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Crumb rubber as a sustainable construction material

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Abstract

With growing concerns about sustainability and environmental conservation, there has been a significant interest in exploring alternative materials for civil engineering applications. Crumb rubber, derived from recycled tires, has emerged as a promising candidate due to its unique properties and potential to mitigate environmental challenges associated with tire disposal. This paper presents a comprehensive review of the utilization of crumb rubber in various civil engineering applications. In addition to asphalt and concrete, crumb rubber has found applications in various civil engineering products, including sound and vibration-dampening materials, rubberized flooring, green roof systems, and composite building products. These applications leverage the unique properties of crumb rubber, such as elasticity, durability, and thermal stability, to address specific engineering challenges while promoting environmental stewardship. Overall, this review underscores the significant potential of crumb rubber as a versatile and sustainable material for various civil engineering applications. Continued research and innovation in this field are essential to further harnessing the benefits of crumb rubber and advancing the development of environmentally conscious infrastructure solutions.

Keywords: Aggregate; construction; crumb rubber; sustainable materials.

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1. Introduction

Crumb rubber, derived from recycled tires, is increasingly being recognized as a sustainable and versatile construction material with a wide range of applications (Li, Zhuge, Gravina & Mills, 2018). This article delves into the various aspects of utilizing crumb rubber in construction projects, exploring its benefits, environmental impact, challenges, and prospects. With a growing emphasis on sustainability in the construction industry, the innovative use of crumb rubber presents a promising solution to reduce waste, enhance performance, and contribute to a greener built environment (Mohajerani et al., 2020). Crumb rubber construction material is a sustainable and versatile option for various building projects. Made from recycled rubber tires, this material offers numerous benefits such as durability, flexibility, and impact resistance (Pham et al., 2019). It can be used in a wide range of applications including playground surfaces, athletic fields, and road construction. Additionally, crumb rubber construction material helps reduce waste in landfills and promotes environmental conservation (Ahmad et al., 2022). Its unique properties make it an attractive choice for builders looking to incorporate eco-friendly materials into their projects.

The recent global concern revolves around waste management, which encompasses various environmental issues. Waste production exceeds 2.01 billion metric tons annually worldwide, and this figure is projected to increase to 3.40 billion metric tons by 2050. Despite the increasing volume of waste, effective waste management strategies have not been implemented, leading to a decrease in available space worldwide. Waste can be classified into degradable and non-degradable categories, with non-degradable waste posing a significant challenge due to its slow decomposition rate, taking anywhere from 10 to 100 years (Alaloul et al., 2020). Examples of non-degradable waste include plastic, metal, glass, and rubber.

In the modern era, rubber production, particularly for tires, plays a crucial role in various industries. However, the widespread use of tires results in a substantial increase in rubber waste. It is estimated that approximately 1.5 billion tires are generated worldwide, with this number expected to rise to 5 billion by 2030. Improper disposal methods, such as burning tires, contribute to air pollution and health hazards, including the breeding of disease-carrying mosquitoes and rodents.

Figure 1

Crumb rubber pollution

Figure 1 shows Crumb Rubber Pollution, and Figure 2 shows Waste tire rubber at the landfill area.

Figure 2

Waste tire rubber at the landfill area

To address the challenges posed by tire waste, some countries have implemented regulations prohibiting tire disposal in landfill areas and promoting the use of waste tire rubber in construction materials. In civil engineering, rubber is often used as a partial replacement for natural resources in concrete and pavement. Rubberized concrete offers benefits such as reduced use of natural resources, improved performance, and enhanced shock and sound absorption (Adeboje et al., 2020; Chai et al., 2023). By incorporating waste tire rubber into construction materials, environmental advantages can be realized by reducing the depletion of natural resources (Puram et al., 2024). Concrete, being a widely used building material due to its affordability and global availability, heavily relies on natural resources for its production. The excessive use of mineral aggregates in concrete has led to a decline in their availability, with global demand surpassing 4.5 billion tons. To mitigate resource constraints, researchers are exploring alternative ingredients and recycling methods. Recycling non-degradable waste materials not only reduces waste bulk but also creates opportunities for innovative material production.

1.1. Purpose of study

This review paper focuses on the utilization of waste tire rubber in concrete as a partial substitute, highlighting various studies that have investigated rubberized concrete over the past decade. It discusses the size, percentage, and mixing procedures of rubber recommended by these studies. By showcasing recent research, the paper aims to demonstrate the feasibility and advantages of incorporating waste rubber into concrete while emphasizing the importance of cautious implementation. Overall, waste rubber utilization in concrete presents promising solutions to waste management and environmental sustainability challenges. The objectives are as follows:

i. To provide a sustainable solution for managing waste tires by incorporating crumb rubber into construction materials.
ii. To enhance the performance and longevity of construction materials, particularly in applications such as asphalt pavements.
iii. Rubberized construction products tend to have lower energy consumption during production and lower emissions compared to conventional materials.
iv. To encompass environmental sustainability, improved performance, reduced maintenance, and enhanced urban livability.

