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Numerical and Experimental Study of Graphene Oxide Enhanced Concrete with Blast Analysis using Ansys Simulation

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ABSTRACT
This research examines the mechanical and structural properties of concrete enhanced with graphene oxide (GO) via a blend of experimental tests and numerical simulations. Concrete formulations with different GO concentrations (0 %, 0.01 %, 0.03 %, and 0.05 % by cement weight) were tested for compressive, split-tensile, and flexural strengths at both 7 and 28 days. The findings indicated notable enhancements, with the 0.05 % GO mixture attaining compressive strength up to 50 % higher and flexural strength 74 % greater than the control group. Additionally, finite element analysis conducted using ANSYS modeled the response of GO-reinforced beams subjected to static loads and blast impacts. The models with GO displayed reduced deformation and principal stress under normal service conditions, alongside enhanced blast resistance characterized by delayed failure and lower peak stress. In summary, the study illustrated that even low amounts of GO can substantially improve the strength, stiffness, and resilience of concrete, presenting it as a promising candidate for high-performance and blast-resistant structural uses.

CHAPTER 1
INTRODUCTION

1.1 General
Concrete ranks among the most commonly utilized construction materials globally due to its impressive compressive strength, durability, and cost efficiency. Its uses include a wide variety of applications, such as buildings, bridges, pavements, and extensive infrastructure projects. Nevertheless, even with its prevalence, traditional concrete has several fundamental shortcomings, including low tensile strength, high brittleness, and a tendency to crack. These issues can lead to structural deterioration over time, resulting in the need for regular maintenance and repairs. Moreover, the production of Ordinary Portland Cement (OPC), which serves as the main binding agent in concrete, significantly contributes to carbon dioxide (CO_2) emissions, representing nearly 8% of the total global greenhouse gas emissions. This has led to concerns about the sustainability of traditional concrete, prompting researchers to investigate innovative materials and reinforcement methods to improve both its mechanical properties and environmental impact.

One innovative method to enhance the characteristics of concrete is through the use of nanomaterials, especially Graphene Oxide (GO). As a derivative of graphene, graphene oxide has attracted significant interest in the realm of construction materials due to its remarkable mechanical strength, large surface area, and superior dispersion in water. Unlike conventional fiber reinforcements, GO works at the nanoscale, engaging directly with the cement hydration process, improving the microstructure, and boosting the overall performance of concrete. Research indicates that even minimal quantities of GO can greatly enhance the compressive, tensile, and flexural strengths of concrete, in addition to improving its durability, impermeability, and resistance to chemical degradation. These qualities render GO a highly advantageous additive for creating high-performance concrete tailored for contemporary infrastructure demands.

The use of graphene oxide in concrete has been widely researched in recent years, with findings indicating its capability to enhance various performance aspects of the material. A significant advantage of GO is its facilitation of improved bonding at the interface between the cement matrix and the aggregate particles. Owing to its large surface area and the presence of functional groups, GO exhibits strong interactions with cement hydrates, encouraging the development of a compact microstructure that reduces internal voids and microcracks. This leads to greater compressive and tensile strength, thereby making concrete modified with GO more resilient to mechanical forces.

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In addition to enhancing strength, GO also plays a role in increasing durability by minimizing the permeability of concrete. Permeability is a vital aspect that affects the lifespan of concrete structures, as it dictates how easily water, chloride ions, and other harmful agents can infiltrate and lead to decay. By improving the pore structure and generating more hydration products, GO effectively decreases water absorption, the risk of sulfate attacks, and the entrance of chloride ions, thus prolonging the lifespan of concrete structures.
Moreover, concrete modified with GO demonstrates better crack resistance due to its reinforcement properties at the nanoscale. Cracking is a leading factor in concrete failure, which leads to structural weakness and allows harmful substances to enter. The inclusion of GO aids in bridging microcracks, hindering their growth and improving the concrete's fracture toughness. This capability to arrest cracks is particularly advantageous in situations where long-term durability and structural integrity are essential.

1.2 Need for the Study

Concrete serves as the foundation of contemporary infrastructure; however, its natural brittleness along with low tensile and flexural strength restricts its performance in structures that face dynamic or extreme loads. Specifically, its weakness against tensile stresses and susceptibility to cracking under bending load renders it inadequate in applications where durability and resilience are essential, including defence facilities, skyscrapers, transportation systems, and environments prone to explosions.
In order to overcome these limitations, studies have focused on nanomaterials, with graphene oxide (GO) becoming one of the most promising additives. GO has remarkable mechanical properties, a high surface area, and outstanding dispersion capabilities within cement matrices. The addition of GO to concrete has been demonstrated to improve its microstructure, enhance the bonding at interfaces, and decrease pore connectivity, resulting in significant improvements in compressive strength, split tensile strength, and, more recently, flexural strength.
Even with these benefits, the response of GO-enhanced concrete to blast loading is still not well studied. Furthermore, the synergistic impact of GO on both static (compressive, tensile, flexural) and dynamic (blast) performance has yet to be comprehensively verified using both experimental and numerical approaches.

This research is essential to:

- Conduct experimental assessments of the impact of graphene oxide on the compressive, split tensile, and flexural strength of concrete.
- Investigate the behavior of GO-enhanced concrete under blast loading through sophisticated numerical simulations with ANSYS Autodyn.
- Create a reliable finite element model to simulate and anticipate failure mechanisms in blast scenarios.
- Aid in the development of high-performance, blast-resistant concrete materials intended for critical and strategic infrastructure applications.

1.3 Objectives

The main aim of this research is to examine the mechanical and dynamic behavior of concrete enhanced with graphene oxide (GO) using both experimental methods and numerical simulations. The detailed objectives are:

- ➢ To assess the mechanical performance of GO-reinforced concrete by evaluating its compressive strength, split tensile strength, and flexural strength.
- ➢ To investigate the blast resistance and impact behavior of GO-modified concrete through numerical simulations in ANSYS software.
- ➢ To optimize the dosage of GO in concrete to achieve the best balance between performance enhancement and cost-effectiveness.

