Mechanical and Thermal Properties of Graphene over Composite Materials: A Technical Review

Md. Mashrur Islam[a*], Sadman Saffaf Ahmed[b], Moshiur Rashid[c], Md. Masum Akanda[d]

[a] Department of Electrical & Electronic Engineering, Rajshahi University of Engineering & Technology, Kazla, Rajshahi-6204, Bangladesh
[b] Department of Electronics & Telecommunication Engineering, Rajshahi University of Engineering & Technology, Kazla, Rajshahi-6204, Bangladesh
[c] Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Kazla, Rajshahi-6204, Bangladesh
[d] Department of Glass & Ceramics Engineering, Rajshahi University of Engineering & Technology, Kazla, Rajshahi-6204, Bangladesh
*e-mail: masumruetgce13@gmail.com

Abstract

The recent years have seen numerous developments in the research and headway of graphene, the thinnest two-dimensional nuclear material. Graphene-based materials and their composites have promising applications in an extensive variety of fields; for example, gadgets, biomedical guides, films, adaptable wearable sensors, and actuators. The most recent investigations and movement in this branch of knowledge regularly deliver conflicting or uncertain outcomes. This article evaluates and outlines the distributed information in order to give a basic and complete diagram of the cutting edge. Initially, the particular basic nature of accessible graphene materials is illustrated as well as the distinctive generation methods accessible thus far. The appraisal at that point talks about the different composites that center diverse sub-practical routines; for example, mechanical and aggregate utilitarian applications (e.g., vitality, hardware biomedical, layers, and sensors). The use of graphene and its subsidiaries in the fabricate of nanocomposites with various polymer frameworks has been inspected. And finally, an ending and point of view are given to talking about the rest of the difficulties for graphene nanocomposites in useful science and building.

1. INTRODUCTION

The fields of nanoscience, nanotechnology, and nanocomposites have developed as of late, and the centrality of this subject growth in the gathering of jobs such as the vehicle, flying, bundling, gadget, biotechnology, adaptable sensor, and different unmistakable applications [1–3]. In such a way, the enhancements of polymer nanocomposites subject to graphene materials have changed into a most imperative advancement. Graphene is a 2D structure of carbon particles that has hexagonal crystalline structure with sp2 bonds, a high surface area (the most raised, adsorption, and surface responses), electron transportability, warm conductivity, and mechanical quality. It has applications in many different fields, including hardware and biomedical [4–8]. It assumes an indispensable job in the upgrade of the relationship between sheets and polymer materials. Graphene-based composite materials are the mainstream for material authorities nowadays, as their crucial improvements result in properties that affect progressively extraordinary applications. In view of its slight physical proximity and helpful electrical, mechanical, and physicochemical properties, graphene is becoming mainstream for the essential vitality fields [9, 10].

In the accompanying areas, we condensed the most recent results in graphene's creation methods (along with its subsidiaries) as well as the properties and development in their composite territory. In the last decade, researches on graphene has been increased expotentially. Those research outputs are very important, this will give us helpful data for the exploration of this zone. The development of this examination area can be obvious from the production record appearing in Figure 1.

a)

b)

c)
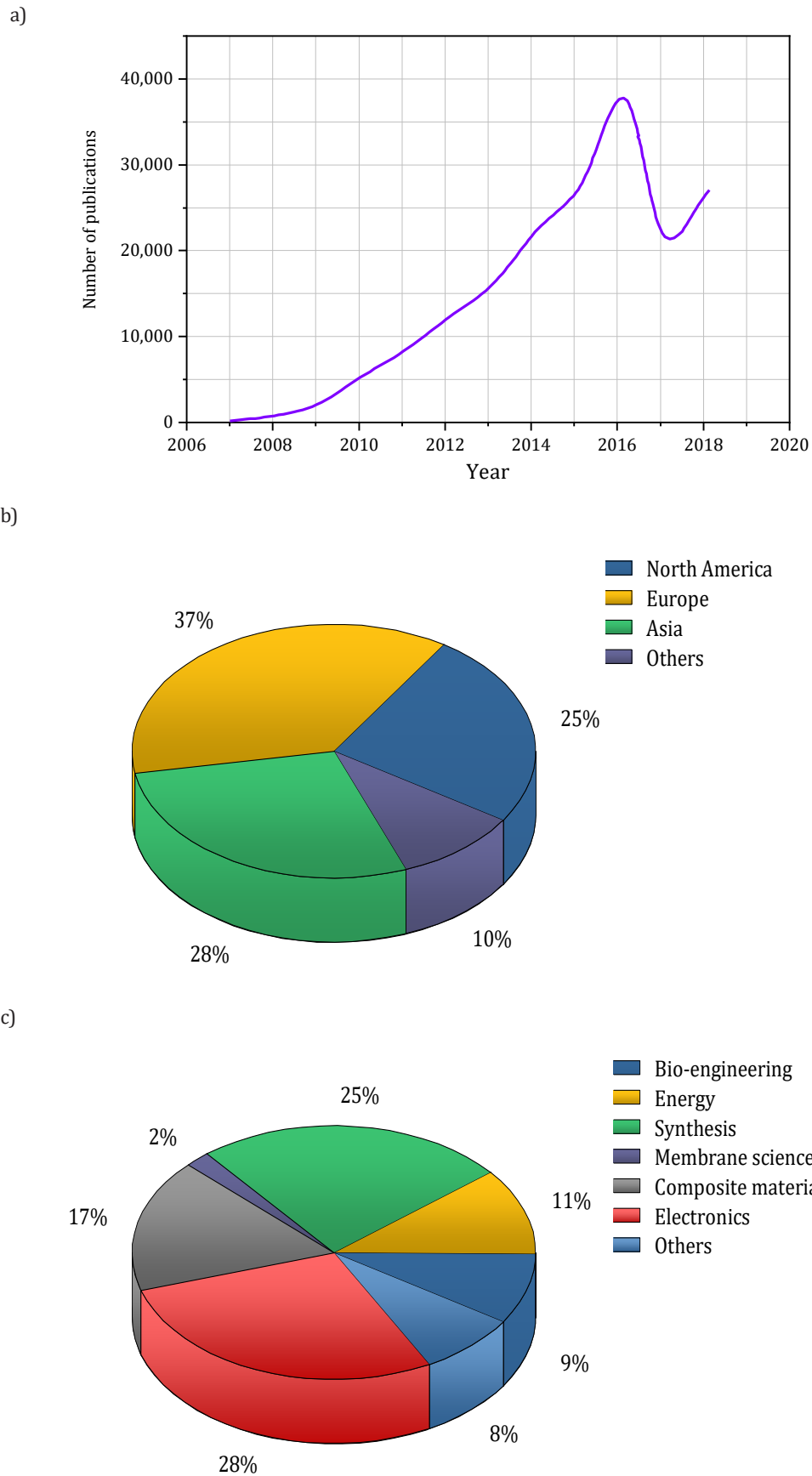
Fig. 1. Researches on graphene in the last decade: a) publications on graphene from 2007 to 2018 (up until August) [Source – SCOPUS & Web of Science], b) proportion of overall publications by countries, and c) by sectors [11]

2. IDEA OF GRAPHENE MATERIALS

Graphene is the slenderest material in its closeness materials. It has a high quantum battle influence, warm conductivity, a high Young's modulus (1 TPa), an unavoidable nature of 130 GPa [12–17], and heat confirmation properties as a solitary sheet. It exhibits the ambipolar electric field influence with section voltage. Graphene is the crucial structure of all other carbon allotropes [18] shown in Figure 2.

It is particularly seen that graphene and its subordinates' potential applications are generally dictated by the unique making of different graphene materials (GO, rGO, fGO, frGO, and mG) with explicit focus on express applications. Those applications are dependent in the chemical behavior of different types of graphene molecular structures. There is an extent of systems and techniques (Fig. 3) that have been advanced. Most of them will be campaigned in the going

with region and characterize promising and what's more versatile systems.

