Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 132 (2019) 206-219 EISSN 2392-2192

An overview of current research trends on graphene and it's applications

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ABSTRACT

Graphene is no doubt called a wonder-material due to its outstanding superlative traits. It has its application near about in every field. Its properties are extraordinary and different from any day-to-day material. Albeit bearing such qualities, its structure is rather simple than most individuals cerebrate of. It has a thickness of an atom. It is a two-dimensional carbon arranged in a honeycomb crystal structure. It could transmute the way we view, in numerous fields of science. Its applications can be an asset to a greener environment for which Graphene engineered cement/concrete composites have an immense potential in the present times when sustainable construction materials are the need of the hour. Graphene can act as a good adsorbent for pollutant abstraction due to its high surface area. Either alone or in coalescence with different materials, it very well may be used for the debasement or deliberation of a sizably voluminous assortment of contaminants through a few strategies. Incipient heights can be achieved as the list of operations for graphene is virtually illimitable. Utilization of graphene in the coming years will give inundating difference to current technologies. This paper fixates on the applications and developments of Graphene in fields like Electronics, Batteries, Filtration, Medicine, Construction, and Composites.

***Keywords*:** Graphene, Doping, Mechanical, Electrical, Properties, Material, Concrete, Sustainability

(Received 04 July 2019; Accepted 22 July 2019; Date of Publication 23 July 2019)

1. INTRODUCTION

Graphene is a nanomaterial consisting of carbon as a rudimentary element which has a two-dimensional orientation with a hexagonal pattern of atomic bonds. It is the principal basic component of different allotropes, including graphite, fullerenes, carbon nanotubes, charcoal [1]. The two-dimensional sheet of sp2-hybridized carbon is called graphene and its lengthened honeycomb system is the fundamental structure square of other important allotropes; it very well may be stacked to form 3D graphite, rolled to create 1D nanotube, and wrapped to make 0D fullerenes.

Long-run π-conjugation in graphene yields phenomenal mechanical, thermal and electrical properties which have for some time been the enthusiasm of numerous hypothetical investigations and all the more as of late turned into an invigorating zone for experimentalists [2]. Graphene, due to its amazing properties has attracted a lot of worldwide attention for a long time. The attention even shifted to graphene-cognate and graphene-like materials.

The stacking of two layers of graphene additionally brings some incipient properties to this material, such as unique electrical properties, optical properties, chemical properties, and phonon thermal properties [3]. It is a precisely magnificent material with a modulus of elasticity of 130 GPa and Young's modulus of 1 TPa and has gotten weighty interests since its disclosure in 2004. Numerous articles about disclosures of mechanical properties have been distributed. These disclosures are backup for the uses of graphene on the grounds that they have given the information that uncovers the mechanical idea of graphene. Past that, the information assumes a central job in planning graphene-predicated creations or different utilizations like graphene coating [4]. It has changed the nanotechnology stage since its disclosure. Till date, several endeavours have been made to orchestrate graphene on a huge scale to meet the necessities of a few enterprises, particularly the composite business. [5].

The ecumenical graphene market size is relied upon to reach USD 552.3 million by 2025, as per a nascent report by Grand View Research, Inc. It is relied upon to extend at a Compound Annual Growth Rate of 38.0% over the estimated time frame. Developing interest for the keen buyer of electronics hardware is foreseen to fuel the market over the estimated time frame. Early item dispatches and lifting utilization of purchaser merchandise in developing markets of China, India, and Thailand is relied upon to decidedly influence the market. The fuse of inventive innovations in electronic products made in Japan and China is relied upon to drive the gadgets to advertise. The business is seeing the presence of various new companies that are concentrating fundamentally on R&D to make sense of the maximum capacity of graphene.

2. SCOPE OF THE REVIEW

A number of studies on graphene and its applications in modern times have already been conducted by various researchers. Several reviews related to different properties of nanomaterials and composites have also been depicted with graphene acquiring a major role. In this review, a noble approach of advancements of graphene in various fields of science has been discussed elaborately.

The first section of the review will discuss the properties of graphene and its related market. The second section will provide the scope of the entire review paper. The third section will discuss the importance of Graphene in modern times. The fourth section will comprehensively discuss the research & development of graphene in various fields of science & technology. The concluding part of the current progress review enlists the current progress and future challenges in research and development of graphene.

