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The Incorporation of Crumb Rubber in Construction Reinforcement: A Review

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Abstract: This study explores the use of rubber crumbs in construction materials, focusing on their impact on structural integrity, flexibility, crack resistance, and vibration dampening. The study highlights the environmental benefits of incorporating rubber crumbs into buildings, such as reducing waste tyre disposal. The study also examines the chemical composition, particle size, and physical properties of rubber crumbs, which significantly affect the mechanical, thermal, and elastic capabilities of various building materials. The study also investigates surface modifications made to rubber crumbs, examining their impact on performance, microstructure, and lifespan. The study also delves into the potential benefits of noise reduction, the development of ecologically sound concrete blocks, and the environmental sustainability and health issues associated with rubber crumbs. The study emphasizes the need to assess the entire lifespan and ecological effects of rubber crumbs treatments, emphasizing their positive effect on road clamping performance despite environmental limitations. Overall, the study highlights the importance of considering the entire lifespan and ecological effects of rubber crumbs in the construction industry.

Keywords: Banana fibre; treatment; filler; hybrid; applications.

1. Introduction

Rubber crumbs, derived from recycled tires, significantly enhance the quality and sustainability of construction materials. Their unique properties make them a valuable resource for addressing key challenges in the building sector, including climate change impacts. (Zhao et al., 2022). Rubber crumbs, produced by blending asphalt with limestone, basalt, and granite aggregate alloys, can enhance the longevity of building materials and enhance the strength of artillery (Mohamed et al., 2023). Na OH pre-treatment enhances crumb rubber adhesion to other substances, enhancing the performance of concrete geopolymer. (Pham et al., 2021). Rubber crumbs in structures reduce tire disposal waste, offer a sustainable, environmentally responsible alternative, and enhance cohesion strength, flow resistance, molar resistance, and colloid homogeneity when added to asphalt materials (Mohamed et al., 2022).

The literature on rubber crumbs in structural reinforcements is dynamic and evolving. Recent research highlights their multifunctionality and effectiveness in various construction applications. A study on concrete and asphalt showed that rubber crumbs improve structural strength and lifetime, highlighting their potential in various materials. Research has shown that waste reduction and sustainable building techniques can have significant environmental benefits. Key areas of focus include improving rubber crumb ratio in composite materials, investigating long-term structural efficacy, and understanding its environmental implications. These developments have significantly enhanced our understanding of how rubber crumbs can revolutionize traditional construction procedures (Aleem et al., 2022).

Rubber crumbs enhance construction material performance by reducing rigidity, increasing flexibility, and improving cracking and deformation resistance. They also increase durability against climate change, reducing the risk of breaking due to temperature changes or adverse conditions. The use of rubber crumbs in structures demonstrates a commitment to efficient and environmentally responsible resource use, aligning with sustainable development goals. Rubber crumb incorporation and active crumb rubber grafting enhance the elasticity and resistance to high-temperature deformation in asphalt terminal rubberized mix (Xie et al., 2023). Because it offers the construction industry both immediate and long-term considerable environmental benefits, it is imperative to recognize and investigate the possible application of rubber crumbs as a reinforcing material.

Numerous scholarly investigations have comprehensively assessed the influence of crumb rubber on the performance of building materials. However, there's still a lot to discover about the characteristics of rubber crumbs. The performance of crumb rubber in building materials, as well as its uses and drawbacks, are examined in this article.

2. Methodology

2.1 Material

Tire scraps are ground into tiny particles or rubber fragments of various sizes to create rubber crumb, which is frequently produced as bits or powders. In the building sector, this material is frequently utilized as a filler in a range of construction applications or as an addition in mixtures of materials like concrete and asphalt. By utilizing a number of material qualities, including flowability, resistance to segregation, density, water absorption, viscosity, elasticity, fracture resistance, and vibration dampening, crumb rubber is used in construction with the goal of enhancing performance. In addition, the addition of rubber crumbs to building materials not only facilitates the recycling of used tires but also lowers the amount of waste left outside (Zrar et al., 2023).

