Experimental Study on Enhancing the Strength of Paver Blocks Using Graphene

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Abstract - *This experimental investigation explores the potential of graphene as a performance-enhancing additive in paver block production, with a focus on optimizing strength and durability while reducing cement content. The study adopts a dual-layer paver block design. Graphene was incorporated into the mix in varying dosages, and the mix proportion was strategically altered to reduce overall cement content without compromising performance. The primary parameters evaluated were compressive strength and water absorption, tested in according to IS 15658:2006. Results showed a significant improvement in compressive strength and a reduction in water absorption, particularly at an optimum graphene dosage. The dual-layer approach, combined with cement reduction, proved effective in enhancing the mechanical properties of the paver blocks while promoting sustainable and economical construction practices. This study concludes that graphene can serve as a promising additive for producing high-performance and eco-friendly paver blocks.*

***Key Words*: Graphene, Nanomaterial, Paver Blocks, Strength Enhancement, Durability, Water Absorption, Sustainable**

1.INTRODUCTION

Paver blocks are widely used in urban infrastructure, pedestrian pathways, and road construction due to their ease of installation and maintenance. However, conventional paver blocks often exhibit limitations such as low tensile strength, increased water absorption, and susceptibility to cracking under heavy loads. Recent advancements in nanomaterials have introduced graphene as a promising additive in cement-based materials. Graphene's exceptional mechanical and chemical properties make it an ideal candidate for reinforcing paver blocks.

The introduction of graphene into concrete has shown potential in enhancing compressive strength and overall durability. By modifying the cement matrix at the nanoscale, graphene improves hydration efficiency, refines the pore structure, and enhances particle bonding. The scope of this research includes an in-depth examination of these enhancements and their implications for real-world applications.

This paper investigates the potential of graphene-enhanced pavement blocks, focusing on their improved structural properties. The study evaluates the effect of different graphene dosages on the compressive strength, durability, and water resistance of paver blocks. By leveraging the superior attributes of graphene, this research aims to develop a more resilient and sustainable alternative to conventional paving materials.

2.LITERATURE REVIEW

This section provides a review of existing studies related to the enhancement of concrete properties through the addition of graphene and the role of lignosulfonate as a dispersing agent.

2.1 Graphene in Cementitious Composites

Syed Wasil et al. (2024) reported that graphene oxide association with the concrete during hydration of concrete by acting as nucleation sites, resulting in a denser microstructure and improved strength [1].

Tahreer Fayyad et al. (2022) explored the potential of graphene concrete as an eco-friendly and sustainable construction material. They found that small dosages of graphene can enhance the mechanical and durability performance of cement-based composites, opening up possibilities for its use in the precast concrete industry [2].

Zhu Pan et al. (2015) found that incorporating as little as 0.05% GO by weight of cement improved the compressive and flexural strength of mortar by over 30%. This was attributed to the bridging of microcracks and the enhancement of interfacial bonding between the cement matrix and aggregates [3].

MD Sohel Ahmed et al. (2023) showed that workability of concrete slightly decreased with increasing graphene content due to higher surface area and water demand [4].

In summary, the incorporation of graphene into cementitious materials offers a promising route to developing next-generation, high-strength, durable, and multifunctional concrete products, including paver blocks.

2.2 Role of Sodium Lignosulfonate as a Dispersing Agent

The effective dispersion of graphene within the cementitious matrix remains a major challenge due to their high surface energy and tendency to agglomerate. In this context, the use of dispersing agents is critical to achieving uniform distribution. Among various dispersants, Sodium Lignosulfonate (Na-LS) has gained attention for its dual functionality as a dispersing agent and plasticizer. Na-LS is an anionic surfactant that adsorbs onto the surface of graphene sheets, imparting electrostatic repulsion and steric stabilization, thereby minimizing agglomeration.

Hongming Lou et al. (2015) reported that Na-LS significantly improved the dispersion of Graphene in aqueous solutions, resulting in enhanced bonding and hydration in cement matrices [5]. They investigated the influence of SL's molecular weight and sulfonic acid group content on dispersion efficiency, finding that lower molecular weight and higher sulfonic acid content enhanced graphene dispersion.

