious materials. The permeability and water absorption of the mortar are affected by the addition of industrial ashes. Since, these industrial by-products have pozzolanic qualities, therefore, they can improve the final cement paste's quality and enable to give fruitful results according to requirement, which can save money and energy. This study's primary goal is to investigate the impermeability of mortar cubes in water while taking various ash kinds into account.

1.1. Research Objectives

- To investigate the effect of adding crumb rubber to concrete on the compressive strength of the material.
- To determine the optimal percentage of crumb rubber to be added to concrete to achieve the desired mechanical properties.
- To evaluate the impact of crumb rubber on the tensile strength and flexural strength of concrete.

- To examine the durability of concrete with crumb rubber in terms of resistance to freeze-thaw cycles, abrasion, and corrosion.
- To study the role of crumb rubber addition of concrete in environmental sustainability.

2. Methodology

The third chapter is concerned with the methodology used for this study. The design of the experimental program can be broken down into two parts: The trial experimental phase and the main experimental phase. The purpose of the trial experimental phase was to determine the particles and optimum replacement content in the concrete mixtures. However, the main experimental phase was to study and further understand the effects on various characteristics such as mechanical, thermal, and acoustic properties of rubberized concrete mixtures. This chapter shows in detail the materials used and the testing procedure in this study.

2.1. Selection of Materials

The materials used in this study included ordinary Portland cement, water fine and coarse aggregate, and rubber particles.

2.2. Tests

2.2.1. Compressive Strength

For all concrete mixes, nine 100 mm cubes were prepared, water-cured at 20 ± 2°C, and tested at an age of 7, 28, and 90 days, and the average of three samples was taken as the final result of the compressive strength. A 3000-kN maximum loads capacity testing machine (see Figure 3-8), was used to test the samples ata loading rate of 0.2 MPa/s, and the test procedure was carried out following ASTM C39/C39M-17b.

Figure3.1compressive strength

2.2.2 Split Tensile Strength

The splitting tensile strength of 150 mm x 300 cylinders was determined following BS 1881-117 (Figure 3-9). Before conducting the splitting tensile test, all samples were moist-cured by immersion in a water tank until the day of testing, and the same machine that was used to test the compressive strength was used at a loading rate of 0.2 MPa/s Figure 3-9, the concrete cylinder specimen was placed horizontally in a frame and load applied. When the sample failed, the loading value was recorded and the average value was recorded. The splitting tensile strength (ft) was calculated using the following equation.

$$\boldsymbol{ft = 2P/\pi DL}$$

Where P is the maximum split load (N), L is the length of the specimen (300 mm), D is the cross-sectional diameter of the specimen (150 mm).

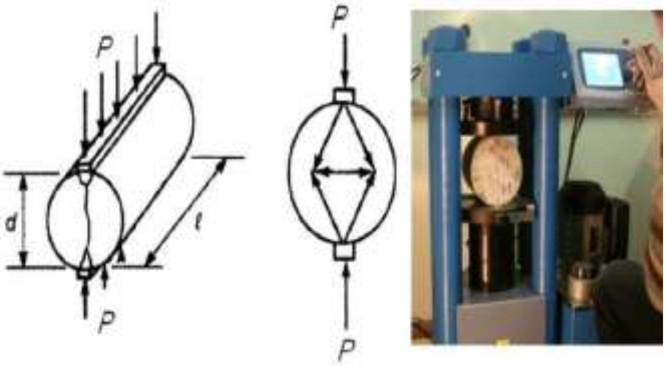

Figure3.2SystematicDiagramof splitting strength

2.3. Crumb Rubber Processing

2.3.1. Collection and Sorting

Used or discarded tires are gathered from various sources, such as automotive repair shops and waste management facilities.

Tires are separated based on criteria like size, type, and condition to facilitate efficient processing.

2.3.2. Shredding

Tires are mechanically shredded into smaller pieces, increasing the surface area for subsequent processing stages.

2.3.3. Steel Removal

Magnets and other techniques are employed to extract steel wires from the shredded rubber. This step is essential for producing clean and high-quality crumb rubber.

2.3.4. Granulation

The shredded and cleaned rubber is further processed through granulation, breaking it down into even smaller particles or granules. This enhances the versatility and applicability of the resulting crumb rubber.

