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A Review on Optimizing the Proportion of Nano-Silica and Rubber Tyre Chips in Concrete

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ABSTRACT

The rapid increase in waste rubber tyre generation poses significant environmental and disposal challenges, necessitating sustainable strategies for their utilization in construction materials. One promising approach is the incorporation of rubber tyre chips as partial replacement for conventional aggregates in concrete, which can enhance ductility, impact resistance, and energy absorption capacity. However, the inclusion of rubber generally results in a reduction of compressive and tensile strengths due to weak interfacial bonding and the hydrophobic nature of rubber particles. To counterbalance these drawbacks, nano-silica has emerged as an effective supplementary cementations material owing to its ultrafine particle size, high pozzolanic activity, and ability to refine the microstructure of concrete. Nano-silica improves the packing density, reduces porosity, enhances the interfacial transition zone, and accelerates the hydration process, thereby mitigating the strength loss caused by rubber addition. This review synthesizes available research on optimizing the proportion of nano-silica and rubber tyre chips in concrete to achieve an optimal balance between mechanical performance, durability, and sustainability. Findings from the literature indicate that rubber content in the range of 5–15% replacement of coarse or fine aggregates, combined with nano-silica dosages of approximately 2–3% by weight of cement, offers the most promising results in terms of compressive strength, flexural performance, impact resistance, and long-term durability. Furthermore, the combined use of these materials contributes to reduced environmental burden, conservation of natural aggregates, and advancement of sustainable construction practices. This paper highlights the synergistic effects of nano-silica and rubber tyre chips in concrete, identifies the critical influencing parameters, and outlines the gaps in current research to guide future studies aimed at developing eco-efficient and high-performance rubberized concrete composites.

Keywords: - rubber tyre, rubber tyre, high pozzolanic activity, nano-silica, natural aggregates, high-performance

Introduction

The growing demand for sustainable and durable construction materials has driven researchers to explore innovative alternatives to conventional concrete, particularly through the incorporation of supplementary materials and industrial waste products. Among these, nano-silica and waste rubber tyre chips have gained significant attention due to their complementary benefits in enhancing concrete properties while addressing environmental challenges. Nano-silica, owing to its ultrafine particle size and high pozzolanic reactivity, improves the microstructure of concrete by refining the pore system, accelerating the hydration process, and increasing the strength and durability of the matrix. On the other hand, rubber tyre chips, derived from discarded automobile tyres, provide a sustainable solution to the disposal of non-biodegradable waste while imparting improved ductility, toughness, and energy absorption capacity to concrete, although their inclusion generally leads to a reduction in compressive strength. Optimizing the proportion of these two materials is therefore crucial, as nano-silica can counterbalance the strength loss caused by rubber aggregates, leading to a more balanced mix with enhanced mechanical and durability characteristics. A systematic review of past studies on this optimization reveals that the right combination not only enhances structural performance but also promotes environmental sustainability by reducing landfill waste and lowering the carbon footprint of construction. Optimizing the proportions of nano-silica and rubber tire chips in concrete is a delicate process aimed at maximizing strength, durability, and sustainability while minimizing the adverse effects of rubber incorporation. Rubber tire chips, when used as a partial replacement for fine aggregates, significantly improve toughness, ductility, impact resistance, and energy absorption capacity of concrete, but they generally lead to a reduction in compressive strength due to their low stiffness, weak bonding with cement paste, and hydrophobic nature. To counter this drawback, nano-silica is introduced as a supplementary cementations material because of its ultrafine particle size, high pozzolanic activity, and ability to density the microstructure by filling voids and reacting with calcium hydroxide to form additional calcium silicate hydrate (C-S-H). This enhances the interfacial transition zone (ITZ), thereby improving the bond between rubber particles and the cementations matrix. Research findings indicate that nano-silica in the range of 2–3% by weight of cement provides the best balance between workability, strength, and durability improvements, while higher dosages may cause agglomeration and reduced workability. Meanwhile, incorporating rubber tire chips within 2–15% as a fine aggregate replacement achieves a balance between sustainability and performance, where lower percentages (2–6%) minimize strength loss and higher percentages (10–15%) enhance ductility and shock resistance for non-structural or impact-absorbing applications. Thus, the combined use of nano-silica and rubber chips in optimized proportions provides an innovative pathway to produce eco-friendly, durable, and high-performance concrete suitable for a wide range of applications.

