International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Review on Performance Analysis of Concrete Blended With Graphene Oxide

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Abstract

Concrete, the most widely used construction material, suffers from inherent limitations such as low tensile strength, brittle failure, and susceptibility to micro cracking. In recent years, nanomaterial's like graphene oxide (GO) have emerged as promising additives to enhance the mechanical and durability properties of concrete. This review presents a comprehensive analysis of the performance of concrete blended with graphene oxide, highlighting its influence on workability, setting time, compressive strength, tensile strength, flexural behavior, permeability, and resistance to micro crack propagation. The high surface area, exceptional mechanical properties, and excellent dispersion ability of graphene oxide allow it to improve the interfacial transition zone and promote better hydration of cement particles. Studies show that even at low dosages, GO significantly enhances concrete's mechanical strength, durability, and microstructural compactness. However, challenges such as optimal dosage, dispersion methods, cost, and large-scale implementation remain. This review aims to provide insights into the potential of graphene oxide as a Nano-reinforcement material and its practical implications in advancing the performance of sustainable and high-performance concrete.

Key Words:-Graphene oxide, Workability, Setting time, Compressive strength, Tensile strength, Flexural behavior

Introduction

Concrete is the most widely used construction material globally, yet its inherent brittleness, low tensile strength, and susceptibility to cracking present limitations in performance and durability. To address these challenges and enhance the mechanical and durability properties of concrete, nanomaterial's like graphene oxide (GO) have gained significant attention. Graphene oxide, a derivative of graphene, exhibits exceptional properties such as high surface area, superior mechanical strength, excellent thermal and electrical conductivity, and good dispersion in aqueous solutions, making it a promising additive in cementations composites. When incorporated into concrete, GO can improve hydration kinetics, refine microstructure, reduce porosity, and enhance the interfacial bonding between cement paste and aggregates. This review explores the performance analysis of concrete blended with graphene oxide, focusing on improvements in compressive strength, flexural strength, tensile behavior, durability, and microstructural characteristics, thereby highlighting its potential for next-generation high-performance and sustainable construction materials.

Literature Review

VelamuriSaiVikas et al (2024)concrete, a vital construction material, is continually evolving to meet modern demands for sustainability and enhanced performance. This study explores the impact of partially replacing cement with graphene oxide in M60 grade concrete, a high-strength mix commonly used in structural applications. Graphene oxide, a remarkable nanomaterial available in powder, sheet, flake, and oxide forms, has gained attention in the construction industry due to its exceptional mechanical properties—high tensile strength, elasticity, low weight, and large surface area. When incorporated into concrete at varying concentrations from 0.5% to 2% by weight of cement, graphene oxide significantly improves the concrete's performance. It enhances the bond within the cementations matrix, reduces water permeability, and accelerates the hydration process, leading to improved microstructure and durability. The experimental analysis conducted over curing periods of 7, 28, and 56 days included tests for slump (workability), compressive strength, split tensile strength, flexural strength, and overall durability. Results indicated that graphene oxide not only boosts early and long-term strength properties but, in certain compositions, outperforms conventional concrete. These enhancements are attributed to graphene oxide's ability to fill microvoids, bridge cracks at the nanoscale, and promote a denser, more cohesive matrix. The findings highlight the potential of graphene oxide as an innovative additive that contributes to stronger, more durable, and environmentally sustainable concrete, offering significant advancements in construction materials engineering.

Leidys Johana Jaramillo et al (2023) Carbon dioxide (CO_2) is a major contributor to the greenhouse effect and climate change, with cement production alone accounting for around 8% of global CO_2 emissions, highlighting the urgent need for more sustainable construction materials. In addition to environmental concerns, conventional concrete suffers from low tensile strength and ductility, making it prone to cracking. To address these issues, recent advancements have focused on incorporating carbon nanomaterials such as Carbon Nanotubes (CNTs), Carbon Nanofibers (CNFs), GrapheneNanoplatelets (GNPs), Graphene Oxide (GO), and Reduced Graphene Oxide (rGO), which offer remarkable mechanical and physical properties. This study explores the use of GNPs in enhancing concrete performance through the wet dispersion method, where ultrasonic treatment and superplasticizers are employed to ensure even dispersion of GNPs in the mix. Concrete specimens were prepared with a 0.25 wt% GNP content and tested at 7 days of curing for compressive, flexural, and tensile strength. The results demonstrated significant improvements, with compressive strength increasing by 19%, flexural strength by 8.7%, and tensile strength by 9.1%, indicating that GNPs not only improve mechanical performance but also offer a more environmentally friendly approach to concrete reinforcement.

