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A review on preparation, properties and applications of graphene composites

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Abstract:
The flexible and bending materials technology is focusing on graphene-based materials. A popular technique for its production is chemical vapour deposition. Raman spectroscopy indicated its high quality; oxidation experiments demonstrate its substantial impermeability, and scanning electron microscopy reveals that the films are continuous over broad areas. Due to its unique properties, such as mechanical, electrical, and optical characteristics and highly readily functionalizable derivatives, graphene has emerged as a perfect candidate for the realisation of flexible electronics. Biomedical assistance, membranes, flexible wearable sensors, actuators, electronics, etc, show great promise for using graphene-based materials and their composites. This study delves into the synthesis methods of graphene composites to explore their various applications and overcome technological problems. It explores the discoveries of better mechanical characteristics and conductivity, providing insight into the future of advanced materials. The findings show that graphene and its derivatives can create nanocomposites with various polymer matrices. Graphene varieties, including pristine graphene, graphene oxide, and reduced graphene oxide, were introduced in our study. This study also investigates nanocomposites containing multiple graphene, inorganic, and polymeric components, including polymer/GR, activated carbon/GR, metal oxide/GR, metal/graphene, and carbon fibre/GR.

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1. Introduction

Sensing techniques are changing to incorporate devices with extremely low thresholds for discovery and great levels of selectivity. The discovery of novel materials frequently results in important developments in a variety of technical and scientific domains. From enhancing current technologies to opening up completely new applications and solving long-standing issues, these materials can have a profound effect on civilization. Materials science is therefore still a vital and developing field of research with wide-ranging consequences, which is a fantastic new amplification of an issue that was previously thought to be intractable.

A material with remarkable electrical, mechanical, thermal, and optical capabilities is graphene, a single-layer sheet of carbon atoms organized in a hexagonal lattice. Graphene has become a ground-breaking material in the field of optics. Graphene composites are the newest and most promising development in materials research. These remarkable materials are the key to unlocking a plethora of technological innovations, known for their excellent strength-to-weight ratio and unmatched conductivity. We must not only choose but also implement graphene composites into a wide range of industries if we are to lead the way into a future where solutions that are stronger, lighter, and more efficient will always prevail. We are setting out on a mission to redefine materials perception and utilization while also pushing the envelope of what is possible by embracing graphene composites.

The objective of this study is to explore new production techniques which will allow for improvement of the properties of graphene composites and fulfil the desire for enhancing the performance characteristics of such materials. Nanotechnologies can facilitate these performances by top-down structures specified by nanotechnology or bottom-up constructs generated chemically/biochemically. Nano- and atomic-level materials have been thoroughly researched in the age of scientific discoveries in order to create new materials that enhance elemental output in a range of applications (Ojha & Thareja, 2020). Nanomaterials have been categorized as 0D, 1D, 2D, and 3D based on their dimensions. The review's emphasis in this section is on 2D carbon materials, or carbon atoms with sp^2 bonds. Graphene, one of the 2D carbon compounds, has sp^2 hybridized carbon atoms organized in planar hexagonal units in 2D (Albers *et al.*, 2022).

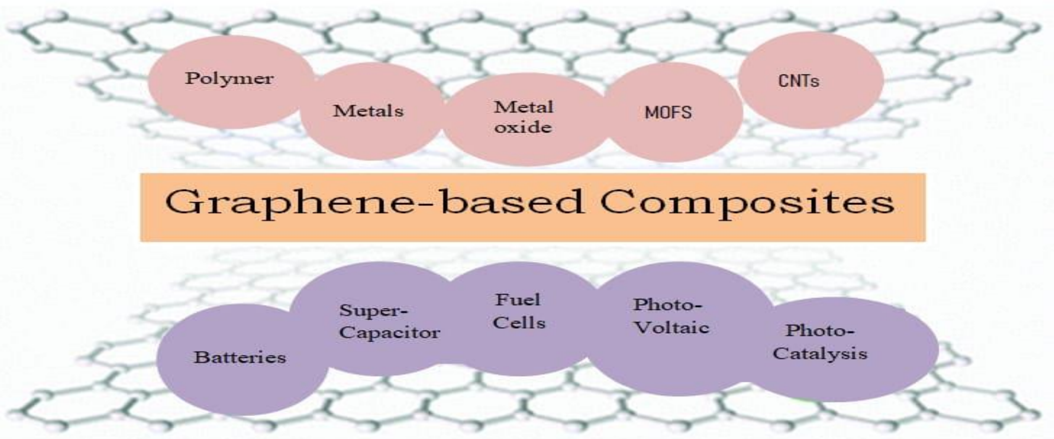
In 2004, Andre Geim and Konstantin Novoselov led the first team to effectively manufacture graphene (Novoselov, 2011). They nevertheless credited Hanns Peter Bohem and other lab scientists with this discovery, as they conducted experiments contrasting graphene with thin graphite particles. Hanns Peter Bohem was the first to use the name “graphene” therefore, in 1986. In graphene, sp^2 hybridization is seen, and the bond length between the C-C atoms is 0.142nm. The thinnest and lightest material yet found, graphene contains a single sheet of atomic thickness and weighs approximately 0.7mg per square meter. Additionally, a high thermal and electrical conductivity is demonstrated. Research indicates that at around 5300 W/mk and 106 S/m, graphene has the highest recorded thermal and electrical conductivity of any material. This substance is comparable to diamond and is the strongest ever found (Sulaiman *et al.*, 2023).

Carbon distinct planar sheets with sp^2-bonded carbon atoms firmly arranged in a honeycomb model make up graphene, an allotrope of carbon as shown in Figure 1 (Tehseen *et al.*, 2024). Graphene compounds show great potential for innovation with many potential applications in industries such as electronics, aircraft, and energy storage. Graphene can be utilized to strengthen other materials because of its tremendous mechanical strength (Shen *et al.*, 2022). It can significantly improve the physical strength of metals, composite materials, and other types of polymers. Aerospace, construction materials, super vehicles, and aircraft can all benefit from the use of graphene-based materials. Graphene is helpful for cooling and heat sink applications due to its thermal conductivity (Yan *et al.*, 2021). Furthermore, graphene can be used in flexible solar panels, medical applications, energy storage devices, and sensing applications due to its high surface-to-volume ratio. Promising qualities are shown not just by graphene but also by its derivatives for possible applications.