2.3.5. Sieving and Classification

The granulated rubber is sieved and classified to separate particles of different sizes. This step helps in producing crumb rubber with specific size specifications suitable for various applications.

2.3.6. Washing and Drying

The sieved crumb rubber undergoes washing to remove any remaining impurities or residues. Subsequently, it is dried to eliminate moisture, ensuring the final product meets quality standards. These six stages collectively form the crumb rubber processing cycle, transforming used tires into valuable recycled material with diverse applications, including sports surfaces, construction materials, and more. Each stage plays a crucial role in producing high-quality crumb rubber while minimizing the environmental impact.

3. Results and Discussion

3.1 Mix Proportions

Volume of Cylinder= Pi*r*r*h
=0.0222 cubic meter
Wet Volume = 1.54* 0.0222
=0.03418 cubic meter
Mix Ratio = 1:2:4

3.2 Concrete Cylinder Casting

Casting of all the 72 cylinders to be tested has been completed in the first phase of the project.

Sr. No.	Description of Concrete Mix	Cement (cu.m)	F.A (cu.m)	C.A (cu.m)	Crumb Rubber (cu.m)	Water (L)
1	Without Crumb Rubber	0.00488	0.00976	0.019	-	0.00292
2	With 5% Crumb rubber	0.00488	0.00928	0.019	0.00048	0.00254
3	With 10% Crumb Rubber	0.00488	0.00879	0.019	0.00097	0.00254
4	With 15% Crumb Rubber	0.00488	0.0083	0.019	0.00146	0.00254

Temp. of Water

Concrete Temp.

Concrete Temp.

Slump Checking

Compressive Strength of Cylinders at 7 days of curing
(0% Crumb Rubber replacement)

Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
A-7	6/1/2023	4018	4059.6
A-7	6/1/2023	3989	
A-7	6/1/2023	4172	

Compressive Strength of Cylinders at 14 days of curing
(0% Crumb Rubber replacement)

Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
A-14	6/1/2023	4450	4531
A-14	6/1/2023	4545	
A-14	6/1/2023	4570	

Compressive Strength of Cylinders at 28 days of curing
(0% Crumb Rubber replacement)

Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
A-28	20/3/2023	4613	4630
A-28	20/3/2023	4763	
A-28	20/3/2023	4514	

Compressive Strength of Cylinders at 7 days of curing
(5% Crumb Rubber)

Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
B-7	6/1/2023	4128	4114
B-7	6/1/2023	4093	
B-7	6/1/2023	4121	

Compressive Strength of Cylinders at 14 days of curing (5% Crumb Rubber)			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
B-14	6/1/2023	4676	4667
B-14	6/1/2023	4624	
B-14	6/1/2023	4703	

Compressive Strength of Cylinders at 28 days of curing (5% Crumb Rubber)			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
B-28	29/3/2023	4890	4876
B-28	20/3/2023	4945	
B-28	20/3/2023	4793	

Compressive Strength of Cylinders at 7 days of curing (10% Crumb Rubber)			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
C-7	6/1/2023	4354	4369.33
C-7	6/1/2023	4333	
C-7	6/1/2023	4421	

Compressive Strength of Cylinders at 14 days of curing (10% Crumb Rubber)			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
C-14	6/1/2023	4894	4904.66
C-14	6/1/2023	4957	
C-14	6/1/2023	4863	

Compressive Strength of Cylinders at 28 days of curing (10% Crumb rubber replacement)			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
C-28	20/3/2023	5033	5067
C-28	20/3/2023	5145	
C-28	20/3/2023	5023	

Compressive Strength of Cylinders at 7 days of curing **15% (Crumb Rubber)**			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
D-7	6/1/2023	4567	4557.66
D-7	6/1/2023	4437	
D-7	6/1/2023	4669	

Compressive Strength of Cylinders at 28 days of curing **(10% Crumb rubber replacement)**			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
C-28	20/3/2023	5033	5067
C-28	20/3/2023	5145	
C-28	20/3/2023	5023	

Compressive Strength of Cylinders at 7 days of curing **15% (Crumb Rubber)**			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
D-7	6/1/2023	4567	4557.66
D-7	6/1/2023	4437	
D-7	6/1/2023	4669	

