A study on the compressive behavior, flexural strength and indirect tensile strength of Graphene oxide (GO) concrete

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بسم الله الرحمن الرحيم

Final Year Design Project Thesis Report

Project ID	GO concrete	Number Of Members	6

Title	A study on the compressive behavior, flexural strength and indirect tensile strength of graphene oxide (GO) concrete

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CHECKLIST

Number of pages attached with this form 57

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Our supervisor has attested the attached document. Yes / No

We confirm to state that this project is free from any type of plagiarism and misuse of copyrighted material. Yes / No

Undertaking

It is declared that the work entitled **"A study on the compressive behavior, flexural strength and indirect tensile strength of graphene oxide (GO) concrete"** presented in this report is an original piece of our own work, except where otherwise acknowledged in text and references. This work has not been submitted in any form for another degree or diploma at any university or other institution for tertiary education and shall not be submitted by us in future for obtaining any degree from this or any other University or Institution.

Group Members Name	Signatures
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Sustainable Development Goals

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11 ✓	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

Concrete is known for being inexpensive, durable, and strong under compression, however the tensile strength is limited by the cementitious bonding between aggregates. This results in crack development exposing embedded steel rebars to the atmosphere, causing reduced service life. Concrete has shown significant improvements in strength and durability when nano-reinforced with graphene oxide (GO) nanomaterial, but research on the failure behavior of GO-concrete under compressive loading is limited. Hence, this research investigates the flexural strength, indirect tensile strength, and compressive behavior of concrete nanoreinforced with GO nanomaterials. A highly oxidized GO variant was synthesized (confirmed via FTIR and XRD characterization tests) and added to concrete at 0.02 - 0.08 % by weight of cement. Results indicate an improvement of 30% in compressive strength, 25% in flexural strength, and 60% in tensile strength of concrete upon GO addition. Significant increase in Young's Modulus was also observed at nanomaterial addition up to 0.04%, but nano-reinforced concrete exhibited a more brittle nature relative to control. Findings of this research indicate a relatively inexpensive method of GO nanoreinforcement to concrete that is compatible with conventional mix designs, hence readily applicable for use in commercial structures.

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Chapter # 1
Introduction

1 Introduction

Concrete is a widely used construction material composed of cement, water, and aggregates. Its versatility and relatively low cost make it a popular choice for construction projects worldwide. Its composition can be modified to meet specific construction requirements, and it can be molded into various shapes and sizes. However, its brittleness and susceptibility to cracking under stress, as well as its tendency to shrink and expand, are significant disadvantages. Additionally, the environmental impact of cement production, including carbon dioxide emissions and resource consumption, is a growing concern.

Despite its drawbacks, concrete remains the second-largest production material globally due to its cost-effectiveness and durability. Efforts are underway to develop more sustainable and eco-friendly alternatives to cement and to improve the properties of concrete through new technologies and materials. Nonetheless, concrete will continue to be an essential construction material in the foreseeable future.

When cracks in concrete are stopped at an early stage of formation, it can significantly improve the durability and lifespan of the structure. In addition to traditional methods of repair, the use of nano materials has emerged as a promising solution to prevent or halt the formation of cracks in concrete.

One such material is geopolymer, which is a type of inorganic polymer made from fly ash, slag, or other industrial by-products. Geopolymers have been shown to improve the strength and durability of concrete, while also reducing its carbon footprint. By incorporating geopolymer into concrete mixtures, the risk of cracking due to shrinkage and thermal expansion can be reduced.

Cementation binders are another type of nano material that can be used to prevent cracks in concrete. These binders, made from nano-sized particles, can improve the bonding between the cement particles in the concrete mixture, resulting in a denser and stronger material. This can help prevent cracks from forming or spreading, even under heavy loads or in harsh environmental conditions.

Fibers, such as carbon nanotubes or nanofibers, can also be incorporated into concrete to prevent cracking. These fibers can improve the mechanical properties of the concrete, such as its tensile strength and toughness, which can help prevent cracks from forming or spreading. Additionally, the high surface area of these nano-sized fibers allows for better bonding between the fibers and the concrete matrix, further enhancing the material's strength and durability.

Bendable reinforcement, such as shape-memory alloys, can also help prevent cracks in concrete. These alloys can be designed to bend and deform under stress, absorbing energy and reducing the risk of cracks forming. Additionally, they can be used to reinforce critical areas of the concrete structure, such as joints or corners, where cracking is more likely to occur.

Finally, the use of nano materials, such as silica or titanium dioxide nanoparticles, can improve the durability and sustainability of concrete. These fillers can improve the concrete's properties by filling in the spaces between the cement particles, resulting in a denser and more impermeable concrete matrix. This can prevent water from penetrating the concrete, which can reduce the risk of cracks forming due to freeze-thaw cycles or chemical exposure.

Graphene oxide (GO) is a form of graphene that has oxygen-containing functional groups attached to its surface. GO can be dispersed in water to form a stable colloidal solution, which makes it a potential candidate for enhancing the ductility of concrete.

Ductility refers to a material's ability to deform without breaking when subjected to stress. Concrete is a brittle material, which means that it tends to fail suddenly and catastrophically when subjected to high stress or strain. By improving the ductility of concrete, it becomes more resistant to cracking and failure, and can therefore have a longer lifespan and improved durability.

Incorporating GO into concrete mixtures has been shown to improve the material's ductility. GO can act as a "bridge" between the cement particles in the concrete, helping to distribute stress more evenly and prevent cracks from forming. Additionally, the oxygen-containing functional groups on the surface of GO can react with the cement particles to form stronger bonds, further enhancing the material's strength and ductility.

Studies have shown that adding small amounts of GO to concrete mixtures can improve the material's toughness and resistance to cracking, without significantly affecting its compressive strength. However, the optimal amount of GO to add to concrete mixtures may vary depending on the specific application and conditions of use. Overall, the use of GO to enhance the ductility of concrete shows promise as a potential method for improving the durability and lifespan of concrete structures. However, further research is needed to fully understand the effects of GO on the properties of concrete, and to develop optimized methods for incorporating GO into concrete mixtures.

The purpose of using graphene oxide in concrete is to improve its ductility, which refers to its ability to deform under stress without fracturing. This is important because concrete is a brittle material that can easily crack or break when subjected to tensile or bending stresses. By adding graphene oxide to the concrete mix, researchers hope to increase its ability to deform under stress and reduce the risk of cracking or failure. Graphene oxide, which is a two-dimensional material made of carbon atoms arranged in a honeycomb lattice, has been shown to have high tensile strength and toughness, making it a promising additive for improving the mechanical properties of concrete.

1.1 Problem statement:

- The behavior of GO concrete under compressive, indirect tensile, and flexural loading conditions is not well-documented.
- Investigating the interfacial bond strength and its influence on the overall cohesion of GO concrete is essential for its successful implementation in structural applications.

1.2 Statement of Project:

The purpose of the study is to evaluate the potential of GO as a nanomaterial reinforcement in concrete and its effect on the material's mechanical qualities. The study will examine the effects of various GO doses on the compressive strength, flexural strength, and indirect tensile strength of the concrete using a methodical experimental methodology that includes sample preparation, testing, and characteriszation. Understanding the interactions between GO and the cement matrix, as well as the distribution and dispersion of GO inside the concrete, will get particular focus.

1.3 Aim and Objective:

The objectives of the proposed project are:

1. To investigate the compressive behavior of GO concrete.
2. To investigate indirect tensile behavior of GO concrete.
3. To determine the flexural strength of GO concrete.

1.4 Methodology

This chapter of the thesis details all the materials used in the experiments brief explanation on which analytical tests were performed, and the methodology for preparation and testing of all nanomaterial and cement samples.

- Materials
- Preliminary trails
- Synthesis of graphene oxide (GO) concrete and its characterization
- Formation of GO concrete
- GO concrete testing

Chapter # 2
Literature Review

2 Literature review

This chapter provides a thorough examination of the use of graphene oxide (GO) as a nanoreinforcement in concrete. It gives a thorough history, summarises the advancements made, and emphasises the difficulties in using GO to reinforce cement in concrete. The chapter also examines GO's chemical makeup and possible interactions with cement during the hydration process. The specific surface chemistry of GO makes it possible for it to form bonds with cement hydrates, which in turn affects the mechanical characteristics and overall effectiveness of the resultant cementitious composites.

2.1 Concrete

A manmade building material that resembles stone is called concrete. "Concrete" is derived from the Latin term concretes, which means "to grow together." Concrete is a composite material made of coarse granular material (the aggregate or filler) that is embedded in a stiff matrix of material (the cement or binder) that fills the spaces between the aggregate particles and holds them together [1].
As an alternative, we may describe concrete as a composite material made mostly of a binding medium with embedded aggregate particles. Concrete may be defined in the simplest form as filler plus binder [1].

$$\text{Concrete} = \text{filler} + \text{binder}$$

A composite material, concrete is made up of numerous essential parts. The main component, cement, serves as a binder and provides concrete with its strength. Typically, limestone, clay, shells, and silica are combined to make cement. When water is added to cement, a process known as hydration occurs, this causes a paste-like material to develop[2].

Concrete also includes aggregates in addition to cement. These materials are separated into fine aggregates like sand and coarse aggregates like crushed stone or gravel. Since they make up the majority of the concrete mixture, aggregates provide the finished structure with volume, stability, and strength. Depending on how the concrete will be utilized, several sizes and types of aggregates may be employed.

Water is a key ingredient in concrete because it makes the hydration process possible, which results in the formation of cement paste. To get the right consistency and strength, the water-to-cement ratio is precisely controlled during mixing. While too little water can result in inadequate hydration and the inability to work the concrete, too much water can weaken it[2].

To create a homogeneous mixture, the cement, aggregates, and water are mixed together. You have two options for doing this: manually or using mechanical mixers. The freshly mixed concrete is subsequently delivered to the site, where it is poured or set into the formwork. Until the concrete solidifies and becomes sufficiently strong, the formwork keeps it in the correct shape.

In the world of concrete, additives are crucial elements because they provide a way to alter and improve the material's qualities as it is being mixed. Admixtures can have a substantial influence on both the fresh and hardened qualities of concrete by introducing small amounts of specialised ingredients. A variety of admixtures are offered for various uses. Plasticisers or water reducers make materials easier to work with by lowering the amount of water needed to get the correct consistency[2].

This is furthered by superplasticizers, which offer improved flowability and enable self-compacting concrete. Accelerators hasten early strength development while retarders prolong the setup period while increasing workability. To increase resistance to freeze-thaw cycles, air-entraining chemicals add tiny air bubbles. Concrete becomes more impermeable and water-resistant by using waterproofing admixtures. A broad variety of colors and artistic effects are added by coloring admixtures, which enhance their aesthetically pleasing qualities. Admixtures may be carefully chosen and used in the right way to create concrete solutions that are suited to a project's needs while maximizing performance, workability, durability, and aesthetics. To improve concrete's performance and characteristics, nanomaterial can be added to the mix as admixtures

Nano-Material

Materials with distinctive characteristics and structures at the nanoscale level, generally spanning from 1 to 100 nanometers, are referred to as nanomaterial or nanomaterial. Due to their large surface area to volume ratio and quantum effects, which might be very different from those of their bulk counterparts, they display distinctive properties.

Nanoparticles, nanofibers, nanotubes, nanocomposites, and nanolaminates are just a few of the several forms of nanomaterial that may be categorized. Optimizing these materials' size, shape, composition, and surface qualities allows for the engineering of specific properties [3].

Carbon, as a nanomaterial, encompasses a diverse group of structures and forms with unique properties and applications. One such carbon nanomaterial is carbon nanotubes (CNTs), which are cylindrical structures, composed of rolled graphene sheets. CNTs possess exceptional mechanical strength, high electrical and thermal conductivity, and are used in various fields including electronics, aerospace, and materials science [4].

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One of the most thoroughly studied materials in recent years is graphene, a single sheet of carbon that is one of the standout examples of carbon nanostructures. It is a newly accessible material with exceptional mechanical and electrical capabilities. To create graphene sheets, many methods have been explored, including the mechanical cleavage of graphite [5].

2.2 Graphene oxide (GO)

Graphite oxide has a layered structure similar to that of graphite, but the plane of carbon atoms in graphite oxide is heavily decorated by oxygen-containing groups, which not only expand the interlayer distance but also make the atomic-thick layers hydrophilic. These oxidized layers could exfoliate in water under ultrasonication. If the exfoliated sheets contain only one or a few layers of carbon atoms like graphene, then these sheets are named graphene oxide (GO) [6].

As can be seen in Figure 2.1 [5], GO is a single-atomic-layered substance made of carbon, hydrogen, and oxygen molecules. Graphite crystals are a cheap and plentiful resource that may be used to make GO. It processes easily and is soluble in water. However, by eliminating the oxygen-containing groups and recovering a conjugated structure, the GO may be (partially) reduced to sheets resembling graphene.

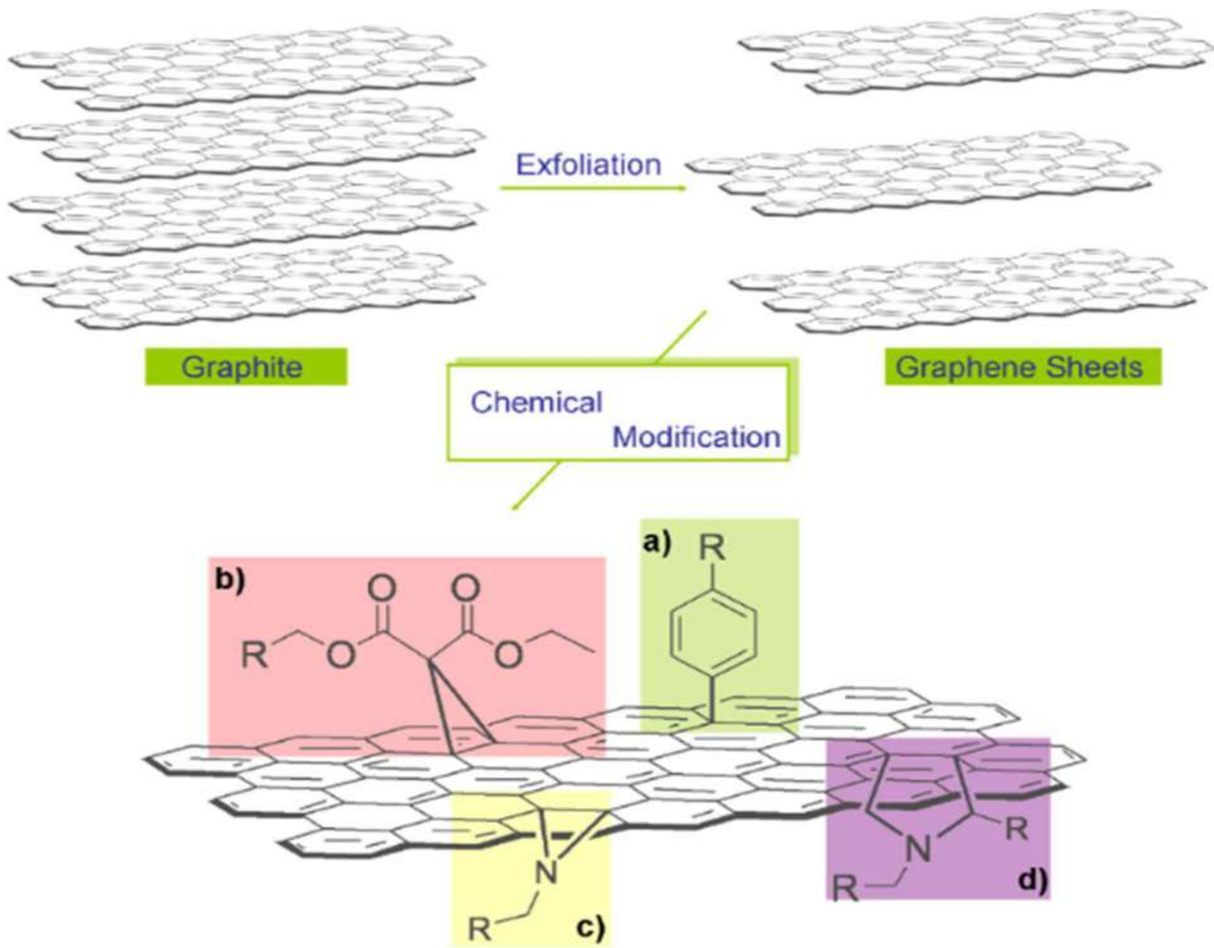


Figure 2.1: General chemical modification routes for exfoliated graphene sheets. (a) [3 + 2] 1,3-dipolar cycloaddition of in situ generated azomethine ylides, (b) [1 + 2] Bingel cycloaddition, (c) aryl diazonium addition, and (d) azide addition.

GO has two significant properties: (i) it can be produced using inexpensive graphite as the raw material and by using efficient chemical methods with a high yield; and (ii) it is highly hydrophilic and can form stable aqueous colloids, which makes it easier for macroscopic structures to be put together using simple and inexpensive solution processes.

With the exception of its minute ripples, the graphene sheet is entirely composed of trigonally connected sp2 carbon atoms and is flat Tetrahedral linked sp3 carbon atoms that are slightly displaced above or below the graphene plane make up a portion of the densely decorated GO sheets[7].GO sheets are atomically rough due to the structural deformation and the presence of covalently bound functional groups [8].

In their studies of the surface of GO, a number of researchers [6] found certain sections to be almost completely intact while others to have severely faulty patches that are likely caused by the presence of oxygen. According to a research, the graphene-like honeycomb lattice in GO is still there, albeit disordered (the carbon atoms connected to functional groups are somewhat shifted), but the total size of the unit cell in GO is still comparable to that of graphene [9].

2.2.1 Preparation of Graphene Oxide

The process first reported by Hummers [10] includes oxidizing graphite using a solution of potassium permanganate in sulfuric acid , which serves as the foundation for current procedures for synthesizing graphene oxide (GO). GO is a by-product of the reaction between the oxidizing chemicals and graphite.

The creation of harmful gases like NO2 and N2O4 is ensured by the use of sodium nitrate in both Brodie and Hummer's procedures, notwithstanding the greater safety of Hummer's technique. Additionally, Mn2O7 has a high oxidizing power and may ignite at temperatures beyond 55 degrees Celsius. Low yield, low purity, and/or the feasibility of large-scale production are other retaining issues that have been addressed by a number of techniques[11].

The most important modification to Hummer's process, as stated in Figure 2.2, was made by Marcano et al. [11] in 2010. They totally eliminated NaNO3, doubled the quantity of KMnO4, and added phosphoric acid (H3PO4) in a ratio of 1:9 parts to sulphuric acid. Even when the increased KMnO4 is taken into account, it was found that the modified Hummer's technique generated a greater yield than the original approach and released no harmful fumes. Additionally, the new product seemed to have more regular structurally, and it was simpler to control the exothermic temperature throughout the reaction. The current yield, however, showed higher oxidation than the previous batch ([11], unfavorable for several electrical and medicinal uses of GO that call for a more pure graphene-like material) [12].