Several methods have been developed recently for the manufacture of graphene. Currently, the most often utilized techniques include chemical exfoliation, mechanical cleaving (exfoliation), chemical synthesis, and thermal Chemical Vapor Deposition (CVD). There have also been reports of additional methods, including microwave synthesis and unzipping nanotubes. While few-layer graphene was shown to be able to be produced by mechanical exfoliation using an AFM cantilever, the technique was limited by the graphene's thickness, which fluctuates to about 10 nm, or thirty-layer graphene (Johnson *et al.*, 2015). The chemical exfoliation method proceeds to exfoliate graphitic material that is already dispersed in a solvent by intercalating the bulk alkali cations in between layers of the graphite. Suggested orderings can also be seen in the making of graphite oxide, it's being solved in the solvent and undergoing reduction by nitric acid in a chemical reaction. Just as in the synthesis of carbon nanotubes, catalytic thermal CVD will clearly stand out in the toolkit for industrial scale graphene production.

Thermal CVD or T-CVD is where thermal CVD is carried out in a resistive heating furnace. Plasma enhanced CVD or PECVD means the use of chemical vapour deposition techniques which involve plasma assisted growth of materials. All synthesis techniques have some disadvantages, depending on how graphene will be used in the end, since nothing in our world is perfect. The mechanical exfoliation approach, for example, can be used to fabricate monolayer to few-layer graphene, although the likelihood of achieving a comparable structure using this method is negligible (Muzyka *et al.*, 2018). Moreover, low-temperature chemical synthesis methods facilitate the fabrication of graphene on a variety of substrate types at room temperature, including polymeric substrates (Preston *et al.*, 2015). Some of the graphene-based composites are shown in the Figure 1.

Figure 1: Graphene based composites



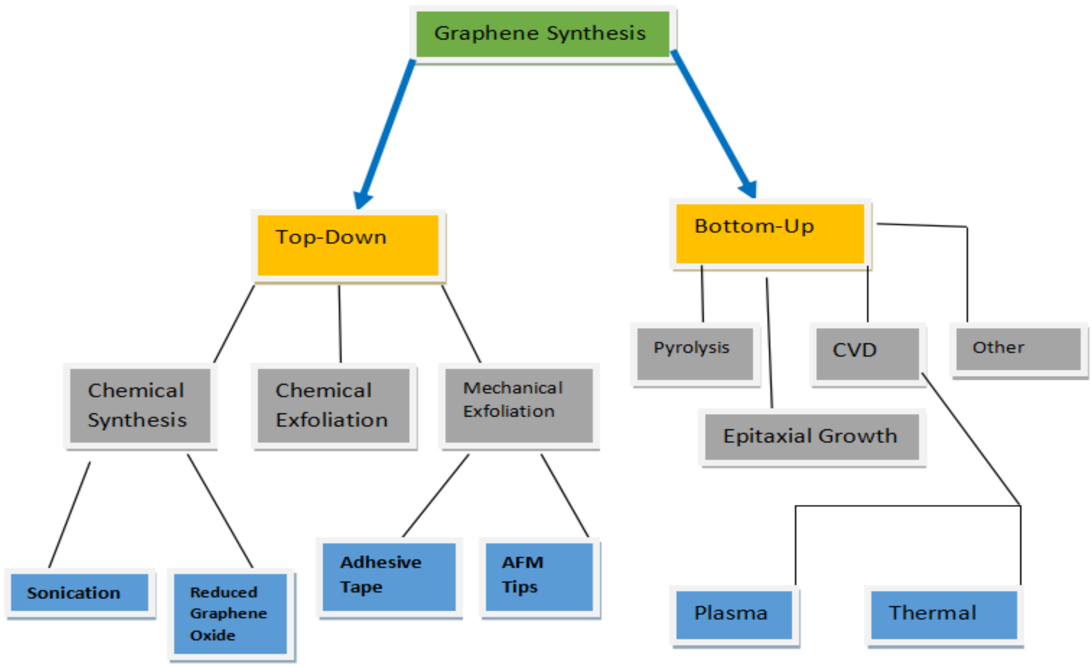
Source: Huang *et al.* (2012)

A vast range of applications in sectors such as electronics, aerospace, and energy storage are demonstrated in the well-researched literature on graphene composites that currently exists. The gaps in the current literature demand more investigation into topics such sophisticated production processes, novel characterisation strategies, and specific uses for graphene composites. Graphene composites are materials made of graphene mixed with other components to produce new materials with improved qualities. These composites can be made to order for specialized uses in fields including aircraft, electronics, energy storage, and more (Surwade *et al.*, 2015). The potential of graphene composites to improve material qualities across a range of industries is what makes them significant. Graphene is a useful ingredient in composite materials because of its remarkable strength, excellent electrical and thermal conductivity, and flexibility. Improved mechanical strength, conductivity, and other crucial properties of the base material can be achieved by adding graphene to composites. Because of their exceptional performance and ability to facilitate the creation of novel goods, graphene composites have the potential to completely transform a number of industries (Patel *et al.*, 2015).

2. Preparation methods of graphene composites

Graphene composites are prepared by various methods. There have been reports of using foam, hydrogel, aerogel, monolith, and sponge among other materials to construct 3D graphene-based structures. The synthesis of the 3D configuration was generally divided into two categories: solution-based synthesis and CVD. The synthesis includes methods for creating 3D graphene-based structures that are both template-assisted and template-free. Physical techniques include chemical vapor deposition, arc discharge method, epitaxial growth and unzipping of carbon nanotubes. In addition, chemical and electrochemical methods have also been adapted for graphene synthesis (Ghany *et al.*, 2017). The numerous methods for graphene synthesis based on both bottom-up and top-down methods are listed in the Figure 2.

Figure 2: Various patterns of classification of the methods of preparation of graphene



Source: Sahu *et al.* (2021)

Top-down approach is the process of converting or diminishing graphite into nano scaled graphene layers which in turn are merely combined with various functional materials to develop new materials. The benefits of the top-down methods are attributed to the fact that it offers substrate transfer, offers price efficiency and higher reliability as compared to the bottom-up approach (Olatomiwa *et al.*, 2022).