3. IMPORTANCE OF GRAPHENE IN MODERN TIMES

Graphene's need in today's world is essential and is gradually increasing. It is a technology that will act as a stepping stone in building our future. It is a disruptive innovation; one that could open up early markets and even supplant subsisting advancements or materials. It is when graphene is used both to enhance a subsisting material and in a transformational limit that its actual potential can be figured it out. The huge number of items procedures and enterprises for which graphene could make a considerable effect all stems from its surprising properties. Blending the majority of graphene's surprising properties could make an effect of the scale last observed with the Industrial Revolution. Research on graphene is making an impact in a number of industries. And this is only the start. The potential of graphene is inhibited only by our imagination. Numerous potential applications for graphene are a work in progress and a lot more have been proposed. These incorporate lightweight, dainty, adaptable, yet tough show screens, electric circuits, and sunlight based cells, just as different therapeutic, chemical and modern industrial procedures improved or empowered by the use of nascent graphene materials. According to an article by Scott Simonsen,5 of the World's Biggest Problems which are clean water, Carbon emissions, Healthcare, Infrastructure, and Energy are being targeted by graphene research.

4. RESEARCH & DEVELOPMENT OF GRAPHENE IN VARIOUS FIELDS OF SCIENCE & TECHNOLOGY

4. 1. Electronics

Song et al. (2018) learned about the improved power age and compelling water filtration utilizing graphene-based film air-cathodes in microbial energy components and expressed that cathodes made with graphene can create power and a superb emanating with low cathode bio fouling. They manufactured graphene contained air-cathode film utilizing a stage reversal strategy to upgrade the exhibition of MFC and to give a sifted profluent. They had the option to demonstrate that graphene adjusted layer arranged by the stage reversal technique was a basic and powerful strategy for improving air-cathode execution in an MFC. The graphical figure plainly clarifies their investigation [6].

Jang et al. (2016) examined late research advance on graphene-based adaptable and stretchable gadgets. Lavish pertinence was shown in an assortment of uses, including contact boards, nano-generators, actuators, biosensors, and organic solar cells. The accomplished outcomes demonstrated the overwhelming capability of graphene as a part in adaptable and stretchable contraptions. Basic difficulties must be routed to delight the business entelechy of graphene-based gadgets. Though difficulties issues still exist, numerous basic parts of in fact achievable methodologies are presently developing. Settling the difficulties will bring the appearance of graphene-based gadgets forward [7].

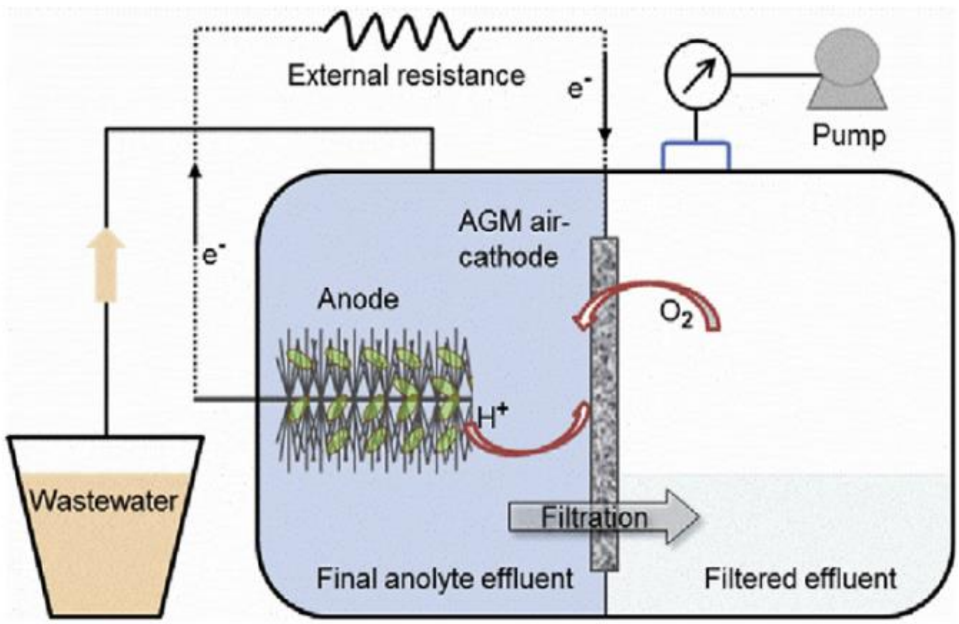

Fig. 1. Upgraded power age and viable water filtration utilizing graphene-based layer air-cathodes in microbial fuel cells [6].