2. Methods and materials

The utilization of crumb rubber as a sustainable material involves several key methodologies aimed at maximizing its environmental benefits. Initially, it entails the recycling of discarded tires through processes such as shredding and grinding, transforming them into small granules or "crumbs." These crumbs are then incorporated into various applications, including road construction, sports surfaces, and landscaping, effectively extending the lifecycle of the rubber and diverting it from landfills.

2.1. Partial aggregate replacement

Concrete, a fundamental construction material, typically consists of a mixture of cement, aggregates (including coarse aggregates), water, and often admixtures. Coarse aggregates, which usually comprise gravel or crushed stone, play a critical role in providing strength and stability to concrete structures. However, their extraction through quarrying poses various environmental challenges, including habitat destruction, landscape alteration, and depletion of natural resources. waste rubber, derived from sources like discarded tires, offers a compelling alternative. Incorporating rubber as a coarse aggregate replacement material achieves environmental protection which utilizing waste rubber in concrete reduces the amount of rubber ending up in landfills or being incinerated, thereby curbing associated environmental pollution and health risks (Meyyappan et al., 2023).

The study evaluated various replacement levels of crumb rubber in the concrete mixtures. Specifically, the replacement percentages varied from 5% to 20% by volume for the fine aggregate component and from 1% to 10% for the overall concrete mixture. This range of replacement levels allowed the researchers to assess the impact of different concentrations of crumb rubber on the properties and performance of the concrete. A compressive strength test was conducted on specimens that had been cured for 28 days, a common duration for assessing concrete strength development. The testing apparatus used for this mechanical test was a compression testing machine with a capacity of 200 tonnes. This machine applies a controlled compressive force to the concrete specimens until failure occurs, allowing for the determination of their respective strengths.

The strength of concrete can be calculated through the following formula –

$$C_s = F/A$$

where, C_s = Strength of concrete(N/mm²)
F = maximum load at which concrete specimen
breaks (in N)
A = Area of concrete cube (in mm²)

2.2. Ethical consideration

Study design and implementation were conducted in accordance with ethical considerations, with particular attention being paid to minimizing adverse effects on the environment.

3. Results

Table 1

Compressive strength of different grades of concrete at 07 and 28 days

Grade of Concrete	Minimum compressive strength N/mm^2 at 7 days	Specified characteristic compressive strength (N/mm^2) at 28 days
M15	10	15
M20	13.5	20
M25	17	25
M30	20	30
M35	23.5	35
M40	27	40
M45	30	45

Table 1 shows the compressive strength of different grades of concrete at 07 and 28 days.

3.1. High-quality mortar

The application of recycled waste tire rubber in construction materials is gaining traction due to its economic, environmental, and technical advantages. This study focuses on investigating the potential utilization of waste tire rubber alkali-activated mortar for effectively repairing damaged reinforced concrete (RC) beams. This mortar offers a minimal embodied carbon footprint compared to conventional repair mortars. To evaluate the efficacy of the proposed mortar for repair purposes, a comprehensive series of small-scale mortar samples with various compositions are formulated, fabricated, and subjected to testing for properties such as compressive strength, flexural strength, bonding strength, and water absorption capacity. Following the identification of an optimal mortar mix that generally yields enhanced performance, large-scale RC beams are designed, constructed, intentionally damaged, repaired using the proposed mortar, and subsequently tested under flexural loading conditions.

The results reveal that the proposed mortar exhibits outstanding performance and holds promise as a repair material. Importantly, it boasts a significantly lower embodied carbon footprint (35.3 kg/m^3) compared to conventional mortar (530.8 kg/m^3). Additionally, the RC beam repaired with the proposed mortar demonstrates superior overall performance, encompassing strength capacity, ductility index, and bonding characteristics, surpassing those of existing mortars. Particularly noteworthy are the experimental findings indicating a notable 20% increase in cracking load and a 30% increase in maximum displacement compared to the undamaged beam, underscoring the efficacy of the proposed mortar in enhancing structural resilience and performance.

3.2. Utilization in road pavement

The increasing consumption of waste tires has generated many problems such as increasing landfill space, environmental pollution, and causing health hazards. Parallel to this is the increase in road construction as a result of heavy traffic on roads.