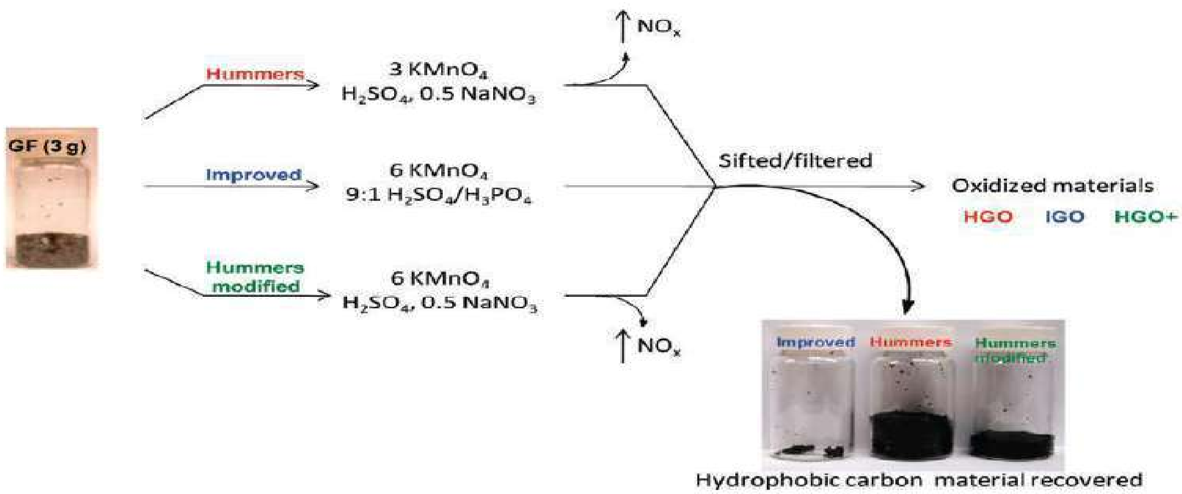


Figure 2.2: Production of GO with Hummers and Modified Hummers [11]

As an alternative, Chen et al. [13] refined Hummer's technique by including water accelerated oxidation with the capacity to regulate the degree of oxidation and functionalization (see Figure 2.3). According to Chen et al. [13], adding 4 mL of water per gram of graphite and keeping the GO-oxidant solution at a frigid 0° Celsius for 48 hours increased the yield of highly oxidized GO by 60 times.

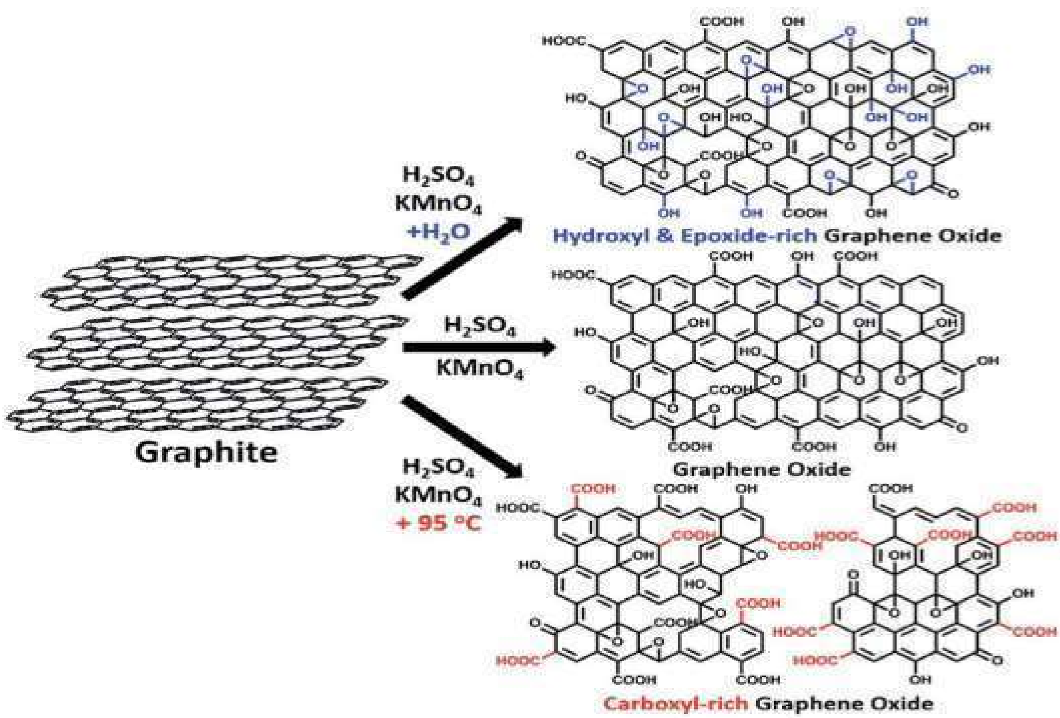


Figure 2.3: Water accelerated oxidation [13]

The increased yield also resulted in GO with enhanced structural integrity when compared to GO synthesized using the original Hummer's technique, as evidenced by the much higher electrical conductivity of the reduced version of the approach as compared to the original [13][12].

Chemically, graphite oxide and GO are relatively similar, but structurally, they differ greatly. The fundamental distinction between graphite oxide and GO is the interplanar space between each compound's individual atomic layers, which is brought on by water intercalation. Both graphite oxide and GO are frequently referred to be electrical insulators because of the greater spacing brought on by the oxidization process, which also disturbs the sp2 bonding network[6].

Graphite oxide may be converted into GO via a few different processes. The methods that are used most frequently include sonication, stirring, or a combination of the two. While sonication can be a very effective and time-efficient method of removing graphite oxide, it can also severely damage graphene flakes, reducing their surface area from microns to nanometers and resulting in a wide range of graphene platelet sizes. The quantity of layers is what distinguishes graphite oxide from GO. There are a few layers and a monolayer of flakes present in the GO dispersion of graphite oxide, despite the fact that it is a multilayer system[6].

For the preparation of GO typically 5 steps use:

1) Graphite intercalation into single or multiple-layer graphene sheets (a transient state); 2) Oxidation of its sheets into GO through a powerful oxidant, often $KMnO_4$ 3) The process is stopped by adding H_2O_2 and H_2O 4) The mix is decontaminated by repeated centrifuging and washing, often with diluted HCl and deionized water, and 5) GO is dispersed in solution using ultrasonication.

2.3 GO-concrete

Concrete is a composite material made of aggregates (such sand and stones), cement (usually Ordinary Portland Cement), and water. A chemical reaction takes place when water is introduced to cement powder, creating a cementitious matrix. This matrix holds the aggregates together, allowing compressive stresses to be transferred effectively throughout the mixture. As a strong and affordable building material, concrete is frequently employed[2].

But one disadvantage of concrete is that it lacks tensile and flexural strength by nature. Under strain, concrete is prone to cracking, which can cause instant failure. Reinforcement materials are used to get around this limitation. Rebars, a type of steel reinforcement, are frequently used to increase the tensile and flexural strength of concrete constructions. At the microscale, fibre-reinforcement or a greater packing density of the concrete mixture can also be used.

Concrete faults including cracking and the development of a weak interfacial transition zone (ITZ) are caused by the cement's hydration reaction. Ettringite crystals (AFt), calcium hydroxide (CH), and calcium silicate hydrate (C-S-H) are the principal hydration products. Although C-S-H helps the cement matrix's bonding properties, CH and AFt are bigger crystals that develop at the hydration sites between the C-S-H gel and other cement or aggregate particles. These crystals have little effect on the growth of bonds and lead to the production of a weak ITZ[14][2].

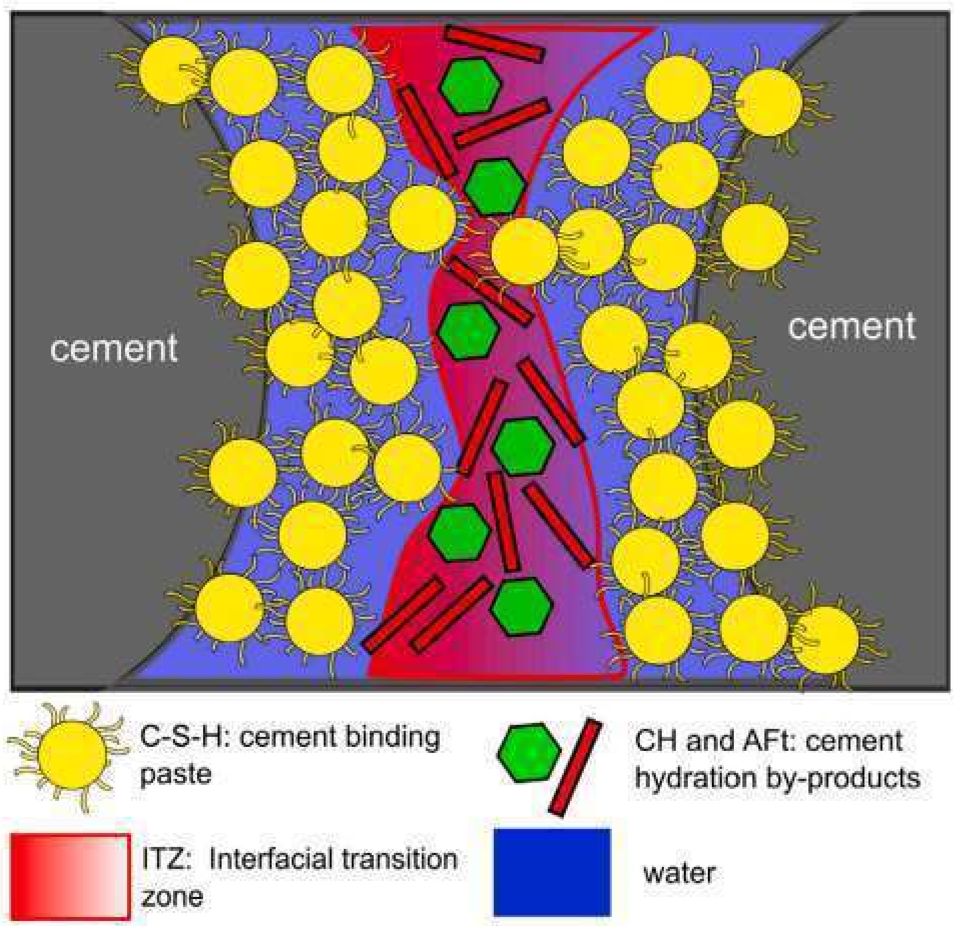


Figure 2.4: Interfacial Transition Zone (ITZ) schematic in visual form [14]

The weak ITZ turns into a zone that is susceptible to crack growth and acts as a route for water to seep out (causing creep and shrinkage) or for toxic substances like chlorides and corrosive chemicals to enter the concrete structure. Although the use of micro reinforcement, such as rebars, enhances the strength and durability of concrete, it serves more as a mitigating than a preventing action.

By bridging and deflecting weak zones at the early stages, nano-reinforcement, on the other hand, shows more potential in avoiding fracture propagation. Particle sizes of the C-S-H gel, a crucial component of concrete, are around 3.5 nm on the nanoscale. The goal of using nano-reinforcements is to strengthen the C-S-H gel and improve its mechanical characteristics, which will ultimately increase the durability and performance of concrete structures[14],[15].

The mechanical characteristics and general performance of concrete can be improved by adding nanoparticles to the cementitious matrix. Due to their distinct chemical compositions and nanoscale dimensions, these nano-reinforcements provide special properties. Graphene, GO, nano-SiO2, and CNT have all demonstrated significant promise for enhancing the durability, strength, and other desired characteristics of concrete[15].

It is essential for maximizing these nanoparticles' efficiency to comprehend their chemical composition and how they interact with concrete and cement. To achieve the necessary improvements in concrete performance, factors including dispersion, surface functionalization, and compatibility with the cementitious matrix are crucial[14].

A significant factor in the development of hydration products in the cement matrix is the interaction of C-S-H (calcium silicate hydrate) and CH (calcium hydroxide) with the carboxyl groups in GO (graphene oxide). The GO's presence encourages the interlocking of the GO sheets, which causes hydration products to develop in the cement paste. In the cement paste, this interaction has been discovered to diminish the amounts of CH and AFt (ettringite), which has an impact on how the interfacial transition zone (ITZ) forms[12],[16],[17].

Studies have demonstrated that thermo-gravimetric analysis (TGA/DTG) leads in a decrease in the H (enthalpy change) values of CH as the concentration of GO in cement increases. According to Wang, Wang, Yao, Farhan, Zheng, and Du [16] this drop in H values points to a decrease in the quantity of CH present in the system. This conclusion is further corroborated by X-ray photoelectron spectroscopy (XPS) research, which shows that when the GO concentration rises, a new product known as Ca(HCOO)2 forms. This by-product of cement hydration is created when the carboxyl groups in GO bond with the free Ca2+ ions in the CH solution [16].

By lowering the quantity of CH and affecting the creation of new compounds, the interaction between GO and the hydration products in the cement matrix modifies the microenvironment. The enhanced composition and structure of the cement matrix can result in improved mechanical characteristics and a decreased susceptibility to cracking and degradation, which has consequences for the durability and strength of the concrete.

Since CH does not contribute mechanically to the hardened cement materials, their bonding with GO platelets enables three-dimensional interlinking of various sheets to occur at locations of hydration where C-S-H is also forming along with CH. This ensures good bondage within the cement matrix and enables GO to contribute to the strength and crack-inhibiting properties of hardened cement paste[16].

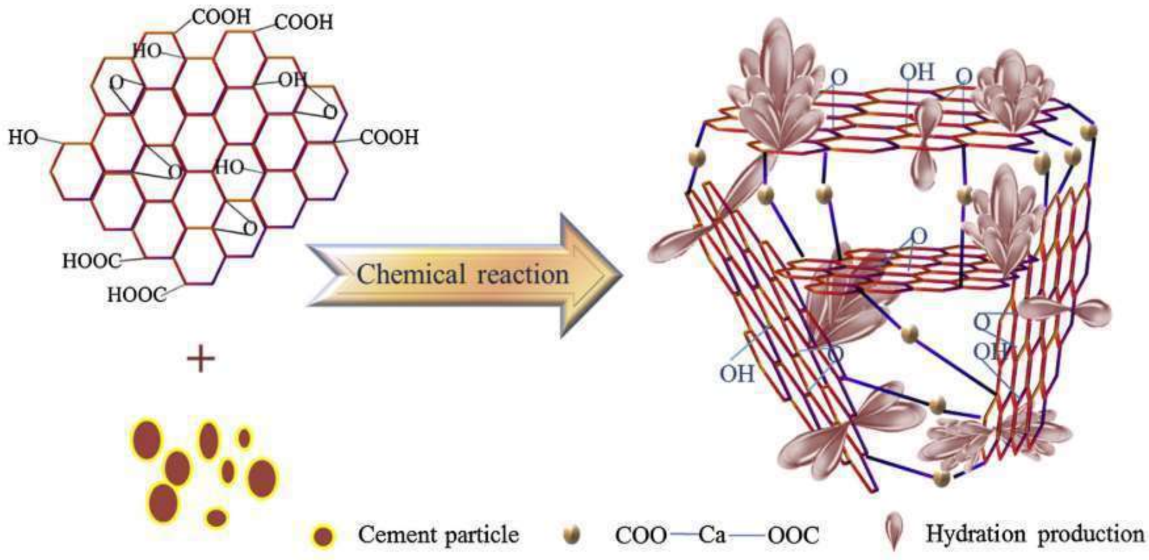


Figure 2.5: The interactions of functionalized GO with cement hydration products [16]

Graphene oxide (GO) is attracted to water by the hydroxyl and epoxy groups that contain oxygen due to their polarity. This characteristic of GO makes it more water-dispersible [16]. Water is essential for the hydration of cement because it starts the chemical processes that cause the cement paste to harden.

By accumulating water molecules and offering "nucleating sites," GO serves as a stimulant for the hydration process. The growth of hydration products like calcium silicate hydrate (C-S-H) gel, which aids in the creation of the cementitious matrix, is encouraged by these nucleating sites. The hydration process can start on the GO surface itself thanks to GO's capacity to draw and hold water molecules.

GO increases the hydration of cement by acting as a catalyst and supplying nucleating sites, which results in the development of a solid and long-lasting cementitious matrix. The uniform distribution of GO within the cement paste is further facilitated by its capacity to disperse in water, ensuring efficient interaction with other cementitious materials and fostering the general improvement of concrete qualities.

The effect of graphene oxide (GO) on the development of calcium silicate hydrate (C-S-H) crystals in the cement matrix was discovered by Lv et al. [18] in 2013 using SEM imaging. They discovered that the formation of organised, flower-like C-S-H crystals was influenced by the cumulative effects of nucleation, the interlocking of GO in three dimensions, and GO's own hexagonal sheet structure. A superior packing and bonding of the cement matrix with the aggregates as a result of this distinct crystal growth pattern increased the cement sample's tensile strength [18], [19],[20].