4. 2. Batteries

Papandrea et al. (2016) examined and built up a freestanding three-dimensional (3D) graphene structure for very effective stacking of sulfur particles utilizing the one-pot synthesis method and making a high limit sulfur cathode. They uncovered that the blend of the exceedingly conductive interconnected and precisely solid 3D graphene and the enwrapped sulfur particles has empowered a superior sulfur-cathode with a record-high limit of 969 mAh•g^{-1} when standardized by the weight of the whole cathode at 0.1 C, and stable cycling perseverance up to 500 times at 1 C with a limit blurring of 0.052% per cycle. Accomplished outcomes exhibited that the unsupported 3DGF with ultra-high sulfur substance can offer a promising pathway to a profoundly vigorous Li–S battery. Below figure shows a magnified view of the graphene-sulfur composite. [8].

Chen et al. (2017) contemplated and planned an ultrafast all-atmosphere aluminium-graphene battery with quarter-million cycle life. They planned a battery with "tri high tri-continuous" (3H3C) graphene film cathode with highlights of superior quality, direction, and channelling for local structures (3H) and persistent electron-conducting lattice, ion dissemination highway, and electro active mass for the entire terminal (3C). Such a cathode holds the high explicit limit of around 120 mAh g^{-1} at an ultrahigh current density of 400 Ag^{-1} (charged in 1.1 s) with 91.7% maintenance after 250,000 cycles, surpassing the previous batteries as far as rate capability and cycle life. The gathered aluminium graphene battery functions admirably inside a wide temperature scope of −40 to 120 °C with exceptional adaptability bearing 10,000 times of folding, promising for all-atmosphere wearable vitality gadgets. Moreover, this examination opens a road for future super-batteries [9].

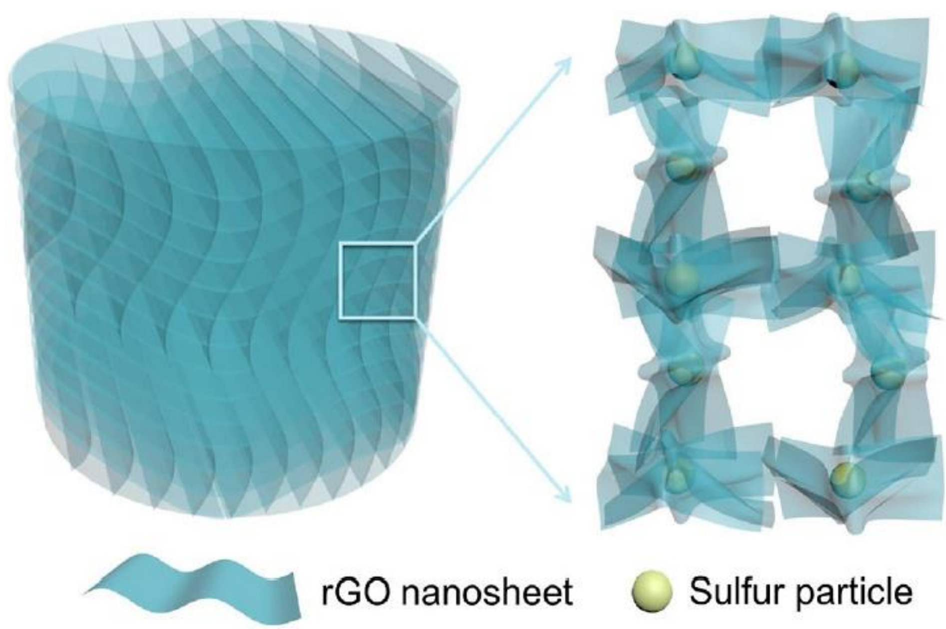

Fig. 2. Schematic of a free-standing 3D graphene-sulfur composite. The left schematic demonstrates a delineation of the 3-dimensional structure, and the right schematic shows the magnified perspective on the cross-segment. The sulfur particles are typified inside the 3D graphene pockets [8].

