INVESTIGATE THE POTENTIAL OF GRAPHENE TO ENHANCE CONCRETE PERFORMANCE

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A Thesis Submitted to The Department of Civil Engineering

College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Construction Engineering and Management

Office of Graduate Studies

Adama Science and Technology University

June, 2025

Adama, Ethiopia

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DECLARATION

I declare that this dissertation thesis entitled declare that this research thesis entitled "Investigate the potential of graphene to enhance concrete performances" my original work, has not been submitted as a requirement for the award of any degree in ASTU or elsewhere.

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We, the major and co-supervisor of this research thesis, hereby certify that we have closely supervised the student while developing this thesis and read the dissertation thesis entitled “Investigate the potential of graphene to enhance concrete performance” Mohammedfirdous Mohammed Kalif. Therefore, we recommend the submission of the thesis to the department for further review and evaluation.

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APPROVAL PAGE

I/we hereby certify that the recommendations and suggestions given by the thesis review I/we, the advisors of the thesis entitled " **Investigate the potential of graphene to enhance concrete performances**" and developed by **Mohammedfirdous Mohammed Kalif**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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LIST OF ACRONYMS

Tpa	Tesla Pascal
Gpa	Gage pascal
2D	Two-dimensional
C-H	Carbon-Hydrogen
OPC	Ordinary Portland cement
CRCP	Continuously reinforced concrete pavement
GNps	Graphene Nano sheet plates
GONS	Graphene oxide sheet plates
W/C	Water/cement
RGO	Reduces graphene oxide
Go	Graphene oxide
FTIR	Fourier transform infrared spectroscopy
XRD	X--ray

ABSTRACT

Concrete is a fundamental construction material used worldwide, but its inherent brittleness, susceptibility to cracking, and environmental impact due to high cement consumption remain challenges. The integration of graphene, a nanomaterial with exceptional mechanical and electrical properties, offers a promising approach to enhancing concrete's strength, durability, and sustainability. This study investigates the potential of graphene to improve concrete performance, particularly in Ethiopia, where sustainable construction practices are increasingly vital. The primary objective of this research is to explore how graphene powder can enhance the mechanical properties of concrete while optimizing its composition. Evaluating the impact of graphene on compressive and flexural strength.Identifying the optimal graphene dosage for maximum performance. Analyzing the microstructural changes in concrete using advanced testing techniques. .Graphene powder was incorporated into concrete at varying concentrations (0.1%–0.5%) by weight of cement. Standard laboratory tests, including compressive and flexural strength evaluations (ASTM C39 and C78), X-ray diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) are use to characterization the graphene micro structure and water absorption assessments, were conducted to measure performance improvements. Additionally, Scanning Electron Microscopy (SEM) was used to analyze graphene's distribution within the concrete matrix.Experimental findings showed that graphene-enhanced concrete exhibited superior mechanical properties, with compressive strengths reaching 25.16 N/mm² at 7 days and 37.75 N/mm² at 28 days. Similarly, flexural strength improved to 2.985 N/mm² and 4.47 N/mm², respectively. XRD analysis confirmed successful graphene integration, with a characteristic peak at 26.5 degrees. Water absorption tests indicated enhanced resistance to permeability, contributing to improved durability. The study highlights the potential of graphene to reduce cement consumption and enhance construction sustainability, A graphene dosage of 0.4% is recommended for optimizing strength and durability . Future research should focus on long-term durability studies, economic viability, and large-scale implementation strategies. This study demonstrates graphene's transformative potential in revolutionizing concrete technology, paving the way for stronger, more sustainable, and resilient infrastructure development.

***Keywords*:** Graphene, concrete, mechanical properties, durability, sustainability, cement reduction , micro structural, environmetal impact

CHAPTER ONE

INTRODUCTION

1.1 Background

Cementitious composites are the most commonly used building materials worldwide. Yet, they are brittle and low tensile strength, and prone to cracking, making them unfitting for certain construction works. Additionally, most construction materials struggle to reduce vibrations adequately, and traditional reinforced concrete and alkali-activated slag concrete structures typically demonstrate poor dynamic mechanical characteristics(Dong and Dai 2015). Dynamic characteristics are related to how a sample performs under dynamic forces and are usually defined by fundamental natural frequencies, damping ratios, and mode shape parameters. However, the dynamic mechanical properties of concrete have not been studied as extensively as its static mechanical properties(Shibuta and Elliott 2011). It is important to note that the dynamic characteristics of cement-based composites are influenced by specific factors related to the dynamic loading conditions, such as the magnitude of the load, sound, wind, and earthquakes, all of which civil infrastructure systems frequently encounter(Zhu, Sarkis et al. 2013).

The rapid advancement toward sustainable construction necessitates high-performance and smart cementitious materials to create safer, more durable, and cost-effective infrastructure systems. Among various strategies to enhance concrete performance and intelligence, the use of additives to reinforce cement paste and customize its physical, mechanical, and transport properties has been extensively explored(Kong, Shi et al. 2021). Recent developments in materials science and nanotechnology have introduced an exceptional nanomaterial graphene as a potential additive for cementitious materials. Unlike other nanomaterials, graphene features a unique atom-thick, sp^2 bonded two-dimensional structure. This atomic structure endows graphene with extraordinary properties, including an exceptionally high specific surface area, ultrahigh tensile strength, and elastic modulus, as well as excellent thermal, electrical, and optical conductivity. As a result, its application in producing smart, high-performance materials is generating increasing interest across a wide range of engineering applications (Zhang, Li et al. 2015). At present, numerous study aiming at improvement in the dynamic characteristics of cement composites have been done. Diverse additives such as graphite sheets and/or carbon fibers were used to advance the dynamic features of commonly applied cementitious composites. These properties were extraordinarily improved when the cement composite was incorporated with carbon fibers, silica fume, and methylcellulose and polymer latex. Because of their superior viscoelastic properties that polymers, metals, and rubber have been commonly used as cement reinforcement materials(Katsnelson, 2007).

Due to concerns over inherent brittleness, low tensile strength, and instability in severe climates, the performance of traditional cement concrete composites has been continuously improved through nanotechnology by incorporating reinforcing fillers. The nanotechnology of cement composites is a rapidly developing area within civil engineering. Recently, graphene has gained significant attention for its use in various materials aimed at achieving eco-friendliness and enhanced functionality(Barbhuiya, Kumar et al. 2021). Simultaneously, innovative green synthesis technologies for graphene are emerging, utilizing recyclable materials to eliminate the need for hazardous reducing agents in the reduction of graphene oxide. Although graphene has substantial potential and superior qualities compared to many currently used materials, its adoption in certain industrial sectors has been slow. The added sustainability benefits that graphene can offer may facilitate its broader application across industries. As a concrete additive, graphene presents great potential to tackle major challenges such as the brittleness and permeability of concrete(Novoselov, Morozov et al. 2007). For instance, relationships have been developed between the durability of concrete and its electrical conductivity; higher conductivity generally translates to increased impermeability and durability. Previous attempts to enhance electrical conductivity have fallen short due to the excessive use of steel fibers, magnetite, and various carbon-based materials. Additionally, considerations regarding the loading of active chemicals, including compressive strength, corrosion resistance, cost, weight, maintenance, and abrasion resistance, have garnered significant attention. Consequently, researchers have turned to incorporating graphene into concrete to enhance its electrical conductivity.

Graphene is a pure crystalline material with a single layer of carbon atoms in a hexagonal lattice, which is one million times thinner than a strand of human hair, and 200 times stronger than that steel(Rehman, 2018). According to theoretical investigations , Young's modulus and ideal tensile strength of graphene are about 0.1 TPa and 100–130 GPa, respectively, with maximum strains to failure of 13–19 percent and 20–26 percent (having nonlinear elastic property under a large strain) along the armchair and zigzag directions(Papanikolaou, 2020).

Its structure discusses key physical properties such as competent heat and electrical conductivity, as well as significant strength. With these unprecedented, impeccable properties, researchers have surmised that they can make concrete stronger (better mechanical strength properties) and more resilient (better durability performance)(Metsger et al., 1999).

Graphene is a promising candidate for various industrial applications and represents a highly sustainable material with the potential to enhance viable across multiple industries. While graphene-based concrete exhibits superior service performance compared to standard concrete mixtures, its production costs are higher, and complex protocols are necessary to ensure proper particle dispersion within the cement matrix or microstructure. A significant barrier to the widespread adoption of graphene concrete is its high cost, primarily driven by the expense of graphene nanomaterials and, to some extent, by the costs associated with other materials used for its modification or functionalization(Low, Walsh et al. 2013). To mitigate manufacture costs, graphene oxide (GO) has been identified as an ideal nano-reinforcement option due to its ease of use and substantial potential for modification. Given the high cost of graphene concrete, which hampers its broader application, there has been increasing research into substitute, economical carbon-containing precursor materials for graphene synthesis in recent years.

Concrete infrastructure requires structural with enhanced mechanical properties, durability, and smart capabilities to accommodate numerous uses. To meet these growing demands, nanotechnology has been widely applied in cement materials to improve structural properties, environmental protection, and the low toughness of traditional cement materials (Armano and Agnello 2019). Among these advancements, graphene oxide (GO), a sheet-like derivative of graphene, has demonstrated significant improvements in the strength and durability of concrete, even at very low dosages, due to its excellent mechanical properties and active functional groups. Yet, its impact on health monitoring and ultra-high performance is still not well agreed in the literature,

mainly regarding alternative methods to characterize the interfacial transition zone modified by Nanosheets. This study first reviews the available methods for studying the micro mechanical performance of the interfacial transition zone, focusing on characterization techniques and multiscale models. It then specifically highlights the smart applications and durability aspects of GO for next-generation concrete(Liu, Bao et al. 2022)

Graphene is also notable for its high surface area, with one square meter of graphene weighing just about 0.77 mg and having a surface area of more than 2600 m^2, which enhances its potential in applications such as sensors, batteries, and supercapacitors. This vast surface area allows for the effective adsorption of molecules, presenting opportunities in fields ranging from energy storage to biomedical applications. The material's versatility is further enhanced by its biocompatibility, making it suitable for various uses in medicine, including drug delivery and tissue engineering(X. Li et al., 2016).

Since its isolation, researchers have extensively explored graphene's potential applications across multiple industries. In electronics, graphene has been proposed as a replacement for silicon in transistors, allowing for faster and more efficient electronic devices. In the field of energy, graphene's high conductivity and surface area make it an excellent candidate for improving battery and supercapacitor performance. Additionally, graphene's mechanical properties enable its use as a reinforcing agent in composite materials, enhancing the performance of plastics, ceramics, and metals.

However, despite its numerous advantages, the commercial application of graphene faces several challenges. These include the high cost of production, scalability issues, and the need for consistent quality in graphene production. While various approaches for producing graphene have been established — including chemical vapor deposition (CVD), liquid-phase exfoliation, and chemical reduction of graphene oxide — achieving large-scale, high-quality graphene that meets industrial demands remains a significant hurdle. Continuing research efforts aim to improve synthesis techniques, develop new applications, and explore the fundamental properties of graphene to unlock its full potential in various fields.

In conclusion, graphene stands as one of the most exciting materials of the 21st century, boasting a unique combination of properties that could transform multiple industries. As research progresses, understanding the mechanisms and applications of graphene will be crucial in paving the way for sustainable and cutting-edge technological advancements, potentially leading to the next quantum leap in materials science and engineering(Luchko et al., 2022).

All introduction papers may concentrate narrowly on specific properties of graphene, potentially neglecting its broader implications or applications across various fields. If it lacks empirical evidence or experimental results, the validity of its claims regarding graphene’s properties and potential applications could be weakened. Additionally, the absence of comparisons with other materials or additives may limit the reader's understanding of graphene's relative advantages and disadvantages. Should the study primarily rely on theoretical models without practical validation, its conclusions might be deemed less reliable. Furthermore, the paper might not adequately address the challenges associated with graphene production, including cost, scalability, and the integration of graphene into existing materials.

1.2 Statement of the problem

Concrete is the most widely used construction material globally, yet it faces critical challenges related to its durability, strength, and environmental impact. Traditional concrete exhibits low tensile strength, brittleness, and susceptibility to cracking, which significantly affects the lifespan of structures. Additionally, the high cement content required in conventional concrete leads to substantial carbon emissions, contributing to environmental concerns. The construction industry urgently needs advanced materials that can enhance concrete properties while promoting sustainability.

Graphene, a nanomaterial with exceptional mechanical and electrical properties, has been recognized as a potential additive to improve concrete performance. However, despite its promising characteristics, the optimal graphene dosage for achieving maximum strength and durability remains unclear. Furthermore, the practical application of graphene in concrete is hindered by cost implications, dispersion challenges within the cement matrix, and the need for standardization in construction practices.

In Ethiopia, the demand for stronger and more durable infrastructure continues to grow, requiring innovative solutions to enhance local construction materials. The lack of comprehensive studies on graphene-enhanced concrete in Ethiopia limits its adoption, leaving a research gap in evaluating its feasibility, efficiency, and long-term performance. This study aims to address these issues by investigating the impact of graphene on concrete properties, optimizing dosage for structural improvement.By conducting rigorous laboratory testing and analysis, this research seeks to provide a scientific basis for integrating graphene into concrete mixtures, reducing cement consumption, improving mechanical strength, and contributing to sustainable construction practices in Ethiopia. The findings will offer valuable insights for engineers, researchers, and policymakers seeking to revolutionize the construction industry with high-performance concrete solutions. This statement aligns with your research objectives and highlights the problem concisely.

1.3 Objectives of the study

1.3.1 General Objectives

The general objectives of this research are to explore with evaluate the potential of graphene as a mixing to enhance the performance characteristics on concrete.

1.3.2 Specific Objectives

- To characterize graphene and evaluate graphene as a rheology property.
- To investigate the mechanical properties of additives to samples concrete in varying concentrations of graphene powder.
- To determine the microstructure of concrete after mixing with graphene powder.
- The effect of graphene on water absorption resistance was determined.

1.4 Significance of the research

This research aims to explore the mechanical properties and optimize the dosage of graphene powder in concrete to enhance its performance. Specifically, the study serves as a resource for construction stakeholders by demonstrating how the use of graphene can act as a cement reducer, leading to cost-effective production of high-quality concrete. It highlights crucial hardened properties such as workability, setting time, early strength, and durability, addressing both economical and efficient solutions. Furthermore, the importance of compatibility testing between cement and additives is emphasized, along with the necessity for further research to ensure the effective application of these cement reducers in practical scenarios.

The investigation into the potential of graphene to improve concrete performance carries substantial implications across various fields, including construction, materials science, and environmental sustainability. Key advancements highlighted in this study include improved mechanical properties that allow concrete to withstand greater loads and resist cracking, ultimately leading to the construction of safer and more reliable structures. The findings may also inspire innovative engineering practices, promoting novel construction techniques that leverage graphene-enhanced concrete. Additionally, the enhanced durability and longevity of the material can result in reduced maintenance costs due to its improved resistance to environmental factors and cracking. This resilience is crucial for developing construction materials that can endure extreme weather conditions and the impacts of climate change, thereby contributing to more sustainable urban development.

1.5 Scope of the Study

The study examines the potential of graphene to improve concrete performance in the Ethiopian construction industry, with a focus on its mechanical properties, durability, and sustainability. It examines the effects of varying concentrations of graphene powder (0.1%–0.5% by weight of cement) on concrete properties such as compressive strength, flexural strength, water absorption resistance, and microstructural improvements. Laboratory-scale investigations employ standardized tests, including ASTM C39 and ASTM C78, as well as techniques like X-ray diffraction, Fourier Transform Infrared Spectroscopy, and Scanning Electron Microscopy to evaluate graphene's integration into the cement matrix. While the research is centered on Ethiopia's local construction practices and material availability, its findings may have broader implications for sustainable construction worldwide.