Graphene oxide (GO) is unfathomably utilized for composites like fiber-fortified polymer. Carbon fiber and carbon surfaces can be effectively framed by GO to broaden the interfacial holding properties through wrapping the polymer cross areas of the composites. By changing graphene into fiber, the holding limit of the material can be expanded [19–21]. Be that as it may, the framework might be superfluously expensive, as the treatment of each fiber is required. Hung et al. verified the GO outwardly of the surfaces by an electrophoretic sworn articulation method to help the interlaminar shear nature of composites. The technique is humbly basic and quicker. The UTS and Young's modulus of the composites were updated under low-temperature conditions, which is advantage temperature of standard flying machines flying in the troposphere [22, 23].
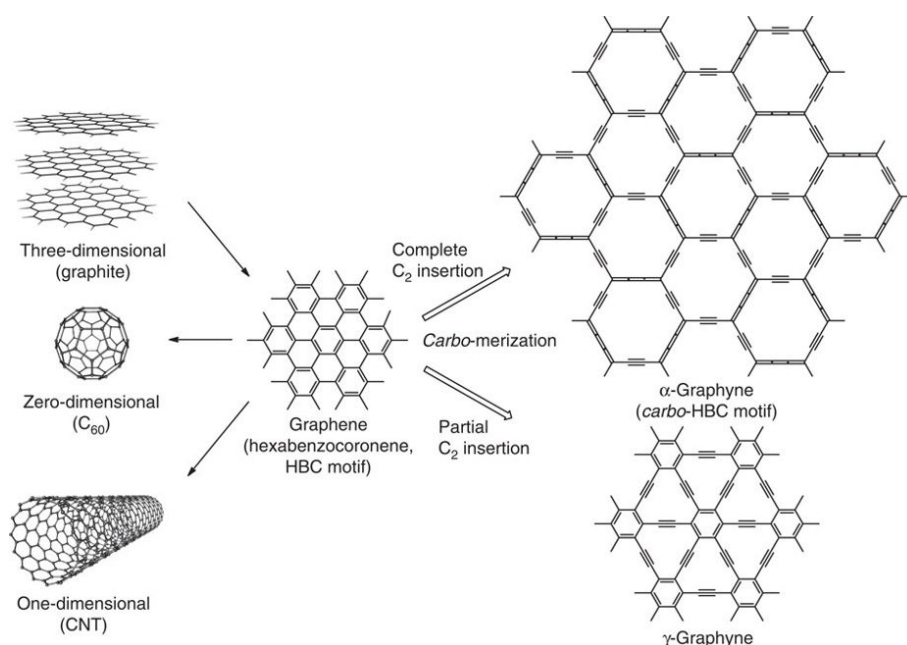

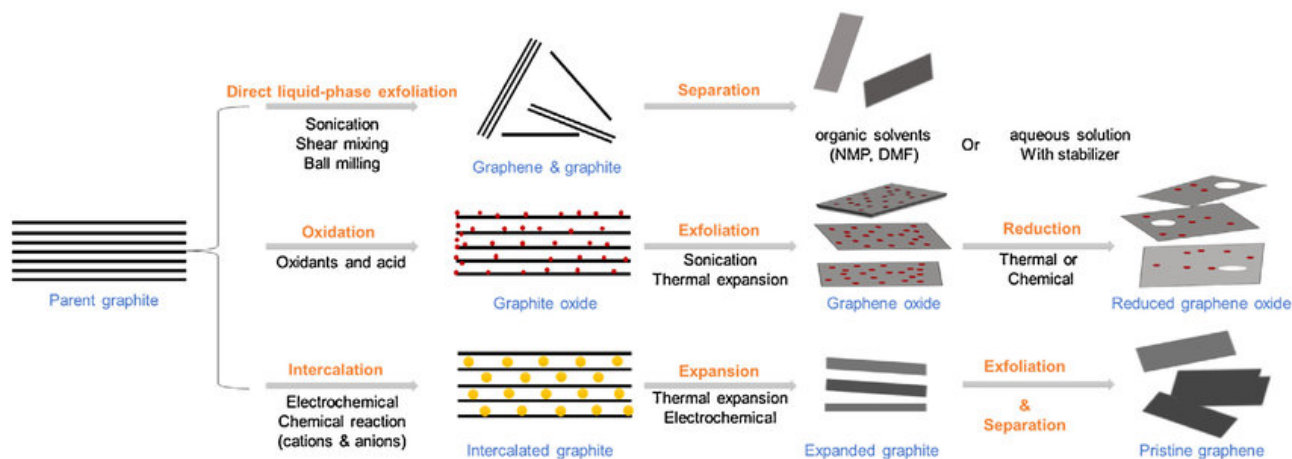**Fig. 2.** Chemical structure of graphene material [3–5]

Fig. 3. Production process of graphene material [14–17]

Starting late, GO is used in a like manner as a dielectric material with the true objective of electric insulation along with polarization to special environments. A slender layer of GO film is installed between carbon surface layers, which act as a terminal to outline an essential capacitor. Likewise, GO film can be utilized as a convincing medium to limit essentialness. The range is about 15 to 1500 V. On account of the growing enthusiasm for unmanned air vehicles (UAVs), the imperativeness amassing the cutoff and load of battery reliably limit their flight length to help the power for UAVs, in which the essentialness is achieved from sun-based sheets attached to the outside of the structures [24, 25]. In this structure, UAVs can support imperativeness free from any other individual in the midst of a flight mission.

3. PREPARATION METHODS

A large portion of the exploration contemplates have not utilized graphene in its unadulterated shape (immaculate graphene) because of its restricted yield from the arrangement perspective. Additionally, graphene subordinates (for example, GO, rGO, and frGO) have turned out to be all the more generally accessible and feature comparable properties to those of graphene. The different advances are given below.

3.1. Combination of materials

Little-scale mechanical stripping, mixture vapor dissemination (CVD), liquid stage decline of graphene oxide, and epitaxial advancement are the four assorted built systems for graphene [26]. They are accumulated as a best-down or base-up philosophy. There are different methods to incorporate graphene oxide/graphene, with the quality and measure of the yield depending upon the procedure. Figure 4 demonstrates diverse techniques to design graphene oxide and its subordinates. For this work, the source material will be graphite, oxidized to shed the graphene oxide layer from the mass.

3.2. Liquid stage partition

Graphite oxide was first ever experimentally extracted by Brodie [27] through the oxidation of graphite with potassium chlorate ($KClO_3$) in a graphite and nitric ruinous (HNO_3) blend. This improved the hugeness of the oxidized GO and consolidated the blend course. Regardless, it has wound up being silly because of the drawn-out term of the entire framework to finish; with the advancement of potassium chlorate (and the ensuing chlorine dioxide gas), it was quite perilous. The blend of potassium chlorate and nitric ruinous was recently used to join carbon nanotubes [28] and fullerenes [29]. Incredibly, this oxidation approach showed a lot of oxygen utilitarian parties and discharged dangerous nitrogen dioxide (NO_2) and di-nitrogen tetroxide (N_2O_4). In this manner, the above systems were not exhaustively utilized because of their numbers of restrictions.