Researchers like Tahreer Fayyad et al. (2022) highlighted the importance of proper dispersion techniques such as ultrasonication and the use of surfactants to avoid agglomeration, which can otherwise adversely affect the workability and mechanical performance of the composite [1]. Yanlin Qin et al. (2016) investigated the dual functionality of sodium lignosulfonate as both a dispersing agent and a water-reducing admixture [6]. Their study concluded that sodium lignosulfonate enhances graphene dispersion, improves workability and compaction by reducing water in the mix. They found that incorporating sodium lignosulfonate significantly improved the concrete's strength and durability, making it an essential additive in high-performance cementitious composites. Na-LS is considered an eco-friendly and cost-effective additive, aligning with the sustainable development goals of the construction industry.

2.3 Optimization of Graphene Dosage in Concrete

Several researchers have explored the optimization of graphene dosage in concrete, focusing on achieving maximum strength and durability while avoiding negative effects like agglomeration. Syed Wasil Amin et al. (2024) investigated that 0.03% and 0.04% GO support in OPC composites have shown the rich arrangement of blossom type polyhedron precious stones which upgraded compressive strength in OPC concrete composites. Supporting 0.04% GO in OPC brought about expanding 46.34% compressive strength separately past 28 days of hydration [1].

James L. Suter et al. (2021) investigated that overdose of graphene in concrete tend to aggregate and thus reducing strength due to uneven distribution of graphene [7]. Xiaojiang Hong et al. (2023) concluded that the ideal range for graphene dosage from 0.02% to 0.04%, where concrete exhibits enhanced compressive strength and durability [8]. Zhu Pan et al. (2015) reported that graphene significantly improves hydration kinetics, accelerating early strength development and refining the microstructure [3]. Many researchers result demonstrated that a small graphene content 0.02% - 0.04% leads to a 15% to 30% increase in compressive strength, making it a cost-effective reinforcement option.

3.MATERIALS

3.1 Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) is the primary binding material used in this study. It acts as a crucial component in the hydration process, reacting with water to form a hardened matrix that binds the aggregates together. OPC 43 grade, has been selected due to its high compressive strength, durability, and faster setting time, making it ideal for paver block applications. The cement provides structural integrity, enhances load-bearing capacity, and ensures resistance to environmental conditions. Its low permeability helps in reducing water ingress, thereby improving the long-term performance of the paver blocks.

Table I: Cement Material Test Results

Test Parameter	OPC Cement
Specific Gravity	3.16
Fineness (%)	0.7%
Bulk Density (kg/m^3)	1440

3.2 Fine Aggregate: Manufactured Sand (M-Sand)

Manufactured Sand (M-Sand) is utilized as the fine aggregate in this study, replacing natural river sand. M-Sand is produced by mechanically crushing hard stones, ensuring a uniform particle size distribution that enhances the workability and strength of the concrete mix. It possesses a rough texture and angular shape, which improves the bonding between cement paste and aggregates. Unlike river sand, M-Sand is free from organic impurities and silt, preventing strength reduction due to contamination. Its superior compaction properties contribute to the increased durability and load-bearing capacity of the paver blocks.

3.3 Coarse Aggregate – 10mm and 20mm Size

Coarse aggregates form the structural framework of paver blocks, providing strength and impact resistance. In this study, crushed granite coarse aggregates of 10mm and 20mm nominal size are used due to their high compressive strength, hardness, and durability. The angular shape of the crushed aggregates enhances the overall stability of the mix by reducing voids, leading to a denser and stronger concrete matrix. The use of high-quality coarse aggregates helps improve the mechanical properties of the paver blocks, making them suitable for heavy-load applications.

Table II: Coarse and Fine Aggregate Material Test Results

Test Parameter	20mm Coarse Aggregate	10mm Coarse Aggregate	M-Sand
Specific Gravity	2.68	2.66	2.63
Particle Size Distribution	100% passing 20mm	100% passing 10mm	100% passing 4.75mm
Water Absorption (%)	1.5%	2%	3.1%
Bulk Density (kg/m^3)	1550	1600	1600
Aggregate Impact Value (%)	15%	17%	8%
Aggregate Crushing Value (%)	25%	27%	-

3.4 Water

Water is a fundamental component in concrete mixing, as it initiates the hydration reaction of cement. Potable water, free from harmful impurities is used in the mix preparation. The quality of water significantly influences the strength and durability of the concrete. The water-cement ratio is carefully controlled to ensure proper workability while preventing excess porosity in the hardened paver blocks. Maintaining an optimal water-cement ratio is essential to achieving higher compressive strength, reducing shrinkage cracks, and ensuring uniform hydration of the cementitious materials.