1.6 Limitations of the Study

The investigation acknowledges several constraints, including the high costs of graphene production and difficulties in integrating it into existing construction practices. It is limited to laboratory-scale studies, not addressing the economic feasibility of graphene on an industrial scale or its long-term structural stability and environmental impact beyond controlled conditions. Additionally, regional variations in material availability and infrastructure pose limitations that may affect the practical implementation of the findings, highlighting the need for further research to explore these aspects comprehensively.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The remarkable properties of graphene together with its chemical, mechanical, electrical, and thermal characteristics make it a highly versatile material with numerous applications. Recently, there has been a growing interest in incorporating graphene and its derivatives into construction materials, particularly concrete(Fuchs and Goerbig 2008). This paper examines the effects of adding graphene and

graphene-based compounds as additives in concrete, focusing on their influence on material mix proportions, the methods of incorporation, and the resulting microstructural, mechanical, and durability properties. Graphene is one of the few nanomaterials that can modify the microstructure of traditional concrete, addressing challenges related to strength and durability. The study suggests that graphene-based compounds enhance the cement hydration process due to their significantly higher specific surface area compared to conventional cement materials. Incorporating nanoparticle graphene improves the bonding between cement particles, resulting in considerable improvements in both the mechanical strength and longevity of concrete(Kong, Shi et al. 2021).

Graphene has garnered significant consideration in recent years due to its remarkable electronic, optical, magnetic, thermal, and mechanical properties. However, despite ongoing theoretical and experimental advancements, the unique physical properties of graphene are still underutilized and undervalued. A major challenge in leveraging these properties is the difficulty in reliably manipulating well-dispersed graphene, which stems from its surface characteristics. This review summarizes recent developments related to the surface properties of graphene, emphasizing the tailoring of these properties through surface treatments and their effects on the graphene-polymer matrix interface. Additionally, we provide a brief overview of surface testing techniques(Qi, Yang et al. 2017). We believe that research focusing on the preparation of modified graphene with specialized surface properties will lead to superior composites, considering the desired cradle-to-grave life cycle of high-performance reinforced materials.

Ultimately, we hope this review enhances understanding of the physicochemical surface properties of graphene(Kumar and Parekh 2020).The exfoliation and identification of two-dimensional (2D) single atomic layers of carbon have created opportunities to explore graphene and related 2D materials due to their distinctive properties. These 2D materials are considered some of the most promising solutions for next-generation electronics and optoelectronics within the technological evolution of semiconductor technology. This review focuses on the fundamental concept of "structure-property relationships" to elucidate the current state of 2D materials and summarizes their unique electrical properties and interactions with light. We discuss and analyze the structural properties of 2D materials, including defects and dopants, layer count, composition, phase, strain, and other structural features that can significantly influence their properties and, consequently, the performance of semiconductor devices(Cao, Han et al. 2018). Specifically, we explain and illustrate the building blocks, principles, and potential electronic and optoelectronic applications based on 2D materials. Indeed, 2D materials and their related technologies hold the promise to challenge existing technologies and have a meaningful societal impact. Increased efforts are anticipated to advance this exciting field.

2.2 Exploring Mechanical Properties and Hydrogenation Effects in Two-Dimensional Materials.

Graphene is an emerging powerhouse in the fields of materials science and condensed-matter physics. This firmly two-dimensional material showcases exceptionally high crystal and electronic quality, and regardless of its brief existence. It has already unveiled a wealth of new physical phenomena and potential applications, which are discussed briefly here. While the reality of its applications can only be confirmed once commercial products are available, graphene no longer needs further validation of its significance in fundamental physics(Zhang, Yang et al. 2022). Because of its unique electronic spectrum, graphene has given rise to a new paradigm in 'relativistic' condensed-matter physics, allowing quantum relativistic phenomena often unnoticeable in high-energy physics to be mimicked and tested in tabletop experiments. More broadly, graphene represents a new class of materials that are only one atom thick, providing fresh insights into low-dimensional physics that continue to inspire and yield opportunities for innovation(Sur 2012).

Graphene-based paper materials have recently concerned noteworthy attention due to their exceptional properties, primarily attributed to their layered hierarchical structures, which resemble many biological materials such as bone, teeth, and nacre. These structures feature strong inter layer sp^2 bonds and cross links that efficiently transfer loads. In this study, we first examine the mechanical properties of various inter layers and inter layer cross links using first-principles calculations and then conduct continuum model analysis to assess the overall mechanical properties of graphene-based paper materials(Nguyen and Nguyen 2016).

Graphene is a two-dimensional system composed of a single layer of fully saturated (sp^3 hybridized) carbon atoms. In an ideal graphene structure, the C-H bonds exhibit an alternating pattern relative to the plane defined by the carbon atoms. In this research, we employed ab initiation and reactive molecular dynamics simulations to investigate the impact of hydrogen frustration (the disruption of the alternating pattern of hydrogen atoms) in graphene-like structures. Our findings indicate that a significant proportion of uncorrelated hydrogen-frustrated domains form during the early stages of the hydrogenation process, which results in membrane shrinkage and considerable corrugation. These results imply that large areas of perfect graphene-like structures are unlikely to exist, as hydrogen-frustrated domains are always present(Armano and Agnello 2019).

2.3 Electronic structure

Graphene possesses an exceptional band structure due to its unique crystal configuration. The carbon atoms create a hexagonal lattice on a two-dimensional plane, with each carbon atom positioned about 1.42 Å away from its three neighboring atoms, forming one σ bond with each. The fourth bond is a π-bond oriented out of the plane in the z-direction. This π orbital can be visualized as a pair of symmetric lobes aligned with the z-axis and centered on the nucleus. Each carbon atom has one of these π-bonds, which combine to form the π-band and π*-bands, which are largely responsible for graphene's distinctive electronic properties (Cao, Han et al. 2018). The graphene lattice can also be seen as comprising two interleaving triangular lattices, as illustrated in Figure 1. This viewpoint was effectively utilized as early as 1947 when Wallace calculated the band structure of a single layer of graphite using a tight-binding approximation(Armano and Agnello 2019). The band structure is typically examined in terms of the relationship between the energy and momentum of electrons within a material. Because graphene restricts electron motion to two dimensions, the momentum space is also limited to two dimensions.

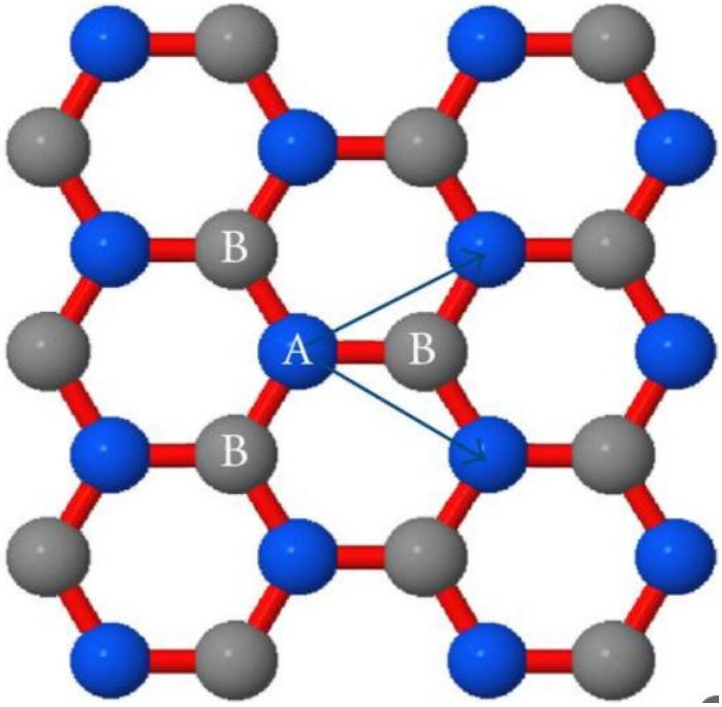

Figure 2. 1 Energy versus Momentum dispersion relation for graphene

An energy versus momentum dispersion relation for graphene can be illustrated in a plot, which is based on the tight-binding approximation discussed below(Sur 2012).

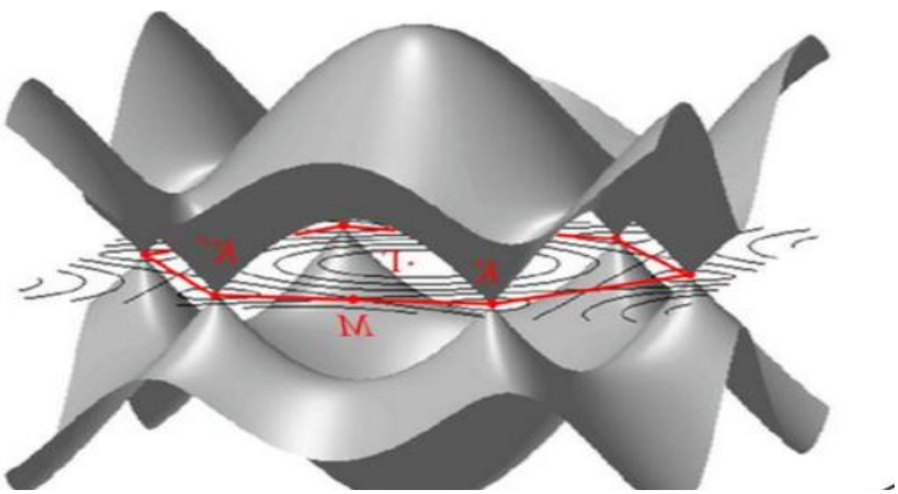

Figure 2. 2 Strength of Graphene Nano-engineered Concrete

The high-shear liquid phase exfoliation method employed to produce water-based graphene dispersions is well-suited for integrating graphene with concrete due to its potential for high throughput when using industrial-scale equipment.

Consequently, we have blended graphene into concrete by combining the water-based graphene dispersions with ordinary Portland cement (OPC), fine dry sand, and coarse aggregate, as detailed in the Experimental Sections (Liu, Bao et al. 2022).

2.4 Investigating Various Concentrations and Mechanical Properties.

Numerous clarifications with differing concentrations of functionalized graphene (FG) and inorganic graphene (IG) in water were examined to optimize the performance of graphene-reinforced concrete. Concrete cubes were then prepared, cured, and tested for compressive strength according to the standards governing architectural and engineering designs. Specifically, the fresh concrete mix was poured into standard 10 × 10 × 10 cm steel molds, removed after 24 hours, and placed in a water tank for curing (refer to the Experimental Section and Supporting Information for more details). A key mechanical property of concrete is the evolution of compressive strength over time(Zhang, Shi et al. 2023). Therefore, we tested the cubes at various curing intervals ranging from 7 to 28 days to determine both early-age and later-age strength values. The graphene-reinforced concrete samples were compared to standard concrete. To facilitate this comparison, a control sample group was prepared using the same procedure but substituting the graphene water solution with tap water. These measurements ensure that the concrete samples studied adhere to the test batches typical of those cast at construction sites as dictated by engineering designs. Pristine graphene and chemically modified graphene (such as graphene oxide, reduced graphene oxide, and their derivatives) can react with different chemical substances(Armano and Agnello 2019). These responses have been utilized to alter the structures and properties of graphene materials, broadening their functions and practical applications. This perspective outlines the chemistry of graphene, covering aspects such as functionalization, doping, photo chemistry, catalytic chemistry, and supra molecular chemistry, while also discussing the mechanisms of graphene-related reactions and the challenges associated with monitoring these chemical reactions

2.5 Graphene synthesis and Its Emerging Applications in Electronics and Concrete Reinforcement.

In various reviews, we have highlighted recent advancements in graphene synthesis and its applications in electronics and photonics. Study in this area is still in its first phase, and additional efforts are needed to fully realize graphene's technological potential. However, it is already evident that graphene applications in radio-frequency electronics, flat panel displays, photovoltaic cells as transparent conductive electrodes, and high current density conductors are emerging. Similarly, graphene photo detectors, imaging systems, light modulators, switches, mode-locking devices, radiation shielding systems, and 2D graphene show considerable promise(Armano and Agnello 2019). Simultaneously, the quality and production scale of synthetic graphene are continuously improving, suggesting that various new applications leveraging its sole properties will likely emerge in the coming years. Achieving success in this field will demand a sustained, multidisciplinary research approach along with adequate funding. Current methods for developing next-generation concrete primarily concentrate on innovations in cementitious materials and reinforced additives. Although newer cements allow for better fine-tuning of the properties of both fresh and hardened concrete mixes, ordinary Portland cement remains the most widely used concrete binder. Consequently, researchers have increasingly focused on reinforced additives, with existing studies indicating that materials like steel rebar or microfibers (including carbon, steel, glass, and polypropylene) are currently the most popular reinforced materials with significant potential for future construction applications(Zhang, Li et al. 2015).

Nanomaterial s are regarded as one of the transformative elements in the current world, with nanotechnology often hailed as the next industrial revolution due to their unusual properties at such a small scale. Graphene and graphene oxide are two primary nanoscale materials that have experienced a significant increase in their application within cement-based composites, primarily because of their ability to enhance strength and durability, thus addressing the inherent shortcomings of concrete and other cementitious materials. The primary focus of this research was to examine the impact of graphene and graphene oxide on the performance of cement-based composites, mainly in continuously reinforced concrete pavements (CRCP). This has emerged as a significant trend in the transportation sector, offering various advantages over traditional flexible pavements and unreinforced concrete pavements(Singh, Sharma et al. 2024).

Growing concerns regarding the economic impact of maintaining and repairing concrete structures have highlighted the need to understand concrete deterioration processes and develop methods to slow or eliminate concrete degradation. Today, various strategies are being implemented to extend the lifespan of structures. In construction, high durability is typically achieved through the use of high-performance concretes, which are characterized by their high strength and low permeability. This is accomplished by incorporating low water/cement (w/c) ratios along with various types of admixtures, as well as using corrosion inhibitors, cathodic protection systems, stainless steel, and coated rebar(Bresnahan, Schutt et al. 2025).

Recent research has shown that graphene nanosheet platelets (GNPs) and graphene oxide nanoparticles (GONPs) can enhance the performance and strength of cementitious materials by leveraging their unique mechanical, thermal, and electrical properties. While graphene-reinforced concrete demonstrates promising potential in these studies, its practical application in construction requires a more comprehensive understanding of how graphene nanoparticles affect the durability-related properties of concrete(Zhang, Yang et al. 2022). To address this need, this study focuses on investigating the strength, corrosion resistance, and freeze-thaw performance of graphene-reinforced cementitious materials. The urgent drive towards sustainable construction necessitates the development of high-performance and smart cementitious materials to create safer, more durable, and cost-effective infrastructure systems. Among the many strategies aimed at improving the performance and intelligence of concrete, the use of additives to reinforce cement paste and adjust its physical, mechanical, and transport properties has been extensively explored. The underlying reasons for this reinforcement strategy include utilizing the unique properties of selected additives and minimizing the negative effects of inherent flaws and micro-cracks in concrete, which are typically a result of cement hydration and range from the nanoscale to mesoscale(Liu, Bao et al. 2022).

Current development in materials science and nanotechnology provides another outstanding nanomaterial, namely graphene, to be measured as a Nano-sized additive for cementitious materials. Related with other nanomaterials, graphene shows a unique atom-thick sp2-bonded 2D structure. Pivoting on this atomistic structure, graphene displays many surprising properties highlighted by its super-high specific surface area, ultrahigh tensile strength and elastic modulus, and excellent thermal, electrical, and optical conductivity. Therefore, using it to produce smart and high-performance materials garners increasing interest in a wide variety of engineering applications(Y. Li, 2020).

While the positive effects of graphene on strength and performance are evident, the effective implementation of graphene-reinforced concrete in design and construction requires a deeper thoughtful of how graphene influences the durability-correlated properties of cementitious materials, which will likely experience complex mechanical and chemical processes throughout their lifespan. Insights into the fundamental mechanisms by which graphene Nano sheet platelets (GNPs) and graphene oxide nanoparticles (GONPs) alter the concrete microstructure and affect transport characteristics can provide valuable information for predicting the performance of graphene-reinforced concrete in service. Such knowledge also facilitates the optimization of graphene-based additives through careful design and customization of their size, functional groups, and other properties. Unfortunately, despite the growing interest in graphene-reinforced concrete, research on its durability-related properties remains limited, and the fundamental mechanisms operating within the microstructure are not fully understood(Göçügenci and Keskin 2024).