Ashok Kumar Suluguru et al (2025) rubber tire waste is generated in massive quantities worldwide every year, and because of its non-biodegradable nature, managing and recycling it poses a major environmental challenge. When burned, tires emit highly toxic and hazardous smoke, while disposing of them in landfills consumes vast areas of land and further leads to soil and groundwater contamination, along with pollution of nearby water bodies. Statistics indicate that over 500 million tires are discarded into landfills annually, and this figure is projected to rise drastically to about 5000 million tires by 2030, making the problem even more critical. To address this issue, researchers have explored the incorporation of waste rubber from old tires into concrete as a partial replacement for natural aggregates. While studies have shown that such rubberized concrete generally experiences reductions in compressive and flexural tensile strengths compared to conventional concrete, it also provides notable benefits, such as enhanced toughness, improved impact resistance, better thermal insulation, and superior acoustic properties, making it a potential sustainable alternative material that reduces the environmental burden of waste tires while offering specialized performance advantages in construction applications.

Raed K. Mohammed Jawad et al (2023) lightweight concrete has emerged as a key focus in sustainable construction because it offers reduced self-weight, cost efficiency, durability, and environmental benefits; it is typically produced by either replacing conventional aggregates with lightweight aggregates or by incorporating foaming agents into the mix, both of which lower its density but often compromise mechanical properties such as compressive strength. To address this drawback, extensive experimental research has been carried out on incorporating various additives—such as steel fibers, industrial and agricultural waste by-products, and nanomaterial's—into lightweight concrete mixes. These additives influence the microstructure and overall performance of the concrete in different ways: steel fibers enhance tensile strength, ductility, and crack resistance; industrial by-products like fly ash, silica fume, or recycled materials can refine pore structure, improve strength, and promote sustainability; and nanomaterial's such as Nano-silica and Nano-clay increase particle packing density, reduce porosity, and enhance interfacial bonding between cement paste and aggregates. However, the effect of these additions is not universally positive, as inappropriate types, excessive dosages, or incompatible mix designs may reduce workability, increase brittleness, or negatively impact compressive strength. Therefore, the performance of lightweight concrete depends on the careful selection of additive type, dosage, manufacturing method, and overall mix composition to achieve the desired balance between low density and adequate mechanical strength.

Minu Antony et al (2023) lightweight concrete (LWC) is commonly used in partition and panel walls of framed structures as it effectively reduces the dead load on the structure, improving overall efficiency and cost-effectiveness. Rubberized lightweight aggregate concrete (RLWC), produced by partially replacing coarse aggregate with waste rubber tyre chips, has been developed to improve ductility, toughness, and impact resistance, though its use generally leads to a reduction in compressive strength, bond strength, and durability due to the weak interfacial transition zone (ITZ) created by rubber particles. To overcome these drawbacks, nanomaterial's have emerged as promising additives, with nano-silica being particularly significant because of its superior pozzolanic reactivity and nano-filler effect compared to traditional mineral admixtures. The incorporation of nano-silica refines the microstructure of concrete, making it more homogeneous and less porous, especially at the ITZ, thereby reducing permeability and enhancing strength and durability. In this study, the focus is on improving the durability properties of rubberized LWC by partially replacing cement with nano-silica at dosages of 1%, 3%, and 5%. The performance is evaluated under simulated marine environmental conditions by analyzing compressive strength, bond strength, and chloride ion penetration resistance at curing ages of 28 and 56 days, with the expectation that nano-silica addition will mitigate the adverse effects of rubber incorporation, resulting in a more durable and sustainable concrete composite.

Ms. Saitejasvi Satyajit Deshmukh et al (2022) in today's construction industry, the importance of developing infrastructure through environmentally responsible and sustainable processes is paramount, as it ensures optimal utilization of resources across a project's entire life-cycle while minimizing environmental harm. One of the major environmental challenges is the disposal of millions of discarded rubber tyres, which often end up in landfills, occupying vast areas of valuable land and creating long-term waste management issues. To address this problem, an innovative approach involves incorporating shredded rubber tyres as a partial replacement for traditional aggregates in concrete. This method not only provides an eco-friendly alternative to waste disposal but also contributes to sustainable construction practices by reducing reliance on natural resources. Furthermore, the addition of a small percentage (0.5–1%) of nano-silica to the concrete mix significantly enhances its mechanical properties, compensating for any reduction in strength caused by the rubber replacement. The inclusion of nano-silica improves the bond between cement paste and rubber particles, refines the pore structure, and increases durability, ultimately resulting in a cost-effective, sustainable, and high-performance construction material suitable for a wide range of applications.