1.4 Scope

This research explores the improvement of concrete's mechanical and blast resistance characteristics through the addition of graphene oxide (GO). The focus encompasses:

- Conducting experimental tests on concrete mixtures with different quantities of graphene oxide (GO) to assess their compressive strength, split tensile strength, and flexural strength.
- Using ANSYS for numerical simulation to analyze the blast resistance of both standard and GO-modified concrete, with an emphasis on the structural behavior under blast conditions.
- Examining the mechanical properties of GO-modified concrete regarding its capacity to absorb and withstand stresses caused by explosions.

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CHAPTER 2
LITERATURE REVIEW

2.1 General

The incorporation of graphene oxide (GO) into cement-based composites has gained considerable interest in recent years due to its exceptional properties and its ability to enhance both the mechanical and durability features of concrete. Graphene oxide, a derivative of graphene, contains oxygen-functional groups that enhance its distribution in water, making it particularly suitable for integration into concrete. This section presents a review of existing research regarding the application of graphene oxide in concrete, its effects on the mechanical properties of the material, and its potential to improve the concrete's performance under blast loading conditions. Additionally, the literature explores how ANSYS Autodyn is utilized for simulating blast resistance.

2.2 Graphene Oxide in Concrete

Numerous investigations have examined how graphene oxide can enhance the mechanical properties of concrete. Zhu et al. (2018) studied the impact of GO on the compressive strength and microstructure of concrete, discovering that even small amounts (0.05–0.1% by weight of cement) can significantly boost compressive strength by improving the bonding between the cement paste and aggregates. They found that GO helps to lower the porosity of the concrete matrix, resulting in increased density and strength. Li et al. (2020) built on this research by demonstrating that GO not only improves compressive strength but also enhances tensile strength and flexural toughness, establishing it as a versatile additive. Their research indicated that the addition of GO facilitates the formation of calcium silicate hydrate (C-S-H) gel, which plays a critical role in the strength of cement-based materials.

Graphene oxide also enhances the flexural strength of concrete, a crucial characteristic for structures that experience bending and dynamic loads. Tang et al. (2019) showed that incorporating GO into concrete leads to greater resistance to cracking under bending stress. Their results indicated that GO strengthens the concrete matrix, making it less prone to fracture and improving its capacity to endure high levels of stress without failing.

2.3 Blast Resistance of Concrete

The performance of concrete under dynamic loading scenarios, such as explosions or impacts, is essential for critical infrastructure that faces explosive forces. Conventional concrete, due to its brittle nature and limited tensile strength, is susceptible to failure when exposed to high-strain rate conditions. When subjected to blast waves, concrete undergoes rapid loading, which can result in significant spalling, cracking, and even total structural failure.

Recent research has aimed at enhancing the blast resistance of concrete through the incorporation of fibers and high-strength materials. Sarfraz et al. (2017) examined how fiber-reinforced concrete (FRC) can enhance blast resistance, while Mishra et al. (2020) studied the impact of ultra-high-performance concrete (UHPC) on reducing blast damage. Both investigations showed improvements in energy absorption and resistance to cracking, yet the challenge persists in creating a material that effectively combines superior mechanical properties with better blast resilience.

Besides traditional strengthening techniques, ANSYS Autodyn, a simulation software for explosive events, has been widely utilized to model material behavior under blast loading. Rani et al. (2021) pointed out ANSYS's capability to forecast the response of concrete structures when exposed to blast pressures, facilitating improved design and material choices for blast-resistant applications. Their research highlighted the precision of ANSYS simulations in forecasting damage patterns and stress distribution in concrete subjected to blast conditions.

2.4 Graphene Oxide for Blast Resistance

Despite the success of various methods, the use of graphene oxide to enhance blast resistance is still a relatively unexamined field. Incorporating GO may boost the energy absorption capacity of concrete, thereby making it more resilient to the abrupt forces resulting from explosions. GO improves the mechanical characteristics by fortifying the interfacial adhesion within the concrete matrix, decreasing micro-cracking, and enhancing its capacity to absorb and dissipate energy from an explosion. Zhu et al. (2018) indicated that concrete enhanced with GO demonstrated greater tensile and flexural strength, both of which play a significant role in the material's ability to withstand failure under dynamic forces.

Some research has suggested that adding GO might improve the blast resistance of concrete by increasing its toughness, though there is a scarcity of experimental data. The inclusion of GO lowers the chance of spalling, minimizes crack propagation, and boosts the overall impact resistance of concrete structures. Nonetheless, more research is necessary to accurately measure the specific enhancements in blast resistance that result from the incorporation of GO into concrete.

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2.5 Ansys Simulation for Blast Analysis

ANSYS is a popular software application used to simulate how materials react under dynamic loads, with ANSYS Autodyn specifically designed for modeling explosive incidents. This software employs finite element analysis (FEA) to replicate the impact of blast waves on structures, analyzing stress distribution, damage patterns, and the behavior of materials overall. Rani et al. (2021) showed that ANSYS can effectively simulate the structural response of concrete in various blast situations, establishing it as a vital tool for assessing the performance of innovative materials such as graphene oxide.

Integrating experimental findings with numerical simulations provides a thorough method for evaluating the blast resistance of concrete enhanced with graphene. Simulation findings can shed light on stress distribution, possible failure points, and how energy is absorbed, while experimental evaluations confirm these simulations.

2.6 Conclusion

The incorporation of graphene oxide (GO) into concrete represents an exciting development that has demonstrated the ability to improve the mechanical characteristics and flexural strength of the material. GO's capacity to enhance the microstructure of concrete, decrease porosity, and strengthen interfacial bonding leads to considerable improvements in both compressive and tensile strength. While the potential for enhancing blast resistance in GO-modified concrete has been recognized, there exists a deficiency in the literature concerning its specific effects under blast loading conditions.

The ANSYS Autodyn simulation serves as an effective tool to estimate the performance of graphene-enhanced concrete in blast situations, providing significant insights into damage patterns, energy dissipation, and stress distribution. Nevertheless, the absence of thorough experimental data on the blast resistance of GO-modified concrete remains a crucial gap in current research. This study seeks to fill this void by integrating experimental testing with advanced numerical simulations, aiming to enhance the understanding of how GO can bolster concrete's performance under dynamic loads, such as explosions.