3.3. Synthetic vapor affidavit

As contemporary techniques (for instance, little scale mechanical, CVD, and epitaxial improvement approaches to managing yield graphene) have ended up being ordinary, a couple of minor takeoffs from these systems have been developed. The move to move the advancement of graphene on copper foils has recently appeared.
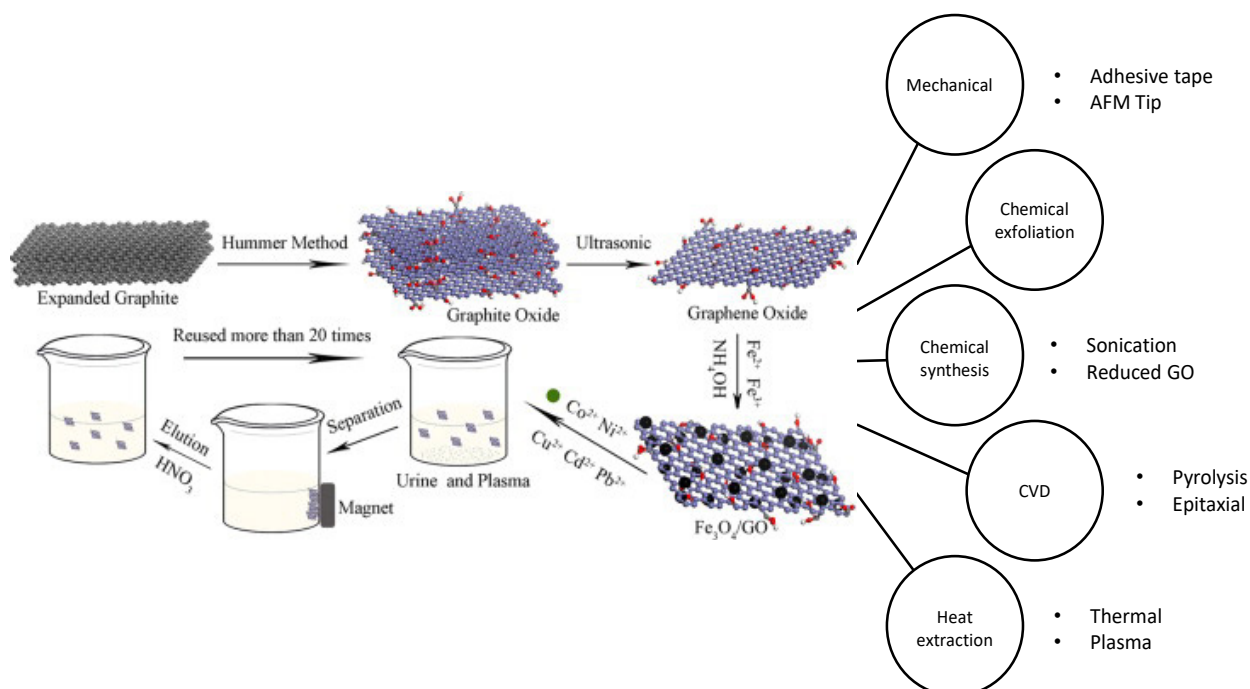

Fig. 4. Methods of extraction of graphene-based oxides [27]

Additionally, thermally stripped or plasma-helped CVD-made graphene powders could result in the age of CNT on a mass sum, which can be equivalent to the present extensive scale of creation methodologies. The usage of super-critical fluid has central focuses to control the atom gauge and for the uniform spread of nanoparticles all through the composite with zero deformations. Be that as it may, it cannot be used as an alternative in a split second due to the explicit confinements implied by the maker of this examination [30–33].

3.4. Reduction of GO

A reduction results in graphene oxide generally coming back to its special state, which improves its properties (especially its electrical conductivity) [34–42]. This is an objective and imperative development to improve or tailor the properties of GO and perhaps alter the structure of the comparable. There are various sorts of oxide reduction methods of GO shown in Figure 5.
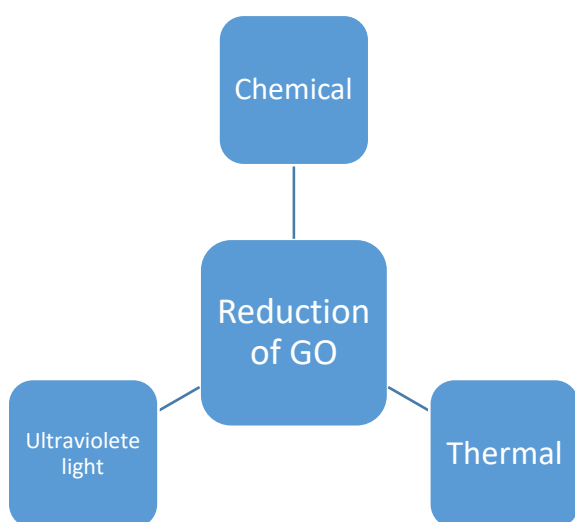

Fig. 5. Reduction methods of GO

Blend decline: Preparation of graphene oxide and decreased graphene oxide in an immense scale, using a convincing and clear strategy [43], wherein GO tests are submerged into a picked engineered lessening master for a particular time allotment and a temperature expanse. This strategy essentially empties the pointless down-to-earth social events (for instance, COOH and OH).

Warm decrease: The warm decay of graphene oxide is more capable of passing on transcendent rGO powders than the vast majority of the materials. In this technique, the GO is reduced at higher temperatures (above or around 1000°C), where the water particles and oxygen reacts very deffusively and is being socked by own [43–49]. UV light decrease: In this strategy, GO is shown to UV light after it is expelled from graphite (either in the suspension shape or the film or powder diagram). On the off chance that the powder GO is to decrease, it will as a rule be scattered in

a dissolvable fluid, as the fluid district of GO holds more UV light (making incredibly diminished GO) [50, 51].

Guo et al. [51] electrochemically lessened graphene nanosheets in which GO suspension was done in a three--cathode framework as a power supply and blended for 2 h. Mohan et al. [3] found that the GO decay process is fundamentally time-reliant, as they diminished GO sheets with various decreasing directors for a reaction period up to 100 h. They found that the decay advances as long as three days, which was checked by spectroscopic portrayal philosophies (for example, XPS, Raman spectroscopy, and FTIR) when GO was lessened for up to 50–68 hours.

Most examinations have utilized hydrohalic acids (for example, hydrazine, hydroiodic, hydrobromic, and hydrochloric) to reduce GO [52], which is incited when making rGO with basically less oxygen and carboxylic utilitarian social gatherings. These functionalities are in charge of their last properties, which can be revamped by fluctuating the centralizations of the reducing heads, decay time, and synchronous warming of the blend while diminishing (controlled air). A solid π-π or ionic coordinated effort is made in the wake of purging these supportive parties that enhance the properties. While the GO decay by substance/electrochemical decrease has seen practical decrease portions, the warm decrease of GO is in a like way generally utilized. The quick warming of GO to 1000°C exhausts these utilitarian get-togethers and likely makes incredibly decreased rGO in the edge powders [53, 54]. Obviously, this cannot hold the film kind of GO, which is a negative stamp.

4. MECHANICAL AND UTILITARIAN PROPERTIES OF GRAPHENE MATERIALS

Graphene materials have stable mechanical properties that have future application prospects in the nanoelectrome-chanical field. The fundamental exact starter examination of the versatile properties and quality of reduced graphene was finished by Lee et al. [55] It was discovered that the graphene exhibits both fragile split and non-arranged versatile leads. Min et al. [56] assessed the shear quality, shear modulus, and split strain of graphene as a part of temperature and chirality through atomic reenactments and announced a break worry of 97.54 GPa and shear nature of 60 GPa when the graphene sheet is exceptionally level. Ovid'ko et al. [57] did experimentation on reduced graphene and had laid down mechanical properties of graphene through test results that ideal graphene has a Young's modulus of 1 TPa and inalienable nature of 130 GPa, which matches the PC reenactments they used for consideration. I.W. Frank et al. [58] revealed that nanometer-thick graphene sheets have a Young's modulus of 0.5 TPa. Neglecting the manner in which that this piece reports conflicting mechanical properties of graphene, it will by and large be comprehended that, when all is said and done, graphene has promising mechanical properties and laudable materials for the further research and application into composite zones. With all of these quality properties, graphene has deserts, for example, openings, grain contacts, and segments that

may cause breaks in a rocker or botch point of reference. Thus, it is fundamental to see these flaws better and propose new research thoughts that will decidedly impact the employment of graphene [59–62].