Bottom-up approach this method is a step by layer process carried out in order to synthesize graphene from small molecular carbon atoms. The advantage of technique consists in such proscribed thickness of the graphene layers using the help of different surface catalysts and growth criteria (Olatomiwa *et al.*, 2022). The major top-down and bottom-up approaches for graphene synthesis are discussed below:

2.1. Chemical exfoliation

A popular technique for creating graphene, a two-dimensional carbon allotrope with exceptional qualities, is chemical exfoliation. A bulk carbon source, such graphite, is broken down into discrete graphene layers using chemical agents. By taking advantage of graphite's weak interlayer bonding, this method enables the separation of graphene. The process of micromechanically cleaving graphite led to the first investigation of graphene. Large, excellent graphene sheets could be produced with this technique, but very limited quantities. Because of this, its limited availability means that its practical applications are mainly limited to basic research and electrical purposes.

The creation of methods for synthesizing graphene by cleavage and exfoliation, as well as the creation of graphene oxide and reduced graphene oxide, has created new opportunities for investigating a variety of uses. The unique properties of graphene oxide include a broad array of surface's exceptional dispersibility and adaptable features have made it a good choice for several uses in the realms of biomedicine, composites, sensors, and energy storage Strong oxidising agents are used to treat graphite, such as sulphuric acid or a sulphuric acid and nitric acid mixture. GO is created when functional groups containing oxygen are introduced into the graphene layers by this procedure. There are layers of graphene oxide, and resultant in the formation of graphene. It dissolves easily in water and other solvents because to the oxygen groups in it. The end product, GO is subsequently reduced chemically or thermally to produce graphene.

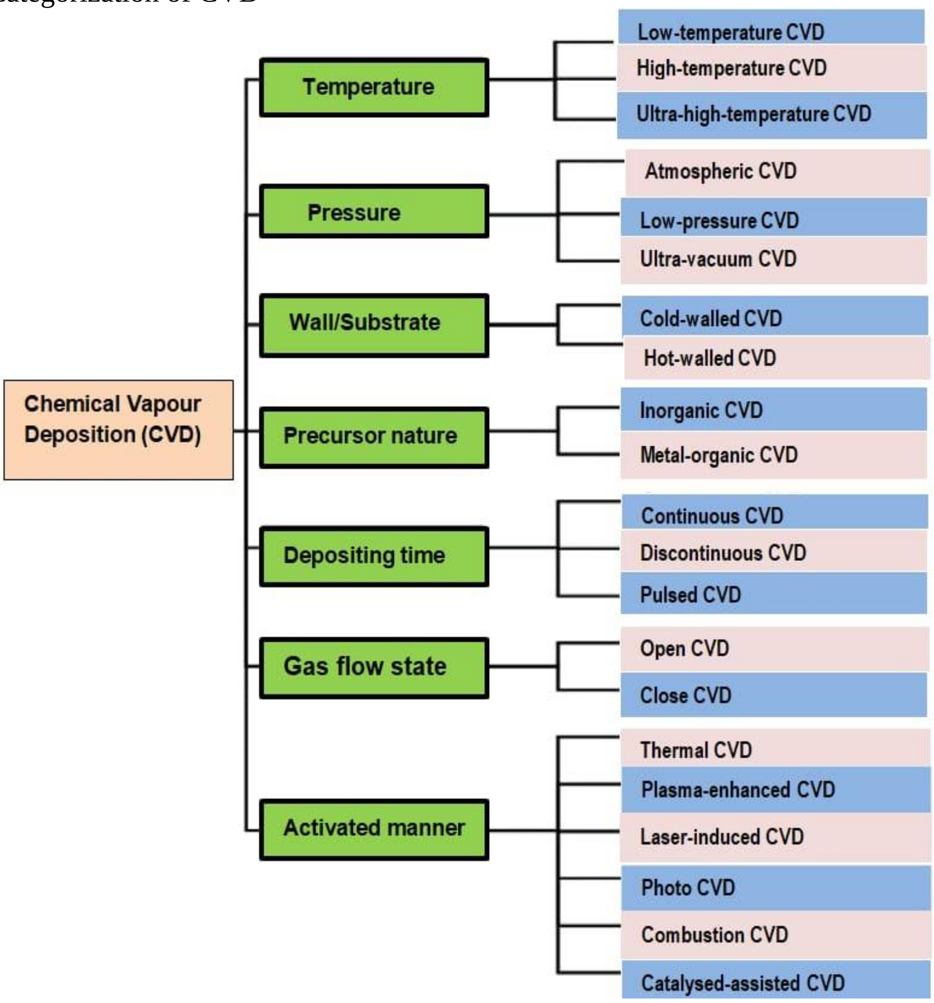
2.2. Chemical Vapor Deposition (CVD)

Conversely, the process of CVD entails using chemical processes such as chemical reactions to deposit material in form of things film from vapour species onto substrates. Numerous intricate variables, such as the system configuration, reactor layout, gas feedstock, gas ratios, reactor pressure, gas partial pressures, reaction temperature, growth time, temperature, etc., influence the process and kinds of different possible chemical reactions that take place in a CVD reactor. By employing LPCVD to develop graphene on Ir, it was possible to investigate the potential of CVD for generating graphene films following the initial isolation of graphene in 2004 (Brownson & Banks, 2012). The ease of setup in research labs, the long-term success of using CVD in industrial settings, and the possibility of scaling up manufacturing are the reasons behind the popularity of this method for growing graphene. Graphene-based products can be synthesized using a range of CVD techniques that are now available.

It has previously been determined that a range of precursors, including solid, liquid, and gaseous carbon sources, are suitable for the synthesis of graphene in the CVD reactor. It is possible to load solid precursors straight into the reactor chamber. Sun and colleagues achieved the production of graphene sheets on a Cu surface by using spin-coated poly (methyl methacrylate) (PMMA) on Cu foil and thermal sublimation assisted by H_2 and Ar (Chen *et al.*, 2017).

Yao et al (2011) reported a liquid carbon source using hexane. With this technique, the hexane was evaporated, and the vapor was injected via bubblers into the CVD reactor. Usually, liquid hexane is blasted with inert gas (like Ar) to regulate the concentration of the vapor. These carbon sources were not used in this work, though, because they can be difficult to manage. Gaseous carbon precursors, such methane (CH_4) gas, are most frequently utilised. A gas delivery system is used to move the gaseous precursor to the reaction chamber (Zhang *et al.*, 2013). The categorization of CVD techniques illustrated in Figure 3.