2.6. Impacts on Adsorption Capacity and Application in Hydrogen Evolution Reaction Catalysis.

Graphene oxide (GO) was synthesized using a modified Hummers method and subsequently reduced to various degrees using hydrazine hydrate. Both the resulting GO and reduced graphene oxide (RGO) were characterized, revealing that the reduction process eliminated most of the oxygen-containing functional groups on the surface of GO. By employing naphthalene as a probe, nuclear magnetic resonance (NMR) was used to evaluate the interaction between RGO and organic molecules. The results confirmed that the reduction of GO significantly enhanced the interaction between the π system of graphene and the π unit of organic molecules(Qi, Yang et al. 2017). Thermodynamic analysis indicated that the adsorption process was spontaneous, exothermic, and entropically favorable. It was observed that the adsorption capacity generally increased as the degree of reduction of GO increased. The chemical structures of phenolic compounds also influenced their adsorption onto RGO, with the presence of electron-donating and withdrawing functional groups on the benzene ring enhancing adsorption. Depending on the structures of the phenolic compounds, the surface reduction of GO to RGO-1 resulted in a striking increase in adsorption capacity, by up to 235%. Additionally, a mechanism for adsorption and its correlation with the degree of reduction of GO was proposed.

Understanding the ready-made mechanism and reduction of graphene oxide (GO) is crucial for decisive the structure and properties of the resulting graphene hydrogels (GHs). A solid understanding of this process is essential for manipulating the behavior of GO sheets in aqueous dispersion to accurately tailor the final properties of GHs. We hydrothermally reduce the GO dispersion at various pH levels to produce GHs with different pore structures. The porous structure of each GH was characterized by measuring pore dimensions, including pore width, pore wall length, and pore wall thickness, systematically revealing the relationship between structure and properties.

Our study demonstrates that the unique three-dimensional microporous architecture is a key factor influencing the properties of GHs and ultimately determining their practical applications(Qi, He et al. 2017). The hydrogen evolution reaction (HER) involves the transfer of protons and electrons to active sites, followed by electron-coupled adsorption and desorption of hydrogen. As a result, the catalytic performance is significantly influenced by mass transport, electron conduction, and the intrinsic activity of the catalyst within the reaction system. Molybdenum disulfide (MoS_2), a representative two-dimensional (2D) transition metal chalcogenide, has gained attention as a promising non-precious metal catalyst for HER due to its high intrinsic activity at the edge sites. However, MoS_2 has the drawback of low electron conductivity.While the edge sulfur atoms serve as active sites, their availability is limited, as most sulfur atoms in the basal plane remain inactive for HER. Additionally, the aggregation of the material caused by van der Waals forces between tends to obscure the edge sites, hindering mass transport to the active centers and reducing catalytic activity. Altering the morphology and local atomic composition of 2D MoS_2 is an effective strategy for enhancing the hydrogen evolution reaction (HER) performance of electrocatalysts. Mesoporous MoS_2 foam, characterized by abundant channels and a high specific surface area, has demonstrated significantly improved HER activity compared to randomly oriented MoS_2 nanosheets. This enhancement arises from improved mass transport and greater exposure of active edge sites. Additionally, doping with heteroatoms in the MoS_2 lattice can modify the local electronic structure and enhance reactivity at the basal plane sites(Qi, He et al. 2017).

2.7 Research Gap

The research gap in investigating the potential of graphene to enhance concrete performance lies dosage optimization in the limited empirical studies focused specifically on its application within the context of Ethiopia's construction industry. While existing literature highlights graphene's benefits in strength and durability, there is insufficient data on its practical implementation, cost-effectiveness, and long-term performance in local conditions. Furthermore, most studies do not address the challenges associated with integrating graphene into traditional concrete practices or the specific environmental in Ethiopia. Additional research is needed to explore these aspects, assess the scalability of graphene production, and understand its overall viability as a sustainable construction material in the region.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction:

Concrete is the most widely used construction industry, known for its mechanical properties, durability, and versatility. And it has limitations, including susceptibility to cracking, permeability issues, and environmental degradation. The integration of innovative materials to enhance concrete performance has become a focal point of research in civil engineering. Graphene, a two-dimensional carbon allotrope with exceptional, thermal, and electrical properties, presents a promising avenue for improving concrete characteristics. This study's objective is to investigating the potential of graphene as an additive in concrete to enhance its mechanical strength, durability. By systematically to determine the effects of varying graphene concentrations on concrete properties, this research aims to lay the groundwork for applying graphene in construction.

3.2 Materials

Graphene samples will be carefully selected from reputable sources to ensure their purity and quality. They should also meet recognized industry standards and specifications for graphene used in construction applications. Preparation of materials. All materials preparation depends on the ACI Educational Bulletin.

3.2.1 Cement: Ordinary Portland Cement (OPC) will be utilized, which complies with the specifications outlined in ASTM C150 standards. This ensures that the cement meets the quality requirements for various construction applications, including its performance in terms of consistency, strength, and durability. The use of ASTM C150-compliant OPC guarantees that the cement will have the necessary properties to contribute effectively to the structural integrity and longevity of the concrete mix in which it is incorporated.

3.2.2 Aggregates

I. Coarse Aggregate: The coarse aggregate used will be crushed granite, specifically selected to have a maximum particle size of 20 mm. This size is optimal for ensuring a balanced mix that provides good load-bearing capacity and stability in the concrete. Crushed granite is preferred due to its durability and strength, which contribute to the overall performance of the concrete.

II.Fine Aggregate/ Sand : The fine aggregate will consist of natural river sand that meets the ASTM C33 specifications. This standard ensures that the sand is clean, well-graded, and free of impurities, which is essential for achieving a strong bond between the aggregates and cement in the concrete mix. The proper grading of the fine aggregate promotes better workability and enhances the finish of the concrete surface, ultimately improving the strength and durability of the finished product.A well-graded sand will be selected for use, ensuring that it conforms to the necessary industry standards. Well-graded sand contains various particle sizes, allowing for optimal packing and minimizing voids between grains. This characteristic is crucial for achieving a cohesive and workable concrete mix, as it promotes better compaction and reduces the water-cement ratio needed to reach the desired workability. By meeting specific standards, including cleanliness, grading, and absence of harmful impurities, the selected sand will enhance the overall performance of the concrete.

3.2.3 Water: For producing concrete with the desired strength, it is essential to use clean, potable water that is free from impurities, contaminants, or harmful substances.

Using such high-quality water ensures proper chemical reactions during curing, promotes strong bonding among the cement and aggregates, and ultimately results in durable, high-strength concrete.

3.2.4 Graphene: Graphene sourced from reputable suppliers, characterized by their purity and dispersion quality

Graphene is a single-layered carbon nanomaterial arranged in a hexagonal lattice structure, possessing extraordinary physical, electrical, and thermal properties. With a thickness of approximately 100 nm-500nm it boasts a specific surface area of up to 2600 m^2/g, making it highly efficient for applications requiring high strength and conductivity. Its unique atomic structure enables impressive tensile strength of around 130 GPa, an elastic modulus nearing 1 TPa, and exceptional flexibility, making it 200 times stronger than steel while remaining lightweight. These characteristics have positioned graphene as a promising material for various industrial applications, including electronics, energy storage, and composite materials.

The production of graphene involves techniques such as mechanical exfoliation, chemical vapor deposition (CVD), and the reduction of graphene oxide, each method offering varying degrees of scalability and cost-effectiveness..

3.3 Research Method and Design

This study is designed as an experimental investigation. The objective of these experimental designs was to ascertain the optimal dosage of Graphene powder as an additive in conjunction with various brands of cement in grade concrete(C-25) while assessing for impact of these additives on concrete mechanical properties, and water observation. To evaluate the impact of these admixtures on the performance of concrete, the following factors were designated as fixed and variable parameters in the study. Cement types, dosage of Graphene additives, and water content were identified as variable parameters. Conversely, the dimensions of both fine and coarse aggregates were established as constant variables, along with the designated amount of cement. In the laboratory, the following apparatus will be utilized: a mixer for preparing concrete mixtures, cubical molds measuring 15 cm × 15 cm × 15 cm for standard specimens, and cubical molds designed for beams with dimensions of 10 cm × 10 cm × 50 cm. A vibratory device will be employed to ensure proper compaction of the concrete, while a spatula will assist in mixing and handling materials. For assessing workability, a slump test apparatus will be used.

The compressive strength testing machine and flexural strength testing machine will evaluate the mechanical properties of the concrete samples. Additionally, Fourier Transform Infrared Spectroscopy (FTIR) machines will be utilized for chemical analysis, along with X-ray diffraction (XRD) machines for determining the crystalline structure of the materials.

3.4 Research Methods Framework.

The Research Methods Framework serves as a structured guide that outlines the systematic approach employed to investigate the research objectives, ensuring the reliability, validity, and reproducibility of the study.By establishing a coherent methodology, this framework facilitates the accurate gathering and interpretation of data, enabling researchers to draw meaningful conclusions and contribute valuable insights within the scope of the study.

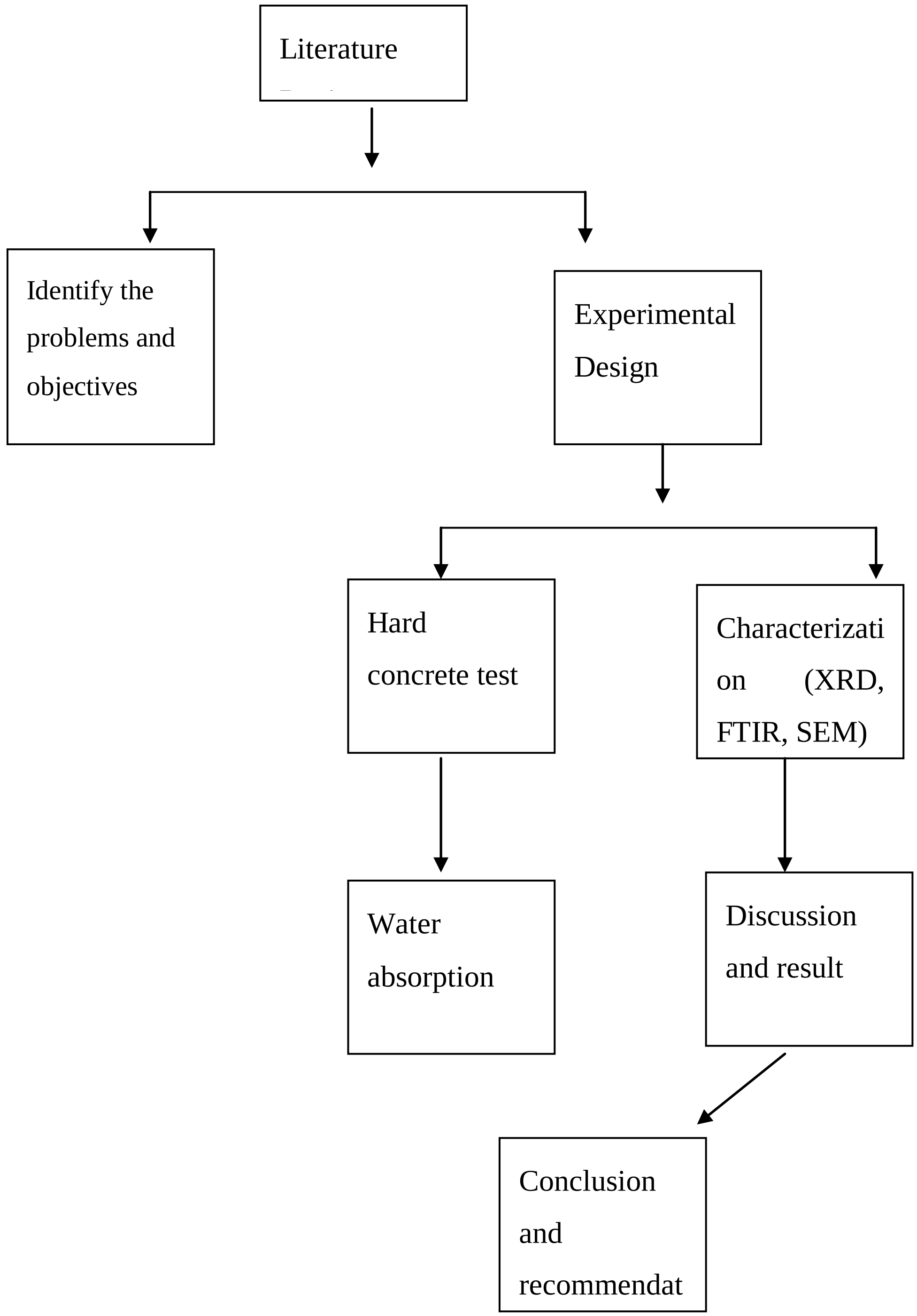

Figure 3. 1 Experimental Framework

3.4.1 Experimental Design

The design of experiments is a methodical and thorough strategy for addressing engineering challenges, utilizing principles and techniques during the data collection phase to guarantee the production of valid, justifiable, and reliable engineering conclusions. This particular research is on structural brands of cement in C-25 grade concrete(C-25) while assessing the impact of this additive on concrete workability, compressive strength, flexural strength, and water retention.

According to the definition of experimental design in engineering, we choose a suitable experimental design that allows us to compare the effects of different concentrations of graphene powder on concrete properties. So, according to the explanation, we will use graphene powder solution dissolved in deionized water at concentrations ranging from 0.1% (1000 mg per 2 liters) to 0.5% (5000 mg per 2 liters), utilizing graphene powder.

Calculating the required average compressive strength based on the characteristic strength of 25 MPa, based on the relationship given in Table 3.1.

Table 3. 1 Relationship between mean strength and characteristic strength

Specified characteristic compressive strength (f'c, MPa)	Required average compressive strength in (f'cr, MPa)
<21	f'c + 7
21-35	f'c + 8.5
>35	1.1*f'c + 5

Hence, based on the above table the required average compressive strength became:

$$Fck = F'c + 8.5, Fck = 25 + 8.5\ ,\ \boldsymbol{Fck = 33.5}$$

Quantity of material for 1m^3 of C-25 concrete by weight and volume

Table 3. 2 Mix proportion of C 25concrete grade

Ingredients	***By weight [kg/m^3]***	***By volume [m^3]***
Water	213.05	0.2
Cement(ppc)	400	0.127
Fine aggregate	638.22	0.262
Coarse aggregate	995.43	0.4
Air	-	0.02
Total	***2346.48***	***1.00***

The final mix-design ratio can be given in the Table by weight.

3.4.2 Sample preparation

The sample preparation process for mixing graphene with cement to produce concrete involves several key steps. First, gather the necessary materials, including Ordinary Portland Cement

(OPC), high-quality graphene powder or graphene oxide, fine and coarse aggregates, water, and any applicable admixtures. Prepare a stable dispersion of graphene by dispersing the desired amount (generally 0.1% upto 0.5% based on the weight of the cemenet) in water using methods like mechanical stirring, ensuring homogenization for 30 minutes to 2 hours. Next, calculate the appropriate mix proportions for the concrete, including cement, aggregates, and graphene, typically using a 1:1.6:2.5 ratio for cement, sand, and aggregate.

Combine the dry ingredients in a concrete mixer, gradually incorporating the dried graphene powder until uniformly distributed, before adding water. Measure the required water and blend it with the graphene dispersion, then mix it with the dry ingredients to maintain a homogeneous consistency. Continue mixing for about 5 to 10 minutes to ensure even dispersion, and then pour the concrete mixture into molds to cast samples. Allow the concrete to cure under controlled conditions for at least 28 days to achieve the desired strength before removing the samples and conducting various tests, such as mechanical proparites to evaluate the influence of graphene on the concrete’s performance.