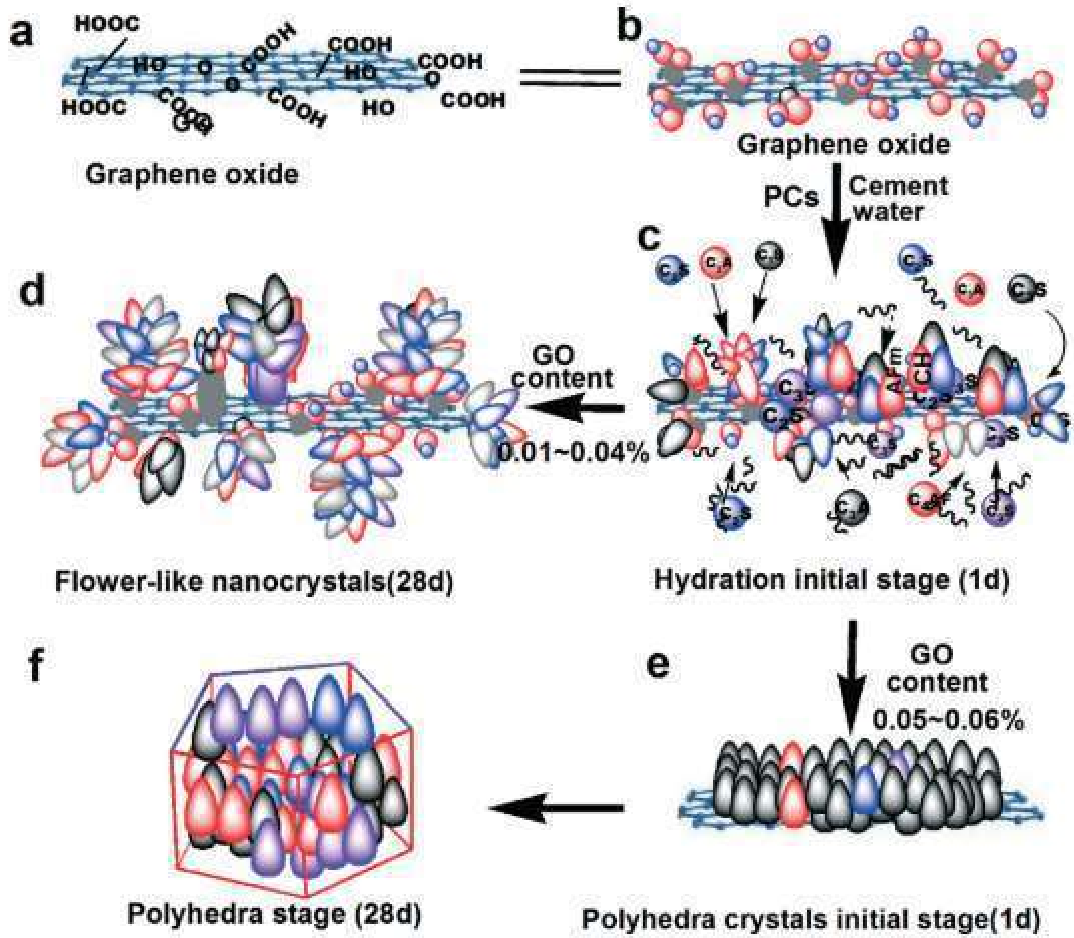


Figure 2.6: By incorporating GO into concrete, hydration crystal formation and regulation are controlled [20]

Lv et al. [18] found that the nucleating sites became too abundant to sustain the production of isolated C-S-H (calcium silicate hydrate) crystals when the concentration of GO (graphene oxide) in cement above 0.04% by weight of cement (bwoc). Instead, the C-S-H particles stuck together and crystallised into polyhedral crystals that resembled columns.

Instead of flower-like crystals, polyhedral column-like crystals formed, which suggests that the C-S-H particles were arranged and packed differently in the cement matrix. The packing and bonding of the cementitious matrix with the aggregates may be modified, which might have an impact on the mechanical qualities of the concrete[18].

According to Lv et al.[18]–[20], the polyhedral column-like crystals formed when the concentration of graphene oxide (GO) in cement exceeded 0.04% by weight of cement (bwoc) have shown to contribute more significantly to the compressive strength of concrete. However, it has been shown that the flower-like crystal formation connected to GO increases concrete's tensile strength.

According to Lv et al. [18] It is discovered that at low GO dosages (0.03%) and high dosages (>0.03%), polyhedral or lamellar crystals are more noticeable than flower-like crystals[18].

Lv et al. [20] has been shown that the presence of graphene oxide (GO) nanosheets causes the production of both flower-like and polyhedron-like crystals in investigations employing hardened cement pastes with various amounts of GO. These crystal formations are more common when there is a higher GO level in the cement, especially when the GO content is between 0.01% and 0.06% by weight[20].

The study of Lv et al. [19] findings show that adding graphene oxide (GO) nanosheets to cement composites significantly affects the growth of flower-shaped crystals and the resulting enhancement of tensile and flexural strength [19].

These results show that GO concentration has a substantial role in determining the crystal shape and enhancing the mechanical characteristics of cement composites, and they offer important information for the development and improvement of concrete materials[12].

Chapter # 3
Research Methodology

3 Methodology

The methodology used to examine the compressive behavior, splitting tensile strength, and flexural strength of graphene oxide concrete is presented in this chapter. Methodology includes materials used and tests to characterize the properties of material, preliminary trails, synthesis of graphene oxide and its characterization using different techniques, casting of GO concrete and then testing. With the use of this systematic methodology, it is anticipated to ensure the precision, validity, and dependability of the research findings and to provide an adequate understanding of the mechanical characteristics of graphene oxide concrete. Figure 3.1 illustrate the methodology used during the study.

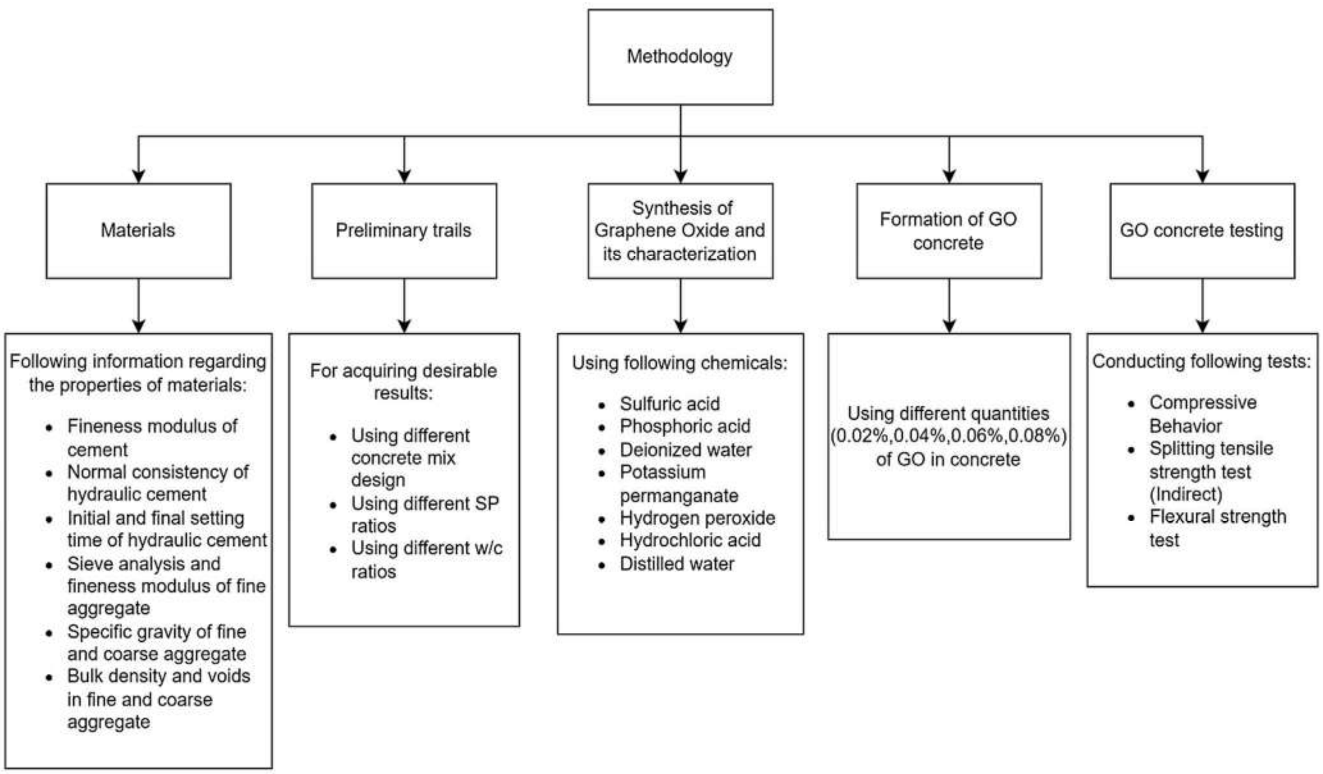


Figure 3.1: Methodology

3.1 Materials

It is essential to comprehend the properties, behavior, and potential applications of the material. The composite material that is the subject of this thesis is composed of graphene oxide as well as regular concrete elements. Different chemicals are used for the synthesis of graphene oxide.

Cement, aggregates (sand and gravel), and water are the three major components of concrete. Typically, Portland cement serves as the cement that holds the particles together. Aggregates gave the concrete mixture volume and solidity, whereas water served as the conduit for hydration and the chemical reaction that allows the concrete to solidify. All of the materials utilized, together with their respective grades and related companies are listed in Table 3.1.1.

Table 3.1.1: Material used in this research

Material	Formula	Company	Purpose
Sulphuric acid	H_2SO_4	Sigma Aldrich	Fulltime intercalant/oxidizer
Graphite (< 20µm, powder)	C	Uni-chem	Primary material
Phosphoric acid	H_3PO_4	Sigma Aldrich	Secondary intercalant/oxidizer
Potassium Permanganate	$KMnO_4$	Sigma Aldrich	Oxidant
Hydrogen Peroxide	H_2O_2	Sigma Aldrich	Chemicals Reaction terminator
Hydrochloric acid	HCl	Sigma Aldrich	Fulltime de-contaminant/washing

For Concrete		
Cement	Dewan Cement Limited	Primary material
Fine aggregate	Local	Primary material
Coarse aggregate	Local	Primary material
Sikament 512 PK	Sika	Superplasticizer

The test title and the ASTM standards were displayed in Table 3.1.2. For cement, tests were performed using various ASTM specifications and the results for cement fineness, consistency, and initial and final setting times were within range. The parameters of fine aggregate (sand) were identified using the relative density, water absorption, sieve analysis, and fineness modulus. For the coarse aggregate, bulk density and voids and relative density and water absorption were used using ASTM specifications. After conducting testing, the results were used in the mix design for the production of the concrete.

Table 3.1.2 Properties of Material

Material	Tests	ASTM standard	Result	Range
Cement	Fineness of hydraulic cement by No. 200 sieve [21]	ASTM C184-94	92 %	90-100%
	Normal consistency of hydraulic cement [22]	ASTM 187-98	28%	25-33%
	Time of setting of hydraulic cement by vicat needle [23]	ASTM C191-08	IST=145 min FST=355 min	IST $\nless$ 45 min FST $\ngtr$380 min
Fine aggregate	Sieve analysis and fineness modulus of fine aggregate [24]	ASTM C136-01	F.M=2.99	F.M=2-3.5
	Relative density (specific gravity) and absorption of fine aggregate (sand) [25]	ASTM C128-07a	Absorption=2.38% Relative density=2.52	Absorption=Max 3% Relative density=2.4-2.9
Coarse aggregate	Bulk density (unit weight) and voids in coarse aggregate aggregate [26]	ASTM C29	CBD=1392.7 kg/m^3 Voids=35.10%	CBD=1200-1750 kg/m^3 Voids=30-45%
	Relative density (specific gravity) and absorption of coarse aggregate [27]	ASTM C127-88	Absorption=0.45% Relative density=2.63	Absorption=Min 2% Relative density=2.5-3

Figure 3.2: Tests performed to determine the properties of material

3.2 Preliminary trails

A series of trial tests were conducted using several mix designs, including ACI 211, BS mix design, and BRE mix design, to get the desired results as shown in Figure 3.3. For ideal water-to-cement ratio, a series of trial-and-error experiments were performed. Different ratios of water and cement were investigated through systematic testing and analysis to identify the most appropriate balance that would produce the necessary properties in the mixture.

Additionally, the trials involved adjusting the percentages of superplasticizer, a kind of admixture used to improve the mixture's workability and flowability. Through these iterative studies, the mix design was improved, and the parameters were optimized to provide the intended effects. Each trial offered comprehensive information and statistics that were used to judiciously modify and enhance later trials. To evaluate the effectiveness of various mix designs and admixture ratios, this approach required comprehensively examining the behavior of the components, measuring critical parameters, and evaluating overall performance.

Figure 3.3: Preliminary trails performed to get the desire results

3.3 Synthesis of graphene oxide (GO) and its characterization

A common method for creating graphene oxide (GO) is the Hummers' process. This method involves mixing concentrated sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) with high-quality graphite in a reaction beaker. The acid mixture is used as an oxidising agent in the following oxidation process.

To begin the oxidation, potassium permanganate ($KMnO_4$) is gradually added to the acid mixture while being continually agitated. Graphene oxide is produced as a result of the oxidation of the graphite during this procedure. To prevent combustion, the reaction temperature is controlled to make sure it never rises beyond 20°C.

After the oxidation process, add hydrogen peroxide (H_2O_2) to the reaction mixture. H_2O_2 minimizes the quantity of pollutants present by serving as a reducing agent and helps in lowering the surplus permanganate and residual acid.

Centrifugation and sonication were used several times to wash out any leftover acids and impurities from the recovered graphene oxide in a diluted solution of hydrochloric acid (HCl) and deionized water. The desired result will be obtained following oven drying.

In order to fully understand the structure, qualities, and properties of graphene oxide, it is essential to characterize it. To investigate various characteristics of graphene oxide, several techniques are used including FTIR and XRD.

3.3.1 Synthesis of HGO

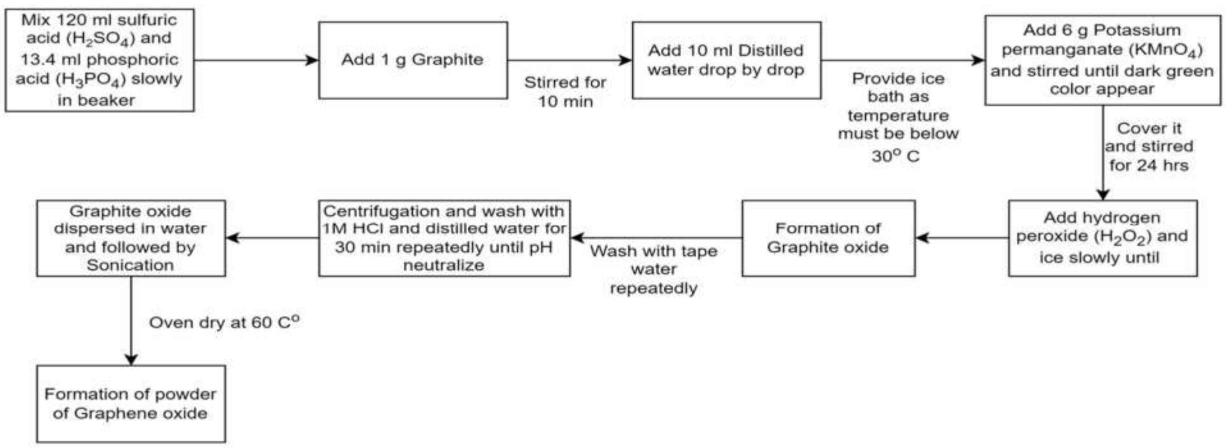


Figure 3.4: Synthesis of HGO

According to Taimur et al.[28] procedure for synthesis of graphene oxide (GO) is as ; For high-hydroxyl graphene oxide (HGO) as per Marcano et al. [11] 13.4 mL 85% phosphoric acid (H_3PO_4 , Sigma Aldrich) was added to 120 mL of 95%–97% concentrated sulphuric acid (H_2SO_4 , Sigma Aldrich) (9:1 ratio) and the mixture was allowed to cool to 20 ºC. The mixture was stirred at 300 rpm for 10 min to allow intercalation after 1 g of graphite powder (20 m UNI-CHEM) was added. The intercalated graphite mixture was gradually added 6 g of solid potassium permanganate ($KMnO_4$; Sigma Aldrich; 6 wt. equivalent) over the course of 5 minutes after the initial 10 minutes. The mixture warmed to around 35 ºC during this time, and then it was stirred continuously for 24 hours at 20 ºC room temperature in a fume hood.

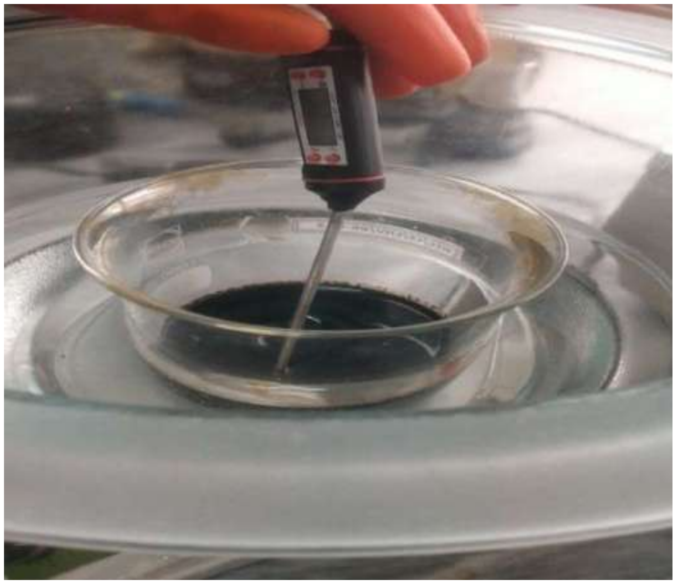


Figure 3.5: Providing water bath to keep the temperature below 40 ºC and adding slowly $KMnO_4$

The temperature was not increased as per Chen et al. findings [13] where keeping a low temperature typically increases the yield of GO. After 24 h, 30% hydrogen peroxide (H_2O_2 , Sigma Aldrich) was added drop-wise alternating with 135 mL of ice cubes to keep the temperature below 60 ◦C. For termination, it is found only 3.5 mL of H_2O_2 was required for the mix to turn pale yellow, and subsequent addition of H_2O_2 resulted in no color change or rise in temperature. The solution was allowed to cool to room temperature and decontamination process was initiated, first by centrifuging each solution at 6000 rpm for 30 min, after which the supernatant was discarded.

Figure 3.6: Samples of HGO for washing

The filtrate was washed with 1 M HCl and centrifuged at 6000 rpm for 30 minutes, after which the filtrate was extracted and subjected to one more round of washing and centrifugation with 1 M HCl. Then the filtrate was washed with distilled water and centrifuged (6000 rpm) for 30 min, and this step was repeated one more time. After final centrifugation, the filtrate was added to 100 mL distilled water and stirred manually until all visible particles were mixed evenly. It was then placed in an ultrasonicating bath and sonicated for 20 min (Elma Transonic 30 kHz, 40% intensity). Finally, distilled water was added until total volume reached 500 mL.

