

Graphene Uses in Construction Industry

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Abstract - Graphene, a two-dimensional crystalline manifestation of carbon, has gained significant attention due to its unique blend of electrical, mechanical, optical, thermal, and sensing characteristics. Its strength, flexibility, and conductivity make it ideal for applications in electronics, energy storage, and biomedical engineering. Graphene research is a new field, leading to a lack of standardized terms for categorizing its different forms. Its future scope includes enhanced structural materials, smart materials and sensors, energy-efficient buildings, sustainable construction practices, and 3D printing and prefabrication. Graphene's characteristics include strength, conductivity, flexibility, transparency, and barrier properties.

Key Words: Graphene, Construction, Unique Material, Carbon, Single Layer

1. INTRODUCTION

The material that has garnered the most attention from researchers in recent years is graphite, specifically in the form of graphene. This unexpected interest can be attributed to the pioneering efforts of Andre Geim and Konstantin Novoselov, who in 2004 managed to extract a single layer of carbon from graphite, thus creating graphene. The International Union of Pure and Applied Chemistry (IUPAC) later officially named this remarkable material "Graphene." Graphene is a two-dimensional crystalline manifestation of carbon, specifically a single-atom-thick, sp²-bonded flat layer of carbon organized in a hexagonal honeycomb pattern. Graphene has sparked significant interest due to its remarkable blend of electrical, mechanical, optical, thermal, and sensing characteristics, all of which were previously believed to be unattainable in a single material. These unique properties include its exceptional strength, flexibility, and conductivity, which enable it to be utilized in fields such as electronics, energy storage, and biomedical engineering.

1.1 Forms of Graphene

Graphene research is a new field, leading to a lack of standardized terms for categorizing its different forms. To address this issue, the International editorial team of Carbon has suggested a classification system for two-dimensional carbon materials. This system is designed to bring clarity and consistency to the classification of Graphene materials.

1.2 Graphene

Graphene, a hexagonal carbon sheet, is a thin, versatile material with lateral dimensions ranging from nanometers to microscale. Its monolayer form is ideal for high-frequency electronics, while bi-layer and tri-layer forms have distinct properties.

1.3 Aim of Graphene

1. **STRENGTH & durability** - Graphene enhances the durability and longevity of traditional construction materials like concrete, asphalt, and composites by reducing cracking and corrosion, thereby enhancing their resilience.
2. **Lightweight material** - Graphene's lightweight properties enable the development of construction materials that reduce structure weight without compromising strength or durability, resulting in more efficient methods and reduced transportation costs.
3. **Thermal and Electrical Conductivity** - Graphene enhances thermal and electrical conductivity in construction materials, improving energy efficiency and performance. It enhances insulation properties, reducing heating and cooling energy consumption.
4. **Water and Gas Barrier** - Graphene's gas and liquid blocking properties make it ideal for building materials like waterproof membranes and gas barriers, enhancing structure strength and longevity.

1.4 Future Scope

1. **Enhanced Structural Materials** - Graphene can enhance the strength, durability, and resilience of conventional construction materials like concrete, steel, and asphalt, paving the way for lighter, stronger, and more resilient buildings.
2. **Smart Materials and Sensors** - Graphene's exceptional electrical and mechanical properties enable the development of intelligent construction materials and sensors, enabling real-time

monitoring of structural well-being, preventing costly repairs, and ensuring structure safety.

3. **Energy-Efficient Buildings** - Graphene-based materials enhance energy efficiency in buildings by improving insulation, reducing thermal conductivity, and enhancing energy storage, thereby reducing indoor temperature regulation and grid reliance.
4. **Sustainable Construction Practices** - Graphene's lightweight, high-strength properties can promote sustainable construction methods, reducing material consumption, waste, and environmental impact. Its use in membranes and coatings enhances building resilience.
5. **3D Printing and Prefabrication** - Graphene-based materials have the potential to revolutionize the construction sector by simplifying the building process, reducing construction time, and enabling unique architectural designs.



Figure 1 Graphene in powder Form

1.5. Characteristics of Graphene

1. **Strength** - Graphene is a highly durable material that surpasses steel in strength and is also lightweight.
2. **Conductivity** - This material is a superior conductor of heat and electricity, surpassing most other materials in these areas.
3. **Flexibility** - Graphene, renowned for its strength and exceptional flexibility, is an ideal choice for various applications that demand flexibility as a key attribute.
4. **Transparency** - The material is transparent, allowing light to pass through, making it suitable for touchscreens, solar panels, and bendable electronics.
5. **Barrier Properties** - Graphene's impermeability to gases makes it valuable for creating barriers in packaging materials and water purification applications.
6. **Potential application** - Graphene has numerous potential applications in fields like electronics, energy storage, medical devices, and aerospace due to its versatile nature

2. METHODOLOGY

A. Mechanical Exfoliation (Scotch Tape Method) -

The Scotch Tape Method, developed by Andre Geim and Konstantin Novoselov, is a time-consuming and inefficient method for extracting single-layer graphene from bulk graphite, leading to their Nobel Prize in Physics in 2010.