Chen et al. (2017) examined the difficulties and promising viewpoints of the graphene-based materials for adaptable energy storage devices. They featured adaptable graphene-based two-dimensional film and one-dimensional fibre super capacitors and different batteries including lithium-ion, lithium–sulfur and different batteries. They outlined the on-going advancement in graphene-based adaptable energy storage devices primarily centred around the SCs and batteries, including LIBs, Li – S batteries and different batteries. In particular, the manufacturing of adaptable graphene-based materials includes 2D graphene-based films and 1D graphene-based fibre. They likewise shrouded the relating applications in different designs of energy storage devices [10].

4. 3. Filtration

Seo et al. (2018) considered and exhibited ocean water desalination by means of a membrane refining procedure utilizing a graphene layer where water penetration is empowered by nanochannels of multilayer, jumbled, halfway covering graphene grains. Their research demonstrated that graphene membranes acquired from sustainable oil show essentially unrivalled maintenance of water vapor transition and salt dismissal rates, and a prevalent antifouling capacity under a blend of saline water containing contaminants, for example, surfactants and oils, contrasted with business refining films. They showed true relevance of their layer by preparing seawater from Sydney Harbor more than 72 h with a macro-scale membrane size of 4 cm^2, handling ~0.5 L every day. Their examination will make ready for huge scale graphene-based antifouling membranes for different water treatment applications [11].

Samantara et al. (2018) extravagantly examined the synthesis or production, functionalization, and composite readiness of graphene for the expulsion of poisonous toxins from the air. They introduced a point by point discourse on the blend, physicochemical properties, and functionalization of graphene pursued by its application towards the air filtration (for the expulsion of, SO_2, CO_2, alkanes, aerogels, particulate matters, and so forth.) [12].

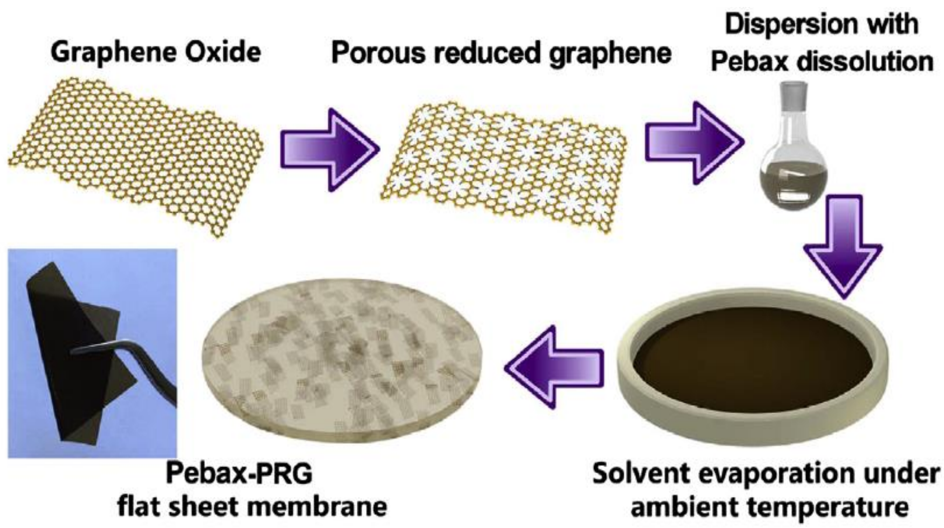

Fig. 3. Schematic introduction of Pebax-PRG composite film creation [12].