Figure 3.7: Appearance of light brown HGO after washing and centrifugation

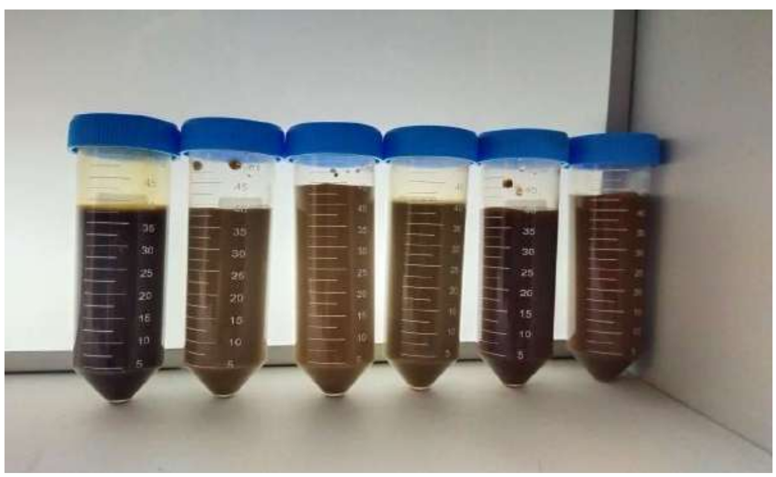


Figure 3.8: Sample of HGO after sonication having concentration of 0.723g for 15 ml

3.3.2 FTIR

Fourier Transform Infrared Spectroscopy (FTIR) is a powerful analytical technique used to study the molecular vibrations and functional groups present in a sample. In FTIR analysis, a beam of infrared light is passed through a sample, and the resulting spectrum is obtained by measuring the absorption or transmission of the light at different wavelengths. The chemical composition and structure details of a variety of materials, including organic compounds, polymers, and inorganic materials, are usefully revealed by FTIR investigation. It can recognize functional groups, spot contaminants, and find out whether a molecule contains particular bonds. An illustration of the FTIR spectrum often takes the form of a plot showing how infrared light transmittance or absorption changes with wavenumber, which is the reciprocal of wavelength. At particular wavenumbers, several functional groups exhibit distinguishing absorption bands that enable their identification and investigation[12].

A common analytical method for characterizing Graphene oxide (GO) to understand its chemical composition and functional groups is Fourier Transform Infrared Spectroscopy (FTIR). The FTIR study of GO reveals a number of distinguishing characteristics in its spectrum.

The presence of hydroxyl (O-H) groups is indicated by a broad, strong peak in the region of 3200-3600 cm-1 in the FTIR spectrum of GO. This peak is associated with the stretching vibration of the O-H bonds, which are widely distributed on the GO surface as a result of oxidation[12].

In the region of 1700–1750 cm-1, a second distinct peak can be seen, which corresponds to the stretching vibration of carbonyl (C=O) groups. The presence of carboxyl and/or carbonyl functional groups as a result of graphene's oxidation is indicated by this peak.

The stretching vibration of the C-O bonds is often associated with a peak in the 1050–1200 cm-1 range in the FTIR spectrum of GO. This peak represents the formation of epoxy (C-O-C) and/or hydroxyl (C-OH) groups during oxidation on the GO surface.

In the FTIR spectrum of GO, the distinctive peak of pure graphene at about 1600–1650 cm-1, which corresponds to the stretching vibration of carbon–carbon (C=C) bonds, is often expanded and moved to a lower wavenumber. This change denotes the entry of functional groups containing oxygen, leading to a reduction in the sp2 carbon concentration[12].

Other peaks associated with particular functional groups, such as alkoxy groups (C-O-R), ether groups (C-O-C), and carboxylic acid groups (O-H stretching and C=O stretching), may also be visible in the FTIR spectrum of GO in addition to these noticeable peaks.

3.3.3 XRD

X-ray Diffraction (XRD) is a technique used to analyze the atomic and molecular structure of materials. It is based on the principle that when a crystalline solid is exposed to X-rays, the X-rays are diffracted by the crystal lattice, resulting in a pattern of constructive and destructive interference. By measuring the angles and intensities of the diffracted X-rays, valuable information about the material's crystal structure, lattice parameters, and phase composition can be obtained. A beam of X-rays is pointed at the sample during the XRD process, and the angles at which the diffracted X-rays are detected are then measured. The wavelength of the X-rays employed in XRD is usually on the order of angstroms (10^-10 metres), which is similar to the distance between atoms in a crystal lattice. At particular angles dictated by Bragg's rule, constructive interference occurs as the X-rays interact with the atoms in the lattice:

$$n\lambda = 2d \sin(\theta)$$

where d is the crystal lattice's interplanar spacing, X-ray wavelength, d is the order of diffraction, and is the diffraction angle. A diffraction pattern is formed by adjusting the angle of detection and measuring the intensity of the diffracted X-rays, and it is representative of the material's crystal structure. The pattern is formed consisting of peaks that represent the various crystal lattice planes that diffract X-rays at particular angles. There are several ways to analyze the diffraction pattern, including indexing the peaks to figure out the crystal system's lattice parameters, enhancing the data to get precise atomic positions, and comparing the pattern to well-known reference patterns to figure out which phases are present in the sample [12].

GO samples can be subjected to XRD examination to find out about their level of oxidation, interlayer spacing, and general crystalline structure.

The sample is made ready for the XRD examination of GO by dispersing it in an appropriate solvent to create a suspension. A thin film or powder is created by drop-casting this suspension onto a sample holder or substrate and letting it dry.

The XRD equipment is configured by correctly aligning the parts, calibrating the device, and choosing appropriate parameters such the X-ray source, detector kind, and measurement geometry. Based on the anticipated diffraction pattern and the precise information required for selecting these parameters[12].

The GO sample is placed in the XRD apparatus after it is ready, and data collection starts by scanning it over a variety of angles (2θ). Diffraction peaks that match the interplanar spacing and crystallographic structure are produced as a result of the X-rays' interactions with the GO structure.

Afterwards, using specialized software or analysis procedures, the resulting diffraction pattern is examined. To determine the interlayer spacing and crystalline phases contained in the GO sample, the diffraction peaks are recognized and examined. The positions, intensities, and forms of the peaks reveal important details regarding the distribution of oxygen-containing functional groups and the degree of oxidation[12].

A comparison with reference patterns or databases is done to assign the detected diffraction peaks. This aids in pinpointing specific crystallographic phases or structures within the GO sample, providing an understanding of the composition and level of oxidation of the material.

3.4 GO Concrete

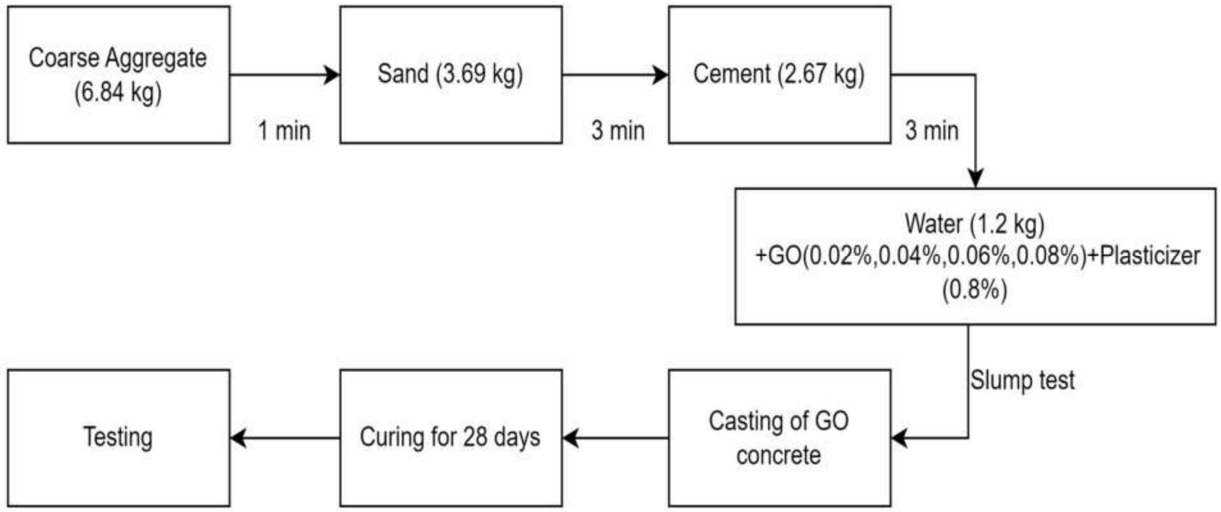


Figure 3.9: Formation of GO concrete (1:1.4:2.5)

BRE concrete mix design manual (Teychenné et al. 1997) was employed, target strength of 40 MPa with slump value of 30mm was set.

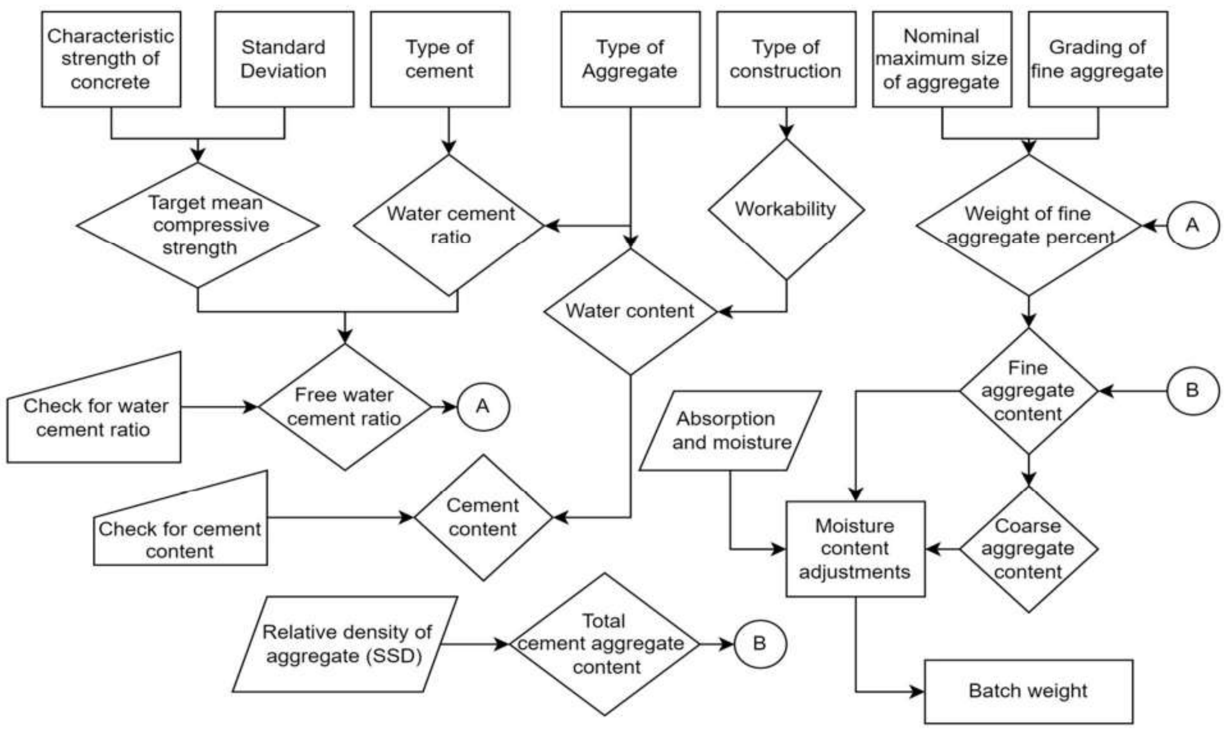


Figure 3.10: BRE mix design (Teychenné et al. 1997)

For the formation of GO concrete, different GO contents (0.02%, 0.04%, 0.06%, 0.08%) were used along with superplasticizer. After different trial and error 0.8% superplasticizer was considered to be appropriate ratio for the concrete samples to ensure sufficient workability. The concrete mixture was prepared by combining cement, aggregates(fine and coarse) and water (1/3 of water mixed with GO and Superplasticizer and 2/3 of water mixed with superplasticizer).

Figure 3.11: Mixing of cement and aggregates with water in a batch mixer

The mixture was poured into moulds after it became homogeneous. Compression and splitting tensile strengths were tested using cylindrical moulds with dimensions of 150 mm in diameter and 300 mm in height. Two separate moulds, one measuring 300*100*100 mm and the other 508*102*102 mm, were used for the flexural test. Before pouring the concrete into the moulds, a slump test was carried out using the ASTM C143 criteria to determine the slump value [29] as shown in Figure 3.12.

Figure 3.12: Slump test

The samples were moulded after 20–24 hours of casting, and they were placed in a water tank for 28 days of curing as shown in Figure 3.13, which will be enough time for the concrete to reach full strength. Later, tests were conducted.

Figure 3.13: Concrete samples in water tank for curing

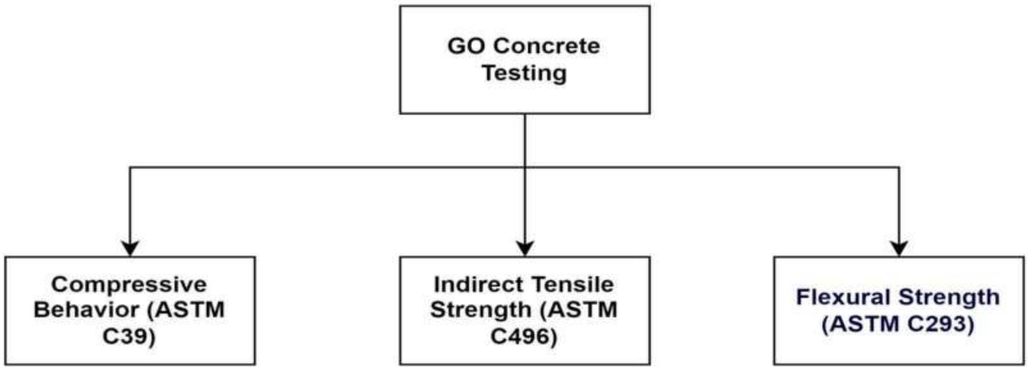
3.5 GO Concrete Testing

The performance and characteristics of graphene oxide (GO) concrete are assessed through extensive testing protocols. To evaluate the impact of GO on the overall behavior of the concrete composite, the testing covers a variety of mechanical, physical, and durability factors.

Compressive strength testing is typically performed to evaluate the compressive behavior. During this method, specimens are put under increasing compressive pressures until they fail. Throughout the test, a continuous record of the load and related deformation is kept. The specimen's ultimate compressive strength, or the highest load it can withstand before failing, is computed. In addition, important parameters like ductility, toughness, and modulus of elasticity can be calculated by graphing the load vs. deformation and studying the stress-strain behavior of GO concrete.

Additionally, the splitting tensile strength test is carried out to evaluate GO concrete's ability to ability to withstand tensile forces that are delivered perpendicular to the direction of loading. This test helps to evaluate how GO affects the concrete's ability to bear tensile stresses and prevent cracking.

To evaluate GO concrete's ability to resist bending or flexural stresses, flexural strength testing is also determined. Deflections and ultimate loads are measured after applying a bending moment to the specimens. The performance of the GO concrete under bending conditions can be evaluated by this test, which is crucial for beam.



3.5.1 Compressive Behavior

The test required that any surface impurities or surface contaminants from the ends of the GO concrete specimens be eliminated. A plaster of Paris coating and a flat grinding machine were used to ensure the ends were parallel and even loading during testing as shown in Figure 3.14.

Figure 3.14: Applying Plaster of Paris coating for flat ends

The ASTM C39 requirements were used for the test [30]. The cylindrical specimen was measured before testing. The sample was then put into the apparatus and suitably positioned for axial loading as shown in Figure 3.15.

Figure 3.15: Specimen placement to assess specimen compressive behavior

The GO concrete specimen was then gradually subjected to compressive loading with displacement control at a constant rate of 0.3 mm/min. After fracture, machine was allowed to continue deforming the sample to observe the compressive behavior. The machine automatically

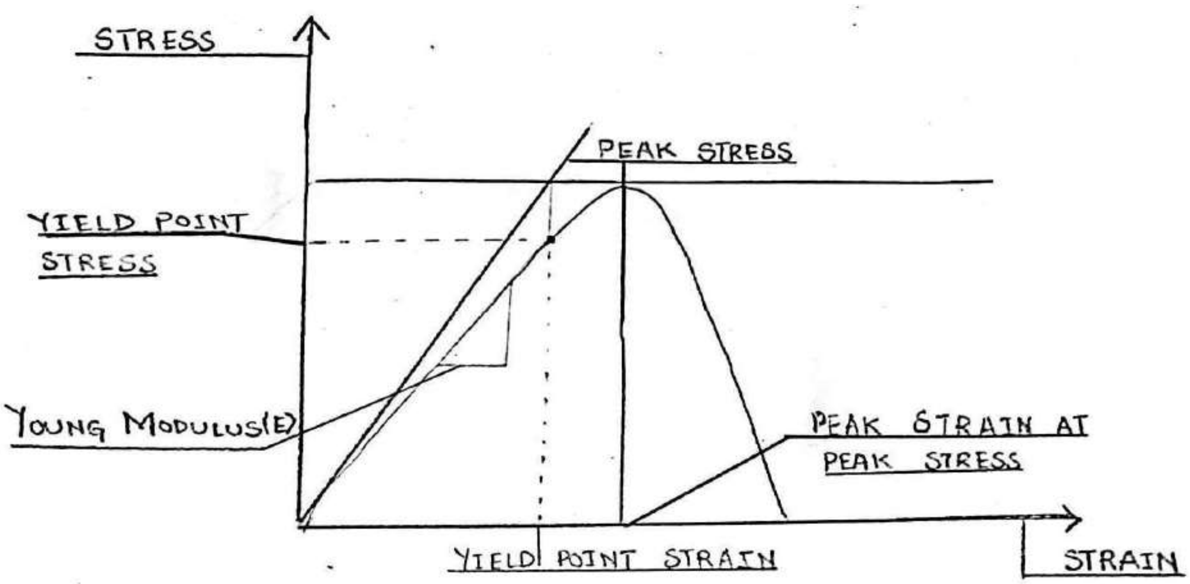


Figure 3.16: Stress-strain graph

stops putting load once either breaks the inhibition of 1% and/or break detection of 80% was reached. The recorded load and displacement values were imported to excel and corresponding stress-strain graphs were drawn. The final stress-strain graphs were aligned with zero strain at zero stress and a moving average function was used to smooth the graph.

The strain-stress graph was used to examine young modulus (E) ,toughness and ductility-related properties consisting of the area under the curve, the strain at failure, the strain at failure, and the yield strength from figure 3.16,3.17.