3.5 Graphene

Graphene, a two-dimensional nanomaterial composed of a single layer of carbon atoms, is incorporated into the mix to enhance the mechanical and durability properties of paver blocks. It is known for its extraordinary tensile strength, lightweight nature, and high surface area, which facilitates superior bonding within the cement matrix. The addition of graphene improves the compressive strength of concrete by refining the microstructure and reducing the formation of micro-cracks. Furthermore, it enhances the resistance of paver blocks to water permeability, chemical attacks, and abrasion, thereby increasing their lifespan. Different dosages of graphene are introduced in this study to evaluate its impact on the overall performance of the paver blocks.

3.6 Sodium Lignosulfonate

Sodium lignosulfonate was used as a dispersing agent to ensure proper distribution of graphene in the cement matrix. Lignosulfonates are water-reducing agents and plasticizers, commonly used in concrete to improve workability and reduce water demand. The addition of sodium lignosulfonate prevents graphene agglomeration, allowing for better dispersion and uniform reinforcement. Furthermore, it enhances the overall flowability of the concrete mix, ensuring proper compaction and reducing internal voids. Studies have shown that sodium lignosulfonate can improve concrete durability, increase strength, and reduce permeability, making it a suitable additive for graphene-enhanced paver blocks.

4. METHODOLOGY

The methodology for this study involves a systematic approach to designing and testing paver blocks incorporating graphene and lignosulfonate as performance-enhancing additives. The process includes mix proportioning, graphene dispersal, sample preparation, and curing, followed by testing to evaluate mechanical properties.

4.1 Mix Proportioning

Two different concrete mix proportions are utilized in this study. Batch A (Control Mix – Without Graphene), a conventional mix with a 1:2:4 ratio (cement: fine aggregate: coarse aggregate) and water-cement ratio 0.45 is used as the control sample, representing standard paver block composition without graphene. To optimize material efficiency while improving performance, a modified mix incorporating graphene and Sodium Lignosulfonate is developed using a 1:3:4 ratio with water-cement ratio 0.35. In Batch B–E (Graphene-Modified Mixes), the cement content is reduced while the fine aggregate (M-Sand) content is increased, ensuring better workability and dispersion of graphene particles. Reducing the cement content while increasing the fine aggregate content helps minimize shrinkage cracks, improve workability, and enhance graphene dispersion in the cementitious matrix. The adjustment in mix proportions aims to achieve cost-effectiveness without compromising strength, as graphene compensates for the reduction in cementitious material.

4.2 Graphene Dispersal Using Sodium Lignosulfonate

One of the critical aspects of this study is ensuring uniform graphene dispersal within the concrete matrix. Graphene has a strong tendency to agglomerate due to van der Waals forces, leading to uneven distribution in concrete. To counteract this, sodium lignosulfonate, a water-reducing and dispersing agent, was used to ensure proper graphene dispersion. Graphene and Sodium Lignosulfonate are measured by weight of cement. The dispersion process followed these steps:

Dry Mixing: Graphene powder was first dry-mixed with sodium lignosulfonate in powder form. Sodium lignosulfonate acts as a surfactant, reducing graphene's tendency to form clusters.

Pre-Wetting Process: The graphene-lignosulfonate mixture was gradually mixed with water using magnetic stirrer to create a uniform suspension. Studies suggest that using sodium lignosulfonate significantly enhances graphene dispersion and cement bonding, leading to improved mechanical properties.

Final Mixing: The graphene-lignosulfonate solution was then added to the concrete mix during the wet mixing stage, ensuring homogeneous distribution throughout the cement matrix.

Proper dispersion of graphene is crucial in achieving its full reinforcement potential, as studies have shown that well-dispersed graphene can improve compressive strength by up to 30%.

4.3 Sample Preparation and Casting

The concrete mix, prepared with the respective proportions, is subjected to a thorough dry mixing process to ensure uniform distribution of fine and coarse aggregates. Subsequently, water containing dispersed graphene and lignosulfonate is added gradually while continuously mixing to achieve homogeneity. The fresh concrete is then poured into Torus paver block moulds pre-coated with a release agent to prevent sticking. The sample preparation followed a two-layer casting approach to optimize the load-bearing properties of the paver blocks.