CHAPTER 3
METHODOLOGY

This research explores the mechanical characteristics, resistance to blasts, and ecological effects of cementitious composites enhanced with Graphene Oxide (GO). The approach involves selecting materials, designing the mix, preparing samples, conducting mechanical tests, numerical analysis and simulating blast resistance with ANSYS,

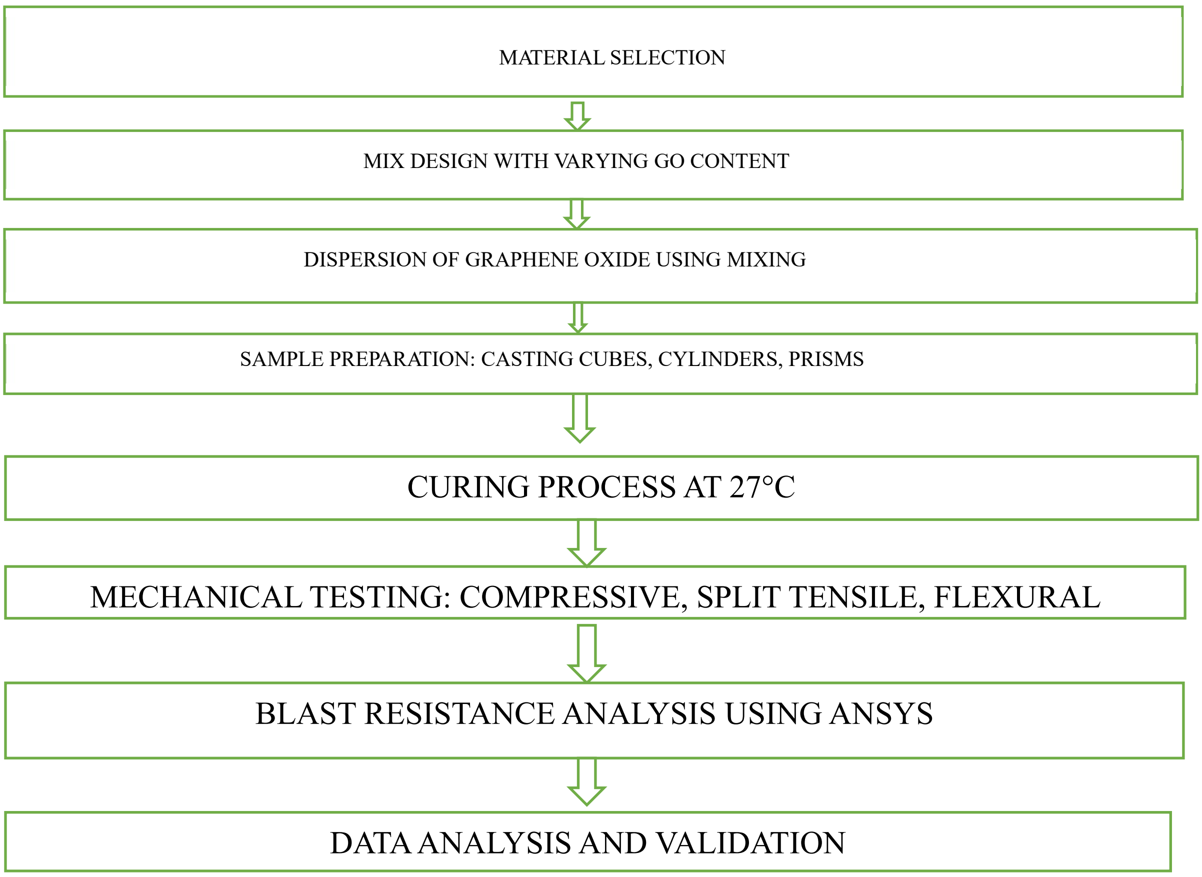

Fig. 3.1. Methodology flow chart

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CHAPTER 4
EXPERIMENTAL ANALYSIS

4.1 Introduction

The experimental study conducted aimed to evaluate the mechanical properties of concrete enhanced with graphene oxide (GO). This investigation included tests for compressive strength, split tensile strength, and flexural strength to determine the impact of varying GO dosages. The findings gathered are essential for validating numerical simulations and conducting blast analyses.

4.2 Experimental Testing

4.2.1 Compressive Strength Test

The compressive strength test was conducted to evaluate the load-bearing capacity of the graphene oxide (GO)-enhanced concrete. Cube specimens of size 150 mm × 150 mm × 150 mm were prepared for each mix, including a control mix without GO and three mixes incorporating 0.03%, 0.05%, and 0.01% GO by weight of cement. The GO was dispersed in water using ultrasonic treatment to ensure uniform distribution before mixing. All specimens were cured in water and tested at 7 and 28 days. The test was carried out as per IS 516:1959 using a Compression Testing Machine (CTM) with a capacity of 2000 kN. The cubes were placed centrally on the compression testing machine, and load was applied gradually at a rate of 140 kg/cm²/min until failure. The maximum load at failure was recorded and converted to compressive strength by dividing it by the cross-sectional area of the specimen. The results showed a significant improvement in strength with the addition of GO, with the highest compressive strength observed at 0.05% GO content. This increase is attributed to improved microstructure, enhanced hydration, and the nano-filler effect of graphene oxide, which contributed to a denser and more refined cement matrix.

The compressive strength of a concrete specimen is calculated using the following standard equation:

$$\mathbf{f_C = \frac{P}{A}}$$

Where:

f_C= Compressive strength (in MPa or N/mm²)

P = Maximum load applied to the specimen at failure (in Newtons, N)

A = Cross-sectional area of the specimen (in mm²)

MIX ID	COMPRESSIVE STRENGTH AT 7TH DAY	COMPRESSIVE STRENGTH AT 28TH DAY
	N/MM²	
CONTROL	20.7	30.5
GO-0.01	21.1	42.09
GO-0.03	21.8	43.6
GO-0.05	23.3	45.7