Suk et al. [63] completed a limited-part framework examination on GO. He found that the versatile modulus of flimsy GO ultra-dainty films was reviewed utilizing AFM estimation joined with FEM. GO ultra-meager movies were found to have a Young's modulus of 207.6 ± 23.4 GPa [64, 65] with a thickness kept at 0.7 nm as observed as identical to that of flawless graphene.
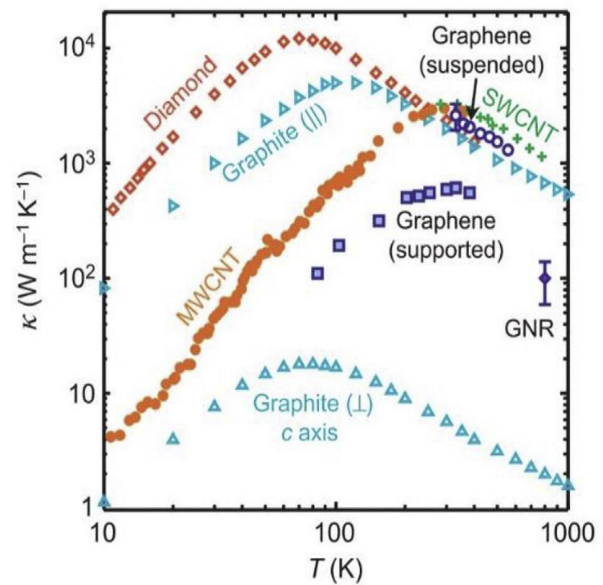
The pre-worry of the graphene oxide films was obtained to be 39.78 MPa, which was noted to be one request of a size lower than that of precisely stripped graphene. This story cream system (consolidating AFM and FEM mapping) displayed a course to find the versatile modulus and prestress of slight graphene oxide films. Table 1 plots the latest research centering on the mechanical properties of graphene subordinates.

5. THERMAL PROPERTIES

The warm properties of a material characterize its attributes, while the nuclear structure decides its conductivity. The warm properties of materials change when they are organized on a nanometer scale. The boundlessly substantial inherent warm conductivity of graphene gems has been uncovered from the hypothetical and test thoughts about [69]. The warm conductivity (κ) of a material is specified with respect to warmth motion per unit zone Q'' (e.g., in $W \cdot m^{-2}$) and in contrast to temperature slope $Q'' = -\kappa \nabla T$. The warm conductivity straightforwardly identifies with the explicit warmth by $\kappa \approx \Sigma C v \lambda$, where v and λ are the appropriately arrived at midpoint of the phonon bunch speed and mean freeway, individually [70]. Warm conductivity κ as a component of temperature: the agent information for suspended graphene appears in Figure 6.

Fig. 6. Thermal conductivity of graphitic materials [70]

6. GRAPHENE-BASED POLYMER COMPOSITES

In this part, we present a sorted-out appraisal of the organization of graphene-based polymer composite distinctive systems, for example, crumble mixing, plan intercalation and atomic estimation scattering of graphene subordinate inside polymer [70–78]. By and large, these sorts of composites have been made utilizing covalently or non-covalently joined systems; for example, in situ polymerization, game-plan mixing/hurling, or dissolve strengthening, or by hybridizing these specific age strategies appropriately.

Based on the properties of the composite material (for example, sub-atomic weight, farthest point, hydrophobicity and open social events), the nanocomposites can be made utilizing these four unquestionable strategies.

Table 1
Survey of mechanical and visual properties of different graphene derivatives

| Synthesis Material	Technique of synthesis	Modulus	Shear strength	Young's modulus	Reference
Graphene	Mechanical exfoliation	100–120	60–72	–	[61]
	Molecular dynamics	–	–	1–1.0234	[62]
	Pyrolysis	150	–	0.96	[58]
	Mechanical exfoliation	100	55–85	0.6–0.92	[66]
	Mechanical exfoliation	70–120	–	1.0223	[67, 68]
	Thermal	200–330	30–32	2	[60–66]

The huge scale delivering strategies ought to fulfill the fundamental scale basics for mechanical testing that is either a kilogram of powder or suspension containing graphene chips (routinely of micrometer scale), or a thousand pieces for determined graphene films (generally more noteworthy than millimeter check). The chemical factors needed for converting GO into nano-composites are: (i) the last recommendation to accomplish the properties and packaging/morphology for target graphene things; (ii) the quality and uses of graphene materials; (iii) the adaptability from research office to industry; and (iv) the quality and controllability of storing up, discovering that the vitality age systems utilized in industry are commonly the shedding of graphite, stripping/decrease of graphite oxide, and CVD [79].

Graphene composites can be set up as functionalized nanosheets, fillers, or movies. Additionally, covalent and non-covalent functionalized graphene-based nanosheets were related as 2D models for polymer advancement; the dissolvability is supposedly stretched out with these composites [80].

Graphene-based filler materials have the properties of electrical, warm, and mechanical (which improved it).

Be that as it may, layered graphene polymer films are unequivocal for photovoltaic and stack bearing film applications. Chen et al. [81] utilized an atomic-estimation blending technique and started a plasma-sintering procedure to make copper-GNP composites. In the resultant composites, the mechanical execution of the copper that at first upgraded the quality by the advancement of graphene began to incapacitate after a specific estimation. Finally, the break stretching kept diminishing from 30 to 3.5%. Notwithstanding what might be ordinary, the yield quality floods up to 310 MPa at a graphene stacking of 0.6 vol.%; after that, it decays to 200 MPa at 4.0 vol.% of graphene augmentation. The microstructures of the composites appear in Figure 7a.

Fundamentally, Tapasztó et al. [82] understood how to comprehend accomplishing the anisotropic electrical warm and mechanical properties by utilizing shine plasma sintering under uniaxial weight conditions to make GNP-stimulated mud composites (Fig. 7b). Assorted dispersing plans by starting plasma sintering and the perfect introduction of GNPs in the silicon nitride sort out were seen under a microstructural examination.
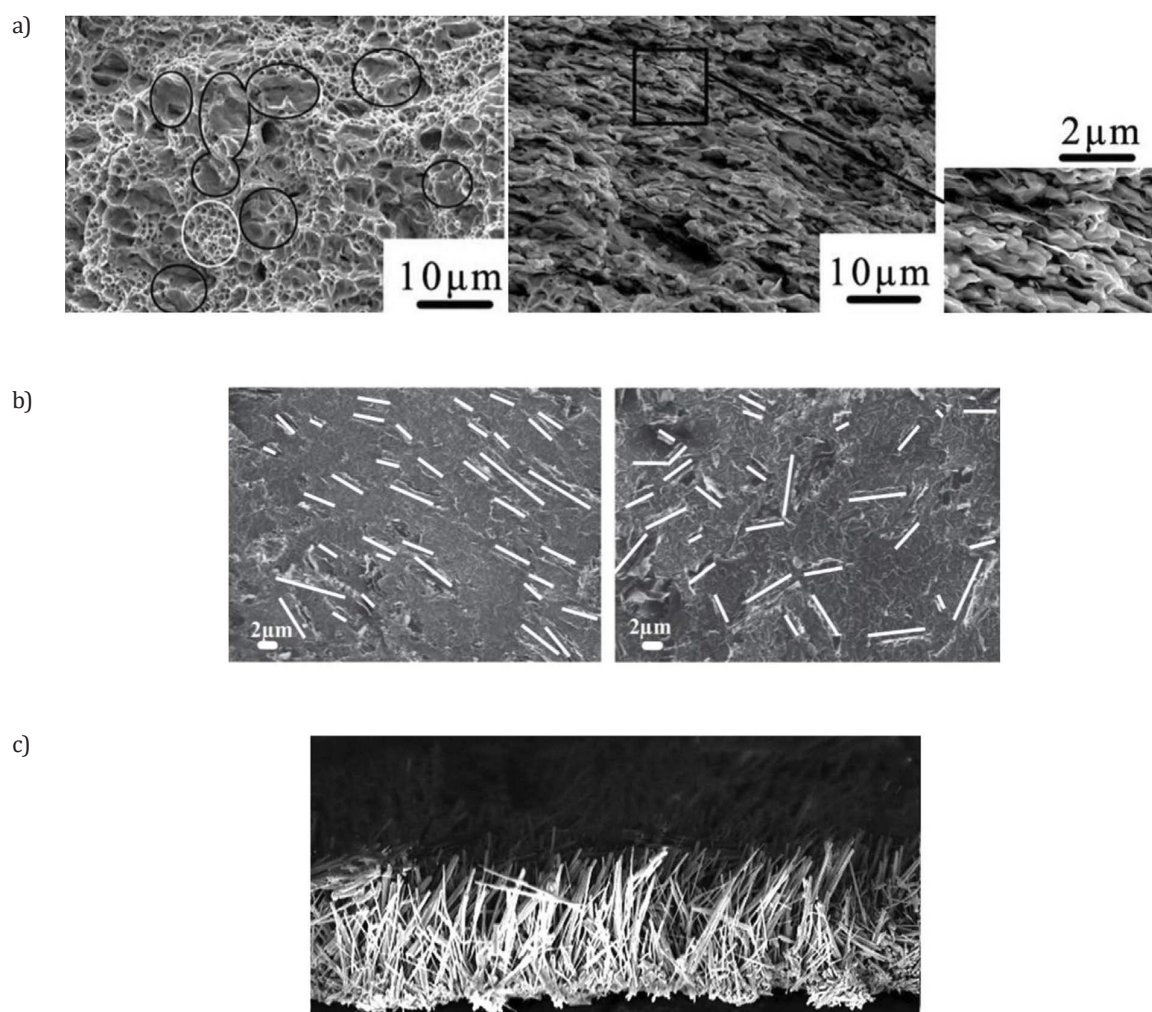
Fig. 7. Micro-chemical analysis using IR imaging: a) spectro images of Cu/GNS composites [78], b) 3 wt.% GNPs in Si3N4 prepared using (left) spark plasma sintering and (right) hot isostatic pressing [81], and c) ZnO2 NWAs/graphene composites [82]