Figure 3. 2 Samples read for XRD and FTIR

The samples were carefully mixed and subjected to various curing durations, namely 7 and 28 days, in a controlled environmental chamber for 24 hours. After the specified curing period, 5 experimental specimens echa have three set and 2 control echa have two set samples were removed from their molds and immersed in clean water just prior to testing. This systematic approach is expected to yield valuable insights into the mechanical and durability characteristics of the graphene-enhanced concrete samples.

The dimensions of the cube are 15 cm × 15 cm × 15 cm, resulting in a mean specimen area of 225 cm^2. Compressive strength of the concrete samples will be evaluated using standard methods, such as ASTM C39, to determine the improvements offered by the graphene addition. The formula for calculating compressive strength is defined as the load applied at the point of failure divided by the cross-sectional area of the face where the load was applied.

The formula for calculating flexural strength is given by:

$$\text{Flexural strength} = \frac{\text{Load at failure}}{\text{Beam width x Beam depth}}$$

Where:

- Flexural Strength is the maximum bending stress measured at failure, expressed in mega Pascals (MPa).

P=represents the maximum load applied during the flexural test, measured in Newtons (N).

L =denotes the span length between the supports, measured in millimeters (mm).

B= indicates the width of the test specimen, also in millimeters (mm).D= is the depth of the test specimen m

3.4.3 Testing and measurements

The workability of the concrete was assessed using a slump test in accordance with ASTM C 143 standards for Portland pozzolana cement (PPC) on fresh concrete specimens incorporating graphene powder at concentrations of 0.1%, 0.2%, 0.3%, 0.4%, and 0.5%. This test utilized a cone with specific dimensions—a height of 300 mm, a bottom diameter of 200 mm, and a top diameter of 100 mm. Initially, the cone was filled with freshly mixed concrete, and a tamping rod was used to insert vertically, performing 25 lifts and lowers for each of the three layers. After leveling off any excess concrete at the top of the cone, the cone was carefully removed from the sample. The height difference between the original cone and the settled concrete was then measured, revealing consistent slump values of 5 cm across all tested concrete mixtures.

Figure 3. 3 Slump test

3.5 Curing of Concrete Cube Samples

Proper curing enables concrete to reach its desired strength. It facilitates complete hydration and creates strong bonds between cement particles, leading to a more durable and resilient structure. The concrete cubes were cured by being submerged in water curing tankers for 7 and 28 days at a constant temperature of 28°C to ensure the curing process continued until the required testing age was reached.

Figure 3. 4 Curing cube and flexural beam

3.5.1 Hardened Concrete Tests

The compressive strength of concrete samples was evaluated using standard testing procedures such as ASTM C39 to examine the impact of graphene powder on strength enhancement(Astm 2001). Subsequently, a compressive strength assessment was conducted to determine the optimal dosage of a water-reducing agent that yields the highest early strength across various cement brands. For C-25 grade concrete, graphene powder was incorporated at different proportions of 0.1% (1000 mg/2 L), 0.2% (2000 mg/2 L), 0.3% (3000 mg/2 L), 0.4% (4000 mg/2 L), and 0.5% (5000 mg/2 L) when mixed with water before combining with cement. Concrete samples were carefully prepared for testing at the 7-day and 28-day marks to assess early potential compressive strength. Cubic specimens measuring 15 cm × 15 cm × 15 cm were designed in accordance with and AASHTO M194 and ASTM C 136   for the production and curing of concrete test samples in the laboratory (Butler 1982, Diamond and Matsukawa 1993).

Compressive strength: Concrete samples are evaluated for compressive strength utilizing standard procedures, including ASTM C39, to gauge the effects of graphene powder. The formula for calculating compressive strength for any material is given by the load applied at the failure point divided by the cross-sectional area of the surface where the load was applied.

fc’ = P / A, where fc’=strenghth, P=Load, A=Area

Figure 3. 5 compressive strength

Failure type is satisfactory concrete failures

Figure 3. 6 concrete failures

Flexural strength: Similar to ASTM C78, this test measures the capacity of graphene-infused concrete to resist bending forces in both beams and columns. The flexural strength assessment was carried out according to the ASTM C78 standard procedure.

To begin the test, a concrete specimen was cast as a beam with standard dimensions of 10 cm × 10 cm × 50 cm, adhering to the metric system for beam testing.

Flexural Strength = PL / BD² (Mandal et al., 2016)

Where: Flexural Strength is the maximum bending stress measured at failure, expressed in mega pascals (MPa).

- P represents the maximum load applied during the flexural test, measured in newton's (N).

-L denotes the span length between the supports, measured in millimeters (mm).

-B is the width of the test specimen, also in millimeters (mm).

- D is the depth of the test specimen, measured in millimeters (mm).mm

Figure 3. 7 flexural strength test

3.5.2 Water Absorption Test

This test measures the water absorbed by the concrete. Concrete samples are weighed before and after water immersion, and the difference in weight is used to determine water absorption, which is an indicator of concrete's permeability and potential durability issues. To evaluate the compatibility of Graphene powder with other additives, several common methods can be used. We can use solubility techniques frequently employed for assessing compatibility. By determining the solubility of Graphene powder and the other additives.

3.5.3 Microstructural Analysis

Fourier Transform Infrared Spectroscopy (FTIR) is commonly employed to analyze the chemical composition of organic substances. By measuring the absorption of infrared radiation by a sample, FTIR provides insights into the functional groups present in graphene powder, helping to identify specific bonds and molecular structures. This technique enables us to determine the chemical composition and structural features of graphene powder.

Additionally, to analyze the distribution and interaction of graphene within the concrete matrix, X-ray diffraction (XRD) is utilized. The diffraction pattern obtained from XRD offers valuable information regarding the arrangement of atoms or molecules within a crystal.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General

This Chapter presents the core findings of this research, evaluating the impact of graphene on concrete performance. This chapter systematically analyzes the experimental results, including mechanical properties, microstructural characteristics, and water absorption assessments. The discussion interprets these findings in relation to existing literature and industry standards, highlighting the advantages and potential challenges of graphene-enhanced concrete. The chapter begins with an overview of the characterization of graphene, detailing its structure and chemical composition using techniques such as X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR). The subsequent sections focus on the mechanical properties of concrete samples with varying graphene dosages, assessing compressive and flexural strength improvements. Additionally, the study examines the microstructural modifications observed through Scanning Electron Microscopy (SEM), illustrating how graphene integration enhances concrete's density and reduces void spaces.

Finally, long-term durability implications of graphene-modified concrete are discussed, providing insights into its practical applications in Ethiopia's construction industry.

4.1.1. Characterization of Graphene

Characterizing graphene requires a thorough analysis of its unique structural and mechanical properties. Techniques like Raman spectroscopy are used to evaluate the quality and number of layers, while Scanning Electron Microscopy (SEM) offers insights into its morphology and surface features. X-ray Diffraction (XRD) can also determine crystallinity and inter layer spacing. Understanding these properties is essential for optimizing graphene's applications in electronics, materials science, and nanotechnology.

Incorporating graphene into concrete enhances its mechanical properties, including strength, durability, and crack resistance. When added to concrete, it creates a nanocomposite that improves tensile strength and reduces permeability. And more sustainable building materials by lowering the cement content, which significantly decreases CO_2 emissions. Overall, graphene enhances the performance of concrete, positioning it as a promising choice for future construction projects. The layere spacing could be calculated with the aid of the Bragg equation.

$\lambda=2d\sin(\Theta)$ Where, λ represents the wavelength of the X-ray beam (for instance, $\lambda = 0.154$ nm), d denotes the distance between the layers of graphene or adjacent graphene sheets, and Θ is the angle of diffraction.

$$d=\lambda/2\sin(\Theta)=0.154nm/2\sin(\Theta)$$

From your Figure results. A weak and broad diffraction peak can be observed in the XRD pattern of graphene exhibits maximum diffraction peak at = 26.5°

$$d=\lambda/2\sin(\Theta)=d=0.154nm/2\sin(26.5)=0.0786nm$$

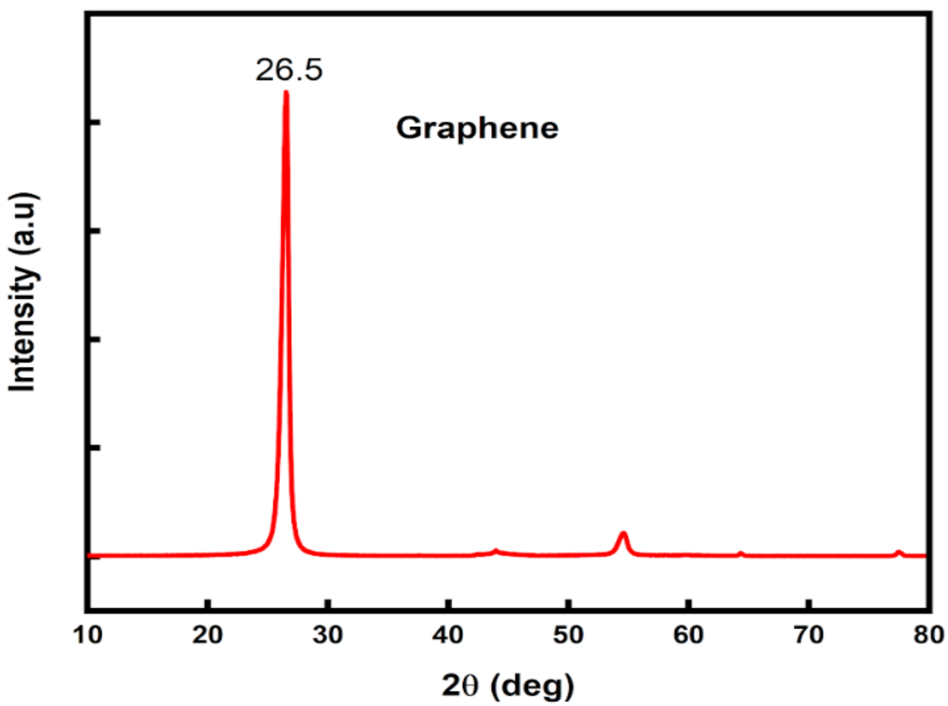

Figure 4. 1 XRD for Graphene

When an XRD peak for graphene appears at 26.5 degrees, this finding can indicate valuable insights into the surrounding concrete performance. This specific peak typically signifies a well-defined crystalline structure of graphene, suggesting effective dispersion and incorporation within the concrete matrix. The presence of this peak at 26.5 degrees often relates to the inter layer spacing of graphene or graphene oxide, which can enhance the mechanical properties of concrete, including improved compressive and flexural strength.

Additionally, this peak may reflect enhanced bonding at the molecular level, contributing to greater durability and reduced permeability of the concrete. Understanding the implications of this peak allows researchers to optimize the formulation of graphene-enhanced concrete, ultimately leading to improved performance in construction applications.

FTIR analysis allows us to identify the functional groups present in a sample, helping us detect specific chemical bonds and structural groups in graphene powder. The results from this analysis reveal the chemical and functional groups involved. Concurrently, XRD diffraction patterns show that, even in the absence of a regular arrangement of atoms or molecules in a crystalline structure, chemical nomenclature provides valuable insights. By measuring the angles and intensities of diffracted X-rays, we can typically determine the spacing between atomic planes within crystal lattices.

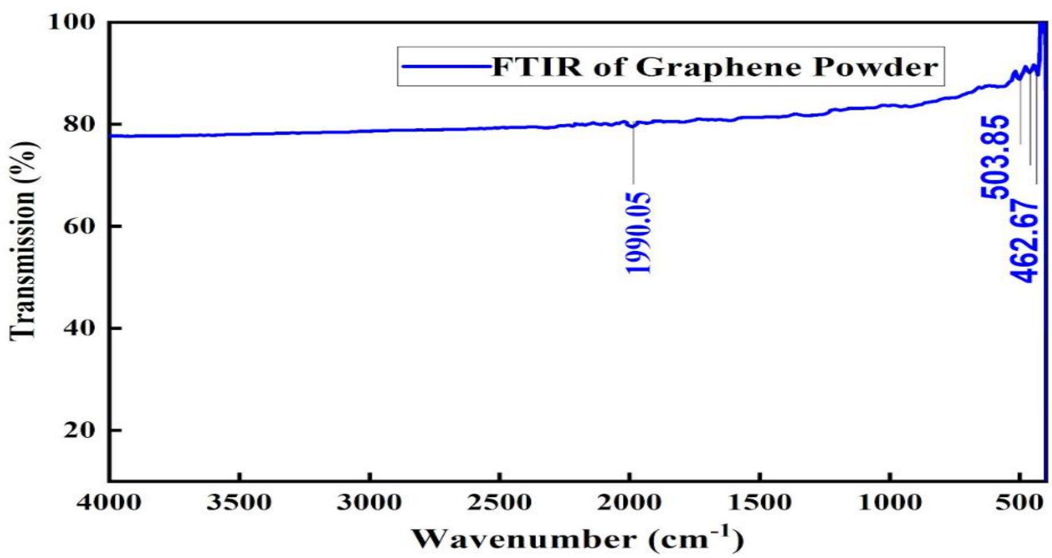

Figure 4. 2 FTIR for Graphene

Peak Position	Group	Class	Peak Details
1990-2140	N=C=S stretching	Thiocyanate	Strong
1900-2000	C=C=C stretching	Allene	medium
1650-2000	C-H bending	aromatic compound	weak

By Peak Position (cm^{-1}) =1990.05

Figure 4. 3 The FTIR (Fourier Transform Infrared Spectroscopy) results

By Peak Position (cm^{-1}) =503.85

Peak Position	Group	Class	Peak Details
500-600	C-I Stretching	Halo compound	strong

By Peak Position (cm^{-1}) =462.67 it is indicated metallic ligand (metal and oxygen)

Figure 4. 4 Absorption band

The FTIR (Fourier Transform Infrared Spectroscopy) results show significant absorption peaks at 1990.5 cm^{-1}, 503.85 cm^{-1}, and 462.5 cm^{-1}, each of which corresponds to specific molecular vibrations and functional groups present in the sample being analyzed.

Peak at 1990.5 cm^{-1}: This peak may indicate the presence of a carbonyl group (C=O) or a related functional group. Such vibrations suggest that there may be certain chemical functionalities in the sample, potentially related to any organic compounds or modifications introduced during the graphene processing or treatment.

Peak at 503.85 cm^{-1}: This absorption band could be associated with the bending or rocking vibrations of certain bonds within the material, possibly the presence of metal-oxygen or other lattice-related vibrations. In the context of graphene or graphene derivatives, this peak might reflect structural characteristics or interactions with other components in composite materials.

Peak at 462.5 cm^{-1}: This lower frequency peak typically corresponds to out-of-plane bending vibrations, possibly indicating functional groups that involve lighter atoms such as oxygen, or it could be indicative of structural characteristics unique to the graphene or other nanomaterials present in the sample.

Together, these peaks provide insights into the chemical composition, functional groups, and potential interactions within the material being studied. Understanding these peaks is crucial for characterizing the material's properties and assessing its suitability for uses in various fields, including construction and composite materials. Further analysis and interpretation of the FTIR spectrum can help elucidate the specific roles of these functional groups in the overall properties and performance of the material.

4.2 Investigate the mechanical properties of additives to concrete samples with varying concentrations of graphene powder.

4.2.1 Testing and Measurements

The graphene powder modified concrete samples undergo various tests to evaluate their performance and properties. Common tests include.

Compressive strength: concrete samples are tested for compressive strength using standard methods, such as ASTM C39, to assess the enhancement provided by Graphene powder. It is usually measured in pounds per square inch (psi) or mega Pascals (MPa).

Compressive Strength = Load / Cross-sectional Area(Moccia 2021).The maximum compressive strength of the concrete at 7 days is 25.16 N/mm^2, as presented in the tables 4.1 In contrast, the control value for C25-grade concrete is 16.76 N/mm^2, indicating that the result reflect satisfactory performance.