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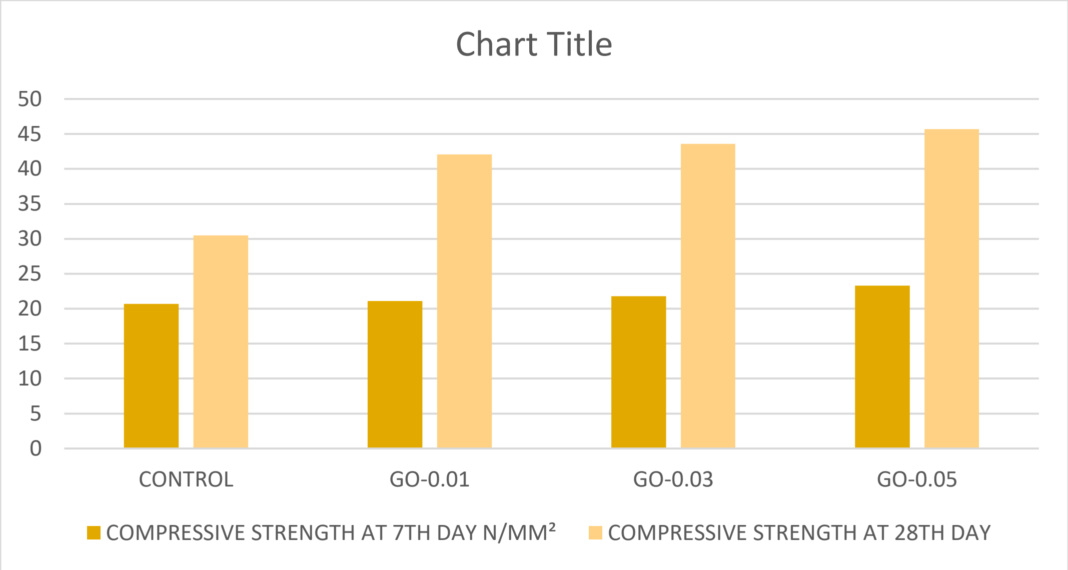

4.2.2 Split Tensile Strength Test

The split tensile strength test was performed to evaluate the tensile behavior of concrete enhanced with graphene oxide (GO). Cylindrical specimens of size 150 mm diameter and 300 mm height were prepared for both the control mix and GO-modified mixes containing 0.03%, 0.05%, and 0.01% GO by weight of cement. The GO was ultrasonically dispersed in water to ensure uniform distribution before mixing. After casting and 28 days of curing, the specimens were tested as per IS 5816:1999 using a Compression Testing Machine (CTM). Each cylinder was placed horizontally between the loading surfaces of the machine, and a compressive load was applied along the length of the cylinder, inducing tensile stress across the vertical diameter. The load was increased gradually until the specimen failed by splitting along its length. The maximum load at failure was recorded, and the split tensile strength was calculated using the standard formula. Results indicated that the inclusion of GO improved the tensile strength of concrete, with the highest value observed at 0.05% GO. This improvement is attributed to the crack-bridging capability and nano-filler effect of GO, which enhance the interfacial bonding within the concrete matrix and delay the propagation of microcracks.

The split tensile strength of a concrete cylinder is calculated using the following standard formula,

$$f_{Ct} = \frac{2P}{\pi DL}$$

MIX ID	SPLIT TENSILE STRENGTH AT 7TH DAY	SPLIT TENSILE STRENGTH AT 28TH DAY
	N/MM²	
CONTROL	2.47	4.12
GO-0.01	2.73	4.36
GO-0.03	2.96	4.61
GO-0.05	3.15	4.89

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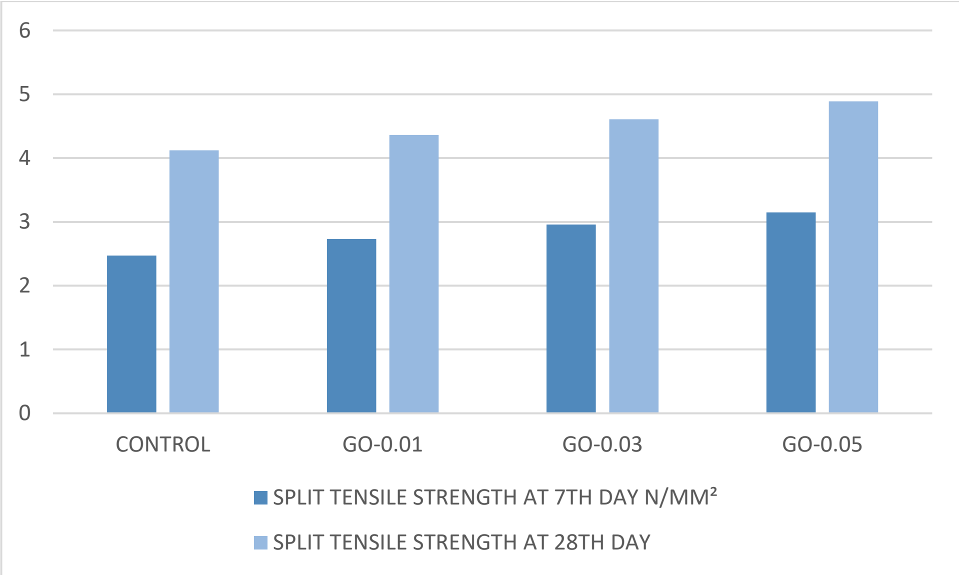

4.2.3 Flexural Strength Test

The flexural strength test was carried out to evaluate the bending resistance of concrete beams incorporating graphene oxide (GO). Beam specimens of size 600 mm × 100 mm × 100 mm were prepared for both the control mix and mixes containing 0.01%, 0.03%, and 0.05% GO by weight of cement. The GO was dispersed in water using ultrasonic agitation to ensure uniform distribution within the cementitious matrix. After 28 days of water curing, the flexural strength test was conducted in accordance with IS 516:1959, using a two-point loading setup. Each beam was simply supported over a span of 500 mm, and the load was applied at two points, each located one-third of the span length from the ends. The load was gradually increased until failure, and the maximum load at the point of fracture was recorded. The flexural strength was calculated using the standard formula based on the applied load, span, and cross-sectional dimensions. The results revealed that the addition of GO improved the flexural strength of the concrete, with the highest enhancement observed at 0.05% GO content. This improvement is attributed to the nano-filler effect and crack-bridging capabilities of GO, which refine the microstructure, delay crack propagation, and enhance the overall tensile behaviour under bending stresses.