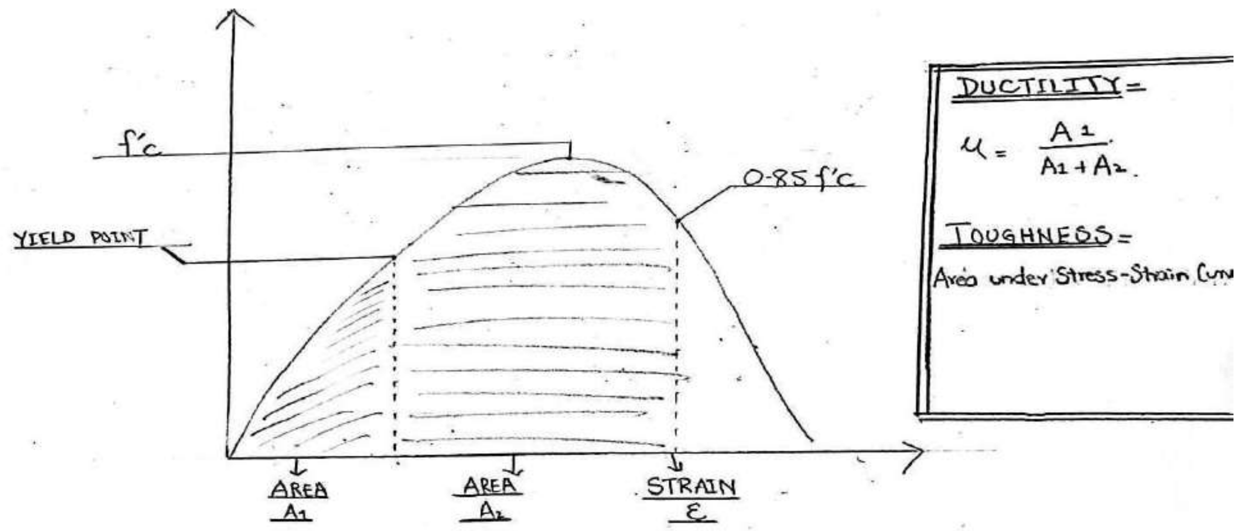


Figure 3.17: Graph of the stress-strain relationship to assess the toughness and ductility

3.5.2 Splitting Tensile Strength Test

The ASTM C496 requirements were used for the test [31]. The cylindrical specimen was mounted on the testing machine's loading fixture once the UTM was set, and it was then properly oriented for diametric loading as shown in Figure 3.16. 106 KN/min of force was applied steadily until the specimen fractured. The applied load was perpendicular to the cylinder's axis. The maximum load applied to the specimen during the test was then recorded, and the appearance of the concrete after failure was observed in order to identify the failure pattern.

Figure 3.18: Placing specimen into UTM for splitting tensile strength test

3.5.3 Flexural strength test

Two different-sized beams were employed for the flexural strength test shown in Figure 3.19. Load was applied to the centre of the specimen during a three-point bending test. The ASTM C293 specifications [32] were used to conduct the test. Prior to testing, specimens were marked and calibrated. The specimen was then carefully centred and precisely aligned before being set on the flexural testing machine's supports. Until until the specimen fractured, 2 KN of load was applied continuously. The greatest applied load that the specimen could withstand before breaking was noted in the data. The specimen was again measured after failure.

Figure 3.19: Placing specimens into UTM for flexural strength test using simple beam with center-point loading

Chapter # 4
Results and Discussions

4 Results

This chapter presents the results obtained from the experimental investigation conducted on the Graphene Oxide (GO) reinforced concrete samples. The objective was to evaluate the impact of GO on the mechanical properties of concrete. The results demonstrate notable improvements in the mechanical performance of GO-reinforced concrete compared to the control samples.

4.1 Workability Tests

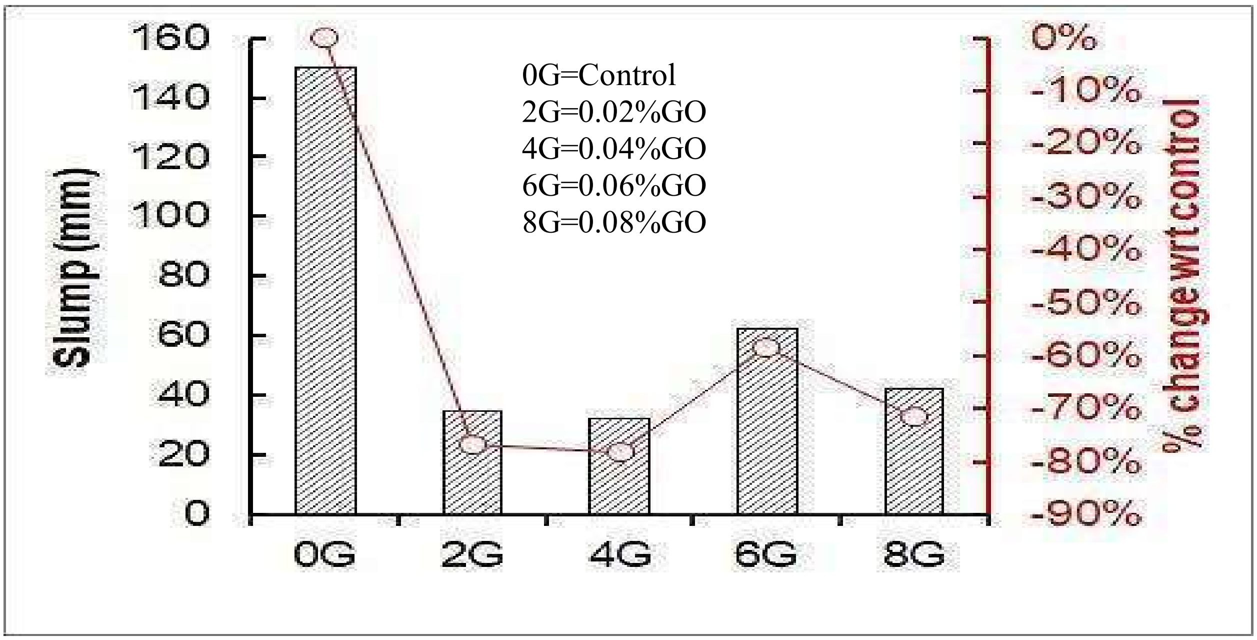


Figure 4.1: Graph between Slump value and GO contents

Workability assessment is essential in understanding the concrete's ability to flow and maintain its shape during the construction process. This section presents the results of the slump test conducted on concrete samples containing varying concentrations of GO, aiming to analyze the impact of GO on the workability of the concrete.

The control sample, which did not contain GO, exhibited a slump value of approximately 150 mm. This value represents the baseline workability of the concrete, indicating its initial flow and consistency.

Concrete samples with a GO concentration of 0.06% demonstrated the maximum slump value, measuring approximately 60 mm. The addition of GO at this concentration led to a significant decrease in slump compared to the control sample. The lower slump value indicates a reduction in the concrete's flowability and suggests a higher degree of cohesiveness and resistance to deformation.

Among the tested samples, the lowest slump value was observed in the concrete samples with a GO concentration of 0.04%, measuring approximately 35 mm. This concentration resulted in a substantial decrease in slump compared to both the control sample and the sample with a higher GO concentration. The decreased slump value indicates a significant reduction in the concrete's flowability and suggests a higher level of stiffness and resistance to deformation. 4.2.4 Trend analysis the trend analysis of slump values across different GO concentrations does not indicate a specific trend. However, it is noteworthy that all the slump values observed with GO additions were lower than the control sample. This implies that the inclusion of GO, regardless of the concentration, had a stiffening effect on the concrete and reduced its flowability.

The assessment of workability through the slump test reveals that the addition of Graphene oxide (GO) to concrete has a significant influence on its flow characteristics. The results indicate that the inclusion of GO led to a reduction in slump values compared to the control sample. This suggests an improvement in the concrete's cohesiveness, stiffness, and resistance to deformation. However, no specific trend was observed in the slump values with varying GO concentrations. Further research is recommended to understand the underlying mechanisms and optimize the GO concentration for achieving the desired workability without compromising other mechanical properties. The use of nanomaterials, such as GO, shows potential for enhancing the workability of concrete and facilitating its handling and placement in construction applications.

4.2 Fourier Transform Infrared Spectroscopy (FTIR) analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was performed to investigate the chemical composition and functional groups present in the Graphene Oxide (GO). The FTIR spectrum of GO typically exhibits several characteristic peaks, and one of the prominent peaks occurs around 1100 cm^-1. The peak observed at approximately 1100 cm^-1 corresponds to the stretching vibrations of the oxygen-containing functional groups present in the GO structure. These functional groups can include hydroxyl (-OH), epoxy (-O), and carboxyl (-COOH) groups, among others. These oxygen functional groups are introduced during the oxidation process used to produce GO from graphite. The intensity and shape of the peak at 1100 cm^-1 provide information about the degree of oxidation and the presence of different functional groups.

A higher peak intensity suggests a higher concentration of oxygen-containing functional groups, indicating a higher level of oxidation in the GO sample. Conversely, a lower peak intensity indicates a lower degree of oxidation or a lower concentration of oxygen-containing groups. The shape of the peak can also provide insights into the chemical structure and bonding of the functional groups. The specific pattern observed in the 1100 cm^-1 region can be attributed to the vibrations of carbon-oxygen (C-O) bonds and carbon-carbon (C-C) bonds adjacent to the oxygen-containing groups. The peak shape can help determine the types of functional groups present and their bonding environment.

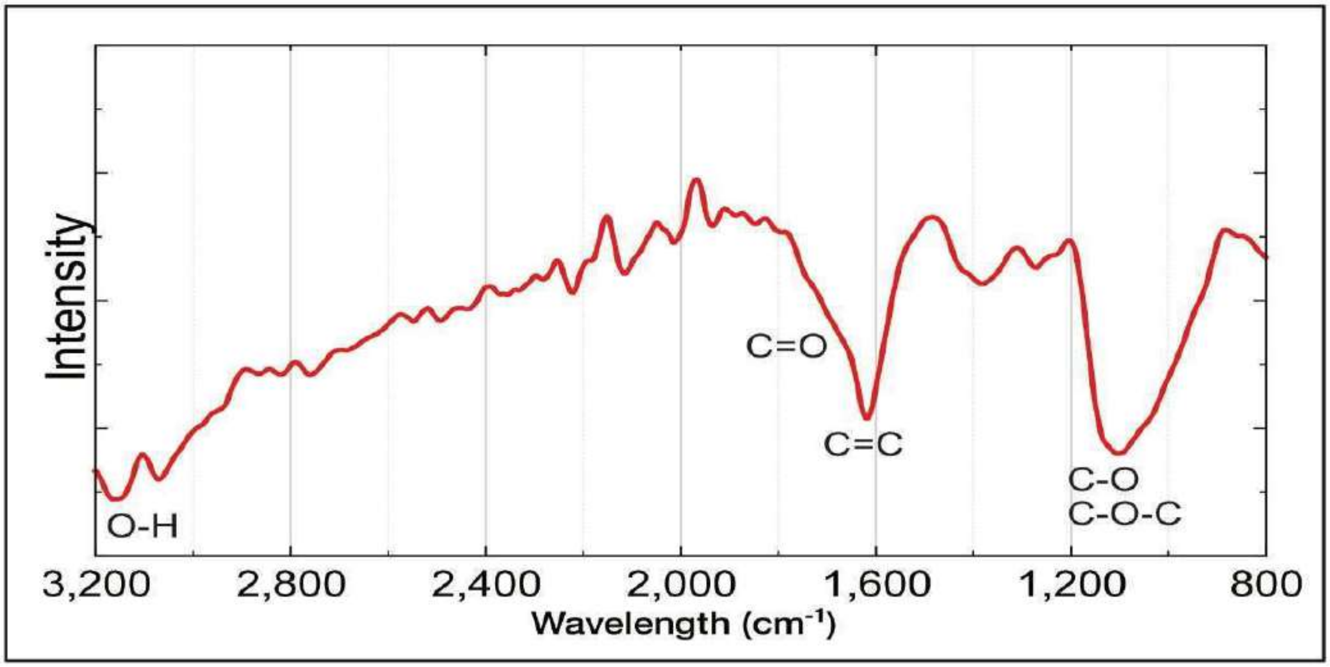


Figure 4.2: FTIR result of GO sample

It is important to note that the interpretation of FTIR spectra should be considered in conjunction with other analytical techniques and characterization methods to gain a comprehensive understanding of the GO sample's chemical composition and structure. In summary, the FTIR analysis of the Graphene Oxide (GO) sample revealed a characteristic peak around 1100 cm^-1, which corresponds to the stretching vibrations of oxygen-containing functional groups. The intensity and shape of this peak provide valuable information about the degree of oxidation and the presence of different functional groups in the GO structure. Understanding the FTIR results helps in elucidating the chemical composition and bonding environment of GO, which are important factors influencing its properties and potential applications.

4.3 X-ray diffraction (XRD)

X-ray diffraction (XRD) analysis was conducted to examine the crystallographic structure of the Graphene sample. The XRD pattern obtained typically shows characteristic peaks that provide insights into the arrangement and orientation of the graphene layers. In this case, the XRD pattern exhibits a prominent peak at approximately 9.8 degrees.

The peak observed at 9.8 degrees corresponds to the (002) reflection peak of graphene. This peak is indicative of the interlayer spacing between adjacent graphene layers. In a pristine graphene sample, this peak is expected to be sharp and intense, suggesting a highly ordered and well-stacked graphene structure.

The position and intensity of the (002) peak can provide valuable information about the quality and structural characteristics of graphene. A shift in the position of the peak towards higher angles indicates a decrease in the interlayer spacing, suggesting a higher degree of graphene layer stacking. Conversely, a shift towards lower angles suggests an expansion of the interlayer spacing.

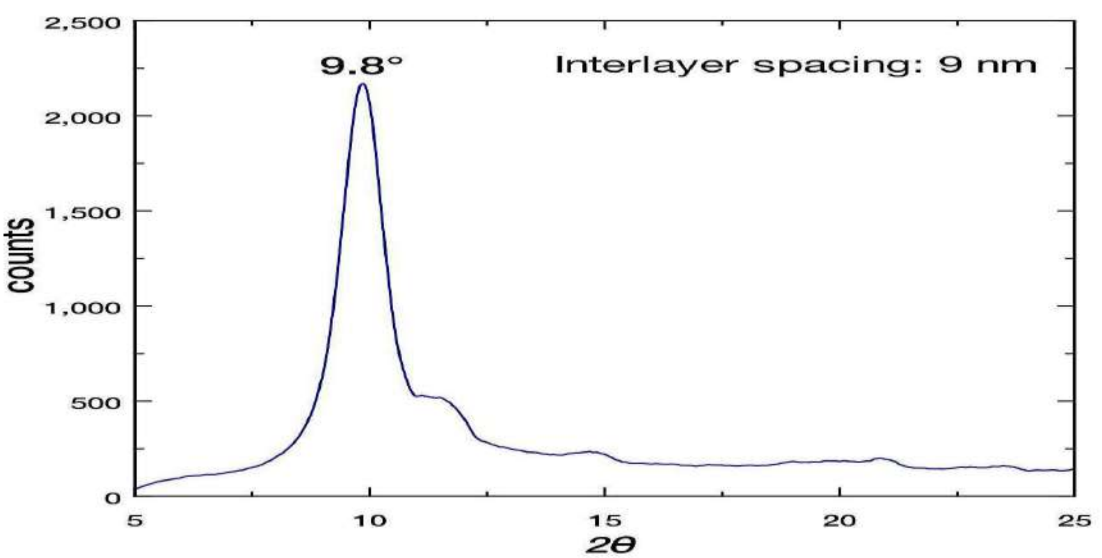


Figure 4.3: XRD result

The broadening or narrowing of the (002) peak can also provide insights into the structural disorder or crystallinity of graphene. A broadened peak suggests the presence of defects or disorder in the graphene layers, while a sharp and narrow peak indicates a more crystalline and well-defined structure. The XRD pattern can be presented graphically as a plot of intensity (or counts) versus the diffraction angle (2θ). The peak at 9.8 degrees will appear as a distinct and prominent peak on the XRD graph.

In your thesis, you can include the XRD graph showing the intensity versus 2θ angle plot, with the peak at 9.8 degrees clearly labeled. You can also discuss the significance of this peak in terms of the crystalline structure and interlayer spacing of graphene. Additionally, you can analyze any observed shifts or broadening of the peak to provide insights into the quality and structural characteristics of the graphene sample.

Overall, the XRD analysis of the Graphene sample revealed a prominent (002) peak at approximately 9.8 degrees, indicating the interlayer spacing and crystalline arrangement of the graphene layers. The XRD graph serves as a visual representation of the peak and provides important information about the structural properties of graphene.

4.4 Split Tensile Strength of Concrete Cylinders

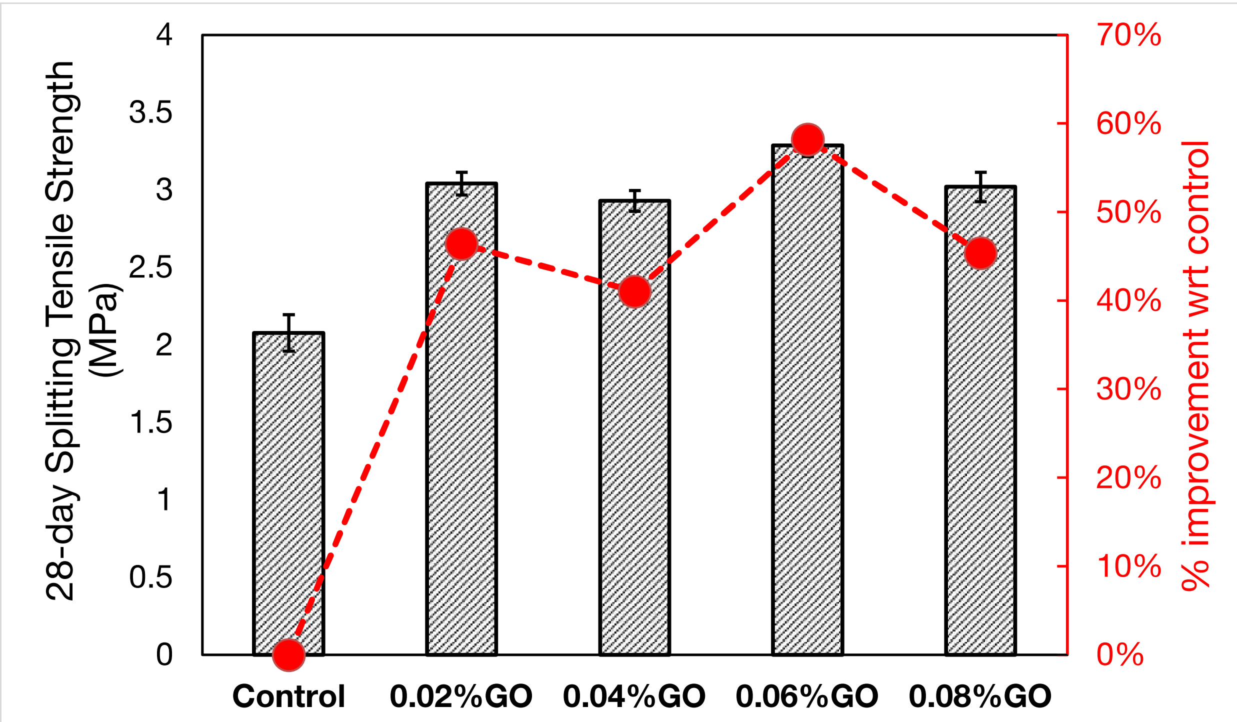


Figure 4.4: 28 days splitting tensile strength of different GO contents

Split tensile strength is a critical parameter that measures the ability of concrete cylinders to resist tensile forces perpendicular to the applied load. This section presents the split tensile strength values obtained from the concrete cylinders incorporating various concentrations of GO, with the objective of assessing the impact of GO on their mechanical behavior.