Figure 3: Categorization of CVD



Source: Saeed *et al.* (2020)

2.3. Liquid Phase Exfoliation (LPE)

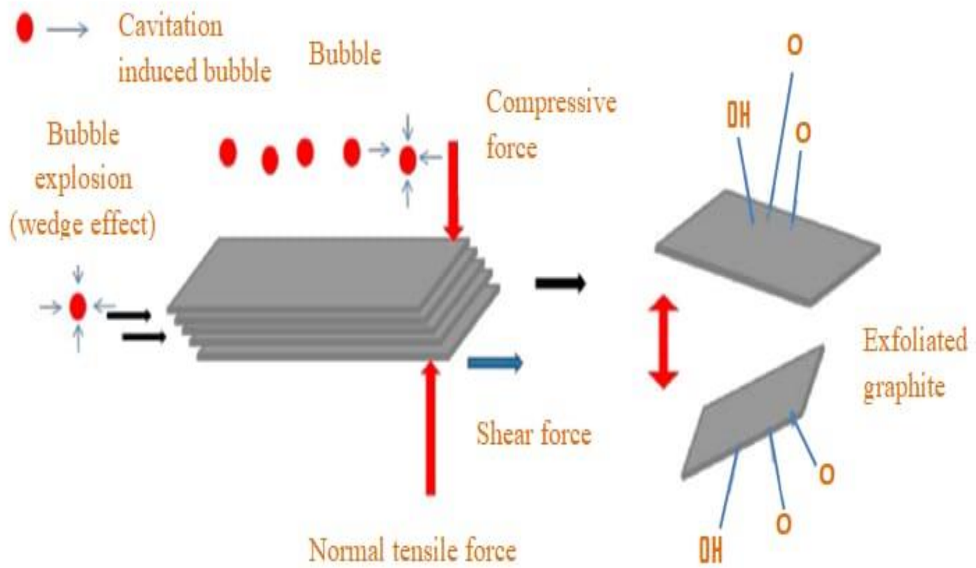
Typically, LPE primarily uses two methods for exfoliating graphite: shear forces in a high-shear mixer and cavitation in sonication. Graphite can be effectively exfoliated using a microfluidizer in appropriate aqueous solutions at high shear rates, as demonstrated recently. Graphene can be produced in large quantities using the simple LPE process. Most people have access to the fundamental sonication or high shear mixing equipment. Furthermore, LPE operates in mild settings and doesn't require high temperature or vacuum systems. However, the low concentration of graphene and the significant energy consumption during the fabrication process have prevented the large-scale implementation of sonication assisted LPE (Xu *et al.*, 2018).

2.4. Sonication

Sonication is not only a practical method of exfoliation, but it may also produce relatively significant quantities of monolayer or few-layer graphene. Sonication is commonly utilised to induce chemical or physical alterations in certain systems by generating cavitation bubbles. Ultrasonic waves propagate through the medium at high and low pressures, pushing and pulling molecules through compressions and rarefactions. Micro bubbles begin to form in the rarefaction phase and grow with every consequent phase, and when it gets to an unstable condition; it will burst and release strong shock waves (Choucair *et al.*, 2009).

Bath Sonication (BS) and Tip Sonication (TS) are the two types of sonication (Buzaglo *et al.*, 2013). They have been used in combination or separately to exfoliate graphene in order to prepare monolayer or few-layer graphene sheets. The process of sonication-assisted LPE typically consists of three steps: (1) preparing the graphite dispersion in a particular solvent; (2) sonicating the dispersion to exfoliate it; and (3) purifying the graphene. The cavitation-induced pressure pulsations in liquids are responsible for the formation and collapse of microbubbles during sonication. Graphite will experience normal and shear forces as a result of the cavitation phenomenon, which creates high-speed microjets and shock waves. When graphite is exfoliated to produce graphene, cavitation and shear forces are important factors (Figure 4).

Figure 4: An example of a potential graphite exfoliation mechanism



Source: Lin *et al.* (2017)

The results shows that rate of centrifugation, the liquid medium used to scatter the graphene nanosheets, and the sonication power, all affect the exfoliation result. The right liquid media are chosen to establish an environment that allows for the stable dispersions of graphene during sonication.

2.5. Mechanical exfoliation

The Scotch tape method or mechanical exfoliation is the only effective procedure when preparing graphene composites. This process involves the continual separation of graphene layers from a source graphite to synthesise high quality graphene flakes. Afterwards, by adding these graphene flakes to composite materials, their mechanical, electrical, and thermal qualities can be improved. For scientists and engineers trying to create cutting-edge materials with better performance qualities, mechanical exfoliation is a useful technique because of its ease of use and efficiency (Mag-isa *et al.*, 2015). Atomic Force Microscopy (AFM) tips and adhesive tape are two essential elements of this method.

- Adhesive type: The use of adhesive coatings is essential for mechanical exfoliation since they are employed to spread fragments of graphene onto a substrate from the source material. Different kinds of various adhesive compounds, such as Polydimethylsiloxane (PDMS), Poly (methyl methacrylate) (PMMA) and polymers including polystyrene (Kyriakopoulos *et al.*, 2022) and polyvinyl alcohol (PVA). Usually, these adhesive substances are applied to the surface of a substrate like silicon or a glass slide, to make the graphene particles easier to transfer.
- AFM tips: In mechanical exfoliation, graphene flakes are probed and then processed with using AFM (atomic force microscopy) tips. In order to detect changes in morphology and height, an AFM works by sweeping a sharp tip across the material's surface. For mechanical exfoliation, AFM is superior. Before applying certain graphene flakes, the tip is typically used to locate and identify them. It should split apart and be mechanically forced onto the glue-covered substrate.

3. Properties of graphene composites

Graphene is a two-dimensional nanomaterial, which means it is there are just one layer of carbon atoms, and they are made in a hexagonal pattern. It has fantastic characteristics that have endeared it to a plethora of industries in fields of scientific research and use. Extreme temperatures, high humidity, and corrosive environments are only a few of the many environmental factors in which graphene exhibits remarkable stability (Novoselov *et al.*, 2012). Its chemical inertness and impermeability to most gases and liquids make it suitable for applications in protective coatings and barrier materials. Graphene possesses an enormous surface area, with one gram of graphene having an estimated area of over 2600 m^2 (Wang *et al.*, 2014). Because of this characteristic, it is favoured for use in energy storage devices like batteries and super-capacitors (Huang *et al.*, 2012).