Crumb Rubber Modified Bitumen (CRMB) is a specialized form of bitumen used in road construction, where crumb rubber derived from recycled tires is incorporated into bitumen to enhance its properties. This modified bitumen plays a crucial role in flexible road pavement, offering improved resistance to temperature variations, water ingress, and overall durability compared to conventional bitumen. Preparing CRMB involves blending crumb rubber with hot bitumen, typically at temperatures ranging from 150 to 160 degrees Celsius. The bitumen is heated to a specific temperature of 160 °C, optimizing its viscosity for the incorporation of crumb rubber. Once the desired temperature is reached, crumb rubber is meticulously added to the bitumen.

Variations in the proportion of crumb rubber are systematically explored, with samples containing 0%, 8%, 10%, 12%, and 14% of crumb rubber by weight. During the blending process, manual mixing is employed for approximately 3 to 4 minutes to ensure thorough integration of the crumb rubber with the bitumen. Subsequently, the mixture undergoes further heating to maintain a consistent temperature of 160 °C. This phase is critical in facilitating chemical bonding between the bitumen and crumb rubber components. The studies show the penetration value test indicates a noteworthy trend: as the quantity of rubber waste added increases, the penetration value decreases. This decrease signifies that the asphalt becomes harder, thereby enhancing the road's durability and reducing susceptibility to water damage. A lower penetration value implies a stiffer grade of asphalt, which contributes to the road's structural integrity.

Similarly, the softening point test reveals that as the amount of rubber waste in the asphalt mix rises, the softening point also increases. This suggests that the bitumen becomes less prone to softening or deformation under high temperatures. Consequently, the asphalt gains resilience against hot weather conditions, thereby prolonging its service life and minimizing maintenance needs (Han et al., 2023). The ductility test results further support the beneficial effects of incorporating rubber waste into bitumen. The tests demonstrate that the addition of rubber waste causes the bitumen to become more viscous and harden.

This characteristic is advantageous in obtaining a stiffer asphalt mix, which can enhance the road's load-bearing capacity and resistance to deformation over time. One of the most significant advantages of utilizing rubberized bitumen is its ability to extend the lifespan of roads compared to conventional bitumen. Despite the potential increase in construction costs associated with incorporating rubber waste, the long-term benefits in terms of reduced maintenance and enhanced road durability outweigh the initial investment. Rubberized bitumen offers improved adhesion between aggregates and binders, resulting in superior strength, stability, and longevity of the pavement structure (Li et al., 2023).

4. Discussion

Rubberized asphalt mixtures are a specialized type of asphalt paving material that incorporates rubber granules from recycled tires into the mix. This innovative approach offers numerous benefits over traditional asphalt mixtures. Typically, rubberized asphalt mixtures comprise asphalt, aggregates, and Tire rubber granules. These rubber aggregates serve dual purposes: they can function as modifiers for the bitumen binder or act as substitutes for natural aggregates within the mixture. There are two primary methods for producing rubberized asphalt mixtures: the "wet process" and the "dry process."

In the wet process, rubber particles are blended with bitumen at elevated temperatures before being mixed with the hot aggregates. Conversely, in the dry process, rubber particles replace a portion of the mineral aggregate in the asphalt mix before the addition of bitumen. Numerous studies have been conducted to investigate the performance of asphalt mixtures produced using both the wet and dry processes. These studies have consistently demonstrated the advantages of rubberized asphalt over conventional mixtures.

Rubberized asphalt exhibits enhanced skid resistance, reduced fatigue cracking, improved resistance to rutting, increased tensile strength and toughness, prolonged pavement life, and decreased maintenance costs compared to conventional mixtures. One of the key advantages of rubberized asphalt mixtures is their superior performance across a range of temperatures and climate conditions. They remain more flexible at low and sub-zero temperatures, which reduces the risk of cracking and damage during freeze-thaw cycles.

Additionally, rubberized asphalt allows for the reduction of asphalt layer thickness without sacrificing performance, potentially leading to cost savings and more sustainable pavement designs. Overall, rubberized asphalt mixtures represent a promising solution for enhancing the durability, safety, and sustainability of road infrastructure. With their proven benefits and versatility, they offer an effective way to address various challenges associated with conventional asphalt pavements while also contributing to the circular economy by repurposing recycled materials.

5. Conclusion

By repurposing waste tires into construction materials, crumb rubber contributes to the circular economy, diverting significant quantities of waste from landfills and reducing environmental pollution. This sustainable approach aligns with global efforts to minimize resource depletion and mitigate the impacts of climate change. The incorporation of crumb rubber into construction products enhances their properties, leading to longer-lasting infrastructure with reduced maintenance requirements.

Whether used in asphalt pavements, concrete, or other building materials, crumb rubber improves resilience to wear and tear enhances thermal properties, and contributes to safer, more sustainable urban environments. The environmental benefits of crumb rubber extend beyond waste management, with reduced energy consumption and emissions during production compared to conventional materials. Furthermore, its application can help mitigate urban heat island effects, improving the quality of life in cities and reducing the demand for energy-intensive cooling systems.

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