Layer 1 (Top Layer - 10mm): This layer consisted of 10mm aggregates, providing a smooth and dense surface finish suitable for abrasion resistance in paver applications

Layer 2 (Bottom Layer - 50mm): This layer incorporated 20mm aggregates, contributing to structural integrity and strength by enhancing the load-bearing capacity of the paver blocks.

Each layer was compacted separately using vibrating table to ensure proper bonding between them, maintaining uniform density and reducing internal voids. The specimens are demoulded after 24 hours and transferred for curing.

Fig-1: Casted Paver Blocks

4.4 Curing and Testing

The demoulded paver blocks are subjected to water curing for 28 days, ensuring adequate hydration and strength development. After the curing period, the blocks are tested for compressive strength and water absorption properties, which are critical for determining their structural performance and durability.

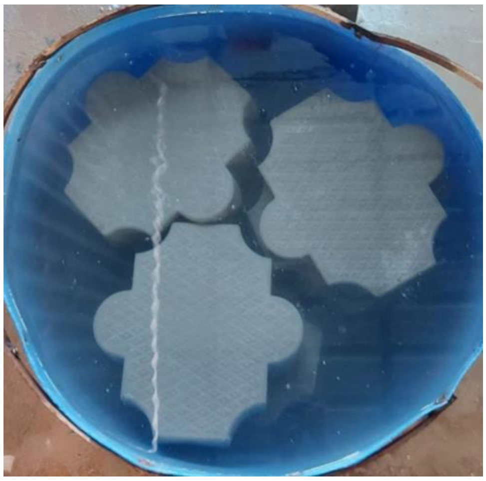

Fig-2: Paver Blocks in Curing Tank

The compressive strength test was conducted in accordance with IS 15658:2006 using a Universal Testing Machine (UTM). The paver blocks were subjected to a gradual axial load until failure, and the ultimate load-bearing capacity was recorded. The results were analyzed to compare the strength enhancement due to graphene incorporation at different dosages (0.01%–0.04%). The effect of graphene in refining the microstructure was also considered, as it contributes to better load distribution and crack resistance.

The water absorption test was performed as per IS 15658:2006, where the paver blocks were oven-dried at 105°C for 24 hours, weighed, and then immersed in water for another 24 hours. After the immersion period, the blocks were weighed again, and the water absorption percentage was calculated based on the difference between wet and dry weights. This test helped determine the permeability and durability of the paver blocks, with lower water absorption indicating a denser and more durable matrix. The results were analyzed to assess the effect of graphene and sodium lignosulfonate in reducing porosity and improving resistance.

5. RESULTS

The experimental study evaluated the compressive strength and water absorption of paver blocks with and without graphene and sodium lignosulfonate. The results indicate that incorporating graphene at varying dosages (0.01%–0.04%) significantly influenced the mechanical and durability properties of the paver blocks. The compressive strength increased with the addition of graphene, while water absorption decreased as the graphene dosage increased.

5.1 Batch A – Control Mix (Without Graphene)

Batch A, the control mix (1:2:4) without graphene, exhibited an average compressive strength of 26.66 MPa. This value represents the baseline strength for conventional paver blocks. The water absorption was measured at 5.8%, which is relatively high due to the porous nature of the mix.

5.2 Batch B – Paver Blocks with 0.01% Graphene

Batch B, containing 0.01% graphene and 0.1% sodium lignosulfonate, demonstrated an improvement in compressive strength to 38.21 MPa, marking a 43.4% increase over the control mix. The water absorption reduced to 5.1%, indicating that graphene's influence on matrix densification had begun.

5.3 Batch C – Paver Blocks with 0.02% Graphene

Batch C, containing 0.02% graphene and 0.15% sodium lignosulfonate, exhibited further strength enhancement, reaching 44.12 MPa, an increase of 65.5% compared to the control mix. At this dosage, graphene's nano-reinforcement effect became more prominent, improving crack resistance. The water absorption dropped to 4.6%, indicating better compaction and improved cement particle bonding.

5.4 Batch D – Paver Blocks with 0.03% Graphene

Batch D, with 0.03% graphene and 0.2% sodium lignosulfonate, recorded an even higher compressive strength of 48.67 MPa, demonstrating an 82.6% increase over the control mix. At this stage, graphene facilitated better crack bridging and enhanced load distribution within the cementitious matrix. The water absorption significantly reduced to 3.9%, suggesting that the mix had reached a more densely packed and less porous structure.