Stephen O.Amiandamhen et al (2021) this study examined the properties and sustainability of cement-bonded composites incorporating industrial residues such as wood chips, tire fibers, and biomass combustion residues like bottom ash (BA) and fly ash (FA). The effects of the cement-to-raw material ratio (C/RM) and aggregate content on thermal and mechanical properties were assessed, along with scanning electron microscopy (SEM) and life cycle analysis (LCA). Results showed that increasing aggregate content enhanced the mechanical strength of wood composites, while tyre fiber composites demonstrated higher thermal conductivity (0.37 W/mK) and volumetric heat capacity (1.2 MJ/m³K) compared to wood composites (0.29 W/mK and 0.81 MJ/m³K, respectively). SEM confirmed good bonding between fibers and the cement matrix, and LCA indicated that raw materials accounted for about 60% of the total primary energy consumption in all composites analyzed.

Haral Shivaji et al (2020) concrete is one of the most widely used construction materials across the world, but the search for alternative, eco-friendly materials that support sustainable development is a major focus of current research. With the increasing generation of waste rubber tires, which are difficult to dispose of due to their slow decomposition and associated environmental hazards, reusing this waste in construction offers a promising solution. Since rubber is an elastic, lightweight, and energy-absorbing material with low specific gravity, it can be used as a partial replacement for coarse aggregates in concrete to produce lightweight concrete. Incorporating rubber waste not only provides a method of recycling but also improves certain properties of concrete, such as reducing cracks, enhancing durability, and improving ductility; however, the compressive strength of concrete generally decreases with rubber inclusion. To overcome this drawback, glass fibers are added at varying proportions (0.5%, 1%, and 1.5% of the weight of cement), as these fibers possess high tensile strength, excellent thermal conductivity, and strong chemical resistance, which help enhance the overall strength and performance of the composite. In this study, rubber chips are used to replace coarse aggregate by 10%, 20%, and 30% (by volume), and glass fibers are introduced to counterbalance the reduction in strength, with the combined approach aiming to produce an innovative, sustainable, and durable concrete mix with improved mechanical and durability properties.

Abhishek Rana et al (2020) the use of scrap tyre rubber in concrete offers a sustainable solution for waste management while contributing to eco-friendly construction practices. In this study, an experimental investigation was carried out to evaluate the feasibility of partially replacing conventional coarse aggregates with scrap tyre rubber chips in M25 grade concrete. Rubber waste, which is non-biodegradable and difficult to dispose of, poses significant environmental challenges, similar to other plastic wastes like water bottles, soft drink bottles, and disposable cups; thus, its incorporation into concrete provides an effective recycling pathway. The research involved preparing concrete specimens by replacing coarse aggregates with tyre rubber chips in varying proportions from 0% to 15% and analyzing their performance. The primary focus was on examining the compressive strength of rubberized concrete compared to normal concrete, thereby assessing its structural viability. The findings aimed to systematically identify the changes in mechanical properties caused by rubber addition, providing insights into cost reduction, sustainable material utilization, and potential applications of rubberized concrete in the construction industry.

Bashar S. Mohammed et al (2018) roller Compacted Concrete (RCC) pavement faces challenges such as high rigidity, low tensile strength, and susceptibility to cracking from shrinkage, flexural, and fatigue loads, made worse by the inability to use dowel bars or reinforcement, leading to higher maintenance costs. To overcome these limitations, High Volume Fly Ash (HVFA) RCC pavement was developed by replacing 50% of cement with fly ash, while crumb rubber was introduced as a partial replacement for fine aggregates (0–30% by volume) to improve flexibility, and nano-silica (0–3% by weight of cementations materials) was added to enhance early strength and offset the strength loss caused by crumb rubber. Performance evaluation through nondestructive tests like rebound hammer test (RHT) and ultrasonic pulse velocity (UPV) revealed that HVFA reduced unit weight, compressive strength, and rebound number, while higher crumb rubber content further decreased strength, density, RN, UPV, and dynamic modulus of elasticity; however, the inclusion of nano-silica countered these reductions by improving strength and durability. To predict compressive strength, combined UPV-RN (Son Reb) models were developed using regression approaches (double power, bilinear, and double exponential), where the exponential combined Son Reb model proved most accurate, showing stronger correlations and predictive ability than single-variable models, thus providing a reliable tool for assessing the strength of HVFA RCC pavements.