Rubber crumbs are made up of a number of different elements, as indicated in Table 1: carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulfur (S). Two different types of water can be used to alter the properties of crumb rubber: tap water (TW) and magnetized water (MW). Table 2 illustrates how the medium has an impact on the characteristics of crumb rubber (Youssf et al., 2023). The properties and functioning of rubber-based building materials are directly impacted by the makeup of rubber crumbs, so it is essential to comprehend this relationship. The final qualities of the construction material generated can be significantly influenced by the rubber component's chemical composition, size distribution, and other physical aspects. Comprehending the composition of rubber crumb is essential to comprehending the behavior of this material when mixed with other materials like asphalt or concrete. It also describes the impact on the mechanical, thermal, elasticity, and crack resistance characteristics of building materials made of rubber. A better knowledge of the amount of rubber crumb in the mixture makes it possible to create a blend that is more effective and optimal and that can be more specifically tailored for construction projects.

Table 1. Properties of crumb rubber (Wu et al., 2022)

Mesh	Color	Bulk density (g/cm^3)	Element content (%)				
			C	H	N	O	S
30	Black	1.6	80.3	7.3	0.6	2.6	2.1

Table 2. Characterizations of tap water and magnetized water (Youssf et al., 2023).

Properties	Tap water (TW)	Magnetised water (MW)
Density (g(/cm^3)	0.975	0.972
Temperature (°C)	25.5	26.3
Total dissolved salts (P.P.M)	200	234
Surface tension (Mn/M)	71.6	65.3
Ph	7.3	8.2

When making rubber concrete structures, it's important to take into account a number of variables, including the production process, mixing technique, additive ingredients, and rubber particle size. Many experimental aspects in the manufacturing of concrete have been studied in a number of experiments. For example, rubber crumbs have been substituted for fine aggregate at varying percentages (0%, 5%, 10%, 15%, and 20%) (Meyyappan et al., 2023), the pre-treatment of crumb rubber using a NaOH solution (Shafqat et al., 2023), the inclusion of steel fibre to mitigate tensile cracking (Amit & Bansal, 2022), and the investigation of ageing time variations (Wanasinghe et al., 2022).

2.2 Preparation, Manufacturing and Testing Method

Experiments were conducted by (Han et al., 2023) to assess the mechanical characteristics of rubber concrete fragments as temperature rose. Numerous elements are taken into consideration by the study's experimental parameters and procedures. The effective water-reducing agent polycarboxylic acid enhances the dispersion of airborne ashes. Sand that is present in the natural world makes up the fine aggregate. Because it fractures with particle sizes ranging from 5 to 20 mm and has a constant gradation, limestone is utilized for coarse aggregates. The rubber crumb is made up of black tyre rubber particles ranging in size from 0.6 mm to 1-3 mm and 3-5 mm. Because it has no bearing on the pressure and traction properties of natural sand concrete, the particle size of 3-5 mm was selected. The density of this rubber crumb is 1.080 g/cm3. Rubber is treated by submerging it in an alkaline solution containing 3% NaOH to eliminate acidic particles from the surface and enhance cement gel adherence. After 15 minutes of stirring and a slow addition of half of the NaOH solution, start the immersion process. For an additional fifteen minutes, stir in the leftover solution. The rubber is then completely cleaned with fresh water multiple times to get rid of any leftover grease before being dried flat for later usage. Three different temperatures 300°C, 500°C, and 700°C were applied to the concrete; the control group was kept at room temperature. The tests included evaluating the elastic modulus, assessing the voltage-tension ratio, and performing strong cube compression, strong lateral traction, and strong uniaxial compression on concrete crumb rubber exposed to high temperatures.

The results of the analysis of variance (ANOVA) show that the composition, treatment strategy, and amount of crumb rubber all significantly affect how well crumb-rubber concrete performs (Assaggaf et al., 2022). Rubber particles with a 30-mesh volume are used in place of sand to create crumb rubber concrete, which is then used to study the impact of the freezing cycle on fatigue stretching and fatigue life. After that, researchers conducted theoretical analysis and experimental experiments. The specimens underwent uniaxial compression and constantamplitude fatigue testing (Xue et al., 2023). When making asphalt rubber crumbs, it's crucial to take into account a number of significant elements to get the perfect mixture. These variables include the size and distribution of rubber particles, the amount of rubber content, the kind of asphalt and its surface temperature, the bonding substance, the mixing methods, and the uses. The researchers found that several types of aggregates, like dense graded and stone matrix asphalt, can be mixed with crumb rubber using varied ratios and weights of aggregate. (Rashed & Al-Hadidy, 2023; Yi et al., 2023)

3. Result and Discussion

Rubber crumbs have numerous physical and mechanical properties, making them a valuable addition to construction materials. Their high elasticity allows them to withstand deformation and cracks, enhancing the durability of concrete and asphalt. However, their high concentration in ballast mixtures can lead to material loss and shape changes due to impact load, affecting the material's integrity (Zhang et al., 2023).