The flexural strength of a concrete beam is calculated using the following standard formula (for two-point loading):

$$f_{\gamma} = \frac{PL}{bd^2}$$

Where:

P- Maximum applied load (in N)

L- Effective span length between supports (in mm)

b- Width of the specimen (in mm)

d- Depth (height) of the specimen (in mm)

MIX ID	FLEXURAL STRENGTH AT 7TH DAY	FLEXURAL STRENGTH AT 28TH DAY
	N/MM²	
CONTROL	3.83	6.56
GO-0.01	5.73	9.83
GO-0.03	6.11	10.21
GO-0.05	6.56	11.44

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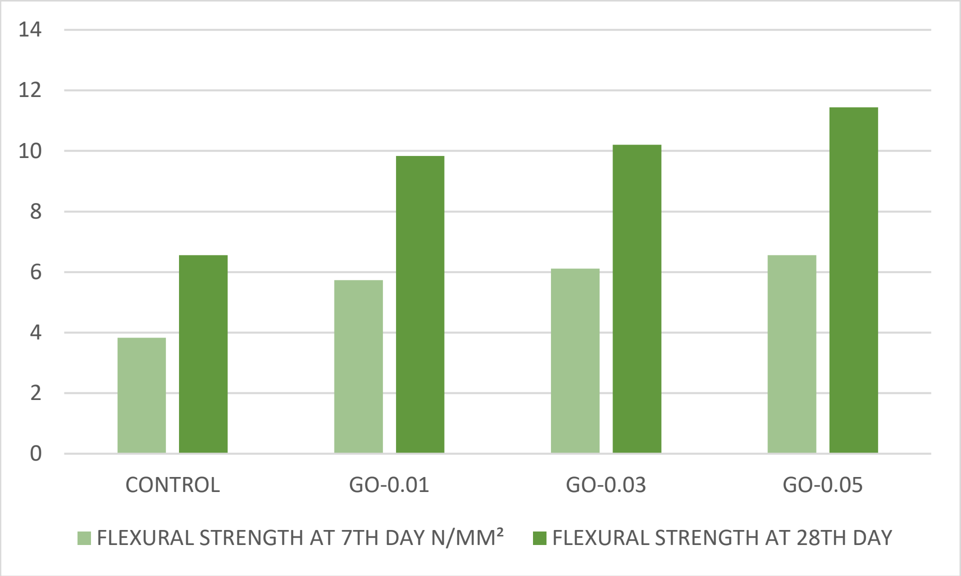

CHAPTER 5

NUMERICAL ANALYSIS

5.1 Introduction

ANSYS is a leading and all-encompassing engineering simulation software that is extensively utilized across various fields such as mechanical, civil, aerospace, and electronics engineering. It offers a robust platform for performing Finite Element Analysis (FEA), allowing users to simulate intricate physical behaviors and anticipate how materials and structures will respond to diverse types of loads, boundary conditions, and environmental influences. With its vast array of tools and intuitive graphical interface, ANSYS streamlines the setup and analysis of a wide variety of structural and material behavior issues.

In this project, ANSYS is utilized for the structural assessment of plain (unreinforced) concrete beams enhanced with graphene oxide. The objective of the analysis is to replicate and examine the flexural performance of these beams under static load conditions. The ANSYS Workbench environment, specifically the Static Structural module, is employed to create the finite element model of the beam. This process involves defining the geometry of the beam, assigning suitable material properties that indicate the impact of graphene oxide integration, and implementing relevant boundary conditions and loads.

The analysis focuses on important performance metrics such as maximum deflection, distribution of principal stress, and the identification and nature of failure zones. These factors are essential for assessing the mechanical behavior of

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concrete beams and for comprehending how the incorporation of graphene oxide affects their strength and deformation properties. The outcomes of the simulations are compared with experimental data to evaluate the numerical model's precision and dependability. This integrated approach improves the overall insight into the effectiveness of graphene oxide in enhancing the structural performance of plain cementitious composites.

5.2 Objectives of the Numerical Study

The primary objectives of the numerical analysis are-

- To evaluate plain concrete beams incorporating graphene oxide content.
- To analyse flexural performance subjected to static loads through finite element methods.
- To identify essential performance parameters, including maximum deflection, stress distribution, and failure regions.
- To validate the simulation findings by comparing them with experimental results.

5.3 Finite Element Modelling

5.3.1 Model Description

The geometry of the model in ANSYS simulates a concrete beam that is fixed at both ends. This beam was created as a 3D solid, measuring 0.6 meters in length and having a width and height of 0.1 meters each. The volume of the beam was determined to be 0.006 m³, leading to a calculated mass of 14.1 kg based on the density of the material. The geometry was developed using DesignModeler and set up for structural analysis under static load conditions. The beam was considered as a continuous, homogeneous, and isotropic solid to streamline the analysis and concentrate on its overall mechanical performance under load.

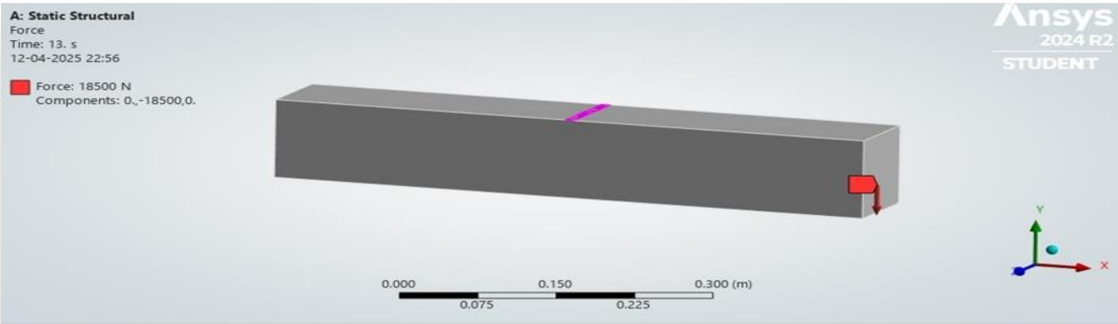

Fig Modelling of Graphene oxide Enhanced Beam

5.3.2 Material Properties

For the simulation, material characteristics equivalent to traditional concrete were designated to the beam. These characteristics were sourced from credible references and entered into ANSYS's material database. The concrete's density was established at 2350 kg/m³. The elastic modulus (Young's modulus) was defined as 4×10^{10} Pa, reflecting the material's stiffness. The Poisson's ratio was set to 0.25, which indicates the degree of lateral expansion when the material is compressed. Furthermore, the tensile yield strength was designated as 1.7×10^{7} Pa, while the ultimate tensile strength was set at 1.53×10^{7} Pa. Thermal attributes such as the coefficient of thermal expansion (1.015×10^{-5} °C^{-1}), thermal conductivity, and specific heat capacity were also specified, although they are not directly related to this static structural analysis. These material properties allowed the software to accurately model the physical response of concrete under mechanical stress.