3.1. Thermal properties

In place of cutting-edge silver-grease thermal pastes, graphene–polymer composites have demonstrated considerable potential as thermal interface materials. Develop them with enough generality for a variety of thermal applications, requiring a greater comprehension of their intrinsic thermal properties independent of their interfacial thermal resistance with other systems (Akhtar *et al.*, 2024).

Conducting contactless measurements of thermal transfer is also necessary for this. Effective contactless approaches for assessing the thermal characteristics of thin-film materials that do not need heating the sample under study from another medium are thermo-optical characterization techniques based on the photothermal effect. To extract the thermal properties of the film-substrate-environment system, they necessitate a meticulous and frequently intricate modelling process, and the outcomes they yield tend to rely on the specific model used to interpret the measured data (Acik & Chabal, 2013).

3.2. Mechanical properties

Carbon-filled epoxy composites have a high specific stiffness, which makes them suitable for use in aircraft structural parts. Graphene nanoplatelets, a recently created, less expensive substance that frequently raises the composite tensile modulus, are brief stacks of individual graphite layers (Yi & Shen, 2015). This experiment involved the fabrication of plain aerospace epoxy (EPON 862 with Curing Agent W) and epoxy composites containing 1 to 6 weight percent of two distinct forms of graphene Nano platelets (XG Sciences xGnP®-M-5 and xGnP®-C-300). Conventional 'bulk' measurements were incorporated in the assessment of tensile properties for these material systems. Furthermore, creep compliance and modulus were evaluated using nano indentation technique. The tensile modulus increased from 2.72 GPa for the clean epoxy to 3.35 GPa for the 6 wt% (3.7 vol%) xGnP®-M-5/epoxy composite, according to the macroscopic measurements 3.10 GPa for 6 wt% (3.7 vol%) xGnP®-C-300/epoxy composite.

3.3. Rheological properties

The inclusion of nanofillers usually results in a sharp drop in the neat polymer's viscosity values. This is due to the fact that the tendency towards uncontrolled flocculation is reduced when metal or metal oxide is uniformly dispersed as nanofiller in a polymer matrix. Polymer filler composite systems typically exhibit Newtonian behaviour at low filler loadings; non-Newtonian behaviour is more likely at higher filler loadings (Charoeythornkhajhornchai *et al.*, 2019).

3.4. Optical properties

Over the past nine years, there has been a consistent effort to create composites using Polystyrene (PS) and different carbon nanoparticles. According to reports, there is interest in using these composite materials as non-volatile memory devices and flame retardants. Comparing to traditional composites made by matrix and fillers, in this work, we paid our attention to radical polymerization of styrene in the presence of GO sheets and pentane to prepare the composites derived from expandable PS and GO. SEM and Dynamic Light Scattering (DLS) were employed to characterize the effect of weight of GO sheets on the PS spheres size.

A styrene polymerization mechanism in the presence of GO and pentane was analysed using Raman scattering and IR spectroscopy. For the first time, the PL emitted by the PS/GO composite was presented, and the involvement of the GO sheets in the PL mechanism of the PS spheres was discussed. In this work, PL also presents that the photo-degradation process of the prepared PS/GO composites with 5 wt.% concentration of GO sheets (Falkovsky, 2008). Table-1 shows the Comparison between graphene composites and traditional Materials based on different key characteristics.

Table-1: Comparison of graphene composites and traditional materials based on different characteristics

Property	Graphene Composites	Traditional Materials
Strength	Remarkable strength due to graphene's unique structural characteristics.	Varies across materials (metals, ceramics, polymers).
Conductivity	Superior conductivity: graphene is highly conductive for heat and electricity.	Metals exhibit excellent conductivity, while ceramics and polymers may have restricted conductivity.
Flexibility	Tremendous flexibility due to graphene's atomic structure; can flex without losing structural integrity.	Varies; metals are less flexible than ceramics and polymers.
Weight	Lighter than many conventional materials, benefiting from graphene's high strength and lightweight nature.	Varies by material; metals are often heavier than ceramics and plastics.
Cost	Typically, more costly than conventional materials due to the expense of production and incorporation of graphene.	Generally, more cost-effective compared to graphene composites.

4. Data collection and analysis technique

The methodology used for this investigation involved a thorough approach to data collecting and analysis in the aim of discovering the seemingly endless possibilities of graphene composites. In order to gather data, a wide range of primary and secondary sources were examined, including academic journals, business reports, and experimental data archives. Relevance, dependability, and current information about developments in graphene composites were given top priority in the selection criteria. After that, a methodical analysis using both qualitative and quantitative methods was performed on the gathered data. In order to find important trends and patterns in the field of graphene composites, data were thematically categorized as part of qualitative analysis. To precisely measure and analyse the data, quantitative analysis approaches including statistical methodologies and data visualization tools were applied concurrently. This thorough process made sure there was a solid basis for investigating the limitless possibilities.

5. Application of graphene composites

Graphene composite is a substance used in many different industries that combines graphene with other materials. The performance of lithium-ion batteries and supercapacitors in energy storage is enhanced by its large specific surface area, strong electrical and thermal conductivity, and enormous electrical conductivity. Because of their high surface area and remarkable electrical and thermal conductivity, graphene-based composites are used in electronics devices. Graphene nanocomposites are promising materials that have shown enhancements in mechanical, electrical and thermal properties; these make them ideal for integration into various technological and engineering applications. These composites are also used in sensing applications, where their surface area, thermal conductivity, and conductivity are advantageous. Moreover, graphene-based composites are utilised in wearable and flexible energy storage devices by taking advantage of their enormous surface area, chemical inertness, and mechanical qualities. Moreover, the optical characteristics of graphene composites high transparency and low opacity benefit transparent energy storage systems (Ullah *et al.*, 2024).

5.1. GO applications in the field of dentistry

It takes interdisciplinary research to create a biomaterial that works well for dental applications. Given that the teeth and the oral and maxillofacial tissues have distinct physical, chemical, and biological properties, dental material design is crucial. Too many attributes for a single component material to offer for dental applications. To satisfy the unique needs of dental applications, composite materials must be applied along with other components. In order to aid in the development of new dental applications, researchers have taken advantage of graphene's antibacterial qualities, ultra-high surface area, functional group presence, and ease of modification when combined with other biomaterials and biomolecules (Tahriri *et al.*, 2019).