The control sample, which did not contain GO, exhibited a split tensile strength value of approximately 2.9 MPa. This value represents the baseline strength of the concrete cylinders in resisting tensile forces.

Concrete cylinders with a GO concentration of 0.06% demonstrated the maximum split tensile strength value, measuring approximately 3.3 MPa. The addition of GO at this concentration led to a significant increase in split tensile strength compared to the control sample. The higher split tensile strength indicates an improved ability of the concrete cylinders to resist tensile forces perpendicular to the applied load.

Among the tested samples, the lowest split tensile strength value was observed in the cylinders with a GO concentration of 0.04%, measuring approximately 2.9 MPa. This concentration resulted in a slight decrease in split tensile strength compared to the maximum value. However, even at this lower concentration, the concrete cylinders still exhibited improved strength compared to the control sample.

The trend analysis of split tensile strength behavior across different GO concentrations indicates that the addition of GO led to an overall increase in split tensile strength compared to the control sample. As the GO concentration increased from 0.04% to 0.06%, the split tensile strength also increased. This suggests that there is a positive correlation between the GO concentration and the split tensile strength of the concrete cylinders.

The investigation of split tensile strength in concrete cylinders with the addition of Graphene oxide (GO) reveals significant enhancements in their resistance to tensile forces perpendicular to the applied load. The results demonstrate that the inclusion of GO up to a concentration of 0.06% led to a notable increase in split tensile strength compared to the control sample. These findings highlight the potential of GO for improving the tensile behavior of concrete cylinders. Further research is recommended to explore the underlying mechanisms and optimize the GO concentration to achieve even greater improvements in split tensile strength. The utilization of nanomaterials, such as GO, shows promise for enhancing the performance and durability of concrete structures.

4.5 Flexural Strength: 28-Day Test Results

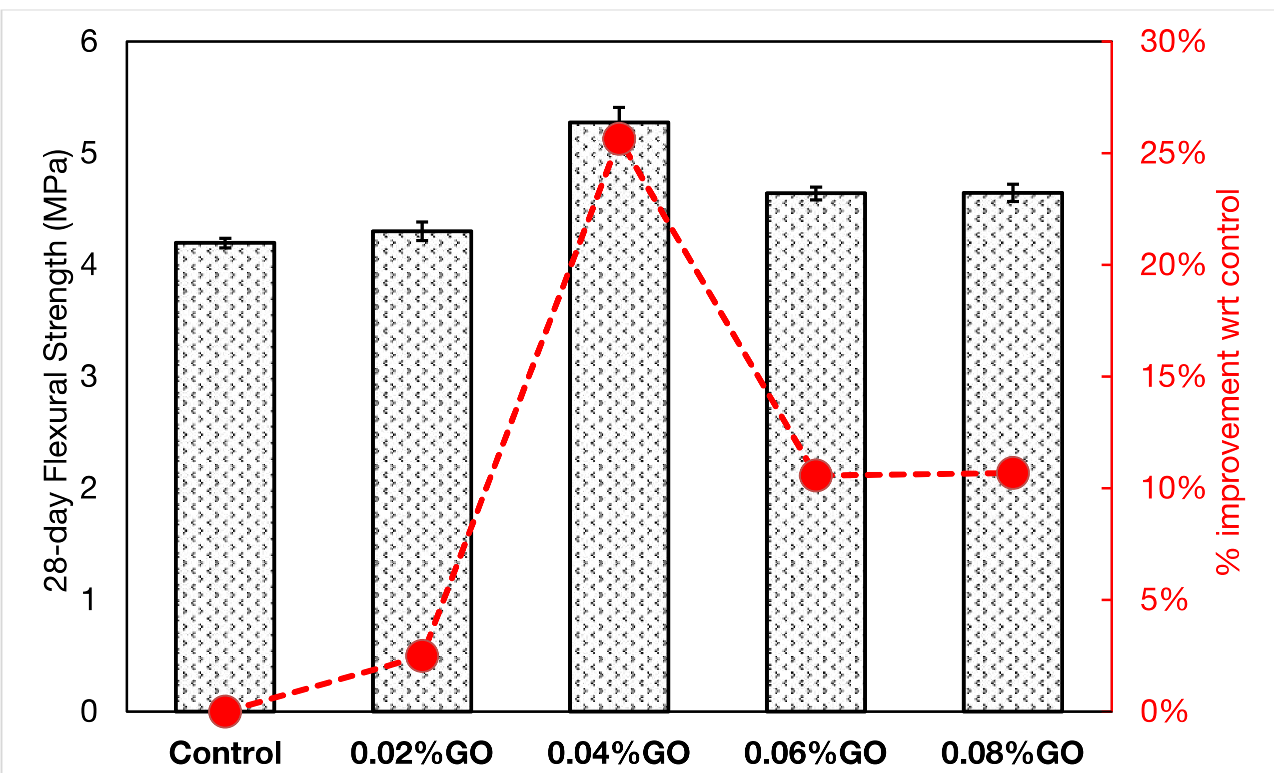


Figure 4.5: 28 day flexural strength of GO contents

The assessment of flexural strength is essential in understanding the concrete's ability to withstand bending forces and maintain its structural integrity. This section presents the results of the 28-day flexural strength test conducted on concrete samples containing varying concentrations of GO, aiming to analyze the impact of GO on the concrete's flexural performance.

The control sample, which did not contain GO, exhibited a flexural strength value of approximately 4.2 MPa after 28 days of casting. This value represents the baseline flexural strength of the concrete without any GO additions.

Concrete samples with a GO concentration of 0.04% demonstrated the maximum flexural strength, measuring approximately 5 MPa after 28 days of casting. The addition of GO at this concentration led to an improvement in flexural strength compared to the control sample. The higher flexural strength indicates an enhanced resistance of the concrete to bending forces and a reduced susceptibility to cracking.

Among the tested samples, the lowest flexural strength value was observed in the concrete samples with a GO concentration of 0.02%, measuring approximately 4.3 MPa after 28 days of casting. This concentration still exhibited improved flexural strength compared to the control sample but to a lesser extent than the sample with a higher GO concentration.

The trend analysis of flexural strength values across different GO concentrations indicates a general improvement in flexural strength with the addition of GO. The flexural strength values increased from the control sample to the sample with a GO concentration of 0.04% and then slightly decreased for the sample with a GO concentration of 0.02%. This suggests that the optimal GO concentration for enhancing flexural strength lies within the range of 0.04%.

The assessment of flexural strength after 28 days of casting reveals that the addition of Graphene oxide (GO) to concrete has a positive influence on its structural performance. The results indicate an improvement in flexural strength compared to the control sample, with the highest value observed at a GO concentration of 0.04%. This implies an increased resistance of the concrete to bending forces and a reduced risk of cracking. Further research is recommended to optimize the GO concentration and investigate its long-term effects on the flexural performance of concrete.

4.5.1 Flexural Strength of 350 mm concrete beams

Flexural strength is a crucial parameter that determines the ability of 350mm concrete beams to resist bending and withstand applied loads. This section presents the flexural strength values obtained from the 350mm concrete beams incorporating various concentrations of GO, with the objective of assessing the impact of GO on the flexural strength behavior.

The control sample, which did not contain GO, exhibited a flexural strength value of approximately 4.2 MPa. This value represents the baseline strength of the 350mm concrete beams in resisting bending forces.

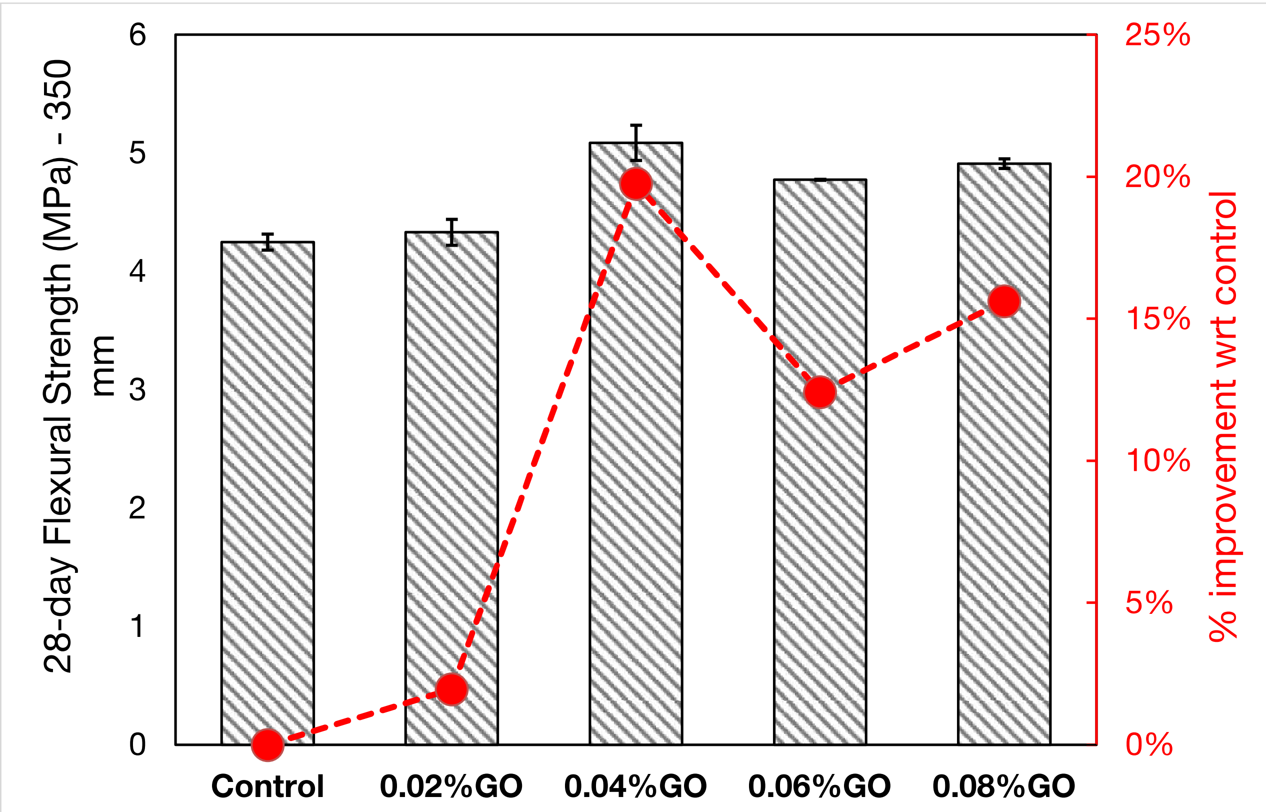


Figure 4.6 : 28 day flexural strength of GO contents for 350mm beams

Concrete beams with a GO concentration of 0.04% demonstrated the highest flexural strength value, measuring approximately 5 MPa. The inclusion of GO at this concentration led to a significant increase in flexural strength compared to the control sample. The higher flexural strength indicates an enhanced ability of the 350mm concrete beams to withstand bending forces and resist deformation.

Among the tested samples, the lowest flexural strength value was observed in the beams with a GO concentration of 0.02%, measuring approximately 4.3 MPa. This concentration resulted in a slight decrease in flexural strength compared to the maximum value. However, even at this lower concentration, the 350mm concrete beams still exhibited improved strength compared to the control sample.

The trend analysis of flexural strength behavior across different GO concentrations indicates that the addition of GO up to a concentration of 0.04% led to an increase in flexural strength compared to the control sample. This trend suggests that there is an optimal concentration range for achieving the maximum flexural strength improvement in the 350mm concrete beams.

The investigation of flexural strength in 350mm concrete beams with the addition of Graphene oxide (GO) demonstrates significant improvements in their ability to resist bending forces. The results indicate that the inclusion of GO up to a concentration of 0.04% led to a notable increase in flexural strength compared to the control sample. This enhancement highlights the potential of GO in enhancing the mechanical properties of 350mm concrete beams. Further research is recommended to explore the underlying mechanisms and optimize the GO concentration for achieving maximum strength improvements in 350mm concrete beam applications. The utilization of nanomaterials, such as GO, holds promise for the development of high-performance and resilient concrete structures.

4.5.2 Flexural Strength of 500mm concrete beams

Flexural strength is a crucial parameter that determines the ability of 500mm concrete beams to resist bending and withstand applied loads. This section presents the flexural strength values obtained from the 500mm concrete beams incorporating various concentrations of GO, with the objective of assessing the impact of GO on the flexural strength behavior.

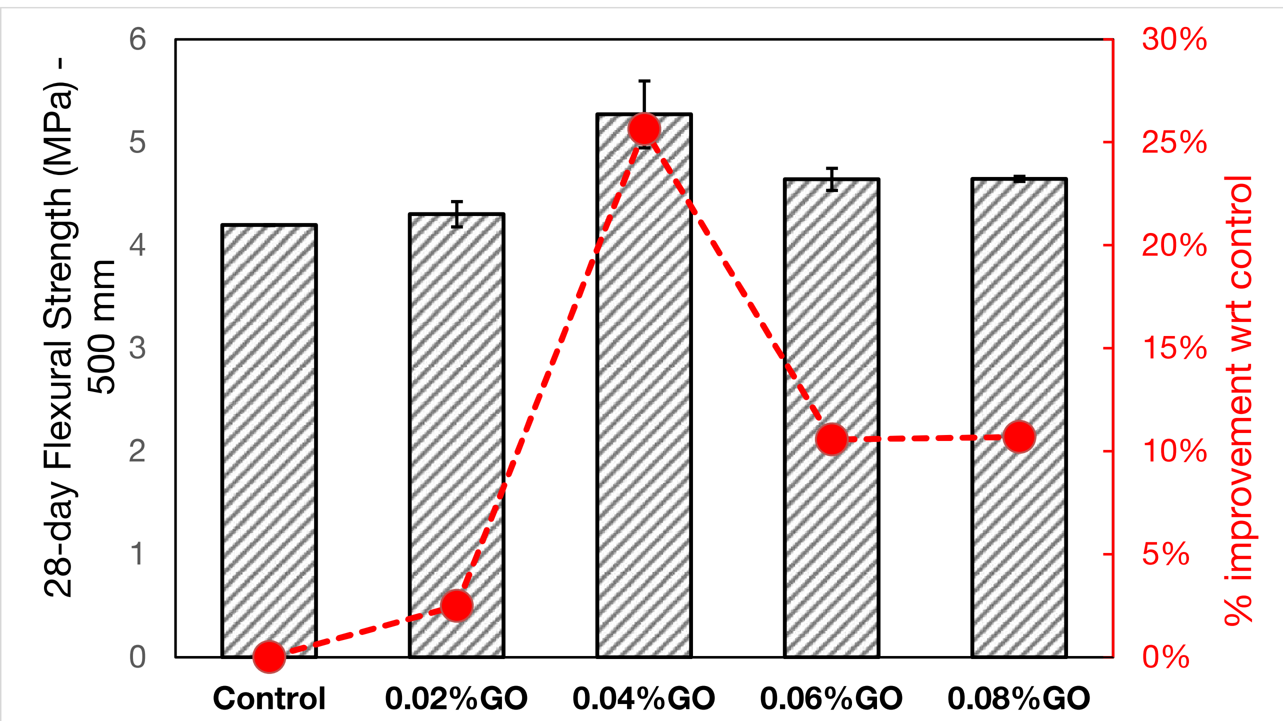


Figure 4.7 : 28 day flexural strength of GO contents for 500 mm beams

The control sample, which did not contain GO, exhibited a flexural strength value of approximately 4.1 MPa. This value represents the baseline strength of the 500mm concrete beams in resisting bending forces.

Concrete beams with a GO concentration of 0.04% demonstrated the highest flexural strength value, measuring approximately 5 MPa. The inclusion of GO at this concentration led to a significant increase in flexural strength compared to the control sample. The higher flexural strength indicates an enhanced ability of the 500mm concrete beams to withstand bending forces and resist deformation.

Among the tested samples, the lowest flexural strength value was observed in the beams with a GO concentration of 0.08%, measuring approximately 4.2 MPa. This concentration resulted in a slight decrease in flexural strength compared to the maximum value. However, even at this lower concentration, the 500mm concrete beams still exhibited improved strength compared to the control sample.

The trend analysis of flexural strength behavior across different GO concentrations indicates that the addition of GO up to a concentration of 0.04% led to an increase in flexural strength compared to the control sample. However, when the GO concentration was further increased to 0.08%, there was a slight decrease in flexural strength. This suggests that there is an optimal concentration range for achieving the maximum flexural strength improvement in the 500mm concrete beams.

The investigation of flexural strength in 500mm concrete beams with the addition of Graphene oxide (GO) demonstrates significant improvements in their ability to resist bending forces. The results indicate that the inclusion of GO up to a concentration of 0.04% led to a notable increase in flexural strength compared to the control sample. However, when the GO concentration was increased to 0.08%, there was a slight decrease in flexural strength. These findings highlight the importance of optimizing the GO concentration for achieving maximum strength improvements in 500mm concrete beam applications. Further research is recommended to investigate the underlying mechanisms and explore the potential of GO for enhancing the mechanical properties of larger-scale concrete structures. The utilization of nanomaterials, such as GO, shows promise for the development of high-performance and resilient concrete beams.

4.4 Compressive Behavior

Compressive strength is a critical mechanical property of concrete, indicating its ability to withstand compressive forces. The compressive strength of concrete samples with different concentrations of GO was assessed at 28 days to evaluate the effects of GO on the strength performance.

The control sample, without the addition of GO, served as the reference point for comparison. It exhibited a compressive strength value of approximately 28 MPa. This value provides the baseline for evaluating the impact of GO on the compressive strength of concrete.

The samples with a GO concentration of 0.04% demonstrated the highest compressive strength, with a maximum value of approximately 36 MPa. This represents an improvement of about 29%

compared to the control sample. The notable enhancement in compressive strength suggests that the inclusion of GO at this concentration level positively influences the structural integrity and load-bearing capacity of the concrete.