Rubber crumbs' mechanical properties, particularly their traction strength and stiffness, are critical in improving the structural integrity of construction materials. Incorporating rubber crumbs into building materials such as concrete improves their traction strength and stiffness, increasing their resistance to strain. (Youssf et al., 2023) investigated the effect of high levels of heat-treated rubber and magnetised water on the efficacy of crumb rubber concrete when combined with Portland cement and sand. This study looked at the duration of rubber heating (1 hour, 2 hours, and 3 hours), the temperature at which the rubber is heated (100 and 200 °C), the water content of magnetised water (25%, 50%, and 100%), the duration of water magnetization (6 hours, 12 hours, 24 hours, and 48 hours), and the proportion of rubber content (40%, 60%, and 80% relative to the volume of sand). Rubber concrete crumbs, specifically those made of rubber that was heat treated at 200 °Celsius for 2 hours and treated with 100% magnetic water for 24 hours, show significant promise. Under these conditions, there is a significant and noticeable improvement in pressure recovery, amounting to 74%. Furthermore, there is a significant improvement in impact resistance, with a 2.2-fold increase at the initial stage of a crack and an exceptional 92% increase at the final stage of collapse, particularly when a 40% pressure force is applied. Rubber is present in the content. Microscopic examinations revealed that heating rubber during the initial treatment effectively incinerates unwanted chemicals within the rubber aggregate, resulting in the formation of a rigid outer layer on the rubber particles. This treatment also effectively reduces the zinc concentration in rubber from 8.32% to 1.89%. As shown in Figure 1, the combined modifications, such as adjusting heating duration and temperature, as well as the presence and duration of magnetised water, improve the pressure durability and impact resistance of rubber concrete fragments (Youssf et al., 2023).

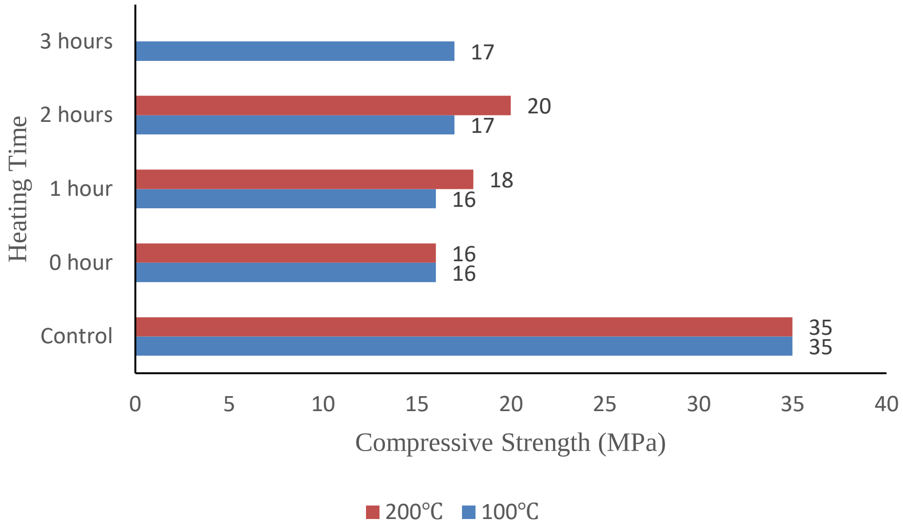

Figure 1. Effect of changing heating time and temperature on crumb rubber concrete compressive strength.

The addition of different compositions of microfillers, silica fume, and fly ash to crumb rubber concrete improves its density, compressive strength, young modulus, tensile strength, and flexural strength. The addition of rubber aggregates to concrete resulted in a significant reduction in the weight of each unit of the material. When compared to the control sample, the weight of concrete units infused with rubber decreased by approximately 17% to 20%. The use of rubber aggregates at 10% and 20% yielded unit weights of 1.70 g/cm3 and 2.00 g/cm3, respectively. Empirical evidence shows that the best material combination for achieving the best traction strength and flexibility strength in concrete formulations is 15% silica fume and 15% fly ash as cement replacements, with 10% rubber crumbs to replace fine particles. Furthermore, a higher concentration of rubber in concrete results in an increase in the amount of air contained within the mixture. Concrete's uniform air pockets act as a buffer for water expansion during the freezing and melting processes in rubber-containing concrete (Akbar et al., 2023). The surface response methodology (RSM) is a method for determining compressive strength. It estimates the ideal parameters using statistically processed data (Dahish, 2023).