Process -

- **Preparation of Starting Material:** The process begins with a piece of highly oriented pyrolytic graphite (HOPG), which typically consists of multiple layers of graphene stacked together.
- **Adhesive Tape:** Scotch Tape is applied to the graphite sample's surface, and gently pressed to ensure good contact.
- **Peeling-off layers:** The tape is applied and carefully removed from the graphite sample surface, removing thin layers of graphite.
- **Repeating the Process:** Repeated application and peeling of tape thins graphite layers, transferring thinner layers onto the tape.
- **Microscopic Inspection:** The tape with graphite layers is examined under an optical or electron microscope to identify single-layer or few-layer graphene areas, which appear as thin, transparent sheets.
- **Transfer onto Substrate:** Identifying suitable graphene flakes allows them to be transferred onto clean substrates like silicon dioxide/silicon wafers for further characterization and device fabrication.

The Scotch Tape Method is a manual method for producing high-quality graphene with minimal imperfections, but not suitable for mass production due to its slowness and scalability.

B. Chemical Vapor Deposition (CVD)

Chemical Vapor Deposition (CVD) is a method that breaks down carbon-containing gas on metal catalyst substrates at high temperatures to grow graphene layer by layer. To start the process, a substrate like copper, nickel, or silicon carbide is prepared by cleaning and polishing to ensure a clean surface for graphene growth. Chemical vapor deposition (CVD) is a process that produces graphene films by placing carbon atoms on a substrate, typically copper, nickel, or silicon carbide wafers. The substrate is placed in a CVD reactor chamber, typically a high-temperature furnace or vacuum chamber, which is emptied of air and gases to regulate graphene growth.

Process –

- **Introduction of Carbon Precursor:** A carbon-containing gas precursor, like methane, ethylene, or acetylene, is introduced into a CVD reactor chamber, which decomposes at high temperatures to release carbon atoms, forming graphene on the substrate surface.
- **Heating and Decomposition:** The substrate is heated to 700°C to 1000°C, depending on the precursor gas and substrate material, causing the precursor gas to decompose and carbon atoms to adsorb onto the substrate surface.
- **Graphene Nucleation and Growth:** Carbon atoms adsorb onto substrate surfaces, nucleating and forming graphene domains. Under optimal conditions, graphene domains cover substrate surface uniformly, controlled by temperature, gas flow rate, and deposition duration.
- **Cooling and Removal from Reactor:** The graphene film thickness is achieved, the substrate is cooled, and the CVD process is stopped. The graphene-coated substrate is then removed for further processing and characterization.
- **Transfer onto Target Substrate:** Wet or dry transfer methods can be used to transfer graphene film onto different substrates for specific applications, preserving its quality and integrity.
- **Characterization and Device Fabrication:** The graphene film, synthesized using Raman spectroscopy, SEM, and AFM techniques, is evaluated for quality, thickness, and structural properties, enabling applications in electronics, photonics, sensors, and energy storage.

C. Chemical Reduction of Graphene Oxide (GO)

Graphene oxide, a precursor for graphene, is created by oxidizing graphite. It is chemically reduced to form reduced graphene oxide (rGO), with functional groups and defects. Although not perfect, rGO offers simpler production and customization for specific applications, restoring sp² carbon-carbon bonds and increasing solubility in aqueous and organic solvents. The process involves substrate heating, carbon adsorption, graphene domain growth, cooling, transfer, and fabrication using Raman spectroscopy, SEM, and AFM to assess the quality, thickness, and structural properties of the synthesized graphene film.

CVD is a technique used to create graphene films with precise control over thickness, quality, and scalability by depositing carbon atoms onto a substrate surface.