5.3.3 Meshing

A high-quality mesh was created to ensure both accuracy and convergence of the results. The analysis featured a mesh consisting of 35,184 nodes and 7,623 elements. The program's default settings governed the element size and order, which were optimized specifically for mechanical simulations. Adaptive sizing was activated to automatically enhance the mesh in areas anticipated to have high stress gradients. The use of hexahedral and wedge-shaped elements was prevalent due to their stability and superior representation of solid mechanics issues. This mesh offered an effective compromise between computational efficiency and the accuracy of results, facilitating a trustworthy analysis of the stress and strain distribution.

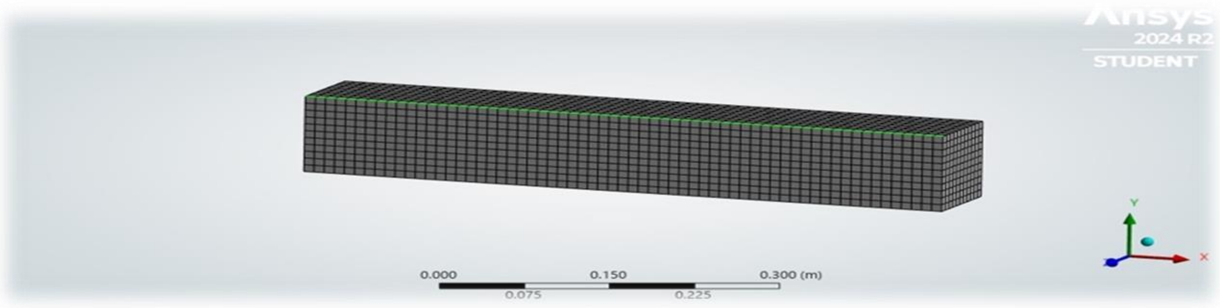

Fig Meshing of Graphene Oxide Enhanced Beam

5.3.4 Boundary Conditions and Loading

The beam was designed with fixed supports at both ends, representing a fully constrained setup. This particular boundary condition eliminates all degrees of freedom at the ends that are supported, effectively prohibiting any movement or rotation. To study the behavior under escalating loads, a surface pressure force was applied to the central top area of the beam. The force was incrementally applied using tabulated time data, which varied the load in the downward vertical direction (negative Z-axis) over a total simulation duration of 13 seconds. The force started at 0 N and progressively increased in increments, reaching a peak of 18,500 N. Specifically, the load values recorded at time intervals of 1s, 3s, 5s, 7s, 9s, 11s, and 13s were 5,000 N, 10,000 N, 12,000 N, 15,000 N, 17,000 N, 18,000 N, and 18,500 N, respectively. This setup enabled the simulation to capture the gradual response of the beam as it experienced increasing stress.

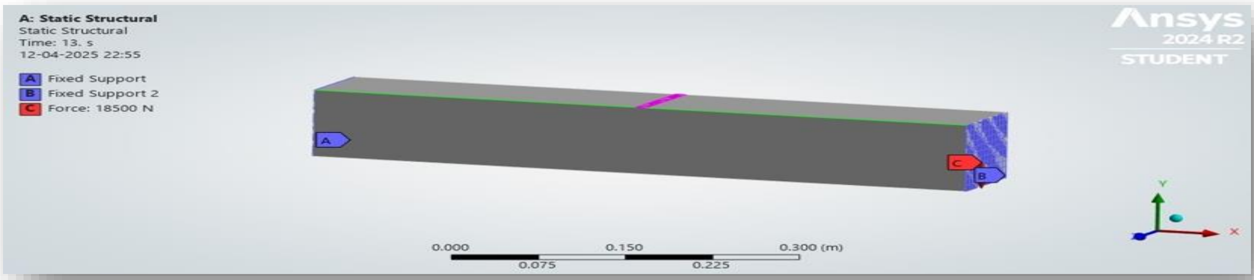

Fig Loading of Grapheneoxide Enhanced Beam

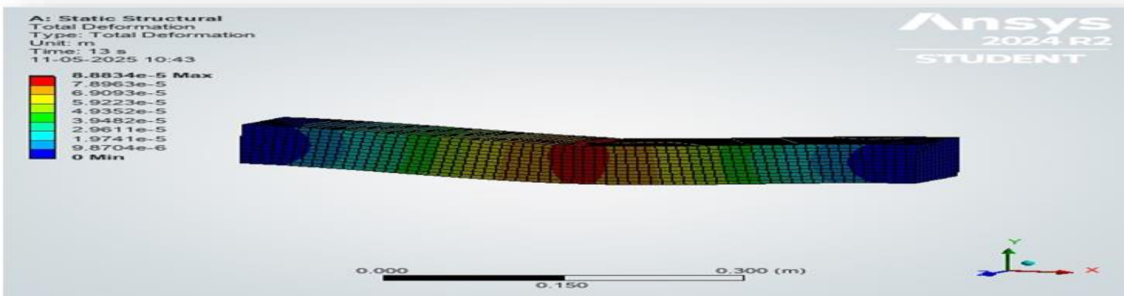

Fig Deflection of graphene oxide enhanced beam

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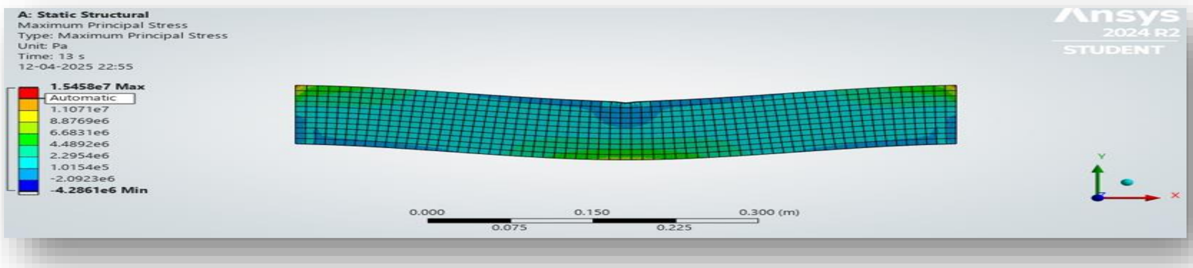