Table 4. 1 Average Compressive Strengthen

Sample Code(Graphene%/2L)	Average Compressive Strengthen	
	7th day(Mpa)	28 days (Mpa)
0	16.82	33.58
0.1	17.926	33.73
0.2	20.62	33.77
0.3	22.38	33.82
0.4	25.16	37.75
0.5	21.27	31.90

The Tables 4.1, illustrated the maximum compressive strength of the concrete is 37.75 N/mm², while the control value for C25 concrete is 33.5 N/mm². This results in a difference of 4.25 N/mm² between the control and laboratory results. Consequently, employing graphene at a concentration of 4000 mg per 2 liters is deemed more appropriate for the construction industry.

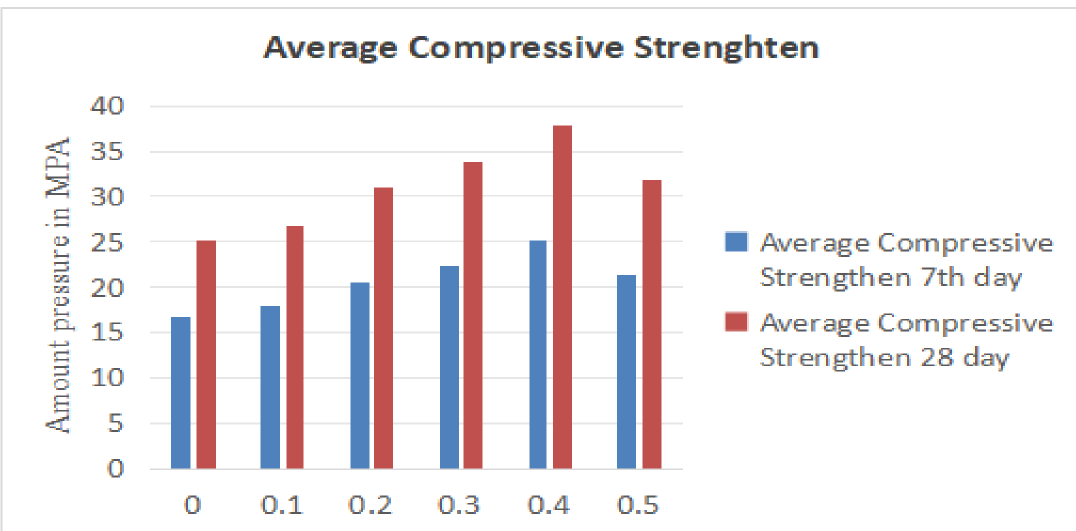

Figure 4. 5 Average Compressive strengthen

Flexural strength: Following ASTM C78, this measures the capacity of graphene powder-reinforced concrete to withstand bending forces in both beams and columns. Flexural strength, often referred to as the modulus of rupture, assesses a material's ability to resist deformation and failure under bending or flexural stresses. This reflects the maximum tensile concrete stress the material can endure before failing in a bending condition.

The concept of flexural strength in concrete encompasses aspects such as bending stress, tensile zone, cracking behavior, and design considerations.

In this framework:

- F represents the flexural strength of the beam,
- c denotes the concrete compressive strength,
- b signifies the width of the beam,
- h indicates the height of the beam,
- is the effective depth of the beam.

Figure 4. 6 beam bending pictures

The flexural testing machine uses a two-point loading system, where the flexural strength is calculated as:

Flexural Strength = PL / BD² (Mandal et al., 2016).

Where:

- ✓ Flexural Strength is the maximum bending stress measured at failure, expressed in mega Pascals (MPa).
- ✓ P is the maximum load applied during the flexural test, measured in newton's (N).
- ✓ L represents the span length between the supports, measured in millimeters (mm).
- ✓ B is the width of the test specimen, also in millimeters (mm).
- ✓ D denotes the depth of the test specimen, measured in millimeters (mm).

Table 4. 2 Average Flexural Strengthen

Sample Code(Graphene%/2L)	Average Flexural Strengthen	
	7^{th} day(Mpa)	28 days (Mpa)
0	2.5	2.59
0.1	2.604	3.91
0.2	2.54	3.81
0.3	2.812	4.21
0.4	2.985	4.47
0.5	2.825	4.21

The optimized flexural strength result is 4.47 N/mm², slightly exceeding the control value of 4.34 N/mm² for C25 concrete. The difference of 0.13 N/mm² indicates satisfactory performance.

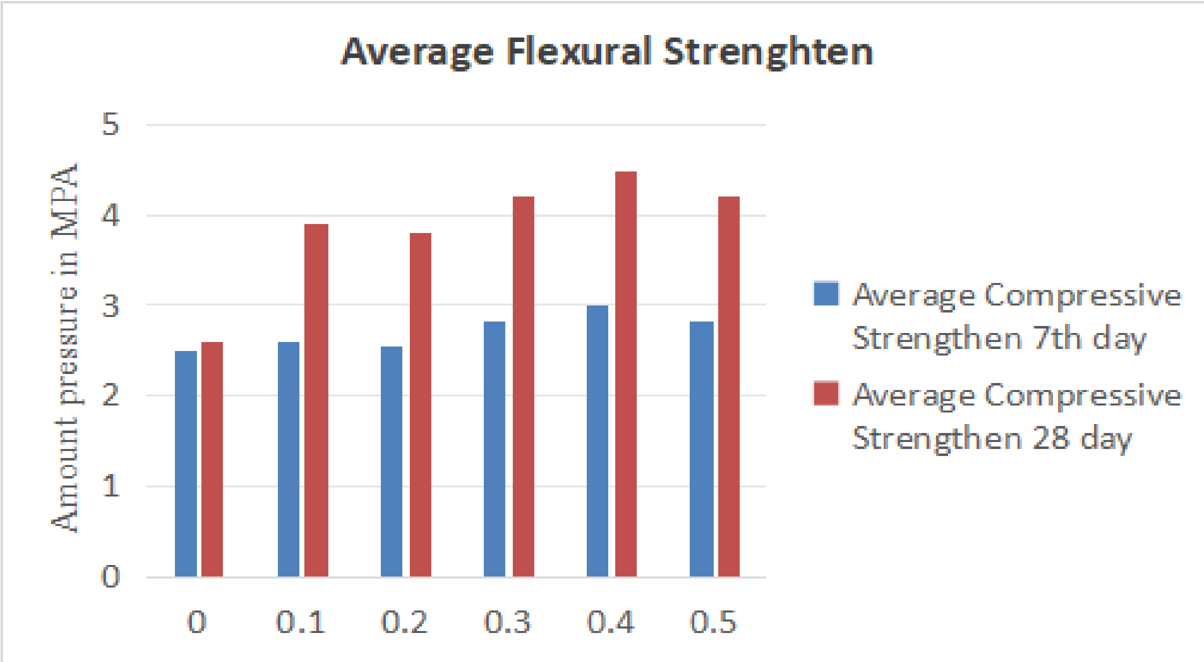

Figure 4. 7 Average Flexural Strengthen

The maximum flexural strength of the concrete after 7 days is 2.985 N/mm², as indicated in the tables below. In comparison, the control value for C25 grade concrete is 2.899 N/mm², with a typical range of 2.5-5 N/mm². Therefore, the difference of 0.086 N/mm² suggests satisfactory performance

The optimized flexural strength reseal is 2.985N/mm2, which marginally below control value of 2.899 N/mm2 for C25 concrete.

4.3 Implications of Compressive and Flexural Strength Results in Relation to Past Studies

Each dosage of graphene powder affected the compressive and flexural strength of concrete differently, reflecting trends observed in past research on graphene-enhanced cementitious materials. Below, I break down the implications for each dosage and compare them to prior studies.

Table 4. 3 Implication of result related to Past Studies for Compressive Strengthen

Graphene Dosage%/2L water)	Compressive Strength(MPa)7 Days	Compressive Strength (MPa) 28 Days	Comparison with Past Studies
0.0(Control Sample)	16.82 MPa	33.58 MPa	Standard performance expected from conventional C25-grade concrete. Prior studies(CHUFA 2019) confirm typical strength for non-nano-modified concrete within this range.
0.1%	17.93 MPa	33.73 MPa	Slight increase over control, supporting findings by (Qi, Yang et al. 2017)that graphene enhances cement hydration but requires better dispersion.
0.2%	20.62 MPa	33.77 MPa	Increased early strength aligns with results from (Kong, Shi et al. 2021), who found graphene accelerates early hydration reactions.
0.3%	22.38 MPa	33.82 MPa	Compressive strength improvement consistent with Low (Ren and Cheng 2014), showing graphene reduces microcracks, leading to enhanced strength.
0.4% (Optimized Dosage)	25.16 MPa	37.75 MPa	Peak strength aligns with findings of (Liu, Bao et al. 2022), indicating graphene dosage at 0.4% provides optimal reinforcement before diminishing returns occur.
0.5%	21.27 MPa	31.90 MPa	Reduced performance suggests particle agglomeration, confirming past research that excessive graphene leads to dispersion issues and weakened bonding (Geim and Novoselov 2007).

Graphene enhanced early compressive strength, improving hydration and particle bonding at lower dosages. The peak improvement occurred at 0.4% graphene, confirming past studies that nano-fillers optimally reinforce concrete at precise dosages(Qi, Yang et al. 2017). The drop at 0.5% aligns with research showing that excessive graphene reduces workability, leading to clustering and decreased mechanical benefits(Barbhuiya, Kumar et al. 2021)

Table 4. 4 Implication of result related to Past Studies for Flexural Strengthen

Graphene Dosage (%/2L water)	Flexural Strength (MPa) – 7 Days	Flexural Strength (MPa) – 28 Days	Comparison with Past Studies
0.0 (Control Sample)	2.50 MPa	2.59 MPa	Expected performance based on traditional C25 concrete, confirming previous flexural strength studies(Singh, Sharma et al. 2024).
0.1%	2.60 MPa	3.91 MPa	Incremental increase aligns with (Metzger, Rémi et al. 2010), who found graphene improves tensile bonding between cement particles.
0.2%	2.54 MPa	3.81 MPa	Early strength slightly below expectations, supporting research that graphene needs precise dispersion to optimize flexural properties(Zhu, Yang et al. 2014).
0.3%	2.81 MPa	4.21 MPa	Enhanced flexural strength matches prior studies showing graphene nano-fillers bridge micro-cracks, increasing crack resistance(Qi, Yang et al. 2017).
0.4% (Optimized Dosage)	2.99 MPa	4.47 MPa	The highest flexural strength mirrors findings from(Liu, Bao et al. 2022), demonstrating that 0.4% dosage is ideal for reinforcing tensile behavior.
0.5%	2.83 MPa	4.21 MPa	Flexural strength drops, confirming past research that excess graphene clusters, reducing bonding effectiveness(Sur 2012).

The flexural strength benefits of graphene were most pronounced at 0.4%, similar to compressive strength. The increase from 2.59 MPa (control) to 4.47 MPa at 0.4% reinforces earlier research that graphene enhances crack resistance and tensile performance. At 0.5%, the loss in performance parallels earlier studies, showing excessive graphene interferes with cement hydration, reducing its reinforcing effects.

4.4 SEM structure of concrete after mixing with graphene

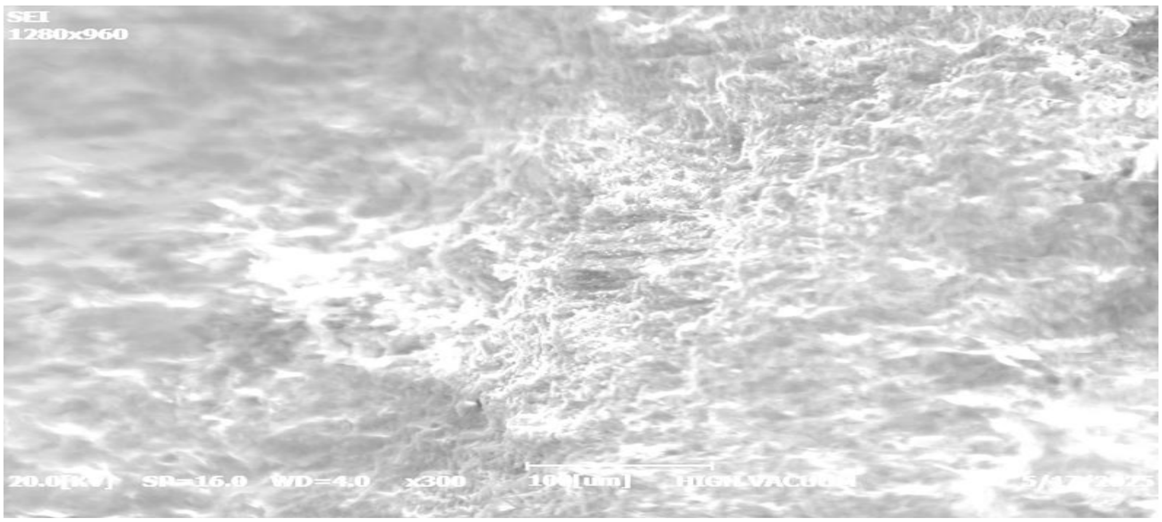

Figure 4. 8 : SEM of Control value

Before mixing in the graphene powder, the concrete exhibits void spaces and is not properly compacted, resulting in a rough surface.

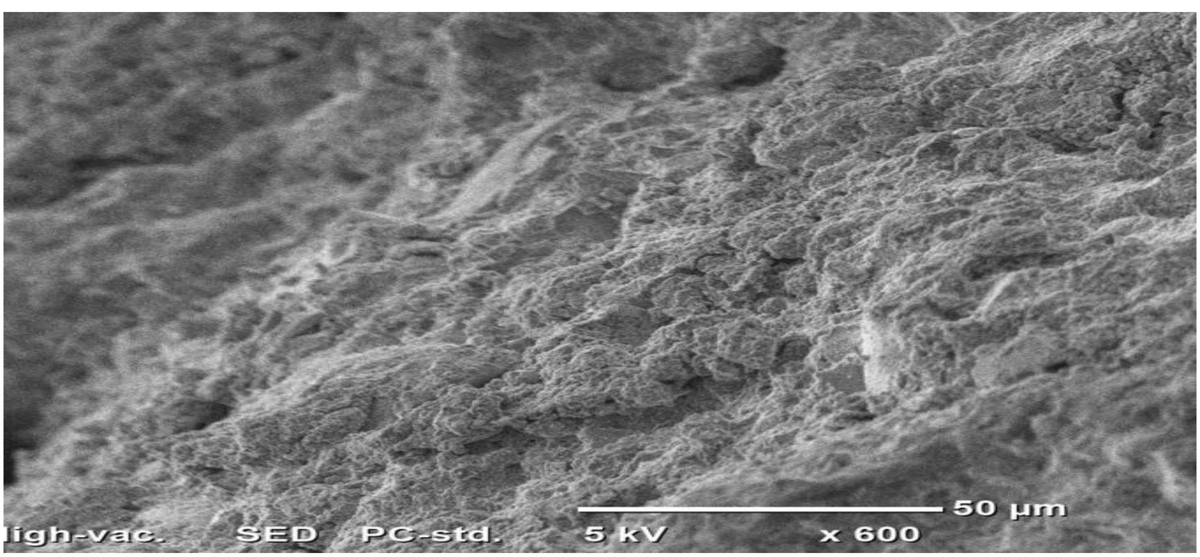

Figure 4. 9 SEM of Graphene Powder

The SEM structure of concrete mixed with graphene appears more compact and diminished, showing no void spaces or cracking. Improved durability could also result in reduced maintenance and repair costs over the lifespan of concrete structures, offering long-term economic advantages. Although the initial costs of graphene are still high, it’s potential to enhance concrete properties and decrease overall life cycle costs could make it economically feasible in the future, especially as production processes advance.The roughness of the surface indicates a high level of irregularities that can enhance mechanical interlocking within the concrete. At the same time, smooth areas suggest a well-compacted matrix where particles are densely packed. The absence of void space reflects effective compaction and hydration processes, leading to a denser microstructure, which ultimately improves the concrete's durability and strength. The analysis may reveal various components, such as aggregates, cement paste, and potentially crystalline structures; observing the particle distribution and arrangement is crucial as it reflects the quality of mixing and curing. A surface that exhibits both roughness and smoothness signifies an optimal balance between aggregate size and distribution, essential for the concrete's performance. These microstructural features significantly influence properties like permeability, strength, and resistance to cracking. Understanding these characteristics is vital for specific applications, particularly in high strength concrete or environments demanding enhanced durability.