Process –

- **Synthesis of Graphene Oxide (GO):** Graphene oxide is created by oxidizing graphite flakes with strong agents like KMnO₄, NaNO₃, or H₂SO₄, introducing oxygen-containing functional groups, forming a layered material with hydrophilic and insulating properties.
- **Dispersion of GO:** The synthesized GO is dispersed in a solvent like water, ethanol, or DMF to form a stable suspension, ensuring uniform exposure of GO sheets to the reducing agent.
- **Chemical Reduction:** Chemical reducing agents like hydrazine, sodium borohydride, hydroquinone, ascorbic acid, and hydrogen iodide are used to reduce GO and produce rGO by donating electrons to oxygen-containing functional groups.
- **Washing and Purification:** Following reduction, the rGO product is purified by multiple rounds of centrifugation, filtration, and solvent washing to remove excess reducing agents, reaction by-products, and residual GO.
- **Drying and Characterization:** The purified rGO is dried and characterized using techniques like XRD, FTIR, Raman spectroscopy, SEM, and AFM to assess its structural, chemical, and morphological properties.

Chemical reduction of GO produces rGO with tunable properties for electronics, energy storage, sensors, and composites. However, defects and structural disorder may affect performance.

- D. Liquid-Phase Exfoliation (LPE): Liquid-Phase Exfoliation (LPE) is a solvent-based process that separates graphene layers, creating sheets for various uses, though the quality and properties of the resulting graphene may vary.
- E. Electrochemical Exfoliation - Electrochemical exfoliation is a technique that involves applying an electric current to a graphite electrode, resulting in the intercalation and exfoliation of graphene layers.

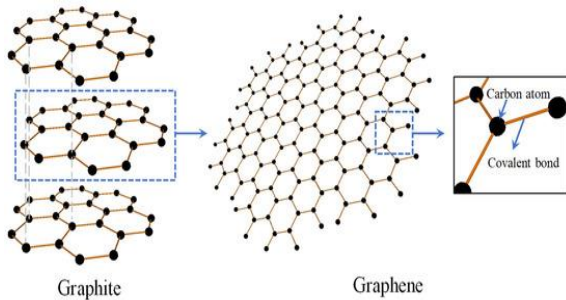


Figure 2 Graphene Single Layer

3. USES OF GRAPHENE IN CONSTRUCTION INDUSTRY

1. Concrete Reinforcement - Graphene can enhance concrete's strength and durability by reducing cracking, increasing corrosion resistance, and enhancing mechanical properties through the dispersion of graphene oxide or nanoplatelets.
2. Coating & Paints - Graphene coatings provide superior protection against corrosion, weathering, and chemical damage, extending the lifespan of steel structures, bridges, and other infrastructure while reducing maintenance costs.
3. Smart Materials - Smart concrete uses graphene-based materials for real-time structural health monitoring, detecting stress, strain, temperature, and humidity changes, enabling early identification of structural problems.
4. Energy Storage - Graphene-based materials offer efficient energy storage solutions in buildings, particularly in the use of graphene-based supercapacitors for powering smart windows, sensors, and structural monitoring systems.
5. Thermal Management - Graphene's high thermal conductivity can improve the thermal properties of construction materials, allowing

for better control of internal temperatures, thereby enhancing energy efficiency and comfort.

6. Waterproofing - Graphene's exceptional impermeability makes it ideal for waterproofing, creating impervious barriers in construction materials to protect structures from water infiltration and moisture damage.
7. Lightweight Composite material - Graphene composites can be used to create lightweight, durable construction materials with improved mechanical properties, making them suitable for aerospace, automotive, and structural sectors.
8. Solar panel - Graphene's exceptional electrical conductivity and transparency make it a promising material for solar panels, potentially improving performance, and longevity, and reducing manufacturing costs.
9. Flexible Electronics - Graphene's electrical conductivity and versatility make it ideal for flexible electronics in construction, enabling energy harvesting, light modulation, and adaptive shading through the integration of sensors and actuators.
10. Lightweight Structural Components - Graphene-derived substances can create lightweight structural elements for buildings and infrastructure by incorporating it into composites and foams, resulting in strong yet lightweight structures.

4. GRAPHENE-BASED PRODUCTS USED IN CONSTRUCTION

A. Graphene Based Concrete -

Graphene-enhanced concrete is a novel type of concrete that incorporates graphene oxide nanoparticles, enhancing its mechanical strength, durability, and overall performance. Graphene's strength surpasses steel due to its distinctive atomic structure and bonding properties.

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1. Atomic Structure: Graphene is a two-dimensional honeycomb lattice structure consisting of a single layer of carbon atoms covalently bonded to three adjacent carbon atoms.
2. Bonding Strength: Graphene's strength is attributed to its carbon-carbon bonds, which

distribute stress evenly throughout the lattice, enhancing its resistance to deformation and fracture.

