

Effect of Graphene Oxide on the Physical and Mechanical Properties of Rubberized Concrete

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Abstract — The disposal of end-of-life tyres presents a persistent environmental problem, prompting the exploration of sustainable alternatives in construction materials. Rubberized concrete has emerged as a promising solution due to its ability to reuse waste rubber while offering advantages such as enhanced ductility and energy absorption. The incorporation of rubber aggregates into concrete contributes to sustainable construction; however, its widespread structural application remains constrained by reductions in strength and stiffness. To mitigate these limitations, this study investigates the effectiveness of graphene oxide (GO) as a performance-enhancing additive in rubberized concrete. Concrete mixtures were produced by partially substituting manufactured sand with recycled rubber aggregates at 5%, 10%, and 15% replacement levels by weight. Graphene oxide was introduced as a partial cement replacement at dosages of 0.01% and 0.05% by weight. Ten different mix proportions were developed and experimentally tested to evaluate compressive, flexural, and split tensile strengths. The results reveal a notable improvement in mechanical performance with the inclusion of graphene oxide, despite the presence of rubber aggregates. This improvement is mainly attributed to enhanced interfacial bonding among the cement matrix, rubber particles, and graphene oxide, supported by the latter's high surface area and superior mechanical properties. Overall, the findings indicate that graphene oxide can effectively counteract the strength loss associated with rubber incorporation, enabling rubberized concrete to be considered for structural applications while maintaining its sustainability benefits.

Keywords: Rubber Aggregate, Rubberized Concrete, Conventional Concrete, Sustainable Construction

I. INTRODUCTION

Concrete remains the most widely used construction material in the world and forms the backbone of modern infrastructure development. Its versatility, availability, and relatively low cost have made it indispensable for the construction of buildings, bridges, dams, highways, and large-scale transportation systems. Over several centuries, advancements in concrete technology have continuously supported urban growth and industrial expansion. However, the unprecedented pace of urbanization and infrastructure development in recent decades has placed immense pressure on the availability of high-quality raw materials required for conventional concrete production. While the demand for concrete continues to increase sharply, the supply of natural resources such as river sand, crushed stone, and limestone is becoming progressively constrained, raising serious concerns regarding long-term sustainability.

The scale of global concrete consumption highlights the magnitude of this challenge. Recent data indicate that annual worldwide concrete production is close to 14 billion cubic meters [1], making it the most consumed man-made material on Earth. This enormous production volume requires vast quantities of natural aggregates, resulting in excessive extraction of sand and gravel from rivers, quarries, and coastal zones. According to reports from the Freedonia Group, global construction aggregate production reached approximately 51.7 billion metric tonnes in 2014, with further growth anticipated in the coming years [2]. In parallel, cement demand continues to rise steadily, with projections suggesting an annual growth rate of about 2.5%, reaching nearly 4.7 billion metric tonnes by 2025 [3]. These trends clearly demonstrate that traditional construction practices are placing unsustainable demands on natural resources, emphasizing the urgent need for alternative materials and innovative approaches within the concrete industry.

Alongside resource depletion, waste management has emerged as another critical global concern, particularly with respect to polymer-based materials. The rapid growth of the automotive sector has led to a significant increase in tire production and consumption worldwide. Automobiles are essential for the movement of people and goods; however, their widespread use generates enormous quantities of waste tires at the end of their service life. Discarded tires constitute one of the largest sources of polymer waste globally, ranking second among waste polymer materials. Estimates suggest that approximately 1.6 billion tires are produced each year, while nearly 1 billion tires are discarded annually. Despite the scale of this problem, only about 10% of end-of-life tires are currently recycled through formal processing systems [4], leaving the majority to be stockpiled, landfilled, or improperly disposed of.

The situation is particularly relevant in developing economies such as India, where rapid economic growth and increasing vehicle ownership have intensified rubber consumption. Statistics indicate that during the 2021–2022 fiscal year, India consumed approximately 1.24 million metric tonnes of natural rubber, with the automotive tire and tube sector accounting for nearly 75% of this demand. Although rubber consumption temporarily declined during the COVID-19 pandemic, it rebounded strongly in the subsequent year. On the global stage, China remains the largest consumer of natural rubber, followed closely by India [5]. Improper disposal of waste tires poses serious environmental and public health risks. Accumulated tires provide favorable conditions for mosquito breeding, contributing to the spread of vector-borne diseases such as dengue and malaria. In addition, tire stockpiles represent a major fire hazard, as tire fires are extremely difficult to

extinguish and release hazardous pollutants and toxic gases into the atmosphere.