Asheeka A et al (2018) the rapid increase in polymeric tyre rubber waste has become a significant global environmental concern, with nearly 1000 million tyres reaching the end of their service life annually and projections indicating that about 5000 million more will be discarded regularly by 2030. Currently, only a small fraction of this massive waste is recycled, while the majority is either stockpiled, landfilled, or buried, leading to serious ecological or land-use issues. In response to this challenge, researchers have been investigating sustainable alternatives, one of which is the incorporation of tyre rubber waste into concrete. Studies show that shredded or chipped tyre rubber can partially replace natural aggregates in concrete, offering potential benefits such as improved impact resistance, ductility, noise reduction, and sustainability, although challenges like reduced compressive strength need to be addressed through proper mix design and additives. This review paper not only examines existing research on the performance of tyre-rubber concrete but also emphasizes its potential application in rigid pavement construction, where its elastic and energy-absorbing properties can enhance pavement durability while simultaneously providing an eco-friendly and cost-effective solution for managing tyre waste.

T. Senthil Vadivel and R. Thenmozhi (2012) conducted an experimental study to identify the most effective way of utilizing scrap rubber from waste tires as a partial replacement for fine aggregate in concrete composites. In their work, 90 specimens, including cubes, cylinders, and beams, were tested and compared against 18 standard concrete samples, with fine aggregate being replaced by rubber chips at varying proportions of 2%, 4%, 6%, 8%, and 10% by weight. The researchers evaluated the workability, compressive strength, tensile strength, and flexural strength of both fresh and hardened concrete. Their results indicated that incorporating rubber chips influences the mechanical performance of concrete, where compressive strength tends to decrease as the replacement level of finely ground rubber increases, and at 10% replacement, tensile strength was reduced by nearly 25%. However, the study also revealed that at an optimum replacement of 6%, rubberized concrete maintained safe strength levels while improving flexural strength by up to 6%, making it the most suitable and balanced proportion for achieving both safety and performance benefits in rubberized composite concrete.

Methodology

The methodology for reviewing and optimizing the proportion of nano-silica and rubber tyre chips in concrete involves a systematic process that begins with an extensive literature survey of previous experimental and analytical studies to identify the effects of these materials on the fresh, mechanical, and durability properties of concrete. Relevant research papers, standards, and case studies are collected and critically analyzed to determine optimum ranges of nano-silica, typically used as a partial replacement of cement, and rubber tyre chips, used as partial replacement of fine or coarse aggregates. The data from selected studies are compared in terms of mix design, replacement levels, water-cement ratio, curing conditions, and testing methods such as compressive strength, flexural strength, split tensile strength, workability, durability indices, and microstructural analysis. Trends are then synthesized to evaluate how nano-silica compensates for the strength reduction caused by rubber while improving the interfacial transition zone and durability. Finally, statistical comparisons and optimization techniques, such as response surface methodology or regression analysis where applicable, are used to propose an optimal proportion of nano-silica and rubber tyre chips for sustainable, high-performance concrete.

Conclusion

The review on optimizing the proportion of nano-silica and rubber tyre chips in concrete highlights the potential of these materials to produce sustainable, durable, and eco-friendly concrete. Rubber tyre chips, when used as a partial replacement of coarse or fine aggregate, significantly improve ductility, toughness, and impact resistance, but they also lead to reductions in compressive strength and stiffness due to their lower modulus of elasticity and weak bonding with cement paste. On the other hand, nano-silica, owing to its high pozzolanic reactivity and ultra-fine particle size, refines the microstructure of concrete, enhances the interfacial transition zone (ITZ), reduces porosity, and improves the mechanical and durability properties. Research indicates that the adverse effects of rubber content on strength can be effectively compensated by incorporating small dosages of nano-silica, with an optimum range of 2–3% by weight of cement, while the most effective rubber replacement levels typically range from 5–15% depending on the application. Beyond these limits, performance tends to decline. The combined use of nano-silica and rubber tyre chips not only addresses the environmental concerns of waste tire disposal and carbon emissions but also creates a more resilient concrete mix suitable for non-structural and semi-structural applications such as pavements, lightweight elements, noise barriers, and shock-absorbing structures. Overall, the optimization of these materials presents a balanced approach that meets sustainability goals without compromising concrete performance, though further long-term durability studies, field applications, and cost–benefit analyses are needed to validate their large-scale implementation.

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