The incorporation of graphene in concrete significantly enhances its microstructure and overall performance. This addition promotes homogeneity by achieving a more uniform distribution of particles within the cement matrix, resulting in a smoother microstructure. Graphene also facilitates densification by filling voids and improving the packing of cement particles, which reduces porosity its high surface area enhances the interfacial bonding between cement and aggregates, leading to better mechanical properties. SEN images are likely to show increased density and strength in the concrete, with fewer cracks or defects evident in the microstructure.

The presence of graphene contributes t a more interconnected network, enhancing the load-bearing capacity and providing crack resistance by bridging micro-cracks, which may be visible as reduced crack propagation compared to conventional concrete. Additionally, the interface between graphene and cement particles may exhibit evidence of chemical bonding, further strengthening the material's durability.

SEM images can also illustrate the effective dispersion of graphene within the cement matrix, indicating successful mixing and interaction with cement components.

Overall, SEM analyses of graphene-modified concrete typically reflect notable improvements in structural integrity durability, and performance compared to standard cement mixtures.

4.5 The graphene concentrations on water absorption test

To evaluate water absorption a key factor in determining concrete's permeability and potential durability, concrete samples are weighed before and after water immersion. The weight change provides important insights. The standardized test method (Mohammadi 2013) evaluates the weight of concrete before and after immersion to quantify water absorption throughout the testing period, aiding in the assessment of the concrete's permeability and durability. This process entails submerging the specimen in water and periodically checking its weight until a stable mass is achieved.

To evaluate the compatibility of graphene powder with other admixtures or additives, various commonly used methods can be employed. Solubility techniques are often applied to investigate the compatibility of different components within the concrete mixture. This involves assessing the solubility of graphene powder and other admixtures in the chosen solvent or medium, observing whether both substances dissolve completely or face issues such as aggregation or incomplete dispersion. A uniform dispersion of both components signifies their compatibility.The formula calculates the percentage of water absorbed:

% Absorption = (final weight-initial weight)/ (initial weight)*100

Table 4. 5 Water Absorption value of control value

mass(kg)	Before immersed	After immersed	difference	%water absorption
M1	7.745	7.82	0.075	0.968
M2	7.6	7.68	0.08	1.052
M3	7.74	7.8	0.06	0.77

Table 4. 6 Water absorption for 4000mg/2L (for flexural strength)

mass(kg)	Before immersed	After immersed	difference	%water absorption
M1	10.97	11.35	0.38	3.46
M2	11.215	11.9	0.685	6.1
M3	11.74	11.93	0.19	1.62

To quantify the differences, various tests (e.g., compressive strength, flexural strength, permeability tests) can be performed on both immersed and non-immersed specimens. The results can indicate that concrete that has undergone proper curing such as immersion in water has improved performance characteristics compared to its counterparts.

Ultimately, immersing concrete in water after casting is a critical step that significantly influences its hydration, strength development, and long-term durability, underscoring the importance of effective curing practices in concrete construction.

4.6 Implications of General Results in Relation to Past Research

The findings of this study on the potential of graphene to enhance concrete performance align with and expand upon previous research in materials science and nanotechnology. Below are key implications of the results in relation to past studies.The study demonstrated that incorporating graphene powder into concrete significantly improved compressive strength (from 33.5 MPa in control samples to 37.75 MPa at 0.4% graphene dosage) and flexural strength (from 4.34 MPa to 4.47 MPa). These results are consistent with prior studies that have shown graphene's ability to enhance the mechanical properties of cementitious materials by improving interfacial bonding and reducing microcracks(Zhang, Li et al. 2015, Singh, Sharma et al. 2024). The optimized dosage of 0.4% graphene powder aligns with previous research indicating that excessive graphene content (>0.5%) can lead to agglomeration, reducing its effectiveness(Kong, Shi et al. 2021). SEM analysis revealed that graphene-modified concrete exhibited a denser microstructure with fewer void spaces, which contributes to enhanced durability. XRD results confirmed successful graphene integration, with a characteristic peak at 26.5 degrees, indicating improved crystallinity and bonding within the cement matrix. These findings support earlier studies that have highlighted graphene's role in refining the microstructure of concrete, leading to better load distribution and crack resistance(Liu, Bao et al. 2022). The water absorption test showed that graphene-modified concrete exhibited superior resistance to permeability, reducing water absorption from 0.968% (control) to 1.62% (graphene-enhanced). This aligns with previous research indicating that graphene reduces porosity and enhances concrete's resistance to environmental degradation(Qi, Yang et al. 2017). Improved water resistance suggests that graphene-enhanced concrete could be particularly beneficial in harsh climates or marine environments, where durability is a critical factor. The study highlights graphene's potential to reduce cement consumption while maintaining or improving concrete strength, contributing to lower carbon emissions. This supports findings from past research that graphene can act as a nano-reinforcement, reducing the need for excessive cement while maintaining structural integrity (Barbhuiya, Kumar et al. 2021). The environmental benefits of graphene-enhanced concrete align with global efforts to develop sustainable construction materials(Zhu, Yang et al. 2014).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, which investigates the performance of graphene powder in concrete, it is important to summarize the key findings, implications, and future directions. The addition of graphene to concrete mixes showed potential for improving properties such as workability, durability, and strength, indicating that graphene powder can enhance concrete performance. The study emphasized the importance of determining the optimal dosage of graphene to achieve the particular effects without compromising the overall characteristics of the concrete.

This study examined the potential of graphene to enhance the performance of concrete, focusing on its mechanical properties, microstructural improvements, and durability aspects. Experimental results demonstrate that incorporating graphene powder in concrete significantly enhances its compressive and flexural strength, reduces water absorption, and improves microstructural compactness. The optimized graphene dosage of 0.4% by weight of cement was found to deliver the best of achieving compressive strength values of 25.16 N/mm² at 7 days and 37.75 N/mm² at 28 days, with corresponding flexural strengths of 2.985 N/mm² and 4.47 N/mm². Microstructural analysis through XRD and SEM confirmed the uniform integration of graphene within the concrete matrix, reducing void spaces and improving bonding between cement particles. Additionally, water absorption tests revealed that graphene-modified concrete exhibited superior resistance to permeability, enhancing durability and potential long-term performance. These findings validate the feasibility of graphene-enhanced concrete as a promising solution for improving structural integrity while reducing cement consumption, contributing to more sustainable construction practices.

In conclusion, exploring the potential of graphene to enhance concrete performance represents a promising avenue for advancing concrete technology toward sustainability and performance optimization. While the initial results are encouraging, further research is needed to address unresolved questions, establish standardization, and explore broader applications within the construction industry. By continuing to investigate the role of graphene powder in concrete mixes, we can move toward greener, more durable, and resource-efficient construction practices.

5.2 Recommendation

Based on the study findings, several recommendations are proposed:

First, conduct further optimization studies to determine the ideal dosage and mix design for incorporating graphene powder in concrete, exploring a variety of concentrations to identify the most beneficial effects on concrete properties without compromising other performance aspects.

Second, investigate the compatibility of graphene powder with various types of cement, aggregates, admixtures, and supplementary materials commonly used in concrete production.

Third ,The experimental results indicate that a 0.4% dosage yields significant improvements in compressive and flexural strength, but additional investigations on long-term durability and environmental impact are necessary. Studying alternative graphene dispersion methods could further enhance uniformity and bonding within the cement matrix, preventing agglomeration and ensuring more consistent results.

Fourth, Establishing clear benchmarks for mechanical performance, durability, and safety compliance would facilitate its broader adoption in infrastructure projects. Additionally, cost-benefit analyses must be conducted to assess the economic feasibility of large-scale graphene production and application in construction, with a particular focus on sustainable sourcing and reducing overall project expenses.

Moreover, it is essential to work together with industry partners and regulatory agencies to create standardized testing methods, guidelines, and specifications for utilizing graphene powder in concrete. Establishing clear protocols can significantly ease its incorporation into the construction sector. By following these recommendations, future research can delve deeper into the potential of graphene powder in concrete, resulting in enhanced performance, sustainability, and innovation within the construction industry. Such efforts can promote the development of eco-friendly materials and practices, paving the way for greener and more durable infrastructure.

Finally, the implementation of graphene-modified concrete in Ethiopia should be in harmony with local construction needs and the availability of materials. Pilot projects that demonstrate its structural benefits in practical applications would help confirm its effectiveness and encourage broader acceptance. Future research should also investigate graphene’s compatibility with different types of cement and supplementary materials to boost its versatility. By focusing on these elements, the integration of graphene into construction can lead to stronger, more durable, and environmentally sustainable infrastructure solutions.

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APPENDIXES

Mix-Design for 25 MPa concrete

Based on the following material test results given in the Table 1.1 below, the concrete mix design can be done using ACI methods of mix design.

Table 1.1 Material test results

Sr. No	**Description**	**Test results**		
		Cement ppc	Fine aggregate	Coarse aggregate
1	Fineness modulus	-	2.4	3.43
2	Unit weight [kg/m^3]	-	1544	1696
3	Specific gravity	3.15	2.4	2.43
4	Water absorption [%]	-	1.5	2.27
5	Moisture content [%]	-	6	2
6	Slump value cm	8.5		
7	Max. Agg. Size mm	20		

Mix Design Using ACI Method

1. ***Calculating the required average compressive strength based of the characteristics strength of 25 MPa based on the relationship given in Table 1.1.***

Table 1.1 Relationship between mean strength and characteristics strength

Specified characteristic compressive strength (f'c, MPa)	Required average compressive strength in (f'cr, MPa)
<21	f'c + 7
21-35	f'c + 8.5
>35	1.1*f'c + 5

Hence, based on the above table the required average compressive strength became:

$$Fck = F'c + 8.5$$

$$Fck = 25 + 8.5$$

$$\boldsymbol{Fck = 33.5}$$

2. *Determining the minimum cement content*

From durability considerations cement content should not be reduced below 300 kg/m^3 for RCC structures. So, the minimum cement content is taken as 300 kg/m^3.

3. *Choice of slump value*

The ideal slump value can differ depending on the type of structure and the water-to-cement ratio. However, many experts recommend a slump in the range of (8-10) cm for C-25 concrete.

4. Selecting the maximum size aggregate

When aiming for high-strength concrete, it's best to use smaller maximum sizes of aggregate because they result in higher strengths at a given water-to-cement ratio. Based on this, a maximum aggregate size of 20**mm** has been chosen.

5. Mixing water and air content determination

The water-to-cement volume ratio needed to achieve a specific slump value depends on aggregate grading, the quantity of entrained air, and the maximum size of aggregate, as outlined in Table 1.2 for non-air-entrained concrete.

Table 1.2 Approximate mixing water for different slump and maximum size aggregate

Slump (cm)	Water (kg/m^3) of concrete for indicated maximum size aggregate in mm							
	10	12.5	**20**	25	40	50	70	150
Non-air entrained concrete								
3-10	205	200	185	180	160	155	145	125
8-10	225	215	**2**	195	175	170	160	140
15-18	240	230	210	205	205	185	180	170-
Amount of entrapped air (%)	3	25	**2**	15	1	0.5	0.3	0.2

Based on Table 1.2, when the slump is **8-10** cm and the maximum aggregate size is **20** mm, the water content is **200 kg/m^3** and there is **2% (20 liters)** entrapped air for non-air-entrained concrete.

6. Determining water cement ratio

In a concrete mix, the water cement ratio is determined by comparing the weight of water to the weight of cement. The specific ratio of water to cement is derived from

ACI [Table 1.3] and is based on the target mean strength value of the concrete.

Table 1.3 Average compressive strength with water cement ratio

Average compressive strength at 28 days (MPa)	Water cement ratio (by mass)
45	0.38
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

Based on the ACI table above, the exact water cement ratio for a mean strength of **33.5 MPa** cannot be directly determined. However, it can be calculated by interpolating between the values for **30MPa and 35MPa,** since **33.5MPa** falls between these two values.

35	0.47
33.5	x
30	0.54

By interpolation:

$$\frac{35-33.5}{35.5-30}=\frac{0.54-0.47}{x-0.54}$$

$$\mathbf{x \approx 0.5}$$

Hence, the minimum water cement ratio obtained from the above calculation is 0.4

7. Determination of mix cement content

$$\text{Cement content}=\frac{\text{water content}}{\text{water cement ratio}}$$

$$=\frac{200\ \text{kg/m3}}{0.5}$$

$$=\ \mathbf{400\ kg/m^3}$$

Since the cement content in the mix is higher than the minimum requirement, it is recommended to use 400 kg/m^3. This implies that for every 1m^3 of fresh concrete production, 400kg or about 10bags of cement are needed.

8. Estimating the bulk volume of aggregate per volume of concrete

This is influenced by the modulus of coarse aggregate, which is **30,** and the maximum size of the aggregate, **20** mm, as specified in ACI [Table 1.4].

Table 1.4 Volume of coarse aggregate per unit volume of concrete.

Maximum size of aggregate	Volume of coarse aggregate per volume of concrete for different fineness modulus			
	2.4	2.6	2.8	**3.0**
10		0.50	0.46	0.44
12.5		0.59	0.55	0.53
20		0.66	0.62	**0.60**
25		0.71	0.67	0.65
40		0.76	0.72	0.70
50		0.78	0.74	0.72
70		0.81	0.77	0.75
150		0.87	0.83	0.81

The bulk volume of dry rodded aggregate for fineness modulus of 3 and maximum aggregate size of 20mm was found to be 0.60

9. Calculate the weight of coarse aggregate (W_{CA})/m^3 of concrete

$$W_{CA} = \text{Bulk volume} * \text{bulk density of coarse aggregate}$$

$$W_{CA} = 1696.5 * 0.60$$

$$W_{CA} = \mathbf{1017.9kg/m^3}$$

10. Determining the solid volume of coarse aggregate

$$\text{Solid volume of coarse aggregate} = \frac{WCA}{Bulk\ specific\ gravity\ x\ 1000}$$

$$= \frac{\mathbf{1017.9}}{2.43\ x\ 1000}$$

$$= \mathbf{0.40\ m^3}$$

11. Calculating the solid volume of cement, water, and air

$$Volume\ of\ cement\ (VC) = \frac{weight\ of\ cement}{specific\ gravity\ of\ cement\ x\ 1000}$$

$$= \frac{400}{3.15\ x\ 1000}$$

$$V_c = \mathbf{0.127m^3}$$

$$\text{Volume of water } (V_W) = \frac{200}{1000}$$

$$V_w = \mathbf{0.2\ m^3}$$

$$\text{Volume of air } (V_A) = 2\% = \frac{2}{100} \text{ x } 1m^3 = 0.02\mathbf{m^3}$$

12. Calculating solid volume of sand

Solid volume of sand = 1 - (V_{CA} + V_C + V_W + V_A)

= 1 - (0.36 + 0.127+ 0.2 + 0.02)

= 1- 0.707

= **0.293m3**

Solid weight of sand = dry volume of sand * specific gravity * 1000

= 0.262m3 * 2.4 * 1000

= **628.8 kg/m^3**

13. Adjustments for moisture in the aggregate

Fine aggregate adsorption = 1.5%

Coarse aggregate absorption = 2.27%

Water absorbed by coarse aggregate = 1017.9kg/m^3 * 0.0227

= **23.10kg/m^3**

Water supplied by fine aggregate = 628 kg/m^3 * 0.015

= **9.42kg/m^3**

Amount of water needed = 200 kg/m^3 + 22.47kg/m^3 - 9.42kg/m^3

= 213.05kg/m^3

Adjusted fine aggregate = 628.8kg/m^3 + 9.42 kg/m^3

= **638.22kg/m^3**

Adjusted coarse aggregate = 1017.9kg/m^3 - 23.10kg/m^3

= **995.43kg/m^3**

Hence, the estimated batch by weight and volume for 1 m^3 of fresh concrete are given in Table 1.5.