In response to these intertwined challenges of resource depletion and waste accumulation, the construction industry has increasingly focused on the development of sustainable and environmentally responsible materials. Rubberized concrete has emerged as a promising alternative that directly addresses both issues. This material is produced by incorporating waste rubber particles—such as crumb rubber, shredded tires, or rubber granules—into conventional concrete mixtures as partial replacements for natural aggregates. The inclusion of rubber alters the mechanical and physical behavior of concrete, imparting unique characteristics that differ from those of traditional mixes.

Numerous studies have demonstrated that rubberized concrete exhibits enhanced toughness, improved energy absorption capacity, and increased ductility compared to conventional concrete. These properties make it particularly attractive for applications subjected to dynamic, impact, or seismic loading, including road pavements, industrial floors, sound barriers, and earthquake-resistant structures. In addition to mechanical benefits, rubberized concrete has been reported to provide superior sound insulation, thermal resistance, and crack resistance, contributing to improved service performance in specific applications.

Beyond performance advantages, the use of rubberized concrete offers significant environmental benefits. By partially replacing natural aggregates with waste rubber, the demand for virgin materials is reduced, thereby limiting resource extraction and associated ecological damage. Simultaneously, incorporating discarded tires into concrete provides a productive end use for a problematic waste stream, diverting rubber from landfills and uncontrolled dumping. As a result, rubberized concrete represents a viable pathway toward more sustainable and circular construction practices.

Despite these advantages, the broader adoption of rubberized concrete in structural applications remains limited, primarily due to reductions in compressive strength and stiffness associated with rubber inclusion. Addressing these limitations while preserving the inherent benefits of rubberized concrete remains an active area of research. Continued innovation and material optimization are therefore essential to unlock the full potential of rubberized concrete as a sustainable construction material capable of meeting the performance demands of modern infrastructure.

Extensive research has been conducted to evaluate the feasibility of incorporating waste tire rubber into concrete as a sustainable construction material. A major challenge associated with rubberized concrete is the weak bonding between rubber particles and the cementitious matrix. Li et al. [6] reported that the hydrophobic nature and low stiffness of rubber aggregates lead to a poor interfacial transition zone, causing stress concentration and reductions in mechanical strength. Their study demonstrated that physical and chemical surface treatments of rubber aggregates can significantly enhance interfacial bonding, resulting in improved strength and durability of rubberized concrete.

Several studies have explored hybrid approaches to mitigate strength loss caused by rubber inclusion. Hossain et al. [7] investigated concrete containing recycled coarse

aggregates, crumb rubber, and polypropylene fibers. While crumb rubber reduced compressive strength, the addition of fibers effectively limited strength degradation, particularly under flexural loading. Similarly, Eisa et al. [12] showed that steel fibers substantially improved the compressive, tensile, and flexural strengths of rubberized concrete, compensating for the negative effects of rubber replacement.

The structural and durability performance of rubberized concrete has also been examined. Akono et al. [8] found that crumb rubber improved fracture toughness, surface friction, and resistance to weathering, indicating suitability for applications such as railway sleepers. Chen et al. [9] reported enhanced flexural fatigue performance and toughness in self-compacting rubberized concrete, despite reductions in stiffness at higher rubber contents. However, Xie et al. [11] observed that rubber incorporation in reinforced concrete slabs led to decreases in compressive strength, elastic modulus, and fatigue endurance, highlighting limitations in structural applications.

Other researchers have focused on optimizing material combinations. Mhaya et al. [13] demonstrated that incorporating granulated blast furnace slag alongside crumb rubber improved compressive strength and durability while reducing water absorption. Durability-related benefits were also noted by Zhu et al. [14], who reported improved resistance to chloride-induced corrosion and enhanced ductility in crumb rubber concrete.