5.2. Antimicrobial effectiveness

The application of nanotechnology has drained more interest in recent years to increase presented methods for tissue and organ renaissance (Tehseen et al., 2024). Graphene has inherent antibacterial properties. The fundamental cause of this behaviour is graphene's physical interaction with microbiological organisms. Graphene's antibacterial activity is primarily influenced by its size, shape, and production of ROS. Prior studies have demonstrated a strong correlation between tooth issues and microorganisms. Moreover, the oral microenvironment and the microbial colonization of the mouth cavity are strictly balanced. Maintaining this equilibrium is crucial to the oral cavity's safety. Unbalanced microbial activity is recognized to be the cause of dental cavities and periodontal diseases. A significant cariogenic microbe called Streptococcus mutans lowers the pH of the oral cavity by producing large amounts of organic acids (Mohammed *et al.*, 2020).

5.3. Aerospace industry

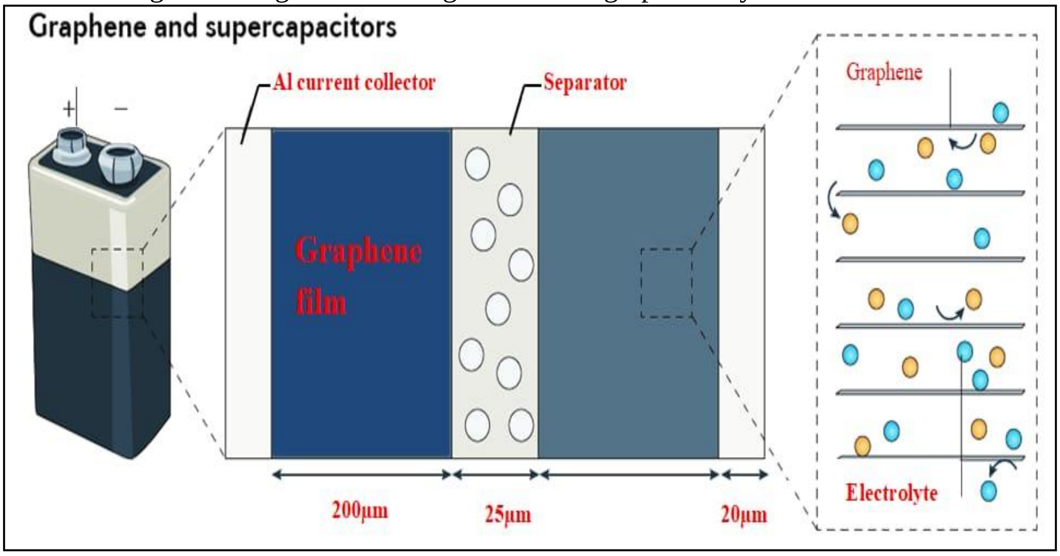
Because of its remarkable qualities, graphene composites have shown considerable potential in the aerospace industry for a variety of applications. Aerospace components can use graphene composites to lighten, increase the strength, and improve the electrical and thermal conductivity. For example, to improve performance and durability while keeping a lightweight design, graphene composites can be used in aeroplane structures like wings and fuselage panels (Kausar *et al.*, 2017). Graphene composites can also be used in aircraft vehicle electromagnetic shielding and thermal management systems. Deduced from the properties of this carbon material, graphene is among the materials that holds massive opportunities for aeronautical advancement (Valorosi *et al.*, 2020).

5.4. Energy storage

A promising material for energy storage purposes is graphene, offering significant improvements in battery, supercapacitor and fuel cell technologies. Graphene exhibits great potential as an anode material due to its ability to hinder nanoparticle segregation, increase the electrode's mechanical integrity, ionic and electronic capacity, and amount of active material required. These advantageous features contribute to achieving desirable outcomes such as high rate performance, increased capacity and enhanced flexibility throughout the charge-discharge process (Ghany *et al.*, 2017).

Graphene is widely used as an anode material in the Li-ion batteries, it exhibits great capacity of about 1000 mAh g-1 which is thrice the capacity of graphite electrodes. Furthermore, the exalted flexibility of graphene enables incorporation into fabrication of solid-state supercapacitor printed based devices suitable for textile which is wear able electronics (Abdelkader *et al.*, 2017). The theoretical specific energy density exhibits an upward trend with an increase in the graphene content within the supercapacitor (as illustrated in Figure 5)

Figure 5: The structure of graphene supercapacitors is depicted, with progressively magnified views, illustrating the arrangement and organization of graphene layers within the device



Source: Mbayachi *et al.* (2021)

6. Challenges and limitations

The public's and legislators' support for climate change initiatives has grown in tandem with the growing desire for net-zero carbon emissions worldwide. A sustainable economy is desperately needed, as seen by the growing trash crisis in landfills and the ocean. However, the amount of electronic trash produced by the widespread use of distributed electronic gadgets presents a serious problem. It is essential to produce ecologically friendly and sustainable materials for these gadgets in order to address this issue. With a long history of many applications, cellulose is a plentiful, CO_2-neutral material with a lot of promise. Novel biobased composites that combine electrically interactive elements with cellulosic materials have been developed, opening up new, potentially more sustainable manufacturing techniques for electronic devices as well as the production of electroactive paper in large quantities (Mohan *et al.*, 2018).

7. Conclusion and prospects

The innovative substances like graphene clearly offer a broad range of remarkable features, synthesis techniques, and applications. Outstanding properties such as great strength, remarkable conductivity, and superior compatibility with other materials make graphene composites stand out. The findings of this research show promise for the creation of strong, lightweight, and high-performing materials that have the potential to completely transform industries by providing hitherto unseen characteristics and properties. The methods for synthesizing graphene have advanced considerably in order to guarantee its effective integration into composite materials, enabling consistent dispersion and robust interfacial bonding. Graphene composites can be made to possess a number of desirable properties; therefore, they can be used in numerous applications. Graphene composites provide a wide range of uses in and different industrial fields including aerospace, automotive and electronics. Preparation of graphene composites require the use of methods such as chemical vapor deposition and mechanical exfoliation. In terms of applications, graphene composites have had a big influence on a lot of different areas, such electronics, materials research, and aerospace. Their special qualities have sparked innovation and pushed the frontiers of technology, enabling ground-breaking breakthroughs. Future research could fill up these gaps by examining novel production processes, conducting in-depth experiments to clarify particular features of graphene composites, and looking into cutting-edge applications in developing industries. We hope to contribute to the continuing progress of knowledge in the field of graphene composites by developing a solid theoretical framework that places our study within well-established principles and frameworks. The revolutionary potential of graphene composites to revolutionize various industries and shape the future of materials engineering is emphasized in this overview chapter.