5.5 Batch E – Paver Blocks with 0.04% Graphene

Batch E, containing 0.04% graphene and 0.25% sodium lignosulfonate, achieved the highest compressive strength of 50.32 MPa, representing an 88.8% improvement over the control mix. This improvement is attributed to graphene's ability to enhance hydration, refine the microstructure, and prevent crack propagation. Furthermore, the water absorption decreased to 3.6%, confirming that the higher graphene content contributed to a denser, more water-resistant matrix.

5.6 Comparative Analysis

Table-3: Compressive Strength Results on 28th Day

Batch	Graphene Dosage (%)	Average Compressive Strength (MPa)	Observations
A (Control)	0%	26.66	Typical strength
B	0.01%	38.21	+43.4%
C	0.02%	44.12	+65.5%
D	0.03%	48.67	+82.6%
E	0.04%	50.32	+88.8%

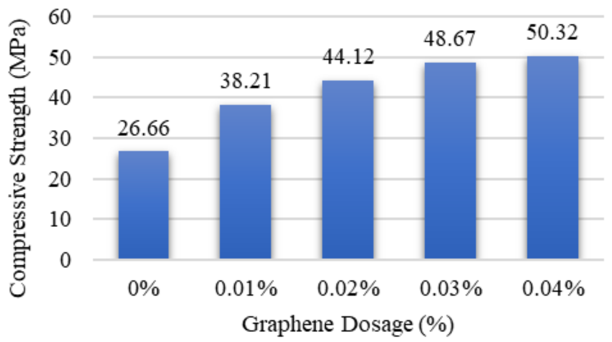

Chart -1 Graph Indicating the Compressive Strength Test Results

Table -4: Water Absorption Results of Paver Block Batches

Batch	Graphene Dosage (%)	Sodium lignosulfonate (%)	Water Absorption (%)	Observations
A (Control)	0%	0%	5.8	Typical Water Absorption
B	0.01%	0.1%	5.1	-12.07%
C	0.02%	0.15%	4.6	-20.69%
D	0.03%	0.2%	3.9	-32.76%
E	0.04%	0.25%	3.6	-37.93%

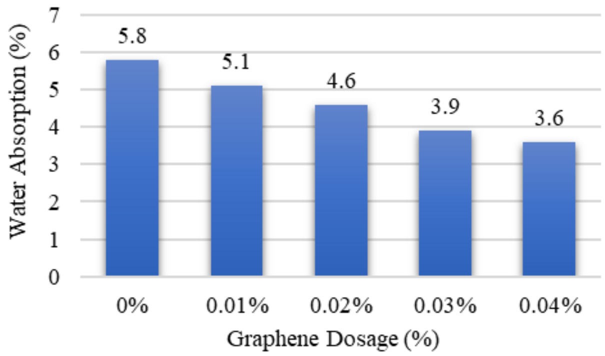

Chart -2 Graph Indicating the Water Absorption Test Results

The results confirm that the inclusion of graphene significantly enhances the compressive strength of paver blocks. The optimum graphene dosage is observed around 0.03%–0.04%, where strength gains are maximized without adversely affecting workability. The incorporation of lignosulfonate effectively facilitated graphene dispersion, ensuring uniform reinforcement throughout the concrete mix. These findings demonstrate that graphene, when used in appropriate proportions, can substantially improve the mechanical properties of paver blocks, making them more durable and resistant to environmental stresses.

6. ECONOMIC AND ENVIRONMENTAL IMPACT

Graphene-enhanced paver blocks offer significant economic and environmental advantages by improving material efficiency and reducing resource consumption. The following benefits were observed:

Cement Production Reduction: Graphene improves concrete performance, allowing less cement to be used while maintaining or even enhancing strength and durability. Since cement production accounts for approximately 8% of global CO_2 emissions, reducing its usage directly lowers the carbon footprint. By using graphene in concrete, Cement production can be reduced.

Enhanced Hydration Efficiency: Graphene promotes a more complete reaction of cement particles, improving packing density, reducing porosity, and increasing durability. This results in a stronger concrete matrix with reduced material waste.

Lower Water Demand: The addition of graphene improves workability, enabling a reduction in the water-cement ratio. Lower water consumption contributes to water resource conservation.

Conserving Natural Resources: the use of manufactured sand (M-Sand) instead of river sand helps in conserving natural resources, addressing the environmental concerns related to excessive sand mining.