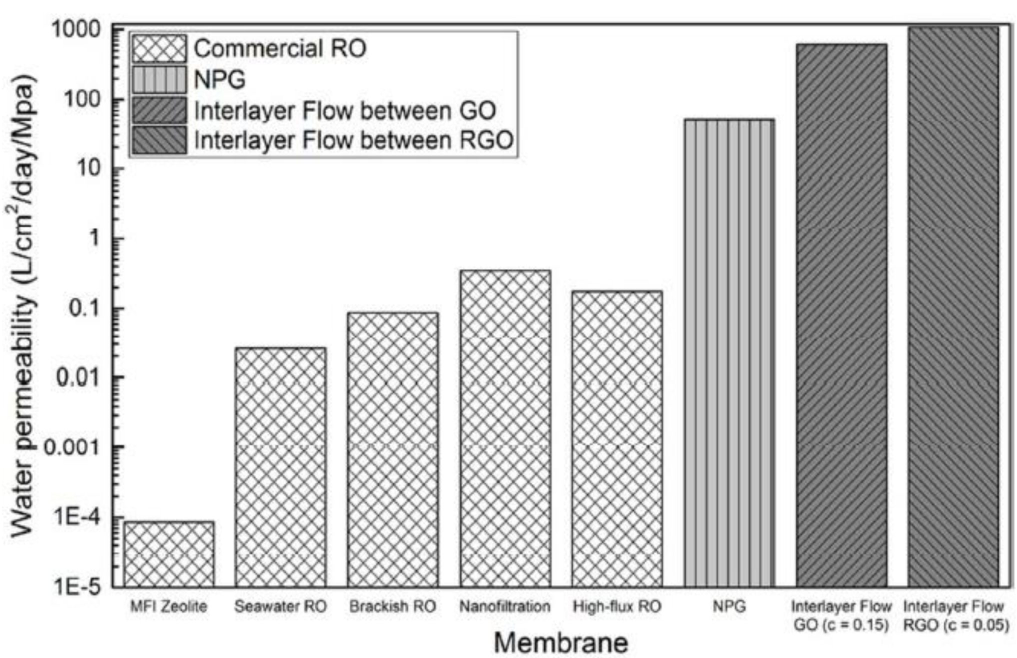

Fig. 4. Execution diagram for interlayer stream between GO just as RGO versus functionalized nanoporous graphene and existing innovations [13].

Chen et al. (2017) examined the instrument of water transport inside the interlayer exhibition between graphene oxide layers, utilizing Molecular Dynamics (MD) simulations. Their examination uncovered that graphene oxide layers could show signs of improvement water porousness after the decrease. Their simulation results demonstrated that upgraded stream rate is contrarily connected with the oxide fixation just as hydrogen cooperations underneath an oxide grouping of 10%, while is reliable at a variable convergence of high qualities. Their examination will be helpful in understanding the idea of water transport through graphene oxide interlamination and can be used to anticipate and plan creative RO-membrane for desalination [13].

4. 4. Medicine

Hussein et al. (2019) examined the utilization of ultrasonicated graphene oxide (UGO) in the medicinal field. Their study focused on bone regeneration and skin wound healing. The investigation uncovered that ultrasonication of a GO arrangement expands the scattering and strength (by expanding the zeta potential) of the GO arrangement. Despite the fact that UGO bears less oxygen-containing gatherings, regardless it shows superb water scattering. The outcomes from their examination clarified the advantages of UGO in skin and bone mending. It improves bone, skin, and vein cells' connection, development, and generation. UGO is a promising material for simultaneously guided bone regeneration and skin tissue regeneration [14].

Zheng et al. (2018) examined the antibacterial utilizations of graphene oxides. They clarified the structure-activity relationships (SARs) associated with GO-incited bacterial carnage and the MIEs incorporating redox response with biomolecules, mechanical pulverization of membranes and catalysis of extracellular metabolites. They outlined the clinical or business utilization of GO-based antibacterial items and talked about their bio-safety in a warm-blooded creature. They investigated the rest of the difficulties in GO for antibacterial applications, which may offer new bits of knowledge for the advancement of nano antibacterial examinations [15].

Shin et al. (2016) examined the ongoing utilization of graphene-based materials in tissue designing and regenerative prescription. They expounded the use of graphene-based materials in bone, heart, ligament, neural, skeletal muscle, and skin/fat tissue designing alongside the potential hazard variables of graphene-based materials in tissue building. They sketched out the open doors in the use of graphene-based materials for clinical applications. Graphene composites can turn out to be earth touchy or can have shape-memory or self-collapsing properties which can expand their biomedical applications [16].

4. 5. Constructio

Zhang et al. (2018) studied and stated that the addition of graphene to geopolymer enhances the properties of the geopolymer. The results showed that the geopolymeric products were detected to be denser, and the interior porosity was reduced after the addition of the graphene. The geopolymer strengths had been significantly amplified, and the compressive strength & bending strength extended to 46.9 MPa and 6.7MPa, respectively [17].