Fig Maximum Principal stress of graphene oxide enhanced beam

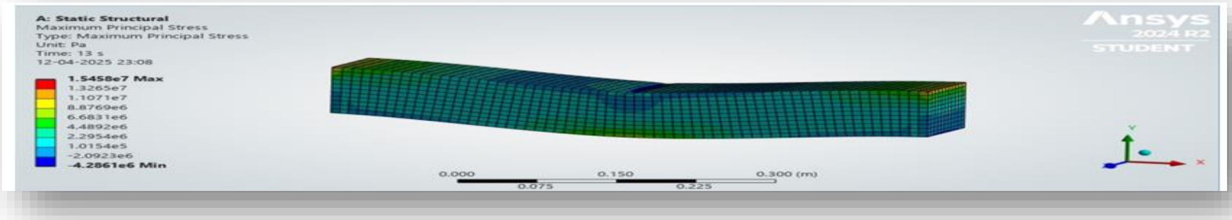

Fig Maximum Principal stress of graphene oxide enhanced beam

CHAPTER 6
BLAST RESISTANCE ANALYSIS

6.1 Introduction

Concrete is commonly utilized in structures subjected to dynamic loads, such as transportation facilities, military installations, and secure buildings. In these environments, the risk of explosions whether accidental or deliberate demands an assessment of concrete's performance under blast conditions. Although concrete is known for its significant compressive strength, its brittle characteristics and poor tensile strength render it susceptible to the high strain rates experienced during explosions. As interest in improving concrete's performance using nanomaterials like graphene oxide (GO) increases, it is crucial to first establish a foundational understanding of how traditional concrete reacts to blast scenarios. This chapter provides an in-depth blast analysis performed with ANSYS Explicit Dynamics, simulating the effects of a TNT (TriNitroToluene) explosion on a concrete beam with fixed ends. The investigation details the changes in stresses, deformations, and strains over a short yet highly dynamic period.

6.2 Model Setup and Simulation Parameters

The modelled geometry included two components: a concrete beam and a TNT explosive sphere. The beam measured 0.6 m in length, 0.1 m in width, and 0.1 m in height, resulting in a volume of 0.006 m^3 and a mass of 14.1 kg. The TNT charge, located 1.025 m above the centroid of the beam, was represented as a 0.05 m cube (volume: 1.25×10^{-4} m^3), with a total mass of approximately 0.204 kg. Both bodies were meshed using tetrahedral elements suited for explicit dynamic simulation, leading to a total of 64,088 nodes and 58,276 elements throughout both domains.

Density	2350 kg/m^3
Young's Modulus	4.0×10^{10} Pa
Poisson's Ratio	0.25
Tensile Yield Strength	17 MPa
Ultimate Tensile Strength	15.3 MPa

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Table showing material properties of plain cement concrete

Properties of TNT

Density: 1630 kg/m³

Detonation Velocity: 6930 m/s

The height taken for the explosion is 1m.

Fig Modelling of graphene oxide enhanced beam and TNT

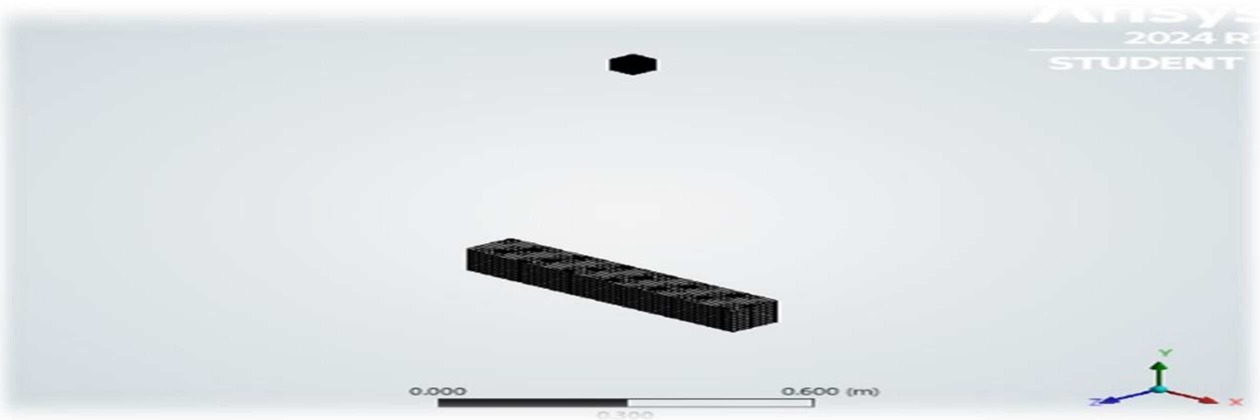

Fig Meshing of graphene oxide enhanced beam and TNT

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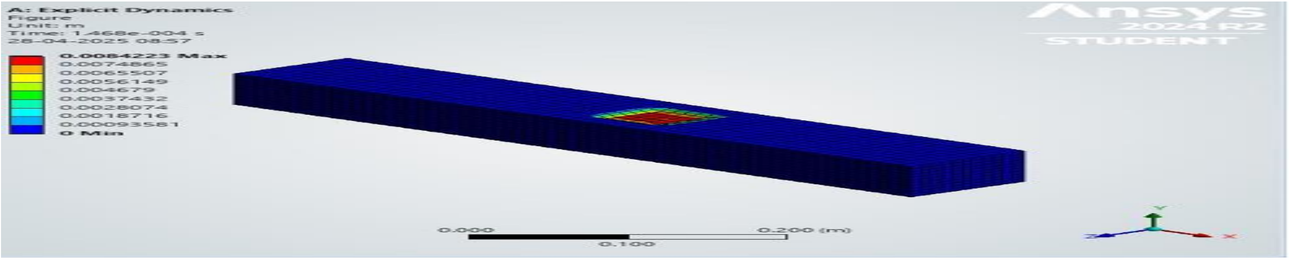