Liu et al. [83] tested the effect of zinc oxide and graphene composite on their optical presentations. The composites were created through a turn covering declaration process as layers of seed ZnO layers being explicitly turned and secured on graphene motion pictures, and ZnO nanowires of around 80 nm were produced hydrothermally from their seeds. This had a higher field enhancement factor of 12,130 with a lower run-on field of 1.74 V/μm as compared to the graphene film layer [84].

The above results exhibit that the comparability of graphene materials in metal lattice composites has been advanced and the dissipating has been cultivated enough using specific techniques; for instance, nuclear measurement mixing and plasma sintering shapes. Zhong et al. [85] orchestrated functionalized diminished graphene oxide (frGO) invigorated styrene butadiene flexible (SBR) for upgraded warm conductivity and developing deterrent. The composites were conveyed from two-miss strengthening sought after by weight forming. The warm conductivity of SBR composites is reliably upgraded with the development of filler content due to the enhanced interfacial correspondence among the frGO and SBR. The warm conductivity was upgraded from 0.15 to 0.38 W/(m·K), and an unbending nature of 22 MPa was cultivated. The developing restriction was extended from 120 h to 240 h, which is twofold the life. This was practiced through amazing dispersing thought the right assurance of functionalizing administrator that manufactures the interfacial bonds between the graphene material and the polymer matrix. The effect of GNP and GO as sustaining pros in high-thickness polyethylene (HDPE) was analyzed by Lin et al. [86] using standard thermo-mechanical blending. In light of the morphological, mechanical similarly as one-of-a-kind physical and thermal property examinations over the ideal polymer graphene, they saw 56% augmentations in the adaptable modulus and 23% development in the most extraordinary weight. The filler loadings were moved from 0.1 to 10% for GNP as well as 0.05 and 1.5% for GO. They saw and assumed that, from their SEM imaging while agglomeration was an issue for the GNP composites at higher weight rates, it was accessible in the GO/MAPE models with loadings as low as 0.25%, attesting that break up blending of GO in HDPE will not result in incredible dissipating.

7. UTILIZATIONS OF GRAPHENE MATERIALS AND THEIR POLYMER COMPOSITES

Because of the likelihood of accomplishing multi-practical properties in polymers by fortifying them with graphene, a few fields have begun utilizing the composites. Fundamentally, there are three primary attributes that characterize the execution of graphene-based polymer nanocomposites:

- nanoscopic detainment of network polymer chains;
- nanoscale inorganic constituents and variety in properties; as revealed by different investigations of their huge change identifying with their size;
- nanoparticle course of action and the making of huge polymer/molecule interfacial region.

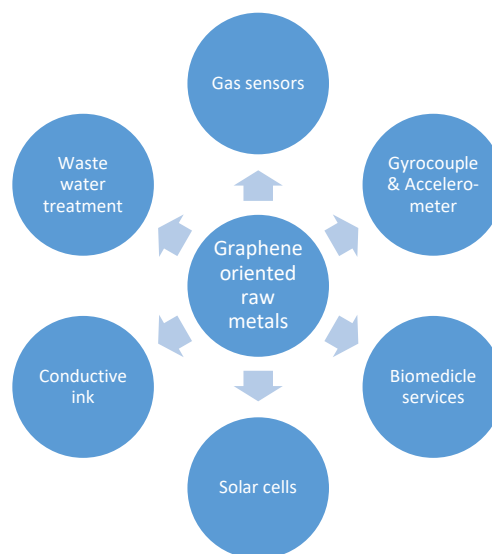Figure 8 presents an alternate field where graphene-based composites are being utilized/inquired about.

Fig. 8. Key applications of graphene-based composites

7.1. Sensors

The properties of graphene characterize them to be amazingly delicate to the Earth. This affectability expands their sensor application from investigations of the attractive field to DNA sequencing. Speed checking of nearby fluid to strain measures with either electrical or optical insights moderately contends its different applications. A further favorable position of utilizing crystalline graphene is its 20% stretch capacity which increases the analog sensing range of such sensors significantly.

7.2. Vitality and gadgets

Obviously, graphene is a piece of the ongoing quest for an exceptionally equipped sustainable power source. Currently, sun-powered cell advances graphene either goes about as the dynamic medium or as a straightforward/appropriated terminal material. Nonetheless, graphene without a bandgap is probably not going to wind up as a planar channel material in the last decade found in elite coordinated rationale circuits. In any case, numerous other less stringent graphene electronic applications are being set up from the accessible material.

A.I. Fernández-Calvo et al. [87] structured a ultra-capacitor with a particular capacitance of 135 F/g in fluid electrolytes, 99 F/g in natural electrolytes, and 75 F/g in ionic electrolytes [88] separately from a synthetically changed graphene material. These versatile electronic capacity gadgets with high power ability and life cycle are likewise called supercapacitors or electrochemical capacitors. In this investigation by Zhang et al. [89], graphene was blended by mechanical peeling pursued by substance treatment. It is a stretchable anode that can be utilized in different electrolytes and are

exceptionally adaptable. For these included properties, supercapacitors can be formulated utilizing a graphene leading polymer composites or graphene change metal oxide composites. A side from utilizing graphene-based metal oxide half and half terminals in supercapacitors for power thickness upgrade, graphene-based batteries are utilized to enhance the vitality thickness. Graphene-leading polymers and graphene-carbon nanotubes were additionally utilized in this application for their conductivity [90].

7.3. Optical applications

Polyamide-diminished graphene nanocomposites had been utilized for LED warm administration by Cho et al. The titanite coupling specialist utilized in this examination diminished the air voids present in decreased graphene sheets by responding with water particles. This expanded the heap exchange over the polymer and graphene as well as the warm conductivity of the composite. With high warm dissemination and better solidness, an LED light was hence made conceivable. A solitary layer of graphene is found to have a warm conductivity of 5300 W/(m·K), the warm conductivity for a PA/rGO had expanded by 53% in this work [91].

7.4. Graphene for composites under low-temperature conditions

Lately, graphene materials are of extraordinary consideration because of their ideal mechanical, electrical, and warm properties. Moreover, their extensive surface region as contrasted and other nano-basic materials make its standards as nano support for some polymer-based composites [92]. Figure 8 demonstrates the particular surface territory of various particles for building applications. Clearly, with a similar weight level of the particles, graphene and graphene oxide (GO) are smallest particles in the chart having moderately big surface region as contrasted and different particles. The utilization of GO, an oxidation type of graphene as fillers for polymer-based auxiliary individuals, has shown up in many building applications. GO is comprised of oxidative trash reinforced solidly to functionalized graphene sheets. It has a substantial surface zone (2630 m^2/g), high inherent portability (200,000 cm^2/V), high Young's modulus (~1.0 TPa), high warm conductivity (~5000 W/(m·K)), and high optical transmittance (~97.7%) [93]. It is typically arranged by the treatment of a graphite piece with anhydrous sulfuric corrosive, sodium nitrate, and potassium permanganate whose polar gatherings are presented onto the graphite's surface in this way, extending the interlayer dispersing of the graphene planes [94]. GO deals well with attributes and high concoction reactivity because of the nearness of the epoxide-, carboxyl-, carbonyl-, and hydroxyl-useful gatherings [95, 96].