II. MATERIALS AND METHODOLOGY

A. Materials

The experimental program employed Ordinary Portland Cement (OPC) of 53 grade conforming to IS:12269–2013, along with manufactured sand (MS), natural coarse aggregate (CA), potable water, recycled rubber aggregate (RA), fly ash (FA), a superplasticizer (SP), and graphene oxide (GO). OPC 53 grade was selected due to its suitability for high-strength concrete applications. Manufactured sand, having a specific gravity of 2.62 and conforming to Zone II grading as per IS:383–2016, was used as fine aggregate. Crushed stone coarse aggregate with a maximum nominal size of 20 mm was adopted to ensure adequate strength and interlocking. Recycled rubber aggregate obtained from waste tyres was used as a partial replacement for fine aggregate; it exhibited a fineness modulus of 2.55, low water absorption, and high flexibility. Fly ash was incorporated as a supplementary cementitious material to improve particle packing and durability. A high-range water-reducing admixture (Kuna Plast PC-50) was used to achieve the desired workability at a low water–binder ratio. Graphene oxide, characterized by its high surface area and nanoscale thickness, was used as a partial cement replacement to enhance interfacial bonding and mechanical performance.

B. Mix Proportions

Concrete mixes were designed for M45 grade with a constant water–binder ratio of 0.347. Manufactured sand was partially replaced by rubber aggregate at levels of 0%, 5%, 10%, and 15% by weight. Graphene oxide was incorporated as a partial replacement of cement at dosages of 0%, 0.01%, and 0.05% by weight. Fly ash constituted a fixed proportion of the total

binder content. Based on these variables, ten distinct mix combinations (H1–H10) were prepared, while the quantities of coarse aggregate, water, and superplasticizer were kept constant.

C. *Mixing, Casting, and Curing*

Concrete was prepared using a pan-type mixer. Initially, manufactured sand and coarse aggregate were dry mixed, followed by the addition of rubber aggregate and binders. Graphene oxide was dispersed in the mixing water containing the superplasticizer to ensure uniform distribution. Mixing was continued until a homogeneous consistency was achieved. Fresh concrete workability was assessed using the slump test. Specimens were cast in standard moulds, compacted using a tamping rod and table vibrator, and demoulded after 24 hours. All specimens were water cured under controlled conditions until testing ages of 7 and 28 days.

D. *Testing Program*

Hardened concrete was evaluated for compressive strength, split tensile strength, and flexural strength at 7 and 28 days in

accordance with relevant IS codes. For each mix and test age, three specimens were tested and average values were reported to ensure reliability of results.

III. RESULTS AND DISCUSSION

A. *Workability*

Slump test results indicated a progressive reduction in workability with increasing rubber aggregate (RA) content. The control mix exhibited the highest slump, while mixes containing 5%, 10%, and 15% RA showed incremental decreases in flowability. This reduction is attributed to the higher surface area, irregular texture, and elastic nature of rubber particles, which increase internal friction within the mix. The incorporation of graphene oxide (GO) further reduced workability due to its high water demand and strong affinity for moisture, which limited free water available for lubrication of the concrete constituents. Fig.1 presents the observed results on workability showing the effect of GO on rubberized concrete.