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References

Abdelkader, A. M., Karim, N., Vallés, C., Afroj, S., Novoselov, K. S., & Yeates, S. G. (2017). Ultraflexible and robust graphene supercapacitors printed on textiles for wearable electronics applications. *2D Materials, 4*(3), 035016. https://doi.org/10.1088/2053-1583/aa7d71

Acik, M., & Chabal, Y. J. (2013). A review on thermal exfoliation of graphene oxide. *Journal of Materials Science Research, 2*(1), 101. http://dx.doi.org/10.5539/jmsr.v2n1p101

Akhtar, I., Gulzar, F., Sajid, S. A., Parveen, A., Saleem, A., Ghaffar, A., . . . Khan, M. J. (2024). Sustainable approaches to thermal energy management. *Remittances Review, 9*(3), 377–400. https://doi.org/10.33282/rr.vx9i2.21

Albers, P. W., Leich, V., Ramirez-Cuesta, A. J., Cheng, Y., Hönig, J., & Parker, S. F. (2022). The characterisation of commercial 2D carbons: graphene, graphene oxide and reduced graphene oxide. *Materials Advances, 3*(6), 2810–2826. https://doi.org/10.1039/D1MA01023A

Brownson, D. A., & Banks, C. E. (2012). The electrochemistry of CVD graphene: progress and prospects. *Physical Chemistry Chemical Physics, 14*(23), 8264–8281. https://doi.org/10.1039/C2CP40225D

Buzaglo, M., Shtein, M., Kober, S., Lovrinčić, R., Vilan, A., & Regev, O. (2013). Critical parameters in exfoliating graphite into graphene. *Physical Chemistry Chemical Physics, 15*(12), 4428–4435. https://doi.org/10.1039/C3CP43205J

Charoeythornkhajhornchai, P., Samthong, C., & Somwangthanaroj, A. (2019). Effect of graphene treated with cyclohexyl diamine by diazonium reaction on cure kinetics, mechanical, thermal, and physical properties of natural rubber/graphene nanocomposite foam. *Polymer Composites, 40*(S2), E1766–E1776. https://doi.org/10.1002/pc.25160

Chen, M., Haddon, R. C., Yan, R., & Bekyarova, E. (2017). Advances in transferring chemical vapour deposition graphene: a review. *Materials Horizons, 4*(6), 1054–1063. https://doi.org/10.1039/C7MH00485K

Choucair, M., Thordarson, P., & Stride, J. A. (2009). Gram-scale production of graphene based on solvothermal synthesis and sonication. *Nature nanotechnology, 4*(1), 30–33.

Falkovsky, L. A. (2008). *Optical properties of graphene.* Paper presented at the Journal of Physics: conference series. https://doi.org/10.1088/1742-6596/129/1/012004

Ghany, N. A. A., Elsherif, S. A., & Handal, H. T. (2017). Revolution of Graphene for different applications: State-of-the-art. *Surfaces and Interfaces, 9,* 93–106. https://doi.org/10.1016/j.surfin.2017.08.004

Huang, X., Qi, X., Boey, F., & Zhang, H. (2012). Graphene-based composites. *Chemical Society Reviews, 41*(2), 666–686. https://doi.org/10.1039/C1CS15078B

Johnson, D. W., Dobson, B. P., & Coleman, K. S. (2015). A manufacturing perspective on graphene dispersions. *Current Opinion in Colloid & Interface Science, 20*(5-6), 367–382. https://doi.org/10.1016/j.cocis.2015.11.004

Kausar, A., Rafique, I., & Muhammad, B. (2017). Aerospace application of polymer nanocomposite with carbon nanotube, graphite, graphene oxide, and nanoclay. *Polymer-Plastics Technology and Engineering, 56*(13), 1438–1456. https://doi.org/10.1080/03602559.2016.1276594

Kyriakopoulos, G. L., Zamparas, M. G., & Kapsalis, V. C. (2022). Investigating the human impacts and the environmental consequences of microplastics disposal into water resources. *Sustainability*, *14*(2), 828. https://doi.org/10.3390/su14020828

Lin, Z., Karthik, P. S., Hada, M., Nishikawa, T., & Hayashi, Y. (2017). Simple technique of exfoliation and dispersion of multilayer graphene from natural graphite by ozone-assisted sonication. *Nanomaterials, 7*(6), 125. https://doi.org/10.3390/nano7060125

Mag-isa, A. E., Kim, J.-H., Lee, H.-J., & Oh, C.-S. (2015). A systematic exfoliation technique for isolating large and pristine samples of 2D materials. *2D Materials*, *2*(3), 034017. https://doi.org/10.1088/2053-1583/2/3/034017

Mbayachi, V. B., Ndayiragije, E., Sammani, T., Taj, S., & Mbuta, E. R. (2021). Graphene synthesis, characterization and its applications: A review. *Results in Chemistry, 3,* 100163. https://doi.org/10.1016/j.rechem.2021.100163

Mohammed, H., Kumar, A., Bekyarova, E., Al-Hadeethi, Y., Zhang, X., Chen, M., . . . Rimondini, L. (2020). Antimicrobial mechanisms and effectiveness of graphene and graphene-functionalized biomaterials. A scope review. *Frontiers in Bioengineering and Biotechnology*, *8*, 465. https://doi.org/10.3389/fbioe.2020.00465

Mohan, V. B., Lau, K.-t., Hui, D., & Bhattacharyya, D. (2018). Graphene-based materials and their composites: A review on production, applications and product limitations. *Composites Part B: Engineering, 142*, 200–220. https://doi.org/10.1016/j.compositesb.2018.01.013

Muzyka, R., Drewniak, S., Pustelny, T., Chrubasik, M., & Gryglewicz, G. (2018). Characterization of graphite oxide and reduced graphene oxide obtained from different graphite precursors and oxidized by different methods using Raman spectroscopy. *Materials*, *11*(7), 1050. https://doi.org/10.3390/ma11071050