7.5. Miscellaneous applications

Graphene-based paints include conductive ink, antistatic, electromagnetic-obstruction protecting, and gas hindrance.

A large portion of graphite mining organizations including the new companies have customized fluid stage or thermally shed graphene in light of the fact that the generation innovation is straightforward and sensibly created.

8. CONCLUSION

From this survey, it can been seen that a couple of examiners consider reported that the age of bewildering graphene auxiliaries in a ground-breaking strategy and on a mass scale remain the bottlenecks that ought to be vanquished at the essential event to engage graphene's feasible applications. A couple of considered explorations propelled the way that artificially functionalizes the outside of graphene (therefore achieving a not too bad interfacial joint effort) would update its pertinence, especially inside the imperativeness and environmental sections. Thus, enhancing the major subtleties (for example, accomplishing a coherently drawn-out morphology) would be firmly persuading on its mechanical properties. Furthermore, the fortifying limit and, thus, their strippings are enhanced by defeating the mutilations and wrinkles in the platelets. Up until this point, biomedicine and other bio-based applications have the epic spotlight graphene related to research fields. Regardless, the purposes of restriction must be crossed considering the conventional estimations of graphene and its reinforcements.

The greater part of the carbon-based nanomaterial has the stunning enemy of bacterial action, with rGO being the most grounded. Thus, further obligations pinpointing the nanocarrier biocompatibility and security redesign along with measure and poisonous quality decay are of the utmost importance.

REFERENCES

[1] Mohan V. (2016). *Development of Functional Polymer-Graphene Nanocomposites* (Doctoral dissertation), ResearchSpace@ Auckland).

[2] Mohan V.B., Liu D., Jayaraman K., Stamm M. & Bhattacharyya D. (2016). Improvements in electronic structure and properties of graphene derivatives. *Advanced Materials Letters*, 7(6), 421–429.

[3] Mohan V.B., Brown R., Jayaraman K. & Bhattacharyya D. (2015). Characterisation of reduced graphene oxide: Effects of reduction variables on electrical conductivity. *Materials Science and Engineering: B*, 193, 49–60.

[4] Novoselo K.S., & Geim A.K. (2007). The rise of graphene. *Nature Materials*, 6(3), 183–191.

[5] Castro Neto A.H., Guinea F., Peres N.M.R., Novoselov K.S. & Geim A.K. (2009). The Electronic Properties of Graphene, *Reviews of Modern Physics*, 81, 109–162.

[6] Moghadam A.D., Omrani E., Menezes P.L. & Rohatgi P.K. (2015). Mechanical and tribological properties of self-lubricating metal matrix nanocomposites reinforced by carbon nanotubes (CNTs) and graphene–a review. *Composites Part B: Engineering*, 77, 402–420.

[7] Stoller M.D., Park S., Zhu Y., An J. & Ruoff R.S. (2008). Graphene-based ultracapacitors. *Nano Letters*, 8(10), 3498–3502.

[8] Kuilla T., Bhadra S., Yao D., Kim N.H., Bose S. & Lee J.H. (2010). Recent advances in graphene based polymer composites. *Progress in polymer science*, 35(11), 1350–1375.

[9] Geim A.K. (2009). Graphene: status and prospects. *Science*, 324(5934), 1530–1534.

[10] Ferrari A.C., Bonaccorso F., Fal'ko V., Novoselov K.S., Roche S., Bøggild P., Borini S., Koppens F.H., Palermo V., Pugno N. & Garrido J.A. (2015). Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems. *Nanoscale*, 7(11), 4598–4810.

[11] 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.

[12] Hossain S.A., Hossen M. & Anower S. (2018). Estimation of damselfish biomass using an acoustic signal processing technique. *Journal of Ocean Technology*, 13(2), 91–109.

[13] Gadipelli S. & Guo Z.X. (2015). Graphene-based materials: Synthesis and gas sorption, storage and separation. *Progress in Materials Science*, 69, 1–60.

[14] Stankovich S., Dikin D.A., Dommett G.H., Kohlhaas K.M., Zimney E.J., Stach E.A., Piner R.D., Nguyen S.B.T. & Ruoff R.S. (2006). Graphene-based composite materials. *Nature*, 442(7100), 282–286.

[15] Novoselov K.S., Fal V.I., Colombo L., Gellert P.R., Schwab M.G. & Kim K. (2012). A roadmap for graphene. *Nature*, 490(7419), 192–200.

[16] Novoselov K.S., Geim A.K., Morozov S., Jiang D., Katsnelson M., Grigorieva I., Dubonos S.V. & Firsov A.A. (2005). Two-dimensional gas of massless Dirac fermions in graphene. *Nature*, 438(7065), 197–200.

[17] Dikin D.A., Stankovich S., Zimney E.J., Piner R.D., Dommett G.H., Evmenenko G., Nguyen S.B.T & Ruoff R.S. (2007). Preparation and characterization of graphene oxide paper. *Nature*, 448(7152), 457–460.

[18] Huang X., Qi, X., Boey F. & Zhang H. (2012). Graphene-based composites. *Chemical Society Reviews*, 41(2), 666–686.

[19] Hung P.Y., Lau K.T., Fox B., Hameed N., Lee J.H. & Hui D. (2018). Surface modification of carbon fibre using graphene-related materials for multifunctional composites. *Composites Part B: Engineering*, 133, 240–257.

[20] Layek R.K., Uddin M.E., Kim N.H., Lau A.K.T. & Lee J.H. (2017). Noncovalent functionalization of reduced graphene oxide with pluronic F127 and its nanocomposites with gum Arabic. *Composites Part B: Engineering*, 128, 155–163.

[21] Sun X., Liu X., Shen X., Wu Y., Wang Z. & Kim J.K. (2016). Graphene foam/carbon nanotube/poly (dimethyl siloxane) composites for exceptional microwave shielding. *Composites Part A: Applied Science and Manufacturing*, 85, 199–206.

[22] Bose S., Kim N.H., Kuila T., Lau K.T. & Lee J.H. (2011). Electrochemical performance of a graphene-polypyrrole nanocomposite as a supercapacitor electrode. *Nanotechnology*, 22(29), 295202.

[23] Bose S., Kuila T., Uddin M.E., Kim N.H., Lau A.K. & Lee J.H. (2010). In-situ synthesis and characterization of electrically conductive polypyrrole/graphene nanocomposites. *Polymer*, 51(25), 5921–5928.

[24] Hung P.Y., Lau K.T., Fox B., Hameed N., Lee J.H. & Hui D. (2018). Surface modification of carbon fibre using graphene-related materials for multifunctional composites. *Composites Part B: Engineering*, 133, 240–257.

[25] Ghosh S., Ghosh R., Guha P.K. & Bhattacharyya T.K. (2015). Humidity sensor based on high proton conductivity of graphene oxide. *IEEE Transactions on Nanotechnology*, 14(5), 931–937.

[26] Hossain S.A., Mallik A. & Arefin M. (2017). A Signal Processing Approach to Estimate Underwater Network Cardinalities with Lower Complexity. *Journal of Electrical and Computer Engineering Innovations*, 5(2), 131–138.

[27] Fang M., Wang K., Lu H., Yang Y. & Nutt S. (2009). Covalent polymer functionalization of graphene nanosheets and mechanical properties of composites. *Journal of Materials Chemistry*, 19(38), 7098–7105.

[28] Rosca I.D., Watari F., Uo M. & Akasaka T. (2005). Oxidation of multiwalled carbon nanotubes by nitric acid. *Carbon*, 43(15), 3124–3131.