Rubber crumb surface modification (CR), such as cement coating, is a beneficial method for improving the mechanical properties of recycled rubber particles in concrete. Despite extensive research on concrete cor, its application to 3D-printed cement material is still limited. (Liu et al., 2022) investigated the relationship between pressure strength and microstructural properties of 3D-printed rubber mortars in their study. The mortars were created by replacing 15% of the weight of river sand with cement-coated rubber crumbs. To achieve different levels of coating quality, different cement-to-rubber ratios (C/R) were used, such as 0.25 (CR-0.25), 0.4 (CR-0.4), and 0.55 (CR-0.55). SEM reveals a strong cement shell surrounding rubber particles, which strengthens the connection between the rubber surface and the cement matrix. Nonetheless, increasing the cement layer to rubber ratio does not uniformly improve the pressure strength of the printed specimens. Variations CR-0.4 and CR-0.55 in particular exhibit significant anisotropy in pressure force, with a Y-direction (printing) strength that is approximately 7% greater than the Z-direction (layer deposition) strength. The mechanical anisotropy in CR-0.4 and CR-0.55 is primarily caused by the poral morphology and its alignment with the external load direction, according to an X-ray study of micro-computed tomography (CT). In the pressure force for CR-0.25, the interface bond between the rubber and the matrix is more important. The pressure force exerted by printed specimens was greater than that of non-printed specimens due to the absence of larger porous fractions (with a diameter of 1 mm or greater) (Liu et al., 2022).

The reclamation of crumb rubber can also have a negative impact on the mechanical properties of cement-based composites. To improve the fresh and hardened properties of the crumb rubber mortar, (Zainal et al., 2023) incorporated synthetic fibres made of polypropylene-polyethylene, coir, and kenaf fibres. The materials were chemically mixed and then evaluated on days 3, 7, and 28. The mixing method adheres to the ASTM (American Society for Testing and Materials) C305 standard practice. This standard practice provides specific instructions for mechanically mixing plastic hydraulic cement pastes and mortars. The ASTM C1473 standard is used to determine the workability of hydraulic cement mortar. The flow of the mortar is tested using the ASTM C230 flow table standard specification. The ASTM C109 standard test method is used to determine the density and compressive strength of the cement. The ASTM C348 standard testing method is used to determine flexural strength. Finally, the tensile strength is determined. A precise composition results in improved performance of cement-based composite materials (Zainal et al., 2023).

Beyond its use as a concrete ingredient, crumb rubber performs a variety of functions in rubber asphalt modification mixtures. These functions include improving asphalt performance, reducing cracks and deformation, recycling scrap tyres, and absorbing noise. Bitumen as the asphalt binder, crumb rubber powder, and organic and chemical warm mix additives are all components of crumb rubber asphalt binders. In 2023, (Bilema et al., 2023)) conducted a study in 2023 in which they combined various components and investigated the impact of warm mix additives on the properties of crumb rubber asphalt binders. Penetration, softening point, viscosity, temperature susceptibility, storage stability, ductility, loss on heating, and modular stiffness were among the properties studied. The properties of crumb rubber asphalt are significantly affected by the additive and temperature used. Other researchers took advantage of the abundant language resources by incorporating nano-crumb rubber and engine oil into the Asphalt Rock Button. According to the research findings, the asphalt aggregate mixture maintained optimal functionality even under high ambient temperatures and wheel loads. The performance of the oil asphalt pen 60/70, in particular, was nearly optimal (Hadiwardoyo et al., 2023). Thermal stability can be improved by using the right combination of crumb rubber and bone glue (Xie et al., 2023).