3. **Defect-Free Structure:** Graphene's strength is due to its flawless crystalline structure, unlike steel's imperfections, which limit its theoretical strength potential.
4. **Size Effect:** Graphene's strength is attributed to its small size, resulting in a high surface-to-volume ratio, which minimizes defects and enhances the effectiveness of its strong covalent bonds.
5. **Flexibility:** Graphene's two-dimensional structure allows it to bend and stretch without breaking, showcasing its superior mechanical characteristics compared to steel.

Graphene concrete is a stronger material than ordinary Portland cement (OPC) concrete, with a compressive strength of 361 MPa. This makes it ideal for construction projects requiring durability and structural integrity. Engineers and builders can create structures that can withstand greater loads and pressures, ensuring long-lasting and resilient infrastructure. The study shows that even 0.03% graphene can significantly enhance concrete compressive strength and flexural strength by 149% and 80% respectively, highlighting the potential of graphene in concrete mixtures.

Properties –

- Graphene nanoparticles enhance concrete's strength and toughness by acting as reinforcement agents within the cementitious matrix, bridging microcracks and defects.
- Graphene improves concrete's mechanical properties by inhibiting crack propagation and reducing brittle failure risk, resulting in more durable structures.
- Graphene-based concrete enhances durability by resisting degradation mechanisms like freeze-thaw cycles, chloride penetration, sulfate attack, and ASR, thereby prolonging the service life of concrete structures.
- Graphene nanoparticles enhance the workability and rheological properties of concrete mixtures, facilitating easier placement, compaction, and finishing during construction, acting as lubricants.
- Graphene-based concrete enhances material usage, structure lifespan, and reduces environmental impact by optimizing

maintenance, resource consumption, and carbon emissions associated with repair and replacement activities.

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B. Graphene Based Asphalt

Graphene-based asphalt, also known as graphene-enhanced asphalt, is a type of asphalt concrete that enhances its mechanical properties, durability, and performance. Graphene-based asphalt typically consists of the following components:

- **Asphalt Binder** - Asphalt concrete is composed of asphalt binder, a viscous, black petroleum substance that acts as a glue, binding aggregates like sand, gravel, and crushed stone.
- **Aggregates** - Aggregates form the structural framework and mechanical properties of asphalt concrete, which is typically graded and mixed with the asphalt binder to create the asphalt mixture.
- **Graphene Nanoparticles** - Graphene nanoparticles are added to asphalt binder in small concentrations to improve its mechanical properties and performance.
- **Additives** - Asphalt mixtures may contain additives like polymers, rejuvenators, fibers, or mineral fillers to enhance performance and modify properties, depending on the specific application requirements.

Benefits – Graphene-based asphalt offers several benefits over traditional asphalt concrete:

- **Improved Mechanical Properties** - Graphene reinforcement improves asphalt concrete's tensile strength, modulus of elasticity, and fatigue resistance, resulting in longer-lasting pavements with reduced cracking and rutting
- **Enhanced Durability** - Graphene-based asphalt offers enhanced durability and longer service life due to its resistance to aging, deformation, moisture damage, and thermal cracking.
- **Reduced Rutting and Deformation** - Graphene nanoparticles enhance the stiffness and rut resistance of asphalt concrete, reducing

permanent deformation under heavy traffic loads and high temperatures

- **Enhanced Thermal Properties** - Graphene's high thermal conductivity efficiently dissipates heat, reducing the risk of thermal cracking and premature pavement failure in hot climates or heavy traffic conditions.
- **Environmental Sustainability** - Graphene-based asphalt can enhance environmental sustainability by prolonging the lifespan of asphalt pavements, reducing the need for frequent repairs and replacements.

Properties –

- **Improved Mechanical Strength**: Graphene reinforcement enhances asphalt concrete's tensile strength, elasticity, and fatigue resistance, resulting in stronger pavement structures and improved resistance to cracking, rutting, and deformation under heavy traffic loads.
- **Enhanced Durability**: Graphene nanoparticles enhance asphalt concrete's aging, thermal stability, and moisture resistance, extending its service life and reducing maintenance requirements compared to traditional asphalt.
- **Better Thermal Conductivity**: Graphene's high thermal conductivity efficiently dissipates heat, reducing the risk of thermal cracking and premature pavement failure in hot climates or heavy traffic conditions.
- **Improved Fatigue Resistance**: Graphene reinforcement improves asphalt concrete's fatigue and crack propagation resistance, reducing pavement failure under repeated loading and cyclic stress conditions, resulting in longer-lasting pavements.
- **Reduced Rutting and Deformation**: Graphene nanoparticles enhance asphalt concrete's stiffness, rut resistance, and deformation resistance, reducing permanent deformation under heavy traffic loads and high temperatures.
- **Environmental Sustainability**: Graphene-based asphalt extends asphalt pavement lifespan, reduces frequent repairs, and contributes to environmental sustainability by reducing life cycle costs, thereby enhancing the durability of transportation infrastructure.