Krystek et.al. (2018) elucidated the synthesis of a cementitious composite combining electrochemically exfoliated graphene (EEG). They revealed that the 0.05 wt% replacement of OPC by graphene results in an increase up to 79%, 8%, and 9% for the tensile strength, compressive strength, and Young's modulus, respectively. They establish that the accumulation of EEG endorses the hydration reaction of both alite and belite, thus developing a large fraction of $3CaO•2SiO_2•3H_2O$ (C-S-H) phase. These findings exemplify a major step advancing towards the practical implementation of nanomaterials in civil engineering applications [18].

Gong et al. (2015) studied the reinforcing effects of graphene oxide (GO) when mixed with Ordinary Portland Cement (OPC) and revealed that the introduction of 0.03% by weight GO sheets into the cement paste can upsurge the compressive strength and tensile strength of the cement composite by more than 40% due to the lessening of the pore structure inside the cement paste matrix. They found that the inclusion of the GO sheets can boost the extent of hydration of the cement paste. The figure helps to support their study [19].

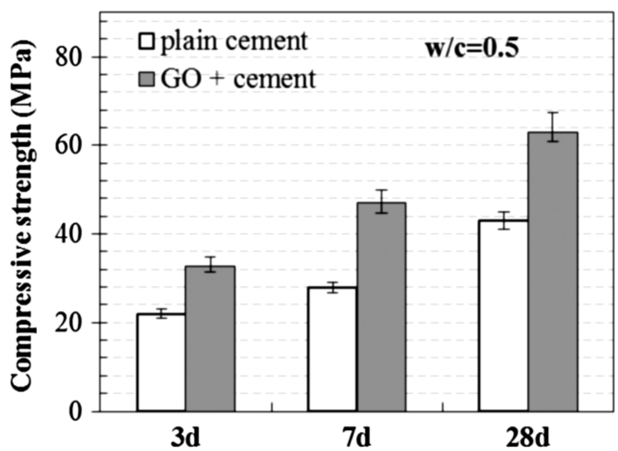

Fig. 5. Compressive qualities for plain concrete and GO-concrete test samples at ages of 3, 7, and 28 days [19].

Lv et al. studied the effect of GO Nano sheet on the mechanical and microstructure of cement concrete. The observation directed that GO can regulate the hydration process which alters the basic microstructure of the hydration product and form flower-like crystals. The results showed that there is a significant increment in compressive strength (38.9%), flexural strength (60.7%) and in tensile strength (78.6%) when the cement was replaced with 0.03% GO. [20].

Liu et al. experimented the effectiveness of GO modified asphalt binders for pavement applications. They conducted their experiments by adding 0.05% of GO in warm mix asphalt binders (WMABs) along with three more additives, these are Sasobit, waste cooking oil (WCO), and Sasobit + WCO. From the experimental investigation, it was found that the GO significantly improved the viscosity, permanent deformation resistance and high-temperature elasticity of the non-modified PG 64-22 asphalt binder [21].

Li et al. investigated the interface between the GO and asphalt binders and the outcome of adding GO on the performance on asphalt based composites. They stated that CO_2 gas emitted during the mixing process; no chemical reaction took place between them i.e. - GO and asphalt binders. The CO2 was created by the disintegration of GO. It was noticed that the penetration and ductility of the asphalt binder were reduced after mixing with GO but in the condradict, the viscosity and softening point of the material were improved. From their experiments that also concluded that the GO can enhance the anti-rutting performance in both high and low temperature along with thermal stability [22].