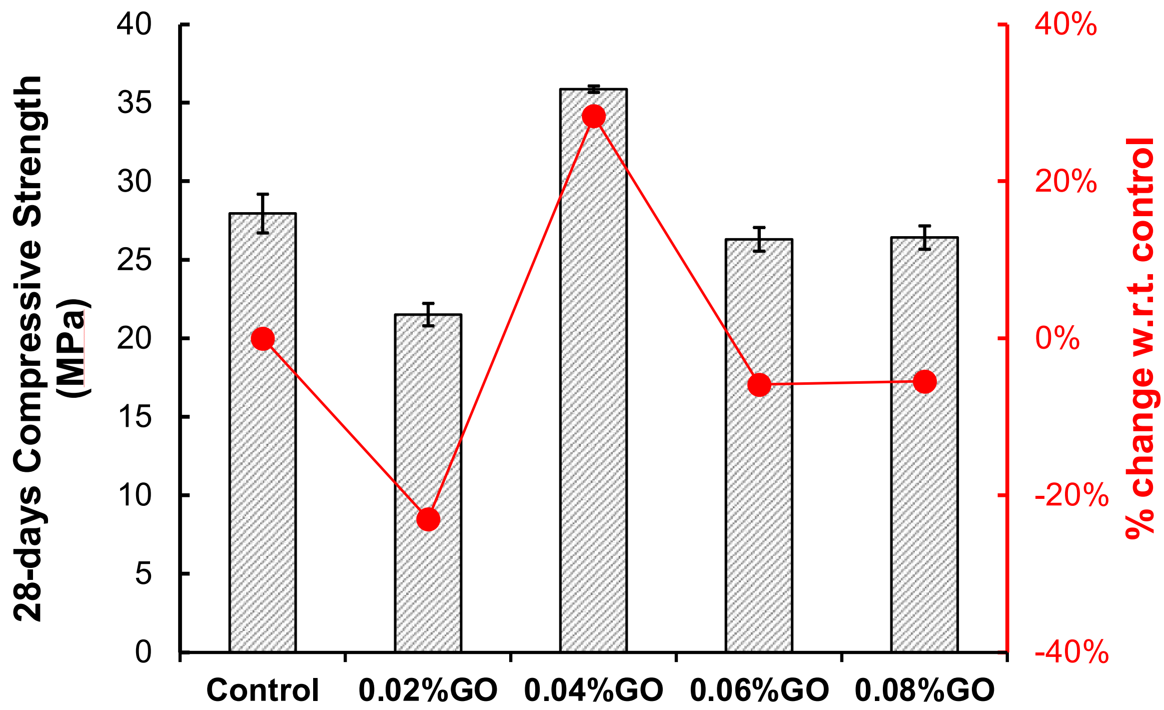


Figure 4.8 : 28 day compressive strength of GO contents

Among the tested samples, the lowest compressive strength was observed in the samples with a GO concentration of 0.02%, with a value of approximately 22 MPa. Although this value is lower than that of the control sample, it still demonstrates acceptable compressive strength. It indicates that even at lower GO concentrations, some improvement in compressive strength can be achieved.

A comprehensive trend analysis of the compressive strength results revealed no specific trend across different GO concentrations. The effects of GO on compressive strength did not show a linear relationship with concentration. However, it is important to note that the maximum compressive strength values were consistently higher than the control sample, suggesting a positive influence of GO on enhancing compressive strength.

The control sample, without the addition of GO, was used as the baseline for comparison. It exhibited a strain-ultimate stress value of approximately 0.005. This value represents the reference point for assessing the influence of GO on the strain-ultimate stress relationship.

The concrete samples with a GO concentration of 0.06% demonstrated the highest strain-ultimate stress value, approximately 0.0051. This slight increase in the strain-ultimate stress indicates a potential improvement in the ductility of the material. Although the change is minimal, it suggests that the incorporation of GO at this concentration level may enhance the ability of the concrete to withstand deformation under compressive forces.

Among the tested samples, the lowest strain-ultimate stress value was observed in the samples with a GO concentration of 0.02%, with a value of approximately 0.002. Despite the lower value compared to the control sample, it still signifies an acceptable strain-ultimate stress relationship. This suggests that even at lower GO concentrations, some enhancement in the ductility and ultimate stress behavior of the concrete can be achieved.

A detailed trend analysis of the strain-ultimate stress relationship indicated no specific trend across different GO concentrations. The effects of GO on the strain-ultimate stress relationship did not exhibit a consistent pattern with concentration. However, it is worth noting that the maximum strain-ultimate stress values were slightly higher than the control sample, indicating a potential enhancement in the ductility of the concrete with the inclusion of GO.

The investigation of the strain-ultimate stress relationship in concrete samples with Graphene oxide (GO) incorporation provides insights into the ductility and ultimate stress behavior of the material. The results indicate a minor improvement in the strain-ultimate stress relationship with GO concentrations of 0.06% and 0.02%. Although no significant trends were observed, these findings suggest the potential of GO to enhance the ductility and deformation resistance of concrete under compressive forces. Further research is necessary to explore the underlying mechanisms and optimize the GO dosage for achieving more pronounced effects. These outcomes contribute to advancing the knowledge of nanomaterials' influence on the mechanical properties of concrete, paving the way for the development of more resilient and durable construction materials.

4.6 Ultimate Stress in Compressive Behavior

The ultimate stress in compressive strength is a vital parameter for assessing the maximum load-carrying capacity and strength of concrete. This section examines the ultimate stress values of concrete samples with varying concentrations of GO, aiming to evaluate the effects of GO on the compressive strength behavior.

The control sample, which did not contain any GO, served as the reference point for comparison. It exhibited an ultimate stress value of approximately 28 MPa. This value represents the baseline strength of the concrete without the addition of GO.

Concrete samples with a GO concentration of 0.04% demonstrated the highest ultimate stress value, measuring approximately 36 MPa. This indicates a notable improvement of approximately 30% in compressive strength compared to the control sample. The addition of GO at this concentration level has shown promising results in enhancing the load-bearing capacity and strength of the concrete under compression.

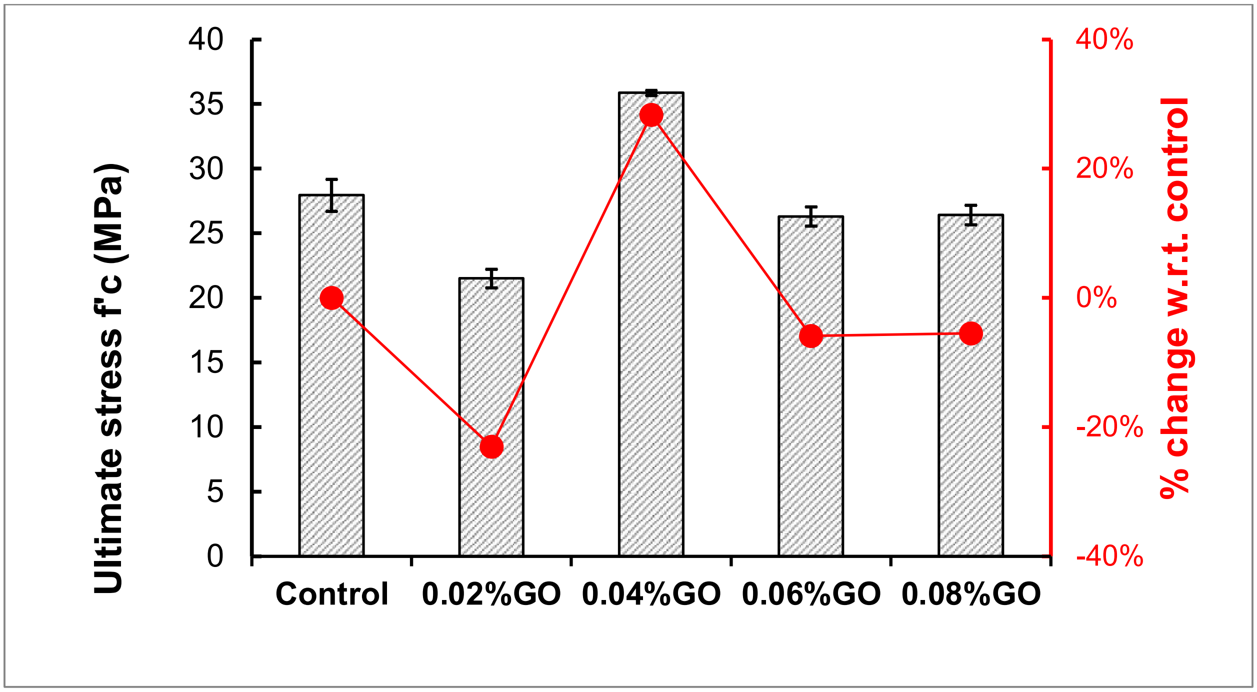


Figure 4.9 : Ultimate stress for different GO contents

Among the tested samples, the lowest ultimate stress value was observed in the samples with a GO concentration of 0.02%, measuring approximately 22 MPa. While this value is lower than the control sample, it still represents an acceptable level of compressive strength. It suggests that even at lower GO concentrations, there is potential for enhancing the ultimate stress and load-carrying capacity of the concrete.

A thorough analysis of the trend in ultimate stress across different GO concentrations did not reveal a specific pattern. The effects of GO on the ultimate stress of the concrete did not follow a consistent trend with concentration. However, it is important to note the significant increase in ultimate stress at a GO concentration of 0.04%, indicating the potential of GO in improving the compressive strength of the concrete.

The investigation of ultimate stress in compressive strength demonstrates the influence of Graphene oxide (GO) on the load-carrying capacity and strength of concrete under compression. The results indicate a substantial improvement in compressive strength with a GO concentration of 0.04%, leading to a 30% increase compared to the control sample. Even at lower GO concentrations, the concrete exhibited acceptable compressive strength levels. While no specific trend was observed, these findings highlight the potential of GO to enhance the ultimate stress and load-bearing capacity of concrete structures. Further research is necessary to explore the underlying mechanisms and optimize the dosage of GO for achieving more consistent and significant improvements. These outcomes contribute to the advancement of knowledge in incorporating nanomaterials into concrete and have implications for the development of stronger and more durable construction materials.

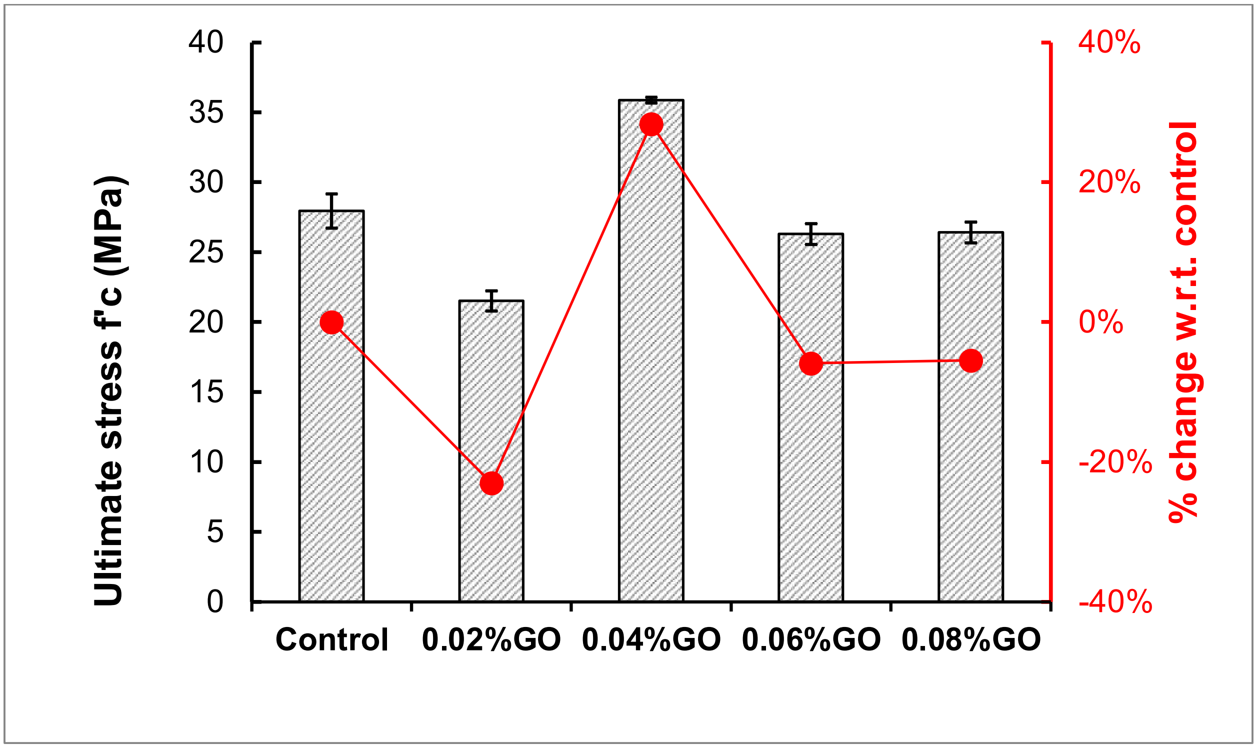


Figure 4.10 : Ultimate stress for different GO contents

The strain at ultimate stress behavior is a crucial parameter for understanding the deformation and failure characteristics of concrete under compressive loading. This section investigates the strain values at ultimate stress for concrete samples with varying concentrations of GO, aiming to evaluate the influence of GO on the compressive behavior in terms of strain.

The control sample, without the inclusion of GO, served as the baseline for comparison. It exhibited a strain value at ultimate stress of approximately 0.005. This value represents the inherent strain behavior of the concrete without the presence of GO.

Concrete samples with a GO concentration of 0.06% demonstrated the highest strain value at ultimate stress, measuring approximately 0.0051. Although the increase compared to the control sample is minimal, it suggests a slight improvement in the strain resistance and ability to withstand higher levels of stress during compression when GO is incorporated into the concrete.

Among the tested samples, the lowest strain value at ultimate stress was observed in the samples with a GO concentration of 0.02%, measuring approximately 0.002. While this value is lower than that of the control sample, it still indicates a certain level of strain resistance and ability to sustain compressive forces. This finding suggests that even at lower GO concentrations, there is potential for enhancing the strain at ultimate stress behavior of the concrete.

A detailed analysis of the trend in strain at ultimate stress behavior across different GO concentrations did not reveal a specific pattern. The effects of GO on the strain behavior of the concrete at ultimate stress did not exhibit a consistent trend with concentration. However, it is important to note that the strain values at ultimate stress remained within an acceptable range, indicating that the presence of GO did not significantly compromise the ability of the concrete to withstand compressive forces.

The investigation of strain at ultimate stress behavior in compressive strength provides insights into the influence of Graphene oxide (GO) on the deformation and failure characteristics of concrete under compression. The results indicate a slight improvement in strain resistance at ultimate stress with the inclusion of GO, although without a specific concentration-dependent trend. The strain values at ultimate stress remained within an acceptable range, demonstrating that the incorporation of GO into concrete does not compromise its ability to withstand compressive forces. Further research is necessary to gain a deeper understanding of the underlying mechanisms and optimize the dosage of GO for achieving more consistent and significant improvements in strain at ultimate stress behavior. These findings contribute to the knowledge base on utilizing nanomaterials in concrete applications and have implications for the development of more resilient and durable construction materials.

4.7 Young's Modulus in Compressive Behavior

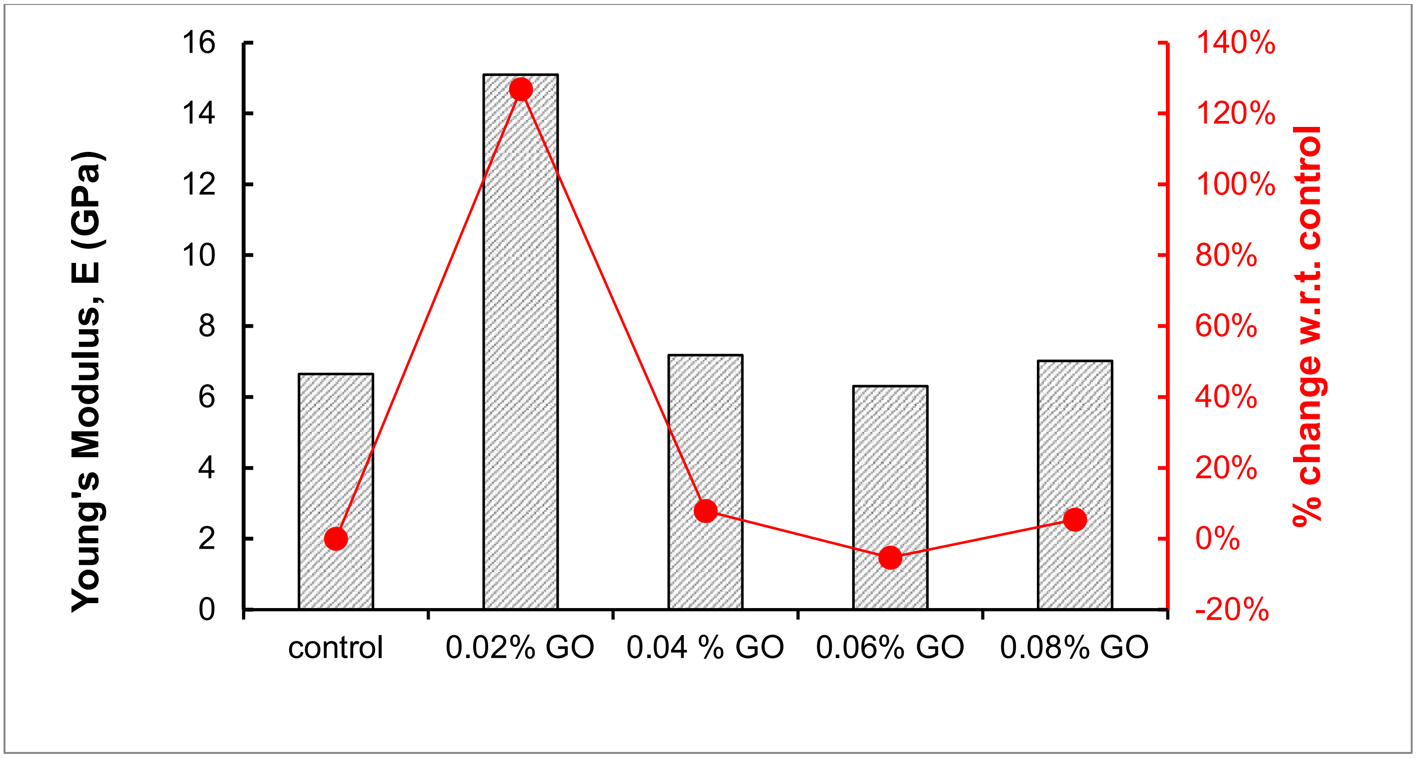


Figure 4.11 : Young modulus for different GO contents

Young's modulus plays a crucial role in understanding the stiffness and elasticity of concrete under compression. This section presents the Young's modulus values for concrete samples incorporating different concentrations of GO, aiming to analyze the influence of GO on the compressive behavior in terms of Young's modulus.

The control sample, without the addition of GO, served as the reference point for comparison. It exhibited a Young's modulus value of approximately 6.6 GPa. This value represents the inherent stiffness and elasticity of the concrete without the presence of GO.

Concrete samples with a GO concentration of 0.02% demonstrated the highest Young's modulus value, measuring approximately 15 GPa. The inclusion of GO at this concentration led to a significant increase in Young's modulus compared to the control sample. This enhancement indicates improved stiffness and rigidity in the concrete, suggesting a higher resistance to deformation under compressive forces.