Compressive Strength of Cylinders at 14 days of curing **15% (Crumb Rubber replacement)**			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
D-14	6/1/2023	5088	5066
D-14	6/1/2023	5175	
D-14	6/1/2023	4985	

Compressive Strength of Cylinders at 28 days of curing **15% (Crumb Rubber replacement)**			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
D-28	20/3/2023	5344	5388
D-28	20/3/2023	5294	
D-28	20/3/2023	5376	

Tensile Strength of Cylinders at 7 days of curing (0% Crumb Rubber)			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
W-7	6/1/2023	403	412
W-7	6/1/2023	418	
W-7	6/1/2023	415	

Tensile Strength of Cylinders at 14 days of curing (0% Crumb Rubber replacement)			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
W-14	6/1/2023	445.7	450
W-14	6/1/2023	457	
W-14	6/1/2023	448	

Tensile Strength of Cylinders at 28 days of curing (0% Crumb Rubber replacement)			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
W-28	20/3/2023	463	453.3
W-28	20/3/2023	423	
W-28	20/3/2023	474	

Tensile Strength of Cylinders at 7 days of curing (5% Crumb Rubber)			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
X-7	6/1/2023	412	413
X-7	6/1/2023	407	
X-7	6/1/2023	421	

Tensile Strength of Cylinders at 14 days of curing (5% Crumb Rubber replacement)			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
B-14	6/1/2023	467	456.66
B-14	6/1/2023	458	
B-14	6/1/2023	445	

Compressive Strength of Cylinders at 28 days of curing **(5% Crumb Rubber replacement)**			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
B-28	29/3/2023	489	494
B-28	20/3/2023	494	
B-28	20/3/2023	499	

Tensile Strength of Cylinders at 7 days of curing **(10% Crumb Rubber)**			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
Y-7	6/1/2023	434	441
Y-7	6/1/2023	447	
Y-7	6/1/2023	442	

Tensile Strength of Cylinders at 14 days of curing **(10% Crumb Rubber replacement)**			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
Y-14	6/1/2023	489	496.33
Y-14	6/1/2023	507	
Y-14	6/1/2023	493	

Tensile Strength of Cylinders at 28 days of curing **(10% Crumb Rubber Reinforcement)**			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
Y-28	20/3/2023	537	545
Y-28	20/3/2023	545	
Y-28	20/3/2023	553	

Tensile Strength of Cylinders at 7 days of curing **(15% Crumb Rubber)**			
Sample Name	Testing Date	7 Days Strength (psi)	Average Strength (psi)
Z-7	6/1/2023	456	450.66
Z-7	6/1/2023	447	
Z-7	6/1/2023	449	

Tensile Strength of Cylinders at 14 days of curing (15% Crumb Rubber)			
Sample Name	Testing Date	14 Days Strength (psi)	Average Strength (psi)
Z-14	6/1/2023	508	515.33
Z-14	6/1/2023	513	
Z-14	6/1/2023	525	

Tensile Strength of Cylinders at 28 days of curing (15% Crumb Rubber)			
Sample Name	Testing Date	28 Days Strength (psi)	Average Strength (psi)
D-28	20/3/2023	537	540
D-28	20/3/2023	544	
D-28	20/3/2023	539	

4. Conclusion

Finally, the paper goes into the mechanical characteristics of concrete when fine aggregate is replaced using rubber crumb. Essentially, the experiment revealed useful information about how the composite material behave. Compressive strength also responded well to inclusion of crumb rubber and this can be applied in structures. Additionally, the authors considered how flexural modulus and tensile could affect resistance to bending and tension on the material respectively. Evaluation of durability as well as permeability research shows that there have been some changes in its ability to withstand weather elements and water penetration. Similarly, this research also studied elastic modulus together with deformation behavior which clarified how materials stiffness changes with loading process. Beyond a mechanistic approach, economic along with environmental aspects were also discussed hence enabling an assessment of practicability for such options. While these findings provide new direction regarding use of crumb rubber in cement, they will certainly influence sustainable construction practices moving forward. From other perspectives, this article offers recommendations on practical solutions considering possible advantages and disadvantages associated. This research will create a foundation for future research undertakings recommending that the exploration of this greener technique to enhance the mechanical properties of concrete should be continued; we therefore have several considerable results corresponding to the intricate engineering problems (CEPs) identified and accomplishing the SDGs.

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