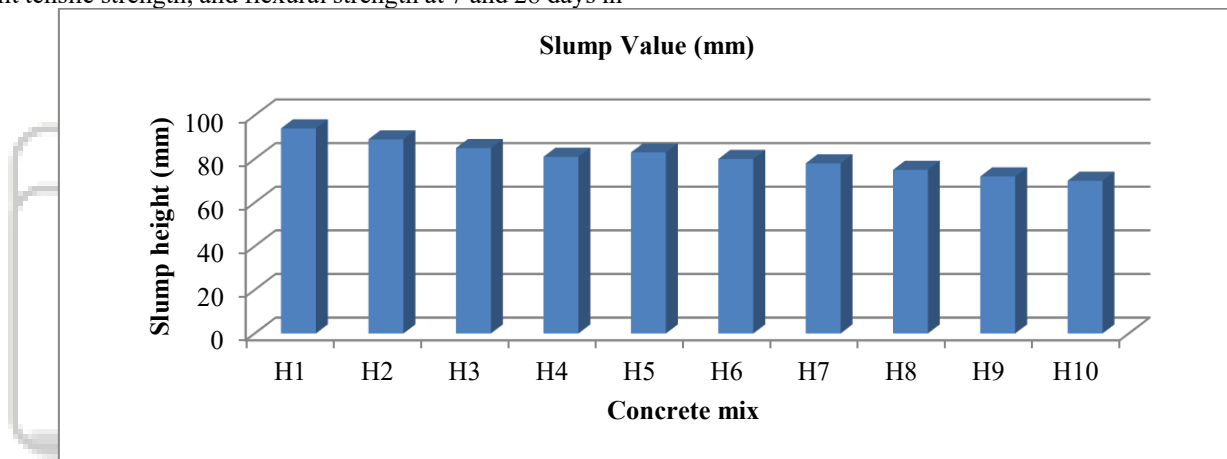


Fig. 1: Workability of concrete mixes

B. *Compressive Strength*

Compressive strength decreased with the inclusion of RA at both 7 and 28 days, reflecting weak interfacial bonding and inefficient stress transfer caused by the low stiffness and smooth surface of rubber particles. In contrast, GO-modified mixes exhibited notable strength recovery and improvement compared to rubberized concrete without GO. This

enhancement is primarily associated with the nano-filler effect of GO, which refines pore structure, promotes denser matrix formation, and improves load transfer within the cementitious system. Fig.2 presents the observed results on compressive strength showing the effect of GO on rubberized concrete.

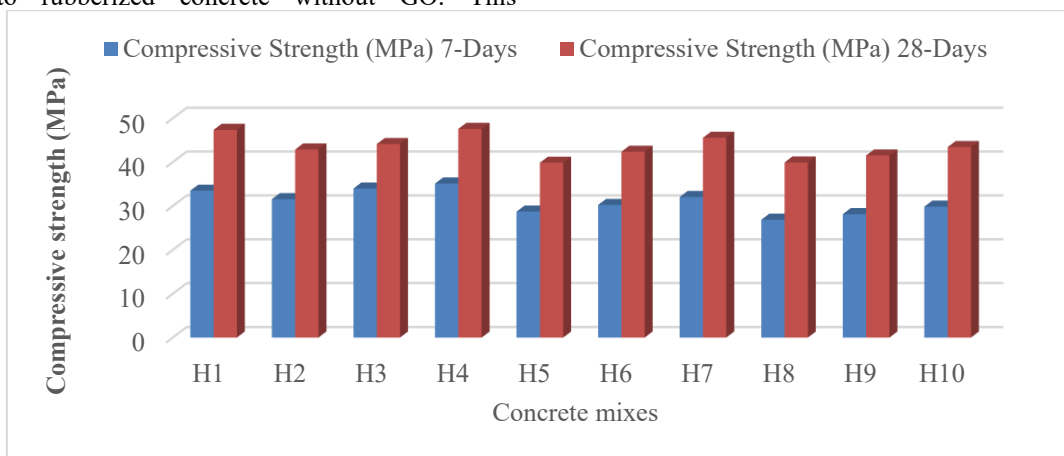


Fig. 2: Compressive strength of concrete mixes

C. Split Tensile Strength

The split tensile strength followed trends similar to compressive strength. RA incorporation resulted in reduced tensile capacity due to poor adhesion between rubber particles and the cement matrix, leading to microcrack

initiation under tensile loading. The addition of GO significantly improved tensile performance across all mixes, owing to improved particle packing, enhanced hydration, and strengthened interfacial bonding. Fig.3 presents the observed results on tensile strength showing the effect of GO on rubberized concrete.