Uses of Graphene-based asphalt –

- **Road Construction**: Graphene-based asphalt offers superior mechanical properties, durability, and performance compared to traditional asphalt, resulting in longer-lasting and more resilient pavements for new road construction.
- **Pavement Rehabilitation**: Graphene-based asphalt is utilized in pavement rehabilitation and maintenance projects to enhance the structural integrity and longevity of aging pavements by applying an overlay or surface treatment.
- **Airport Runways and Taxiways**: Graphene-based asphalt is ideal for airport runway and taxiway construction due to its strength, durability, and resistance to deformation, making it suitable for heavy aircraft loads and high traffic volumes.
- **Parking Lots and Driveways**: Graphene-based asphalt is a popular choice for low-traffic pavement surfaces due to its enhanced resistance to cracking, rutting, and moisture damage, resulting in smoother, longer-lasting pavement.
- **Bicycle Lanes and Pedestrian Pathways**: Graphene-based asphalt is a sustainable and eco-friendly material suitable for the construction of bicycle lanes, pedestrian pathways, and recreational trails, offering enhanced safety, comfort, and durability.
- **Racetracks and Sports Surfaces**: Graphene-based asphalt is a versatile material used in the construction of racetracks, sports surfaces, and athletic tracks, offering superior traction, performance, and durability.
- **Specialty Applications**: Graphene-based asphalt is ideal for specialty pavement projects in industrial facilities, military installations, and high-security areas due to its enhanced performance characteristics.

5. DEMERITS OF GRAPHENE –

- **Cost**: Despite its high cost, graphene production may hinder its widespread use in the construction sector, but advancements in production methods could potentially address this issue.

- **Scalability:** The construction industry faces challenges in scaling up graphene production, but developing scalable manufacturing processes is crucial for increasing its accessibility.
- **Standardization:** The absence of standardized testing methods and regulations for graphene-based construction materials could hinder their adoption, necessitating the establishment of industry standards for their reliability and consistency.
- **Compatibility:** Graphene-based materials may necessitate modifications to existing construction processes and infrastructure, posing logistical challenges for proper integration and compatibility.
- **Safety Concerns:** Despite being generally safe, there are concerns about the potential health and environmental impacts of graphene production and use, necessitating comprehensive risk assessments and safety protocols.

6. GRAPHENE GREEN MATERIAL

Graphene's unique properties and potential applications in construction make it a green product, contributing to sustainability in various industries.

- **Resource Efficiency** - Graphene, a sustainable alternative to traditional construction materials, is derived from abundant carbon sources like graphite and produced using simple chemical or mechanical methods.
- **Energy Efficiency** - Graphene-based materials can enhance energy efficiency in buildings and infrastructure, such as concrete, by reducing heating and cooling requirements and greenhouse gas emissions.
- **Durability and Longevity** - Graphene reinforcement improves construction material durability, reducing frequent repairs and maintenance, conserving resources and minimizing environmental impact in production, transportation, and disposal.
- **Recyclability** - Graphene-based materials like composites can be recycled or biodegradable, promoting the circular economy and reducing waste, thus conserving resources and minimizing environmental impact in construction projects.

- **Reduced Carbon Footprint** - Graphene-based materials can significantly reduce construction's carbon footprint by enhancing building performance and sustainability, such as in graphene-enhanced concrete, resulting in lower embodied carbon and lifecycle emissions.
- **Innovative Applications** - Graphene offers sustainable construction solutions like self-sensing materials, energy-efficient coatings, and lightweight composites, addressing environmental challenges and promoting sustainable development in the industry.

Considering the entire lifecycle of graphene-based materials, including production, use, and disposal, is crucial for assessing their environmental impact and optimizing their sustainability.

7. CONCLUSIONS

Graphene, a unique material with strength, conductivity, flexibility, and impermeability, has the potential to revolutionize the construction industry by enhancing structure durability, reducing maintenance costs, and reducing environmental impact. Graphene enhances safety, efficiency, and sustainability in construction projects by incorporating it into coatings, paints, smart materials, and energy storage solutions, enhancing real-time monitoring and adaptation. Graphene holds immense potential in construction, but challenges like scalability, cost, and standardization require further research for widespread use and improved materials and technologies. Graphene holds immense potential for innovation, sustainability, and resilience in the construction industry, necessitating continuous research, development, and collaboration to fully harness its capabilities.

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