Novoselov, K. S. (2011). Graphene: the magic of flat carbon. *The Electrochemical Society Interface, 20*(1), 20-45. https://doi.org/10.1149/2.F04111if

Novoselov, K. S., Colombo, L., Gellert, P., Schwab, M., & Kim, K. (2012). A roadmap for graphene. *Nature, 490*(7419), 192–200. https://doi.org/10.1038/nature11458

Ojha, A., & Thareja, P. (2020). Graphene-based nanostructures for enhanced photocatalytic degradation of industrial dyes. *Emergent Materials, 3*, 169–180. https://doi.org/10.1016/j.synthmet.2020.116494

Olatomiwa, A. L., Adam, T., Gopinath, S. C., Kolawole, S. Y., Olayinka, O. H., & Hashim, U. (2022). Graphene synthesis, fabrication, characterization based on bottom-up and top-down approaches: An overview. *Journal of Semiconductors, 43*(6), 061101. https://doi.org/10.1088/1674-4926/43/6/061101

Patel, J., Shah, S., Thakkar, P., & Kotecha, K. (2015). Predicting stock and stock price index movement using trend deterministic data preparation and machine learning techniques. *Expert systems with applications, 42*(1), 259–268. https://doi.org/10.1016/j.eswa.2014.07.040

Preston, D. J., Mafra, D. L., Miljkovic, N., Kong, J., & Wang, E. N. (2015). Scalable graphene coatings for enhanced condensation heat transfer. *Nano letters, 15*(5), 2902–2909. https://doi.org/10.1021/nl504628s

Saeed, M., Alshammari, Y., Majeed, S. A., & Al-Nasrallah, E. (2020). Chemical vapour deposition of graphene—Synthesis, characterisation, and applications: A review. *Molecules, 25*(17), 3856. https://doi.org/10.3390/molecules25173856

Sahu, D., Sutar, H., Senapati, P., Murmu, R., & Roy, D. (2021). Graphene, graphene-derivatives and composites: fundamentals, synthesis approaches to applications. *Journal of Composites Science, 5*(7), 181. https://doi.org/10.3390/jcs5070181

Shen, B., Ji, Z., Lin, Q., Gong, P., Xuan, N., Chen, S., . . . Sun, Z. (2022). Graphenization of diamond. *Chemistry of Materials, 34*(9), 3941–3947. https://doi.org/10.1021/acs.chemmater.1c04322

Sulaiman, R., Ghaffar, A., Perveen, S., Ashraf, D., Tariq, I., & Shakir, T. (2023). Synthesis, Characterization, and Biomedical Applications of Zinc Oxide Nanoparticles. *BME Horizon, 1*(3). https://doi.org/10.37155/2972-449X-vol1(3)-89

Surwade, S. P., Smirnov, S. N., Vlassiouk, I. V., Unocic, R. R., Veith, G. M., Dai, S., & Mahurin, S. M. (2015). Water desalination using nanoporous single-layer graphene. *Nature Nanotechnology, 10*(5), 459–464. https://doi.org/10.1016/j.msec.2019.04.051

Tahriri, M., Del Monico, M., Moghanian, A., Yaraki, M. T., Torres, R., Yadegari, A., & Tayebi, L. (2019). Graphene and its derivatives: Opportunities and challenges in dentistry. *Materials Science and Engineering: C, 102*, 171-185. https://doi.org/10.1016/j.msec.2019.04.051

Tehseen, P., Mahmood, U., Ghaffar, A., Khan, M. J., Muhammad, Z., Noor, F., . . . Asghar, M. (2024). Graphene Nano Composites for High Performance Super Capacitor. *Remittances Review, 9*(3), 401-424. https://doi.org/10.33282/rr.vx9i2.21

Tehseen, P., Mahmood, U., Gulzar, F., Afzal, R., Ghaffar, A., Nawaz, I., . . . Saleem, R. (2024). *Journal of Population Therapeutics and Clinical Pharmacology, 31*(6), 929-954. https://doi.org/10.53555/jptcp.v31i6.6589

Ullah, Q., Ishaq, A., Mumtaz, A., Fatima, F., Mehwish, S., Ghaffar, A., & Bibi, R. (2024). Assessing the Risk, Bioavailability, and Phytoremediation of Heavy Metals in Agricultural Soils: Implications for Crop Safety and Human Health. *Indonesian Journal of Agriculture and Environmental Analytics, 3*(2), 91–104. https://doi.org/10.55927/ijaea.v3i2.10536

Valorosi, F., De Meo, E., Blanco-Varela, T., Martorana, B., Veca, A., Pugno, N., . . . Bertocchi, F. (2020). Graphene and related materials in hierarchical fiber composites: Production techniques and key industrial benefits. *Composites Science and Technology, 185*, 107848. https://doi.org/10.1016/j.compscitech.2019.107848

Xu, Y., Cao, H., Xue, Y., Li, B., & Cai, W. (2018). Liquid-phase exfoliation of graphene: an overview on exfoliation media, techniques, and challenges. *Nanomaterials, 8*(11), 942. https://doi.org/10.3390/nano8110942

Yan, Q., Alam, F. E., Gao, J., Dai, W., Tan, X., Lv, L., . . . Nishimura, K. (2021). Soft and self-adhesive thermal interface materials based on vertically aligned, covalently bonded graphene nanowalls for efficient microelectronic cooling. *Advanced Functional Materials, 31*(36), 2104062. https://doi.org/10.1002/adfm.202104062

Yao Y., Li Z., Lin Z., Moon K. S., Agar J., Wong C. (2011). Controlled growth of multilayer, few-layer, and single-layer graphene on metal substrates. *The Journal of Physical Chemistry C., 115*(13), 5232–5238. https://doi.org/10.1021/jp109002p

Yi, M., & Shen, Z. (2015). A review on mechanical exfoliation for the scalable production of graphene. *Journal of Materials Chemistry A, 3*(22), 11700–11715. https://doi.org/10.1039/C5TA00252D

Zhang, Y., Zhang, L., & Zhou, C. (2013). Review of chemical vapor deposition of graphene and related applications. *Accounts of chemical research, 46*(10), 2329–2339. https://doi.org/10.1021/ar300203n