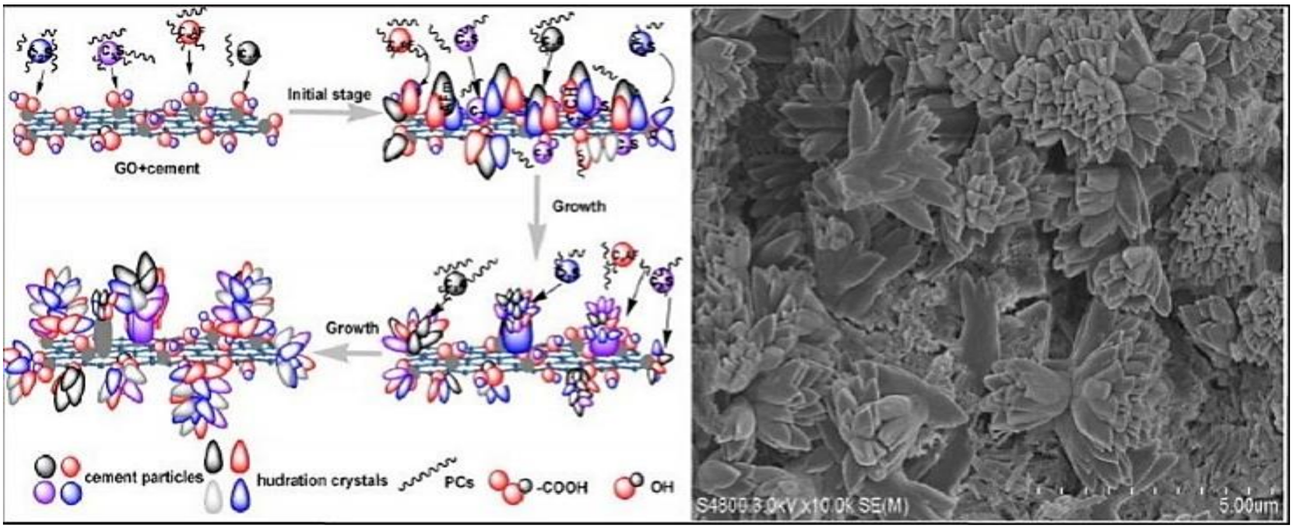

Fig. 6. Flower-like crystals formed in GO-Cement based concrete [20].

4. 6. Composites

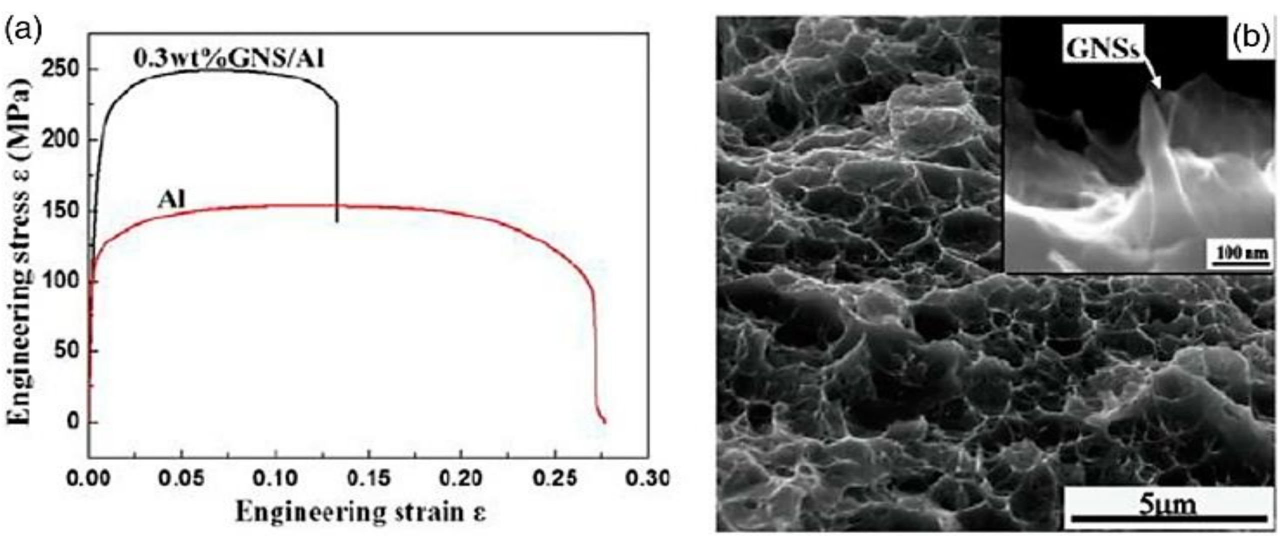

Fig. 7. (a) GNS reinforced Al-composite stress-strain behaviour **(b)** SEM image of GNS-Al-composites [23]

Wang et al. experimented that Aluminum-composites reinforced with graphene nanosheets (GNSs) and synthesize the composite through flake powder metallurgy. They found the tensile strength of Al composite strengthened with 0.3 wt-% GNSs was 249 MPa. The results indicated that a 62% improvement of the tensile strength of the GO reinforced composites over the Al-composite without GO. The results were not as good as theoretical projections, but it established for the first time that GNSs can actually act as effective reinforcements in MMCs. Figure 7a displays the tensile properties of the composite and the equivalent Al specimen; Fig. 7b shows the GNs Al-composite [23].