Researchers discovered that early application of lightweight oils to crumb rubber (CR) reduces the thickness of modified asphalt, improving the compatibility and workability of the modified CR (CRMA) mixture. The study by Zhao et al. (2023) aimed to understand the impact of pre-inflammation CR on the rheological properties of CRMA and the mechanisms of viscosity reduction using aromatic oils and naftenates. The researchers used various tests, including frequency swivel, temperature swell, molar and double voltage recovery (MSCR), and storage stability, to analyze the properties of aromatic oils, naphthenate oils, and asphalt components in CRMA during the pre-inflammation stage. The results showed that aromatic oils and naftenates significantly reduced CRMA viscosity, improved its resistance to cracking at low temperatures, and maintained storage stability. However, their influence on high-temperature CRMA properties varied. The addition of aromatic oils and naftenates reduced the binding energy between asphalt molecules, primarily responsible for the CRMA's viscosity decrease. However, there were differences in the distribution of these oils within the asphalate binders. (Zhao et al., 2023).

(Wu et al., 2022) study compared the temperature susceptibility and rheological properties of microwave-activated crumb rubber modified asphalt (MCRA) and cra, highlighting the potential of microwave activation to improve thermal storage stability and asphalt pavement performance. The study used scanning electron microscopy (SEM) to analyze the microstructure of CR particles after microwave radiation, and rheological tests were used to evaluate the asphalt's properties. Results showed that microwave activation increased surface roughness and specific surface area of CR particles, improved the elasticity of base asphalt, strengthened the polymeric network of asphalt, and reduced thermal sensitivity. The optimal MCR content for balanced high temperature and fatigue properties was found to be 20%-25%.

4. Applications and Limitations

The use of sand, crumb rubber, and geofoam in train tracks and drill depths has been shown to reduce noise levels and improve filtration efficiency. Eco-friendly hollow concrete blocks made from high-density polyethylene, low-density polyethylene, and crumb tyre rubber have also been found to reduce oil consumption, energy usage, and CO2 emissions. However, waste disposal must adhere to sustainability standards to minimize environmental impact. (Los Santos-Ortega et al., 2023) investigated the environmental feasibility of using rubber crumb waste as a mortar component. The construction life cycle is divided into four phases, but the transportation of recycled material can be harmful. (Chen et al., 2023) studied the ageing stages and evolutionary properties of aged modified crumb rubber (CRMA) asphalt performance, finding that degradation progresses rapidly as individuals age. The Multiple Stress Creep Recovery (MSCR) test was found effective in detecting degradation and suggesting strategies for rejuvenating old CRMA. Research on the impact of crumb rubber chemicals on human health and the environment has led to policies being developed by countries like the European Union, UK, US, Canada, China, Qatar, and the United Nations Global Stockholm Convention (Zuccaro et al., 2022) .

Crumb rubber has limitations in mixed asphalt due to factors like vehicle load, extreme weather, temperature, and service life. However, it performs similarly to traditional SBS-modified bitumen asphalt (PMB 45/80-60), which is modified with SBS rubber (Sierra-Carrillo de Albornoz et al., 2022). Rubber crumbs, particularly asphalt-modified rubber crumbs, offer improved sustainability and a longer service life of 2 to 4 years per cycle compared to asphalt concrete. A lifecycle cost analysis is necessary to determine the overall cost of the product throughout its life cycle. This is particularly true when thin layers or stone-scented asphalt damar are used (Riekstins et al., 2022).

Research on the negative effects of rubber crumbs on human health and regulatory measures is limited. The exposure of freshwater and soil organisms to heavy metals and polycyclic aromatic hydrocarbons can be determined by analyzing their amounts. Results show significant freshwater pollution issues, particularly with elevated zinc levels and polycyclic aromatics, which inhibit the growth of sweetwater organisms Desmodesmus subspicatus and Lemna minor. Soil worm mortality is also a significant issue. This knowledge can be used to develop a systematic strategy for implementing the circular economy. (Fořt et al., 2022) .

5. Conclusions

Crumb rubber (CR) is a versatile material used in construction due to its increased elasticity, reduced crack occurrence, and greater resistance to material deformation. Its elastic properties enhance the durability of concrete and asphalt, while its crack resistance is enhanced. However, the use of CR in asphalt requires additional modifications to improve thermal stability and compatibility. CR also offers benefits like reduced noise levels on railway tracks, reduced oil usage and CO2 emissions in concrete, and improved asphalt performance. However, sustainability principles must be considered when managing discarded tires. Research shows that CR deteriorates over time, necessitating the need to extend its lifespan. Despite some application limitations, CR provides performance comparable to SBS-modified bituminous asphalt. The long-term use of CR requires a comprehensive assessment of its life cycle, environmental effects, and the health of water and soil organisms.

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