Longer Lifespan, Less Maintenance & Long-term Cost Savings: Graphene improves the durability and abrasion resistance of paver blocks, extending their lifespan. This reduces the frequency of replacements, ultimately decreasing overall material consumption and environmental impact resulting in long-term cost savings.

Stronger, Lighter Structures: The increased strength provided by graphene allows for thinner and lighter paver blocks without compromising performance, reducing material requirements in construction projects.

Rainwater Infiltration & Groundwater Recharge: Interlocking gaps of paver blocks that facilitate rainwater infiltration, allowing water to pass through the spaces between pavers and seep into the ground. This reduces surface runoff and promotes natural groundwater recharge. Unlike conventional pavers that are often limited to pedestrian pathways and parking areas, these high-strength, durable paver blocks can be installed in more exposed areas, including heavy-load zones such as industrial yards, roadways, and public infrastructure, ensuring long-term performance under varying environmental conditions.

7. POTENTIAL APPLICATIONS

Graphene-enhanced paver blocks offer a wide range of applications due to their superior mechanical strength, durability, and resistance to environmental degradation. The potential applications include:

Urban Roadways and Pedestrian Walkways: The increased strength and durability of graphene-enhanced pavement blocks make them ideal for high-traffic urban roads and pedestrian pathways. Their ability to withstand heavy loads and resist wear ensures long-term performance with minimal maintenance.

Industrial Flooring and Heavy-Duty Pavements: These paver blocks can be used in industrial areas, warehouses, and loading docks where heavy machinery and equipment exert significant stress on the pavement. The enhanced mechanical properties provide better load-bearing capacity and longevity.

Airport Pavements and Taxiways: Graphene-reinforced paver blocks can be deployed in airport taxiways and aprons, where high compressive strength and durability are crucial. Their reduced water absorption also minimizes the risk of freeze-thaw damage in colder climates.

Coastal and Marine Infrastructure: The enhanced impermeability of graphene-infused concrete makes it suitable for marine environments, including ports, harbors, and seawalls. Its resistance to chloride-induced corrosion helps in prolonging the lifespan of structures exposed to seawater.

Public Parks and Recreational Spaces: These paver blocks are an excellent choice for public parks, cycling tracks, and jogging paths. Their durability ensures that they remain in good condition despite exposure to varying weather conditions and foot traffic.

Smart Cities and Sustainable Infrastructure: Graphene-enhanced paver blocks contribute to sustainable urban development by reducing the carbon footprint of construction materials, increasing pavement lifespan, and enhancing permeability for effective rainwater management and groundwater recharge.

Due to their high strength and durability, graphene-enhanced paver blocks can be utilized in a wide range of applications beyond traditional pedestrian pathways and parking areas. They are well-suited for heavy-load zones such as industrial yards, roadways, airport pavements, and public infrastructure. Their enhanced mechanical properties ensure long-term performance even in high-traffic and exposed environments, making them a versatile solution for various construction and urban development projects.

8. CONCLUSION

This study demonstrates the incorporation of graphene significantly enhances the mechanical performance and microstructural characteristics of paver blocks. Increasing graphene dosage from 0.01% to 0.04% led to a steady rise in compressive strength, with Batch E (0.04%) reaching 50.32 MPa, an 88.8% increase over the control mix (26.66 MPa). This improvement is attributed to graphene's nano-filler effect, which fills micro voids, restricts crack propagation, and enables efficient load transfer. Sodium lignosulfonate, acting as a dispersing agent for uniform graphene distribution, improved cement hydration, and produced a denser, cohesive structure.

In addition to strength enhancement, Water absorption decreased from 5.8% in the control mix to 3.6% in Batch E, a 38% reduction. This decline in permeability reflects a denser microstructure, enhancing resistance to moisture ingress, freeze-thaw cycles, and other environmental degradation. Reduced porosity extended the service life of concrete used in harsh weather conditions.

The optimized 1:3:4 mix design delivered superior mechanical properties and achieved a 12.6% reduction in cement content, supporting environmental sustainability. As cement production significantly contributes to global CO_2 emissions, reducing its usage lowers construction's carbon footprint. These findings position graphene-enhanced paver blocks as a high-performance, eco-friendly alternative for heavy-duty applications like urban roads, airport runways, and marine structures. Future work should explore large-scale field trials, long term durability, cost-benefit analysis, and advanced dispersion methods, along with potential integration into smart or energy-harvesting pavement systems.

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