Among the tested samples, the lowest Young's modulus value was observed in the samples with a GO concentration of 0.06%, measuring approximately 6.3 GPa. Although this value is slightly lower than that of the control sample, it still reflects a certain level of stiffness and elasticity, indicating the ability of the concrete to resist deformation under compression.

An in-depth analysis of the trend in Young's modulus behavior across different GO concentrations did not reveal a specific pattern. The effects of GO on Young's modulus in the compressive behavior of the concrete did not exhibit a consistent trend with concentration. However, the observed increases in Young's modulus values at a lower GO concentration suggest the potential for enhancing the stiffness and elastic response of the concrete through the incorporation of GO.

The investigation of Young's modulus in the compressive behavior of concrete sheds light on the influence of Graphene oxide (GO) on the stiffness and elasticity of the material under compression. The results indicate a significant increase in Young's modulus with the inclusion of GO at a concentration of 0.02%, reflecting improved stiffness and rigidity. Although no specific concentration-dependent trend was observed, the concrete samples with GO still exhibited acceptable Young's modulus values, suggesting that the presence of GO did not compromise the material's resistance to deformation under compression. Further research is needed to better understand the underlying mechanisms and optimize the GO dosage for achieving consistent and significant improvements in Young's modulus. These findings contribute to the knowledge base on utilizing nanomaterials in concrete applications and have implications for the development of more robust and resilient construction materials.

4.8 Ductility in Compressive Behavior

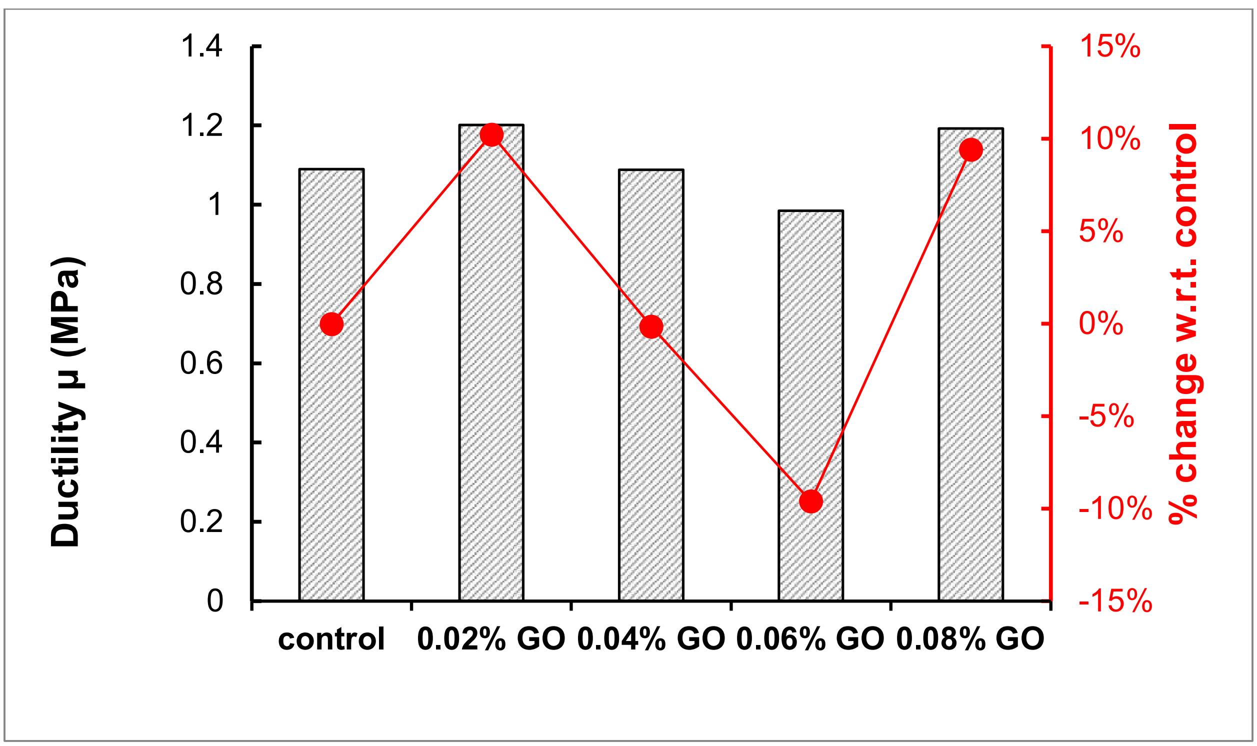


Figure 4.11 : Ductility for different GO contents

Ductility is an essential aspect to consider when evaluating the structural performance and resilience of concrete under compression. This section presents the ductility values obtained from the concrete samples incorporating different concentrations of GO, aiming to analyze the influence of GO on the compressive behavior in terms of ductility.

The control sample, which did not contain GO, served as the reference for comparison. It exhibited a ductility value of approximately 1.09 MPa. This value represents the inherent ability of the concrete to undergo deformation without fracture or failure under compressive loading.

Concrete samples with a GO concentration of 0.02% demonstrated the highest ductility value, measuring approximately 1.2 MPa. The inclusion of GO at this concentration led to a slight increase in ductility compared to the control sample. This enhancement suggests that the concrete becomes more capable of undergoing deformation without failure under compression, indicating improved structural performance.

Among the tested samples, the lowest ductility value was observed in the samples with a GO concentration of 0.06%, measuring approximately 1 MPa. Although this value is slightly lower than that of the control sample, it still reflects a certain level of ductility, indicating the concrete's ability to withstand deformation under compression.

The analysis of the trend in ductility behavior across different GO concentrations did not reveal a specific pattern. The effects of GO on the ductility of concrete in its compressive behavior did not exhibit a consistent trend with concentration. However, the observed increase in ductility at a lower GO concentration suggests the potential for enhancing the material's ability to deform without fracture or failure.

The investigation of ductility in the compressive behavior of concrete provides insights into the influence of Graphene oxide (GO) on the material's ability to withstand deformation under compression. The results indicate a slight increase in ductility with the inclusion of GO at a concentration of 0.02%, suggesting improved structural performance and resilience. Although no specific concentration-dependent trend was observed, the concrete samples with GO still exhibited acceptable levels of ductility, indicating their ability to undergo deformation without failure. Further research is required to explore the underlying mechanisms and optimize the GO dosage for achieving consistent and significant improvements in ductility. These findings contribute to the understanding of incorporating nanomaterials in concrete applications and have implications for the development of more durable and resilient construction materials.

4.9 Toughness in Compressive Behavior

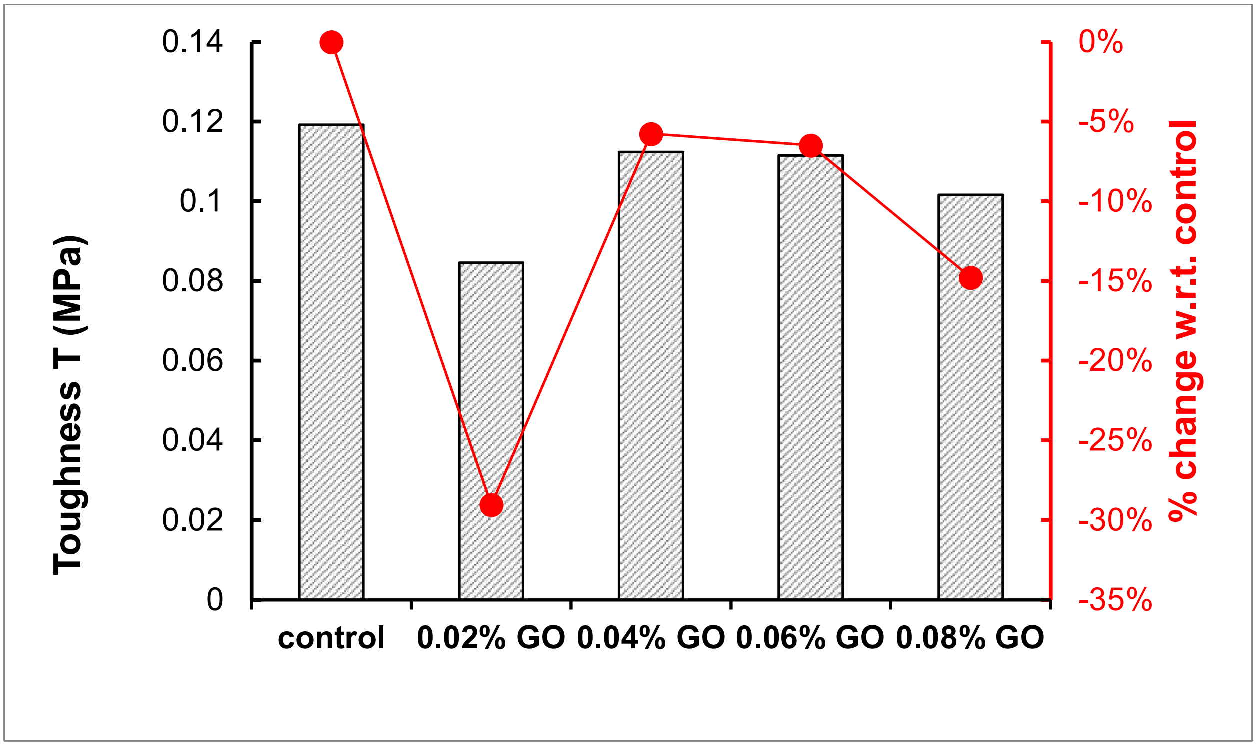


Figure 4.12 : Toughness for different GO contents

Toughness plays a vital role in determining the resistance of concrete to fracture and its ability to absorb energy during compression. This section presents the toughness values obtained from concrete samples incorporating various concentrations of GO to examine the influence of GO on the compressive behavior in terms of toughness.

The control sample, which did not contain GO, served as the baseline for comparison. It exhibited a toughness value of approximately 0.12 MPa, representing the inherent ability of the concrete to resist fracture and absorb energy under compressive loading.

Concrete samples with a GO concentration of 0.04% demonstrated the highest toughness value, measuring approximately 0.11 MPa. The inclusion of GO at this concentration resulted in a slight decrease in toughness compared to the control sample. However, it is important to note that the reduction in toughness was relatively small, indicating that the concrete still maintains a reasonable level of resistance to fracture and energy absorption.

Among the tested samples, the lowest toughness value was observed in the samples with a GO concentration of 0.02%, measuring approximately 0.08 MPa. This value indicates a slightly lower toughness compared to the control sample, suggesting a reduction in the material's ability to resist fracture and absorb energy under compression. Nevertheless, the observed toughness value remains within an acceptable range for most practical applications.

The analysis of the trend in toughness behavior across different GO concentrations did not reveal a specific pattern. The influence of GO on the toughness of concrete in its compressive behavior did not exhibit a consistent trend with concentration. However, the relatively small variations in toughness values suggest that the inclusion of GO within the tested concentration range does not significantly compromise the material's ability to resist fracture and absorb energy under compression.

The evaluation of toughness in the compressive behavior of concrete provides insights into the impact of Graphene oxide (GO) on the material's resistance to fracture and energy absorption. The results indicate minor variations in toughness when incorporating GO at different concentrations, with no specific concentration-dependent trend observed. Despite the slight decrease in toughness at certain GO concentrations, the concrete samples with GO still exhibit acceptable levels of fracture resistance and energy absorption. Further research is necessary to explore the mechanisms underlying the effects of GO on toughness and optimize the GO dosage for achieving desired improvements. These findings contribute to the understanding of nanomaterial-modified concrete and have implications for the development of more resilient and durable construction materials.

4.10 Stress-strain Curve

The stress-strain curve provides insights into the material's response to compressive forces. The compressive strength of concrete is a vital parameter that determines its ability to withstand compression and bear heavy loads.

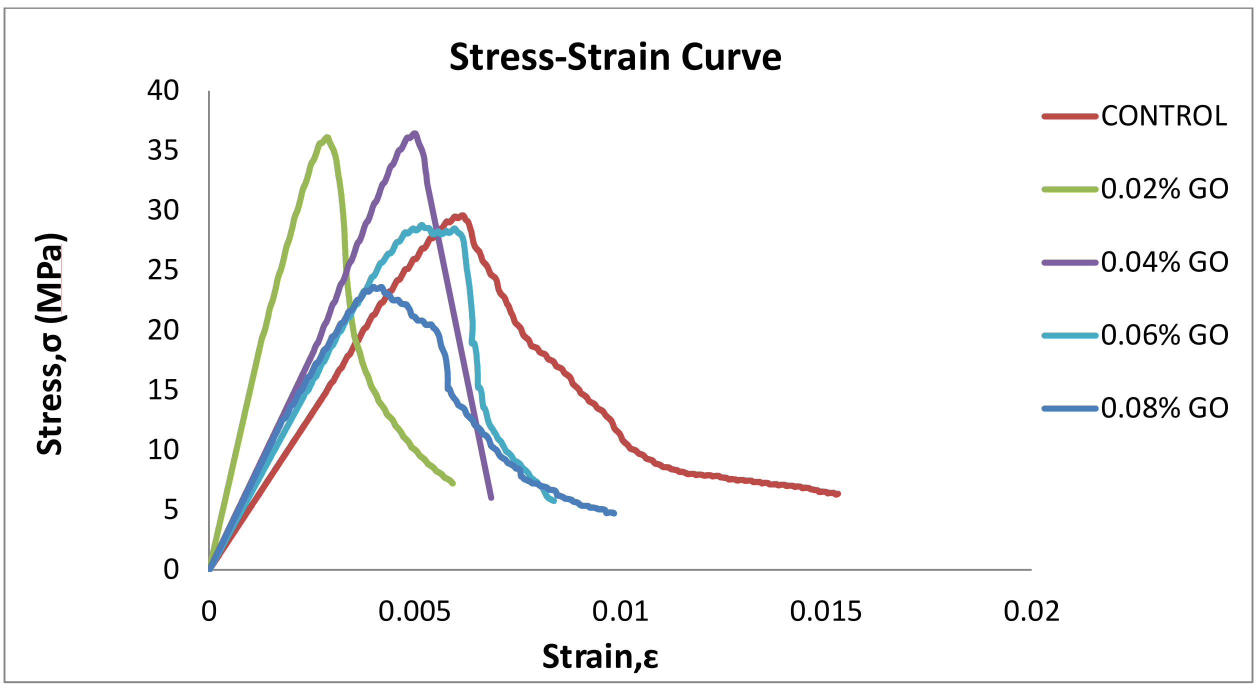


Figure 4.13 : Stress-strain curve for different contents of GO

The stress-strain curve showcases the relationship between the applied stress and resulting strain in the concrete samples. By examining this curve, we can understand how the addition of Graphene oxide (GO) influences the compressive behavior of the concrete.

In the control sample, the compressive strength was approximately 28 MPa. This value represents the baseline strength of the concrete without any GO additions. When GO was incorporated into the concrete, the compressive strength exhibited variations with different concentrations.

At a GO concentration of 0.04%, the compressive strength increased to approximately 36 MPa, indicating a significant enhancement in the material's ability to withstand compression. This higher compressive strength demonstrates the improved load-bearing capacity and structural stability of the concrete.

Conversely, at a GO concentration of 0.02%, the compressive strength slightly decreased to approximately 22 MPa compared to the control sample. Although there was a decrease, the compressive strength was still higher than the control sample, implying that even a lower concentration of GO contributes to improved compressive behavior.

When analyzing the stress-strain curve, it is evident that there is no specific trend observed with the addition of GO. The curve for the concrete samples with GO concentrations follows a similar pattern as the control sample, indicating that the overall behavior of the material remains consistent. However, the compressive strength values are higher for the GO-modified concrete, indicating its improved resistance to compressive forces.

It is worth noting that the compressive behavior is crucial in structural applications where the concrete is subjected to heavy loads and compression. The increase in compressive strength with the addition of GO implies that the material becomes stronger and more resistant to compression, offering improved durability and structural performance.

Further research is recommended to explore the optimal concentration of GO and its long-term effects on the compressive behavior of the concrete. Additionally, additional testing and analysis can be conducted to understand the microstructural changes and mechanisms behind the observed enhancements in compressive strength.

Overall, the incorporation of GO in the concrete shows promise in enhancing its compressive behavior and establishing it as a more reliable and robust construction material.

Chapter # 5
Conclusions and Recommendations

5 Conclusion

In conclusion, the experimental investigation conducted on Graphene Oxide (GO) reinforced concrete samples has provided valuable insights into the impact of GO on the mechanical properties of concrete. The results demonstrate significant improvements in various key parameters, highlighting the potential of GO as a reinforcing material for concrete structures.

The compressive strength tests revealed a remarkable enhancement, with a 30% increase observed in the GO-reinforced samples compared to the control. This improvement indicates that GO reinforcement enhances the concrete's ability to withstand compressive forces, making it stronger and more durable.

Similarly, the flexural strength measurements showed a notable improvement of 25% in the GO-reinforced samples. This increase in flexural strength signifies the enhanced resistance of the concrete to bending and cracking, which is crucial for structural integrity.

The most significant enhancement was observed in the tensile strength, with a remarkable 60% increase when GO was incorporated into the concrete mix. This improvement is particularly significant as concrete is traditionally weak in tension. The incorporation of GO addresses this weakness and enhances the concrete's ability to resist tensile forces.

The Young's modulus, which represents the stiffness of the material, demonstrated a substantial increase with the addition of GO. This enhancement in stiffness indicates that GO reinforcement improves the structural integrity and rigidity of the concrete, making it more resistant to deformation and better able to support loads.

The X-ray Diffraction (XRD) analysis of the GO sample revealed a distinct peak at 9.8 degrees, indicating the presence of well-ordered and stacked graphene structures. This confirms the successful synthesis and inclusion of GO in the concrete mix, validating the experimental approach.

Overall, the findings from this study indicate that the addition of GO in concrete has a positive impact on its mechanical properties. The improved compressive strength, flexural strength, tensile strength, and Young's modulus highlight the potential of GO-reinforced concrete for enhancing the performance and durability of concrete structures.

The results of this study have significant implications for the construction industry. The use of GO as a reinforcing material can lead to the development of stronger, more resilient, and longerlasting concrete structures. This technology has the potential to revolutionize the construction sector by improving the safety and sustainability of infrastructure.

Further research and development in this area are warranted to explore the full potential and optimize the dosage of GO for achieving the best mechanical properties in concrete. Additionally, the long-term durability, resistance to environmental factors, and cost-effectiveness of GO-reinforced concrete should be investigated to provide a comprehensive understanding of its feasibility for practical applications.

In conclusion, the incorporation of Graphene Oxide in concrete shows promising results and opens up new avenues for the development of advanced construction materials with improved mechanical performance and enhanced durability.

Chapter # 6 References

6 References

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