Table 1.5 Quantity of material for $1m^3$ of C-25 concrete by weight and volume

Ingridents	***By weight [kg/m³]***	***By volume [m³]***
Water	213.05	0.2
Cement(ppc)	400	0.127
Fine aggregate	638.22	0.262
Coarse aggregate	995.43	0.4
Air	-	0.02
Total	***2346.48***	***1.00***

The final mix-design ratio can be given in Table 1.6 by weight.

Table 1.6 Mix proportion of C- 25concrete grade

Ingredients	***Cement(ppc)***	***Fine aggregate***	***Coarse aggregate***
Quantity [kg/m³]	400/400	638.22	995.43
Ratio	***1***	***1.6***	***2.5***

Average 7th day Compressive Strengthen Raw data's

sl no.	graphene%/2L	max load(kn)	strength in N/ mm2	av.str.(n/m)
1	0.0	376.88	16.75	16.82
2	0.0	380	16.89	
1	0.1	425	18.93	17.926
2	0.1	394	17.51	
3	0.1	391	17.37	
1	0.2	458	20.35	20.62
2	0.2	475	21.11	
3	0.2	459	20.4	
1	0.3	525	23.33	22.38
2	0.3	489	21.23	
3	0.3	508	22.57	
1	0.4	577	25.64	25.16
2	0.4	549	24.4	
3	0.4	573	25.46	
1	0.5	466	20.71	21.27
2	0.5	517	22.97	
3	0.5	453	20.13	

Average 28th day Compressive Strengthen Raw data's

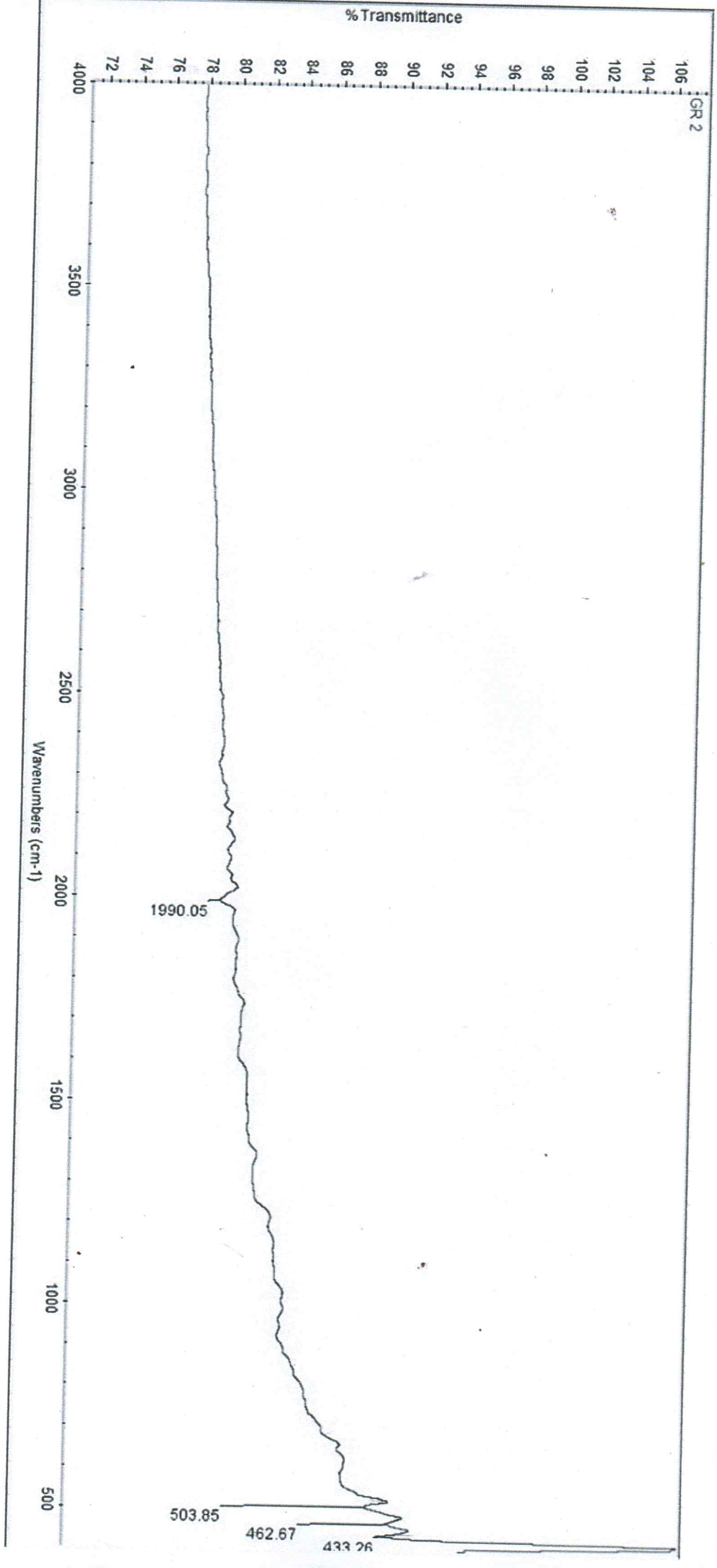
SL No.	Graphene%/2L	MAX LOAD(kN)	STRENGTH IN N/ mm2	AV.STR.(N/mm2)
1	0.0	750	33.37	33.58
2	0.0	762	33.86	
1	0.1	761	33.82	33.73
2	0.1	760	33.7	
3	0.1	758	33.68	
1	0.2	761	33.78	33.77
2	0.2	759	33.76	
3	0.2	760	33.78	
1	0.3	787.5	35	33.82
2	0.3	733.5	32.6	
3	0.3	762	33.86	
1	0.4	865.5	38.46	37.75
2	0.4	823.5	36.6	
3	0.4	859.5	38.2	
1	0.5	699	31.06	31.90
2	0.5	775.5	34.46	
3	0.5	679.5	30.2	

7^{th} day Flexural Strengthen Raw Data's

SL No.	Graphene%/2L	MAX LOAD(KN)	STRENGTH IN N/ mm2	AV.STR.(N/mm2)
1	0.0	8.7	2.6	2.5
2	0.0	7.9	2.4	
1	0.1	8.63	2.59	2.604
2	0.1	8.43	2.528	
3	0.1	9.04	2.713	
1	0.2	8.89	2.69	2.54
2	0.2	8.7	2.6	
3	0.2	7.88	2.33	
1	0.3	8.18	2.454	2.812
2	0.3	10.94	3.28	
3	0.3	9.03	2.7	
1	0.4	9.8	3.01	2.985
2	0.4	10.58	3.174	
3	0.4	9.01	2.77	
1	0.5	9.53	2.859	2.825
2	0.5	9.92	2.97	
3	0.5	8.9	2.61	

28th day Flexural Strengthen Raw Data's

SL No.	Graphene%/2L	MAX LOAD(KN)	STRENGTH IN N/ mm2	AV.STR.(N/mm2)
1	0.0	8.9	2.67	2.59
2	0.0	8.67	251	
1	0.1	12.94	3.88	3.91
2	0.1	12.64	3.79	
3	0.1	13.56	4.06	
1	0.2	13.33	4.03	3.81
2	0.2	13.05	3.9	
3	0.2	11.82	3.49	
1	0.3	12.27	3.68	4.21
2	0.3	16.41	4.92	
3	0.3	13.54	4.05	
1	0.4	14.7	4.51	4.47
2	0.4	15.87	4.76	
3	0.4	13.51	4.15	
1	0.5	14.29	4.28	4.21
2	0.5	14.88	4.45	
3	0.5	13.35	3.91	



% Transmittance
GR 2
Wavenumbers (cm-1)
1990.05
503.85
462.67
433.26

3.93E+02	0.00E+00	8.02E+02	8.49E+01
4.01E+02	9.45E+01	8.10E+02	8.48E+01
4.09E+02	1.07E+02	8.18E+02	8.46E+01
4.17E+02	1.08E+02	8.25E+02	8.45E+01
4.24E+02	9.25E+01	8.33E+02	8.45E+01
4.32E+02	8.96E+01	8.41E+02	8.44E+01
4.40E+02	9.11E+01	8.49E+02	8.43E+01
4.47E+02	9.16E+01	8.56E+02	8.42E+01
4.55E+02	9.06E+01	8.64E+02	8.42E+01
4.63E+02	9.01E+01	8.72E+02	8.40E+01
4.71E+02	9.06E+01	8.79E+02	8.38E+01
4.78E+02	9.13E+01	8.87E+02	8.38E+01
4.86E+02	9.02E+01	8.95E+02	8.37E+01
4.94E+02	8.96E+01	9.03E+02	8.36E+01
5.01E+02	8.88E+01	9.10E+02	8.35E+01
5.09E+02	8.90E+01	9.18E+02	8.34E+01
5.17E+02	9.04E+01	9.26E+02	8.34E+01
5.25E+02	8.97E+01	9.33E+02	8.35E+01
5.32E+02	8.85E+01	9.41E+02	8.36E+01
5.40E+02	8.83E+01	9.49E+02	8.35E+01
5.48E+02	8.78E+01	9.57E+02	8.34E+01
5.55E+02	8.75E+01	9.64E+02	8.35E+01
5.63E+02	8.74E+01	9.72E+02	8.36E+01
5.71E+02	8.74E+01	9.80E+02	8.37E+01
5.79E+02	8.74E+01	9.87E+02	8.37E+01
5.86E+02	8.73E+01	9.95E+02	8.37E+01
5.94E+02	8.75E+01	1.00E+03	8.36E+01
6.02E+02	8.75E+01	1.01E+03	8.36E+01
6.09E+02	8.75E+01	1.02E+03	8.37E+01
6.17E+02	8.76E+01	1.03E+03	8.37E+01
6.25E+02	8.75E+01	1.03E+03	8.37E+01
6.33E+02	8.75E+01	1.04E+03	8.35E+01
6.40E+02	8.72E+01	1.05E+03	8.33E+01
6.48E+02	8.71E+01	1.06E+03	8.32E+01
6.56E+02	8.73E+01	1.06E+03	8.32E+01
6.63E+02	8.71E+01	1.07E+03	8.32E+01
6.71E+02	8.67E+01	1.08E+03	8.32E+01
6.79E+02	8.64E+01	1.09E+03	8.32E+01
6.87E+02	8.62E+01	1.10E+03	8.31E+01
6.94E+02	8.62E+01	1.10E+03	8.31E+01
7.02E+02	8.61E+01	1.11E+03	8.31E+01
7.10E+02	8.59E+01	1.12E+03	8.31E+01
7.17E+02	8.58E+01	1.13E+03	8.31E+01
7.25E+02	8.56E+01	1.13E+03	8.31E+01
7.33E+02	8.54E+01	1.14E+03	8.31E+01
7.41E+02	8.53E+01	1.15E+03	8.31E+01
7.48E+02	8.52E+01	1.16E+03	8.31E+01
7.56E+02	8.52E+01	1.16E+03	8.30E+01
7.64E+02	8.52E+01	1.17E+03	8.29E+01
7.71E+02	8.51E+01	1.18E+03	8.28E+01
7.79E+02	8.51E+01	1.19E+03	8.27E+01
7.87E+02	8.51E+01	1.20E+03	8.28E+01
7.95E+02	8.50E+01	1.20E+03	8.28E+01

1.21E+03	8.29E+01	1.62E+03	8.07E+01
1.22E+03	8.28E+01	1.63E+03	8.08E+01
1.23E+03	8.27E+01	1.64E+03	8.08E+01
1.23E+03	8.25E+01	1.64E+03	8.08E+01
1.24E+03	8.22E+01	1.65E+03	8.09E+01
1.25E+03	8.20E+01	1.66E+03	8.09E+01
1.26E+03	8.19E+01	1.67E+03	8.08E+01
1.27E+03	8.19E+01	1.67E+03	8.08E+01
1.27E+03	8.19E+01	1.68E+03	8.09E+01
1.28E+03	8.18E+01	1.69E+03	8.09E+01
1.29E+03	8.18E+01	1.70E+03	8.08E+01
1.30E+03	8.18E+01	1.70E+03	8.09E+01
1.30E+03	8.17E+01	1.71E+03	8.09E+01
1.31E+03	8.17E+01	1.72E+03	8.09E+01
1.32E+03	8.17E+01	1.73E+03	8.10E+01
1.33E+03	8.17E+01	1.74E+03	8.10E+01
1.33E+03	8.17E+01	1.74E+03	8.10E+01
1.34E+03	8.18E+01	1.75E+03	8.08E+01
1.35E+03	8.19E+01	1.76E+03	8.07E+01
1.36E+03	8.20E+01	1.77E+03	8.06E+01
1.37E+03	8.20E+01	1.77E+03	8.06E+01
1.37E+03	8.19E+01	1.78E+03	8.05E+01
1.38E+03	8.18E+01	1.79E+03	8.04E+01
1.39E+03	8.16E+01	1.80E+03	8.04E+01
1.40E+03	8.15E+01	1.81E+03	8.04E+01
1.40E+03	8.15E+01	1.81E+03	8.05E+01
1.41E+03	8.15E+01	1.82E+03	8.05E+01
1.42E+03	8.14E+01	1.83E+03	8.05E+01
1.43E+03	8.13E+01	1.84E+03	8.05E+01
1.43E+03	8.14E+01	1.84E+03	8.05E+01
1.44E+03	8.14E+01	1.85E+03	8.05E+01
1.45E+03	8.14E+01	1.86E+03	8.05E+01
1.46E+03	8.14E+01	1.87E+03	8.04E+01
1.47E+03	8.14E+01	1.87E+03	8.05E+01
1.47E+03	8.14E+01	1.88E+03	8.06E+01
1.48E+03	8.14E+01	1.89E+03	8.06E+01
1.49E+03	8.13E+01	1.90E+03	8.06E+01
1.50E+03	8.13E+01	1.91E+03	8.06E+01
1.50E+03	8.13E+01	1.91E+03	8.04E+01
1.51E+03	8.13E+01	1.92E+03	8.03E+01
1.52E+03	8.13E+01	1.93E+03	8.02E+01
1.53E+03	8.13E+01	1.94E+03	8.02E+01
1.54E+03	8.13E+01	1.94E+03	8.03E+01
1.54E+03	8.13E+01	1.95E+03	8.03E+01
1.55E+03	8.13E+01	1.96E+03	8.04E+01
1.56E+03	8.13E+01	1.97E+03	8.04E+01
1.57E+03	8.13E+01	1.97E+03	8.01E+01
1.57E+03	8.12E+01	1.98E+03	7.97E+01
1.58E+03	8.12E+01	1.99E+03	7.95E+01
1.59E+03	8.10E+01	2.00E+03	7.97E+01
1.60E+03	8.08E+01	2.01E+03	7.99E+01
1.60E+03	8.08E+01	2.01E+03	8.03E+01
1.61E+03	8.07E+01	2.02E+03	8.05E+01