[29] Istrate O.M., Paton K.R., Khan U., O'Neill A., Bell A.P. & Coleman J.N. (2014). Reinforcement in melt-processed polymer–graphene composites at extremely low graphene loading level. *Carbon*, 78, 243–249.

[30] Padmajan Sasikala S., Poulin P. & Aymonier C. (2016). Prospects of Supercritical Fluids in Realizing Graphene-Based Functional Materials. *Advanced Materials*, 28(14), 2663–2691.

[31] Zhang L.L., Zhou R., & Zhao X.S. (2010). Graphene-based materials as supercapacitor electrodes. *Journal of Materials Chemistry*, 20(29), 5983–5992.

[32] Chua C.K., & Pumera M. (2014). Chemical reduction of graphene oxide: a synthetic chemistry viewpoint. *Chemical Society Reviews*, 43(1), 291–312.

[33] Gao X., Jang J. & Nagase S. (2009). Hydrazine and thermal reduction of graphene oxide: reaction mechanisms, product structures, and reaction design. *The Journal of Physical Chemistry C*, 114(2), 832–842.

[34] 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.

[35] Liu H., Zhang L., Guo Y., Cheng C., Yang L., Jiang L., Yu G., Hu W., Liu Y. & Zhu D. (2013). Reduction of graphene oxide to highly conductive graphene by Lawesson's reagent and its electrical applications. *Journal of Materials Chemistry C*, 1(18), 3104–3109.

[36] Park S., An J., Potts J.R., Velamakanni A., Murali S. & Ruoff R.S. (2011). Hydrazine-reduction of graphite-and graphene oxide. *Carbon*, 49(9), 3019–3023.

[37] Hossain S.A., Ali M.F., Akif M.I., Islam R., Paul A.K. & Halder A. (2016). A determination process of the number and distance of sea objects using CHIRP signal in a three sensors based underwater network. In: *2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT)*. IEEE, 1–6.

[38] Pei S., Zhao J., Du J., Ren W. & Cheng H.M. (2010). Direct reduction of graphene oxide films into highly conductive and flexible graphene films by hydrohalic acids. *Carbon*, 48(15), 4466–4474.

[39] Pham T.A., Kim J., Kim J.S. & Jeong Y.T. (2011). One-step reduction of graphene oxide with L-glutathione. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 384(1–3), 543–548.

[40] Shin H.J., Kim K.K., Benayad A., Yoon S.M., Park H.K., Jung I.S., Jin M.I., Jeong H.-K., Kim J.M., Choi J.Y. & Lee Y.H. (2009). Efficient reduction of graphite oxide by sodium borohydride and its effect on electrical conductance. *Advanced Functional Materials*, 19(12), 1987–1992.

[41] Zhang J., Yang H., Shen G., Cheng P., Zhang J. & Guo S. (2010). Reduction of graphene oxide via L-ascorbic acid. *Chemical Communications*, 46(7), 1112–1114.

[42] Shen J., Hu Y., Shi M., Lu X., Qin C., Li C. & Ye M. (2009). Fast and facile preparation of graphene oxide and reduced graphene oxide nanoplatelets. *Chemistry of Materials*, 21(15), 3514–3520.

[43] Shen J., Hu Y., Shi M., Lu X., Qin C., Li C. & Ye M. (2009). Fast and facile preparation of graphene oxide and reduced graphene oxide nanoplatelets. *Chemistry of Materials*, 21(15), 3514–3520.

[44] Tang H., Ehlert G.J., Lin Y. & Sodano H.A. (2011). Highly efficient synthesis of graphene nanocomposites. *Nano Letters*, 12(1), 84–90.

[45] Gao X., Jang J. & Nagase S. (2009). Hydrazine and thermal reduction of graphene oxide: reaction mechanisms, product structures, and reaction design. *The Journal of Physical Chemistry C*, 114(2), 832–842.

[46] Wei Z., Wang D., Kim S., Kim S.Y., Hu Y., Yakes M.K., Laracuente A.R., Dai Z., Marder S.R., Berger C., King W.P., de Heer W.A., Sheehan P.E. & King W.P. (2010). Nanoscale tunable reduction of graphene oxide for graphene electronics. *Science*, 328(5984), 1373–1376.

[47] Chen W. & Yan L. (2010). Preparation of graphene by a low-temperature thermal reduction at atmosphere pressure. *Nanoscale*, 2(4), 559–563.

[48] Chen W., Yan L. & Bangal P.R. (2010). Preparation of graphene by the rapid and mild thermal reduction of graphene oxide induced by microwaves. *Carbon*, 48(4), 1146–1152.

[49] Wu T., Liu S., Li H., Wang L. & Sun X. (2011). Production of reduced graphene oxide by UV irradiation. *Journal of nanoscience and nanotechnology*, 11(11), 10078–10081.

[50] Lee G., Lee W., Nah S., Ji S., Hwang J.Y., Lee S.S., Parke S., Chae S.S. & Lee J.O. (2019). Solution-processable method for producing high-quality reduced graphene oxide displaying 'self-catalytic healing'. *Carbon*, 141, 774–781.

[51] Sadhukhan S., Ghosh T.K., Roy I., Rana D., Bhattacharyya A., Saha R., Chattopadhyay S., Khatua S., Acharya K. & Chattopadhyay D. (2019). Green synthesis of cadmium oxide decorated reduced graphene oxide nanocomposites and its electrical and antibacterial properties. *Materials Science and Engineering: C*, 99, 696–709.

[52] Tang H., Ehlert G.J., Lin Y., & Sodano H.A. (2011). Highly efficient synthesis of graphene nanocomposites. *Nano Letters*, 12(1), 84–90.

[53] McAllister M.J., Li J.L., Adamson D.H., Schniepp H.C., Abdala A.A., Liu J., Herrera-Alonso M., Milius D.L., Car R., Prud'homme R.K. & Aksay I.A. (2007). Single sheet functionalized graphene by oxidation and thermal expansion of graphite. *Chemistry of Materials*, 19(18), 4396–4404.

[54] Prusty K., Barik S. & Swain S.K. (2019). A Correlation between the Graphene Surface Area, Functional Groups, Defects, and Porosity on the Performance of the Nanocomposites. In: *Functionalized Graphene Nanocomposites and their Derivatives*, Elsevier, 265–283.

[55] Sun Y., Pan J., Zhang Z., Zhang K., Liang J., Wang W., Yuan Z., Hao Y., Wang B., Wang J. & Wu Y. (2019). Elastic Properties and Fracture Behaviors of Biaxially-Deformed, Polymorphic MoTe$_2$. *Nano Letters*, 19(2), 761–769.

[56] Chu L., Shi J. & Braun R. (2019). The equivalent Young's modulus prediction for vacancy defected graphene under shear stress. *Physica E: Low-dimensional Systems and Nanostructures*, 110, 115–122.

[57] Sari E., Uzek R. & Merkoçi A. (2019). Paper Based Photoluminescent Sensing Platform with Recognition Sites for Tributyltin. *ACS sensors*.

[58] Xu Y., Peng Y., You T., Yao L. Geng J., Dearn K.D. & Hu X. (2018). Nano-MoS$_2$ and Graphene Additives in Oil for Tribological Applications. In: *Nanotechnology in Oil and Gas Industries*, Springer, Cham, 151–191.

[59] 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.

[60] Luceño Sánchez J., Peña Capilla R. & Díez-Pascual A. (2018). High-Performance PEDOT: PSS/Hexamethylene Diisocyanate-Functionalized Graphene Oxide Nanocomposites: Preparation and Properties. *Polymers*, 10(10), 1169.

[61] 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.

[62] Sun X.Y., Liu H. & Ju S. (2019). Dependence of wrinkling geometric patterns on the chirality of monolayer graphene under shear deformation. *Physica E: Low-dimensional Systems and Nanostructures*, 105, 62–67.

[63] Farshid B., Lalwani G., Shir Mohammadi M., Srinivas Sankaran J., Patel S., Judex S., Simonsen J. & Sitharaman B. (2019). Two-dimensional graphene oxide reinforced porous biodegradable polymeric nanocomposites for bone tissue engineering. *Journal of Biomedical Materials Research Part A*, 14(3), 900–909.