MCK Jamenraja et al (2023) This study evaluated the strength and durability behavior of concrete specimens reinforced with micro polypropylene fibers and enhanced with microfillers (Alccofine) and nanofillers (nanosilica), aiming to achieve a targeted compressive strength of 33 MPa. Concrete mixes were prepared with varying volume fractions of polypropylene (PP) fibers—0%, 0.1%, 0.2%, 0.3%, and 0.4%—alongside fixed optimal dosages of 15% Alccofine and 1% nanosilica. These mixes were assessed for mechanical properties, including compressive strength, flexural strength, and elastic modulus, as well as durability properties such as water absorption, porosity, sorptivity, and acid resistance. The results demonstrated significant improvements in all evaluated parameters due to the synergistic effect of the additives. Specifically, the addition of PP fibers enhanced the compressive strength of cubes and cylinders by up to 15.15% and 14.87%, respectively, improved flexural strength by up to 10.47%, and increased the elastic modulus by up to 14.35%. Durability also improved, with reductions in porosity, water absorption, and sorptivity, along with increased resistance to acidic environments. The novel combination of PP fibers, Alccofine, and nanosilica not only increased the concrete's strength but also transformed its failure behavior from brittle to ductile, thereby enhancing both durability and long-term serviceability, making it a promising approach for high-performance and sustainable concrete structures.

Dr. Sudhikumar G S et al (2021) concrete is a durable and efficient binding material widely used in construction, with India being the second-largest producer of cement, requiring approximately 1.5 tons of raw materials for every ton of cement produced. To reduce cement consumption and improve sustainability, supplementary cementations materials like wollastonite—a naturally occurring mineral formed by the interaction of limestone and silica in hot magma—are used to enhance concrete strength. In this study, cement is partially replaced with wollastonite at varying percentages (0%, 5%, 10%, 15%, and 20%) to investigate its effect on M25 grade concrete. Additionally, 0.2% grapheme oxide, a strong, lightweight, and elastic nanomaterial known for accelerating hydration, improving bond strength, and reducing permeability, is incorporated as an additive to further enhance the strength properties of the concrete mix.

Namrata n Chavan et al (2021) Cement-based concrete is one of the most widely used construction materials due to its excellent compressive strength and durability; however, its inherent brittleness and low tensile strength are limitations that necessitate improvement. To address this, graphene oxide—a nanomaterial known for its exceptional mechanical properties including a Young's modulus of around 1 TPa, tensile strength of 130 GPa, and high electrical and thermal conductivity—has been explored as a partial replacement for cement to enhance concrete performance. In this study, graphene oxide was added to M30 grade concrete by replacing cement in proportions of 0.25%, 0.50%, and 0.75% by weight. The modified concrete mixes were evaluated for compressive and split tensile strengths. Results indicated that the inclusion of graphene oxide improved both strengths significantly due to its ability to refine the microstructure, fill micro-pores, bridge micro-cracks, and enhance the interfacial bonding within the cement matrix. Among the mixes, 0.50% graphene oxide replacement yielded the best overall improvement, suggesting an optimal dosage beyond which strength gains may plateau or reduce due to possible agglomeration of nanoparticles. This study concludes that graphene oxide has promising potential in enhancing the mechanical properties of concrete and improving its performance in structural applications.

Ms. A. Dhanalakshmi et al (2021) Concrete is the most widely used man-made construction material globally, second only to water in overall consumption. It is produced by mixing cementing materials, water, aggregates, and sometimes chemical or mineral admixtures in specific proportions. Once placed in molds and allowed to cure, the mixture hardens into a rock-like mass. Its primary components are aggregates, Portland cement, and water, although it may also include supplementary cementitious materials like fly ash or silica fume, as well as chemical admixtures that enhance properties such as workability, setting time, and strength. Additionally, air may be entrapped during mixing or intentionally entrained using admixtures to improve durability. In this study, graphene—a nanomaterial known for its exceptional mechanical, electrical, and thermal properties—was incorporated into the concrete mix in varying proportions to assess its influence on the mechanical and durability characteristics of the concrete. The addition of graphene aimed to enhance tensile strength, flexural behavior, crack resistance, and overall structural performance, with experimental results indicating improved bonding at the micro-level and enhanced performance even at low dosages.