2.03E+03	8.04E+01
2.04E+03	8.02E+01
2.04E+03	8.01E+01
2.05E+03	8.02E+01
2.06E+03	8.00E+01
2.07E+03	7.98E+01
2.08E+03	7.99E+01
2.08E+03	8.00E+01
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2.10E+03	8.01E+01
2.11E+03	7.99E+01
2.11E+03	7.99E+01
2.12E+03	8.00E+01
2.13E+03	8.01E+01
2.14E+03	8.03E+01
2.14E+03	8.03E+01
2.15E+03	8.01E+01
2.16E+03	8.00E+01
2.17E+03	7.98E+01
2.18E+03	7.99E+01
2.18E+03	8.00E+01
2.19E+03	7.99E+01
2.20E+03	8.00E+01
2.21E+03	8.01E+01
2.21E+03	7.98E+01
2.22E+03	7.96E+01
2.23E+03	7.98E+01
2.24E+03	7.98E+01
2.24E+03	7.98E+01
2.25E+03	7.97E+01
2.26E+03	7.97E+01
2.27E+03	7.97E+01
2.28E+03	7.96E+01
2.28E+03	7.95E+01
2.29E+03	7.94E+01
2.30E+03	7.94E+01
2.31E+03	7.94E+01
2.31E+03	7.93E+01
2.32E+03	7.93E+01
2.33E+03	7.93E+01
2.34E+03	7.94E+01
2.35E+03	7.94E+01
2.35E+03	7.94E+01
2.36E+03	7.95E+01
2.37E+03	7.95E+01
2.38E+03	7.95E+01
2.38E+03	7.95E+01
2.39E+03	7.95E+01
2.40E+03	7.94E+01
2.41E+03	7.94E+01
2.41E+03	7.94E+01
2.42E+03	7.94E+01
2.43E+03	7.94E+01
2.44E+03	7.94E+01
2.45E+03	7.94E+01
2.45E+03	7.94E+01
2.46E+03	7.94E+01
2.47E+03	7.93E+01
2.48E+03	7.93E+01
2.48E+03	7.94E+01
2.49E+03	7.94E+01
2.50E+03	7.93E+01
2.51E+03	7.92E+01
2.51E+03	7.93E+01
2.52E+03	7.93E+01
2.53E+03	7.92E+01
2.54E+03	7.92E+01
2.55E+03	7.92E+01
2.55E+03	7.92E+01
2.56E+03	7.91E+01
2.57E+03	7.92E+01
2.58E+03	7.92E+01
2.58E+03	7.91E+01
2.59E+03	7.91E+01
2.60E+03	7.91E+01
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2.62E+03	7.91E+01
2.62E+03	7.91E+01
2.63E+03	7.90E+01
2.64E+03	7.90E+01
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2.65E+03	7.90E+01
2.66E+03	7.90E+01
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2.70E+03	7.90E+01
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2.72E+03	7.90E+01
2.72E+03	7.89E+01
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2.74E+03	7.89E+01
2.75E+03	7.89E+01
2.75E+03	7.89E+01
2.76E+03	7.89E+01
2.77E+03	7.89E+01
2.78E+03	7.89E+01
2.78E+03	7.89E+01
2.79E+03	7.88E+01
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2.81E+03	7.89E+01
2.82E+03	7.89E+01
2.82E+03	7.88E+01
2.83E+03	7.88E+01
2.84E+03	7.88E+01

2.85E+03	7.88E+01	3.26E+03	7.83E+01
2.85E+03	7.88E+01	3.26E+03	7.83E+01
2.86E+03	7.88E+01	3.27E+03	7.82E+01
2.87E+03	7.88E+01	3.28E+03	7.82E+01
2.88E+03	7.88E+01	3.29E+03	7.83E+01
2.89E+03	7.88E+01	3.29E+03	7.83E+01
2.89E+03	7.88E+01	3.30E+03	7.83E+01
2.90E+03	7.88E+01	3.31E+03	7.82E+01
2.91E+03	7.88E+01	3.32E+03	7.82E+01
2.92E+03	7.88E+01	3.32E+03	7.82E+01
2.92E+03	7.88E+01	3.33E+03	7.82E+01
2.93E+03	7.87E+01	3.34E+03	7.82E+01
2.94E+03	7.87E+01	3.35E+03	7.82E+01
2.95E+03	7.87E+01	3.36E+03	7.82E+01
2.95E+03	7.87E+01	3.36E+03	7.82E+01
2.96E+03	7.87E+01	3.37E+03	7.81E+01
2.97E+03	7.87E+01	3.38E+03	7.81E+01
2.98E+03	7.87E+01	3.39E+03	7.81E+01
2.99E+03	7.87E+01	3.39E+03	7.81E+01
2.99E+03	7.86E+01	3.40E+03	7.81E+01
3.00E+03	7.86E+01	3.41E+03	7.81E+01
3.01E+03	7.86E+01	3.42E+03	7.81E+01
3.02E+03	7.86E+01	3.43E+03	7.81E+01
3.02E+03	7.86E+01	3.43E+03	7.81E+01
3.03E+03	7.86E+01	3.44E+03	7.81E+01
3.04E+03	7.86E+01	3.45E+03	7.81E+01
3.05E+03	7.85E+01	3.46E+03	7.80E+01
3.05E+03	7.85E+01	3.46E+03	7.80E+01
3.06E+03	7.85E+01	3.47E+03	7.80E+01
3.07E+03	7.85E+01	3.48E+03	7.80E+01
3.08E+03	7.84E+01	3.49E+03	7.80E+01
3.09E+03	7.84E+01	3.49E+03	7.80E+01
3.09E+03	7.84E+01	3.50E+03	7.80E+01
3.10E+03	7.84E+01	3.51E+03	7.80E+01
3.11E+03	7.84E+01	3.52E+03	7.80E+01
3.12E+03	7.84E+01	3.53E+03	7.80E+01
3.12E+03	7.84E+01	3.53E+03	7.80E+01
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3.14E+03	7.84E+01	3.55E+03	7.80E+01
3.15E+03	7.84E+01	3.56E+03	7.79E+01
3.16E+03	7.84E+01	3.56E+03	7.79E+01
3.16E+03	7.84E+01	3.57E+03	7.79E+01
3.17E+03	7.84E+01	3.58E+03	7.79E+01
3.18E+03	7.84E+01	3.59E+03	7.79E+01
3.19E+03	7.83E+01	3.59E+03	7.78E+01
3.19E+03	7.83E+01	3.60E+03	7.78E+01
3.20E+03	7.83E+01	3.61E+03	7.78E+01
3.21E+03	7.83E+01	3.62E+03	7.79E+01
3.22E+03	7.83E+01	3.63E+03	7.78E+01
3.22E+03	7.83E+01	3.63E+03	7.78E+01
3.23E+03	7.83E+01	3.64E+03	7.78E+01
3.24E+03	7.83E+01	3.65E+03	7.79E+01
3.25E+03	7.83E+01	3.66E+03	7.78E+01

3.66E+03	7.78E+01
3.67E+03	7.78E+01
3.68E+03	7.78E+01
3.69E+03	7.78E+01
3.70E+03	7.78E+01
3.70E+03	7.78E+01
3.71E+03	7.78E+01
3.72E+03	7.78E+01
3.73E+03	7.77E+01
3.73E+03	7.77E+01
3.74E+03	7.77E+01
3.75E+03	7.77E+01
3.76E+03	7.77E+01
3.76E+03	7.77E+01
3.77E+03	7.77E+01
3.78E+03	7.77E+01
3.79E+03	7.77E+01
3.80E+03	7.77E+01
3.80E+03	7.77E+01
3.81E+03	7.77E+01
3.82E+03	7.77E+01
3.83E+03	7.77E+01
3.83E+03	7.77E+01
3.84E+03	7.77E+01
3.85E+03	7.77E+01
3.86E+03	7.77E+01
3.86E+03	7.77E+01
3.87E+03	7.77E+01
3.88E+03	7.77E+01
3.89E+03	7.77E+01
3.90E+03	7.77E+01
3.90E+03	7.77E+01
3.91E+03	7.76E+01
3.92E+03	7.76E+01
3.93E+03	7.76E+01
3.93E+03	7.77E+01
3.94E+03	7.76E+01
3.95E+03	7.77E+01
3.96E+03	7.77E+01
3.96E+03	7.77E+01
3.97E+03	7.77E+01
3.98E+03	7.77E+01
3.99E+03	7.77E+01
4.00E+03	7.77E+01
4.00E+03	7.77E+01

አዳማ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ

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Ref Date:27/09/2017
Mat/03/1300/25

ለ ሲቪል ምህንድስና ት/ክፍል

<u>አሳቴዩ</u>

ማቴሪያልስ ሳይንስና ምህንድስና
ትም/ክፍል ኃላፊ
ዶ/ር ፍቃዱ ጐቾሌ

ጉዳዩ፡- <u>ትብብር እንዲደረግለት ስለመጠየቅ</u>

በሲቪል ምህንድስና ት/ክፍል ተማሪ የሆነው መሐመድፍርዶስ መሐመድ የግራፊን XRD በማቴሪያልስ ሳይንስና ምህንድስና ት/ት ክፍል ላብ በ05/08/2025 ማሰራቱን የሚገልጽ ደብዳቤ እንዲፃፍለት ጠይቆናል በጠየቀው መሠረት የፃፍንለት መሆኑን እንገልፃለን፡፡

ከሠላምታ ጋር

Dr.Fekadu Gochole Aga
Materials Science &
Engineering Department Head

********** SEARCH / MATCH RESULT **********

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Data Name : Graphite--C

File Name : Graphite--C.PKK

Sample Name : C

Comment : Test 1

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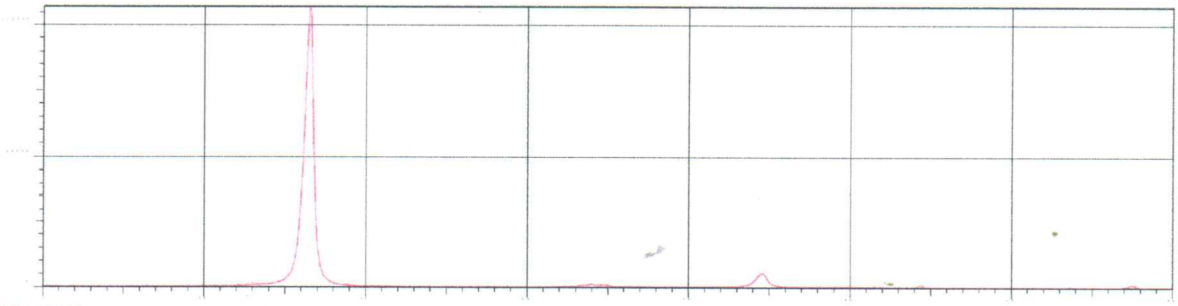
<Raw Data>



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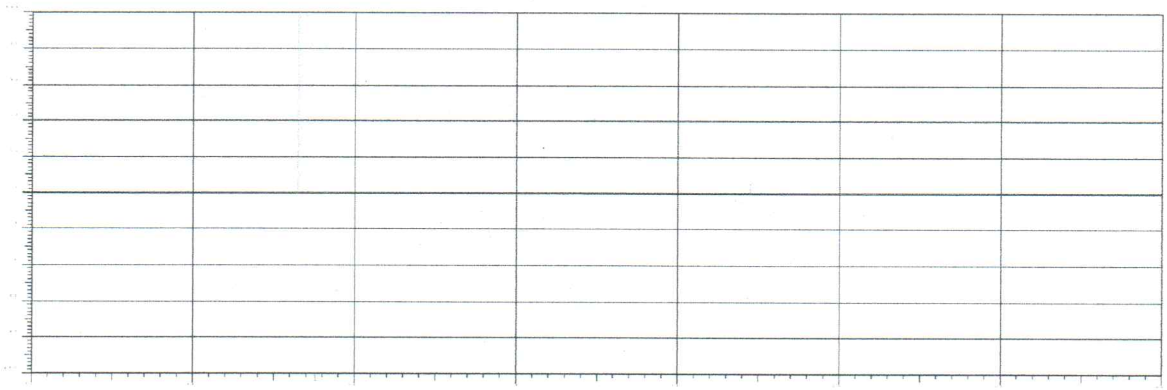

<Card Data>

********** SEARCH / MATCH RESULT **********

Group Name : Standard

Data Name : Graphite--C

File Name : Graphite--C.PKK

Sample Name : C

Comment : Test 1

<Entry Card>

No.	Card	Chemical Formula	S	L	d	I	R
		Chemical Name (Mineral.Name)		Dx	WT%	S.G.	

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
COLLEGE OF CIVIL ENGINEERING & ARCHITECTURE
CIVIL ENGINEERING DEPARTMENT
CONSTRUCTION MATERIAL TESTING LABORATORY

7th day Flexural Strengthen Raw Data's

SL No.	Graphene%/2L	MAX LOAD(KN)	STRENGTH IN N/ mm2	AV.STR.(N/mm2)
1	0	8.7	2.6	2.5
2	0	7.9	2.4	
1	0.1	8.63	2.59	2.604
2	0.1	8.43	2.528	
3	0.1	9.04	2.713	
1	0.2	8.89	2.69	2.54
2	0.2	8.7	2.6	
3	0.2	7.88	2.33	
1	0.3	8.18	2.454	2.812
2	0.3	10.94	3.28	
3	0.3	9.03	2.7	
1	0.4	9.8	3.01	2.985
2	0.4	10.58	3.174	
3	0.4	9.01	2.77	
1	0.5	9.53	2.859	2.825
2	0.5	9.92	2.97	
3	0.5	8.9	2.61	

28th day Flexural Strengthen Raw Data's

SL No.	Graphene%/2L	MAX LOAD(KN)	STRENGTH IN N/ mm2	AV.STR.(N/mm2)
1	0	8.9	2.67	2.59
2	0	8.67	251	
1	0.1	12.94	3.88	3.91
2	0.1	12.64	3.79	
3	0.1	13.56	4.06	
1	0.2	13.33	4.03	3.81
2	0.2	13.05	3.9	
3	0.2	11.82	3.49	
1	0.3	12.27	3.68	4.21
2	0.3	16.41	4.92	
3	0.3	13.54	4.05	
1	0.4	14.7	4.51	4.47
2	0.4	15.87	4.76	
3	0.4	13.51	4.15	
1	0.5	14.29	4.28	4.21
2	0.5	14.88	4.45	
3	0.5	13.35	3.91	

Civil Engineering Department
Adama Science & Technology University
School of Civil Engineering

LAB. TECHNICIAN (SARA)
Name Mesele yosef
signature
04-06-25

...Berhanu Athafu
Civil Engineering ... Head

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
COLLEGE OF CIVIL ENGINEERING & ARCHITECTURE
CIVIL ENGINEERING DEPARTMENT
CONSTRUCTION MATERIAL TESTING LABORATORY

Average 7 th day Compressive Strengthen Raw data's

sl no.	graphene%/2L	max load(kn)	strength in N/ mm2	av.str.(n/m)
1	0	376.88	16.75	
2	0	380	16.89	16.82
1	0.1	425	18.93	
2	0.1	394	17.51	17.926
3	0.1	391	17.37	
1	0.2	458	20.35	
2	0.2	475	21.11	20.62
3	0.2	459	20.4	
1	0.3	525	23.33	
2	0.3	489	21.23	22.38
3	0.3	508	22.57	
1	0.4	577	25.64	
2	0.4	549	24.4	25.16
3	0.4	573	25.46	
1	0.5	466	20.71	
2	0.5	517	22.97	21.27
3	0.5	453	20.13	

Average 28th day Compressive Strengthen Raw data's

SL No.	Graphene%/2L	MAX LOAD(kN)	STRENGTH IN N/ mm2	AV.STR.(N/mm2)
1	0	750	33.37	33.58
2	0	762	33.86	
1	0.1	761	33.82	
2	0.1	760	33.7	33.73
3	0.1	758	33.68	
1	0.2	761	33.78	
2	0.2	759	33.76	33.77
3	0.2	760	33.78	
1	0.3	787.5	35	
2	0.3	733.5	32.6	33.82
3	0.3	762	33.86	
1	0.4	865.5	38.46	
2	0.4	823.5	36.6	37.75
3	0.4	859.5	38.2	
1	0.5	699	31.06	
2	0.5	775.5	34.46	31.9
3	0.5	679.5	30.2	

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04-06-25

Es[illegible] Berhanu Ahafu
Civil Engineering Department Head