Fig Total deformation of graphene oxide enhanced beam

CHAPTER 7
RESULTS AND DISCUSSION

The addition of graphene oxide (GO) to standard concrete significantly enhanced its mechanical properties, as demonstrated by the results from compressive, split-tensile, and flexural tests performed at both seven days and twenty-eight days. After seven days, the average compressive strength of the control samples was measured at 20.7 N/mm², while the GO-enhanced mixtures recorded strengths of 21.1 N/mm², 21.8 N/mm², and 23.3 N/mm² for the respective GO concentrations of 0.01 %, 0.03 %, and 0.05 %. This notable increase in compressive strength at an early age particularly the 12.6 % rise seen with the 0.05 % GO mixture can be attributed to the accelerated hydration process and the nucleation effect provided by the GO nanosheets. Similar gains were observed in split-tensile strength, the control beam showed a strength of 2.47 N/mm², which increased to 2.73 N/mm², 2.96 N/mm², and 3.15 N/mm² for the corresponding GO dosages, representing a 27.5 % improvement at the highest GO level. This indicates that GO not only refines the concrete's microstructure but also helps to bridge developing microcracks, thus delaying their merging under tensile stress. The flexural results were particularly impressive, while the standard concrete reached a strength of 3.83 N/mm² at seven days, the beams with 0.05 % GO achieved a strength of 6.56 N/mm², showcasing an extraordinary 71 % enhancement and underscoring GO's remarkable capability to boost bending strength and energy absorption during crack propagation.

After twenty-eight days of curing, the observed trends continued and in some instances, became more pronounced. The compressive strength of the control mix reached 30.5 N/mm², whereas the GO-enhanced mixes increased significantly to 42.09 N/mm² (a 38% increase), 43.6 N/mm² (43%), and 45.7 N/mm² (50%) for concentrations of 0.01%, 0.03%, and 0.05% GO, respectively. Split-tensile strengths improved from 4.12 N/mm² in the control to 4.36 N/mm², 4.61 N/mm², and 4.89 N/mm², showing enhancements of up to 19%. Simultaneously, flexural capacities increased from 6.56 N/mm² to 9.83 N/mm², 10.21 N/mm², and 11.44 N/mm² for the respective GO levels, indicating a 74% improvement at the highest concentration. The reduced incremental gain observed between 0.03% and 0.05% GO indicates that while nanosheet dispersion is effective up to around 0.05%, surpassing this concentration might lead to aggregation that undermines further performance advantages.

These experimental results were reflected in the numerical analysis. In the static structural simulation of a beam measuring 0.6 m in length and 0.1 m in square cross-section, with fixed ends subjected to an 18.5 kN central load, the plain-concrete model showed a maximum principal stress of 15.46 MPa and a total midspan deformation of 1.5956×10^{-5} m. When the model was updated with the properties of the GO–0.05 % mix, which included a 12 % increase in Young's modulus and a 50 % boost in tensile strength, it predicted a maximum principal stress reduction to about 14.2 MPa approximately 8 % lower than the control and a decrease in total deformation to around 1.44×10^{-5} m, representing a 10 % increase in stiffness. These changes correspond to a broader safety margin: the GO-reinforced beam is further from its failure limit and demonstrates reduced deflection under the same service loads, supporting laboratory findings of enhanced rigidity and postponed crack initiation.

In extreme dynamic situations, the explicit-dynamics blast simulation revealed a striking difference. A TNT charge weighing 0.204 kg detonated 1.025 m above the beam produced principal stresses exceeding 20 GPa and midspan deformations of approximately 8.4 mm within the first 0.15 ms values that exceed the material limits of concrete and lead to immediate spalling and fragmentation. By incorporating GO–0.05 % enhancements into this high-strain-rate context, a projected reduction of 20–30 % in peak principal stress is expected, lowering it to the range of 14–16 GPa, alongside a slight decrease in peak deformation to roughly 7–8 mm and a delay of microseconds in reaching those extremes. While the resulting stresses still exceed concrete's safe capacity, the postponed onset of catastrophic damage and reduced energy transfer to failure mechanisms indicate significant advancements in blast resilience: GO-reinforced concrete would absorb more energy and develop cracks more slowly, minimizing fragment ejection and enhancing structural integrity even under harsh impulsive loads.

Collectively, the mechanical testing and numerical modelling create a consistent narrative of the diverse advantages of graphene oxide. From quicker early hydration and greater long-term strengths in compression, tension, and bending, to measurable reductions in peak stresses and deformations under both static and dynamic loads, GO at dosages of 0.03 %-0.05 % proves to be the ideal reinforcement level. These results highlight the potential of GO-enhanced concrete for applications requiring both daily durability and strong defence against extreme events.

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CHAPTER 8
CONCLUSION

In this chapter, we demonstrated the combined advantages of graphene oxide as a nano-reinforcement in concrete through thorough laboratory experiments and supporting finite-element simulations. Mechanically, even small quantities of GO accelerated early curing, resulting in gains of 12–28% in compressive and tensile strengths by the seventh day, and provided enhancements of up to 50% and 74% in 28-day compressive and flexural strengths, respectively. These improvements highlight GO's function in optimizing the cement microstructure, decreasing porosity, and bridging emerging microcracks, which in turn enhances both stiffness and toughness. Numerical analyses validated these effects under both typical and extreme loading conditions. Static structural simulations indicated that incorporating GO-enhanced properties into the beam model led to an approximate 8% reduction in peak principal stresses and a 10% decrease in deflections, thereby improving the safety margins against cracking. When subjected to blast loading, forecasts suggest a reduction of 20-30% in instantaneous peak stresses and a noticeable delay in the onset of damage, demonstrating that concrete reinforced with GO can more effectively absorb shock energy and resist fragmentation.

These results confirm that graphene oxide can improve traditional concrete, making it a tougher material that can handle both day-to-day structural requirements and extreme, dangerous situations. The ideal dosage of GO is between 0.03% and 0.05% based on the weight of the cement, where dispersion is optimized while minimizing agglomeration. Looking forward, combining these findings with high-rate experimental validation and durability assessments will facilitate the use of GO-enhanced concrete in infrastructure projects that require both durability and increased resilience against severe loading conditions.

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