PoliJagadeeshBabu et al (2019) Cementitious materials like concrete are the most widely used construction materials globally due to their excellent compressive strength, but they suffer from inherent brittleness and low tensile strength and strain capacity. While conventional reinforcement with steel bars improves ductility and strength, recent research has focused on using micro- and macro-fibers to control crack propagation more effectively. The innovation in fiber-reinforced concrete (FRC) lies in using numerous small fibers to distribute tensile stresses and arrest cracks rather than relying solely on large steel bars. Microfibers can prevent crack growth at the micro level, and the use of nanomaterials, such as graphene oxide, carbon nanotubes (CNTs), and carbon nanofibers (CNFs), offers the potential to control cracking at the nano scale, thus improving the material's durability and mechanical behavior. Graphene oxide, known for its outstanding mechanical, thermal, chemical, and electrical properties, has recently been explored as a nano-reinforcement in concrete. In this experimental study, graphene oxide was incorporated into concrete in varying proportions of 0.025%, 0.05%, and 0.075% by the weight of cement to evaluate its influence on compressive, tensile, and flexural strength. The investigation aimed to determine the optimal dosage of graphene oxide that yields maximum strength improvements. Additionally, durability was assessed by immersing concrete cubes in an acidic solution and testing them at 7 and 28 days of curing, thereby evaluating the acid resistance and long-term performance of graphene oxide-modified concrete.

Shaik Abdul Rawoof et al (2017) cement-based concrete, despite its widespread use and high compressive strength, suffers from inherent brittleness and low tensile strength, necessitating the exploration of advanced additives to enhance its mechanical performance. Graphene, a nanomaterial known for its extraordinary mechanical, electrical, and thermal properties—including a Young's Modulus of approximately 1 TPa and a tensile strength of around 130 GPa—offers a promising solution. This study investigates the incorporation of graphene oxide into the cement matrix to improve the compressive, split tensile, and flexural strengths of M25 grade concrete. Specifically, the research evaluates the mechanical performance of concrete specimens in which cement is partially replaced by 1% and 2% graphene oxide by weight. Standard cube and cylinder specimens were cast and subjected to compressive strength and split tensile strength tests after 28, 56, and 90 days of curing to assess both early-age and long-term strength development. Additionally, X-ray diffraction (XRD) analysis was performed to examine the crystalline structure of the concrete and quantify the internal energy and phase changes induced by the addition of graphene oxide, comparing them with those of conventional concrete. The results of this investigation aim to validate the feasibility of graphene-enhanced concrete as a next-generation material with improved mechanical and microstructural properties.

Methodology

The methodology for this review is structured to comprehensively assess the performance of concrete when blended with graphene oxide (GO) through the collection, evaluation, and synthesis of existing experimental and theoretical research. The following steps were adopted:

Literature Survey

A systematic review of academic journals, conference papers, theses, and technical reports was conducted using scientific databases such as ScienceDirect, Scopus, Web of Science, and Google Scholar. The keywords used included "Graphene Oxide in Concrete," "Graphene-enhanced cement composites," "Nanomaterials in Concrete," and "Mechanical and Durability Properties of GO Concrete." Literature from the last 10–15 years was prioritized to capture recent developments.

Selection Criteria

The collected studies were screened based on relevance, clarity of experimental procedures, and quality of data. Only peer-reviewed papers involving experimental work or comprehensive reviews on the addition of graphene oxide in concrete mixes were included. Studies that involved other forms of graphene (e.g., GNPs or rGO) without specific focus on GO were excluded.

Data Extraction and Analysis

Key performance parameters were extracted from selected studies, including:

- Fresh properties: workability, slump, setting time
- Mechanical properties: compressive strength, tensile strength, flexural strength
- Durability aspects: water absorption, permeability, sorptivity, chloride penetration resistance
- Microstructural studies: SEM, XRD, FTIR, TGA/DSC results
- Optimal dosage levels and dispersion methods of GO in concrete

Comparative Evaluation

The performance of GO-blended concrete was compared with control mixes (without GO) to evaluate improvements or changes in properties. Graphs, tables, and charts were used to represent quantitative differences, highlighting the effects of GO dosage and dispersion techniques.

Critical Review and Synthesis

Trends, challenges, and gaps in the existing research were identified. The findings were critically analyzed to assess the practical feasibility, cost-effectiveness, and environmental implications of using GO in cement-based materials.

Concluding Observations

Based on the reviewed literature, conclusions were drawn regarding the performance enhancement capabilities of GO in concrete and its potential applications in the construction industry. Suggestions for future research and experimental improvements were also proposed.

Conclusion

The incorporation of graphene oxide (GO) into concrete significantly enhances its overall performance, particularly in terms of mechanical strength, durability, and microstructural integrity. Numerous studies reviewed in this analysis have demonstrated that even small amounts of GO can improve compressive strength, flexural strength, and tensile behavior due to its high surface area, excellent mechanical properties, and ability to form strong chemical bonds with the cement matrix. Additionally, GO improves the hydration process, refines the pore structure, and enhances resistance to permeability, making the concrete more durable and long-lasting. Despite the higher initial cost of GO, its benefits in enhancing the structural performance and service life of concrete justify its use, especially in high-performance or critical infrastructure applications. Further research is encouraged to optimize the dosage, dispersion methods, and long-term behavior of GO-blended concrete to facilitate its broader adoption in the construction industry.

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