Jagannadham reported that Cu graphene composites can be synthesized for different applications. They contrived by dripping the GO solution on the Cu substrate and after they dried a thin film of Cu and placed it on top of the GO particulates by laser physical vapor deposition (LPVD), and then converted GO to graphene. This process has been continual to make six layers of Cu film, containing the dispersion of graphene on the Cu substrates to synthesize the desired specimen. Figure 8 shows the SEM image in the backscattering mode of the Cu-graphene layers. It was revealed that the dark regions in the image are graphene, and the connected grey regions forming a mesh-like structure are Cu film. They conveyed that the cross-plane thermal conductivity is abbreviated because of the low thermal conductivity of graphene perpendicular to the ab planes, and a-plane; thermal conductivity in the Cu-graphene layers was not reduced. Graphene a-b plane orientation will disturb the thermal conductivity of composites; random positioning of graphene in composites will attain isotropic thermal conductivity [24].

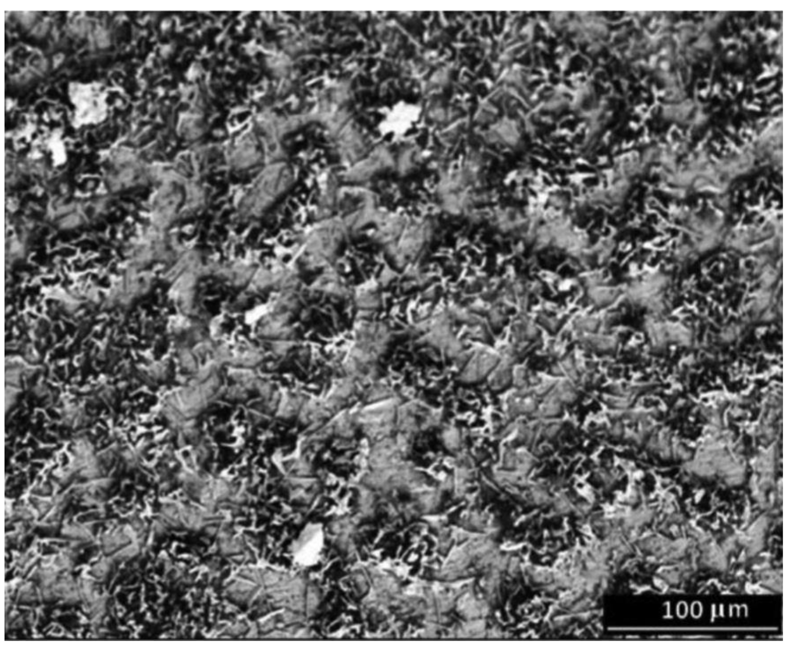

Fig. 8. SEM image of Cu-GO composite[24].

5. CONCLUSIONS

The dynamic research in graphene amid late years has uncovered various fascinating discoveries and leaps forward on the manufacture and utilization of these materials. The expanding number of research papers and patent licenses in graphene during these on-going years shows the development of innovative work in graphene. The industrialized utilization of graphene materials is consistently extending from mechanical, medical, material, and electrical properties to a different scope of potential applications, for example, batteries, capacitors, semiconductors, bio-sensors, furthermore, semiconductors gadgets. The consistent events of the rising terms lately additionally demonstrate a strong and broadening R&D field. The study has concluded that Graphene and its derivatives show promising growth in technology and has proved useful and efficient enough in a wide range of applications. It is a cost-efficient material and productions of some of its derivatives are simple and scalable. It is an emerging material and still needs research to explore its full potentiality. Due to the quality and quantity of work, graphene has attracted worldwide attention in a very short span of time since its evolution. For a long period of time, one big hurdle of graphene is its mass production which is on its way to being solved. This review paper presents the advancements in research of graphene in various fields.

ACKNOWLEDGMENT

The authors are thankful to Dr. Syed Mohammed Mustakim and CSIR-IMMT, Bhubaneswar for the support and scientific literature asses which indeed made a significant contribution for preparing this manuscript.

BIOGRAPHY

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Dr. Syed Mohommed Mustakim is a senior technical officer at CSIRIMMT, Bhubaneswar, Odisha, India. He has more than sixteen years of experience in the field of cement, brick manufacturing and concrete technology. He has two patents and several international and national publications in reputed peer reviewed journals.

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