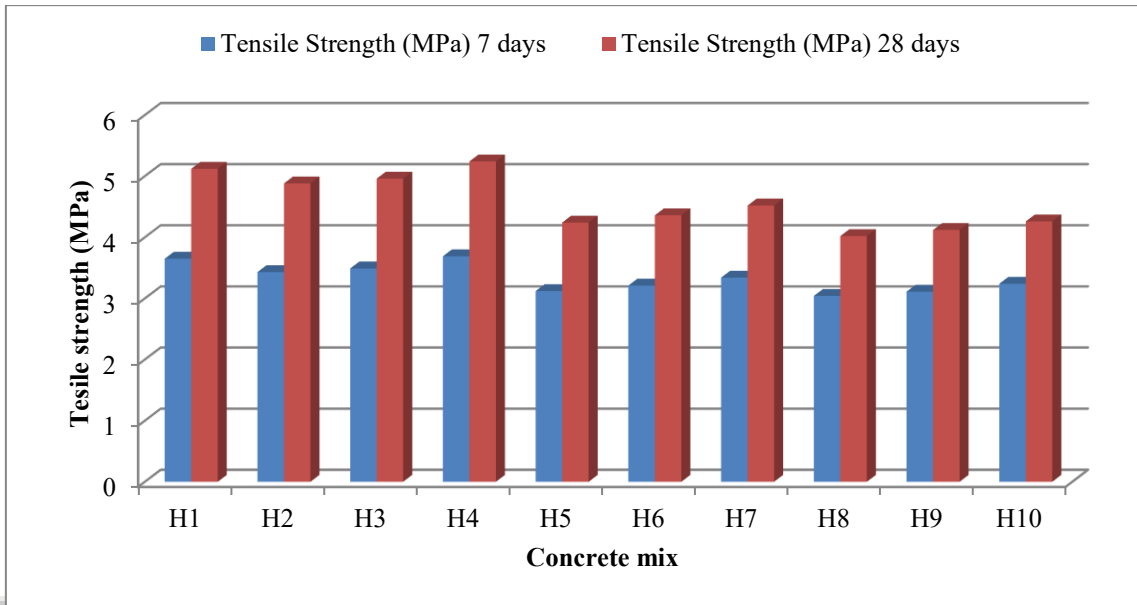


Fig. 3: Tensile strength of concrete mixes

D. Flexural Strength

Flexural strength declined with increasing RA content, mainly due to reduced stiffness and weak interfacial zones. However, GO addition effectively mitigated this reduction, resulting in improved flexural behavior. The enhanced performance is attributed to matrix densification and reduced

porosity induced by GO. Overall, the results demonstrate that while RA adversely affects mechanical properties, graphene oxide can successfully compensate for these losses, enabling improved performance of rubberized concrete. Fig.4 presents the observed results on flexural strength showing the effect of GO on rubberized concrete.

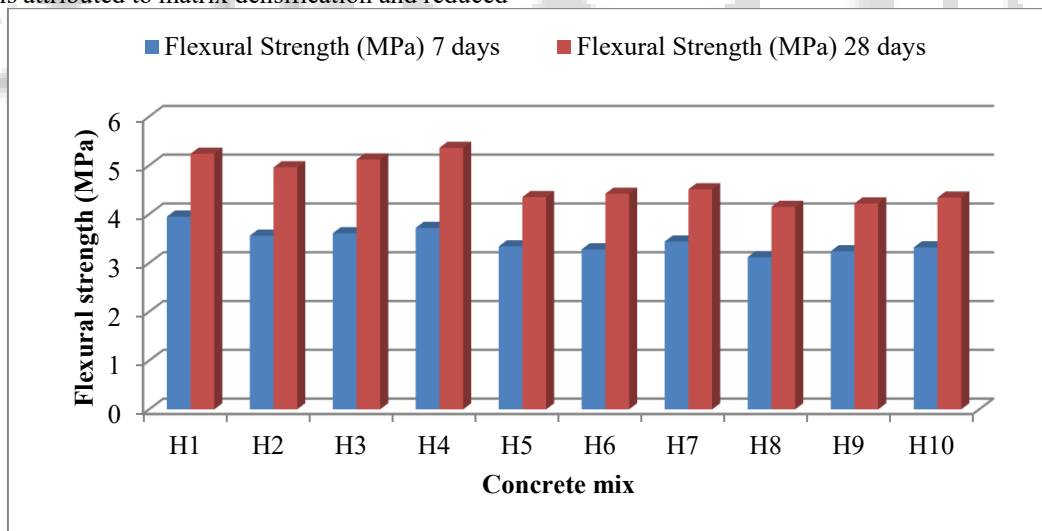


Fig. 4: Flexural strength of concrete mixes

IV. CONCLUSION

This study demonstrates that sustainable rubberized concrete can be effectively engineered through the controlled incorporation of graphene oxide (GO). While the use of rubber aggregate reduced workability and adversely affected compressive, tensile, and flexural strengths due to weak interfacial bonding and low stiffness, the addition of GO significantly compensated for these losses. GO refined the

microstructure, enhanced hydration, improved particle bonding, and promoted crack-bridging, leading to notable strength recovery and overall performance improvement. An optimal GO dosage enabled rubberized concrete to achieve acceptable mechanical properties without compromising sustainability goals. The combined use of waste tyre rubber and graphene oxide thus offers a viable pathway for developing eco-friendly, high-performance concrete suitable for practical construction applications.

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