[64] Guan L.Z., Zhao L., Wan Y.J. & Tang L.C. (2018). Three-dimensional graphene-based polymer nanocomposites: preparation, properties and applications. *Nanoscale*, 10(31), 14788–14811.

[65] Sakorikar T., Kavitha M.K., Tong S.W., Vayalamkuzhi P., Loh K.P. & Jaiswal M. (2018, May). Graphene: Polymer composites as moisture barrier and charge transport layer toward solar cell applications. In: *AIP Conference Proceedings*, Vol. 1953, No. 1, AIP Publishing, 100029.

[66] Young R.J., Kinloch I.A., Gong L. & Novoselov K.S. (2012). The mechanics of graphene nanocomposites: a review. *Composites Science and Technology*, 72(12), 1459–1476.

[67] Ren S., Cui M., Li Q., Li W., Pu J., Xue Q. & Wang L. (2019). Barrier mechanism of nitrogen-doped graphene against atomic oxygen irradiation. *Applied Surface Science*, 79, 669–678.

[68] Kumar A., Sharma K. & Dixit A.R. (2019). A review of the mechanical and thermal properties of graphene and its hybrid polymer nanocomposites for structural applications. *Journal of Materials Science*, 8, 1–35.

[69] Gavrilov S.N., Krivtsov A.M. & Tsvetkov D.V. (2019). Heat transfer in a one-dimensional harmonic crystal in a viscous environment subjected to an external heat supply. *Continuum Mechanics and Thermodynamics*, 31(1), 255–272.

[70] Moghaddasi Fereidani R. & Segal D. (2019). Phononic heat transport in molecular junctions: quantum effects and vibrational mismatch. *The Journal of Chemical Physics*, 150(2), 024105.

[71] Chowdhury S., Pan S., Balasubramanian R. & Das P. (2019). Three-Dimensional Graphene-Based Macroscopic Assemblies as Super-Absorbents for Oils and Organic Solvents. In: *A New Generation Material Graphene: Applications in Water Technology*, Springer, Cham, 43–68.

[72] Mallik A., Hossain S.A., Karim A.B. & Hasan S.M. (2019). Development of LOCAL-IP based Environmental Condition Monitoring using Wireless Sensor Network. *International Journal of Sensors, Wireless Communications and Control*, 9, 1–8

[73] Hajjar Z., Morad Rashidi A. & Ghozatloo A. (2014). Enhanced thermal conductivities of graphene oxide nanofluids. *International Communications in Heat and Mass Transfer*, 57, 128–131.

[74] Renteria J.D., Ramirez S., Malekpour H., Alonso B., Centeno A., Zurutuza A., Cocemasov A.I., Nika D.L. & Balandin A.A. (2015). Strongly anisotropic thermal conductivity of free-standing reduced graphene oxide films annealed at high temperature. *Advanced Functional Materials*, 25(29), 4664–4672.

[75] Wang F., Wang H. & Mao J. (2019). Aligned-graphene composites: a review. *Journal of Materials Science*, 54(1), 36–61.

[76] Tian J., Shi H., Hu H., Chen B., Bao Y. & Tang P. (2019). Implementation of Atomically Thick Graphene and Its Derivatives in Electromagnetic Absorbers. *Applied Sciences*, 9(3), 388.

[77] Del Giudice F., Cunning B.V., Ruoff R.S. & Shen A.Q. (2018). Filling the gap between transient and steady shear rheology of aqueous graphene oxide dispersions. *Rheologica Acta*, 57(4), 293–306.

[78] Shahzad F., Alhabeb M., Hatter C.B., Anasori B., Hong S.M., Koo C.M. & Gogotsi Y. (2016). Electromagnetic interference shielding with 2D transition metal carbides (MXenes). *Science*, 353(6304), 1137–1140.

[79] Henriques P.C., Borges I., Pinto A.M., Magalhaes F.D. & Gonçalves I.C. (2018). Fabrication and antimicrobial performance of surfaces integrating graphene-based materials. *Carbon*, 132, 709–732.

[80] Avijit M. & Hasan M. (2018). PV/T Systems for Renewable Energy Storage: A Review. *World Scientific News*, 96, 83–95.

[81] Chen F., Ying J., Wang Y., Du S., Liu Z. & Huang Q. (2016). Effects of graphene content on the microstructure and properties of copper matrix composites. *Carbon*, 96, 836–842.

[82] Tapasztó O., Tapasztó L., Lemmel H., Puchy V., Dusza J., Balázsi C. & Balázsi K. (2016). High orientation degree of graphene nanoplatelets in silicon nitride composites prepared by spark plasma sintering. *Ceramics International*, 42(1), 1002–1006.

[83] Karim A.B., Avro S.S. & Shahriar S. (2019). Prospect of Geothermal Energy Resources in Bangladesh. *International Journal of Renewable Energy Resources*, 8(2), 22–28.

[84] Wang X.D., Zhou J., Lao C.S., Song J.H., Xu N.S. & Wang Z.L. (2007). In situ field emission of density-controlled ZnO nanowire arrays. *Advanced Materials*, 19(12), 1627–1631.

[85] Zhong B., Dong H., Luo Y., Zhang D., Jia Z., Jia D. & Liu F. (2017). Simultaneous reduction and functionalization of graphene oxide via antioxidant for highly aging resistant and thermal conductive elastomer composites. *Composites Science and Technology*, 151, 156–163.

[86] Svidró J. & Diószegi A. (2018). New Possibilities in Thermal Analysis of Molding Materials. *Journal of Casting & Materials Engineering*, 2(4), 67–69.

[87] Fernández-Calvo A.I., Lizarralde I., Sal E., Rodriguez P., de Zabalegui E.O., Cia I. & Rios A. (2019). Grain-Size Prediction Model in Aluminum Castings Manufactured by Low-Pressure Technology. *Journal of Casting & Materials Engineering*, 2(4), 71–77.

[88] Mallik A., Arefin M.A. & Shahadat M.M.Z. (2018). Design and feasibility analysis of a low-cost water treatment plant for rural regions of Bangladesh. *AIMS Agriculture and Food*, 3(3), 181–204. Doi: 10.3934/agrfood.2018.3.181.

[89] Kaiser M.S. (2018). Effects of solution treatment on wear behaviour of Al-12Si-1Mg piston alloy containing trace Zr. *Journal of Casting & Materials Engineering*, 2(2), 30–37.

[90] Hossain S.A., Ali M. F., Akif M. I., Islam R., Paul A.K., & Halder A. (2016). A determination process of the number and distance of sea objects using CHIRP signal in a three sensors based underwater network. In: *Electrical Engineering and Information Communication Technology (ICEEICT), 2016 3rd International Conference on*, 1–6. IEEE, 2016.

[91] Nahian M.R., Zaman M.S., Islam M.N. & Rokunuzzaman M. (2018). Development of a Pressure Sensing Module and Flow Control System for a Prototype Pump Test Bed. *Indonesian Journal of Electronics and Instrumentation Systems*, 8(2), 155–166.

[92] Huang C., Fu S., Zhang Y., Lauke B., Li L. & Ye L. (2005). Cryogenic properties of SiO_2/epoxy nanocomposites. *Cryogenics*, 45(6), 450–454.

[93] Kim S., Young J.C., Hwi J.W., Qijun S., Sungjoo L., Moon S.K., Young J.S., Zhong L.W. & Jeong H.C. (2018). Piezotronic Graphene Barristor: Efficient and Interactive Modulation of Schottky Barrier. *Nano Energy*, 50, 598–605.

[94] Lim N., Tae J.Y., Jin T.K., Yusin P., Yogeenth K., Hyeonghun K., Woochul K., Byoung H.L. & Gun Y.J. (2018). Tunable graphene doping by modulating the nanopore geometry on a SiO_2/Si substrate. *RSC Advances*, 8(17), 9031–9037.

[95] Li Z., Wang R., Young R.J., Deng L., Yang F. & Hao L. (2013). Control of the functionality of graphene oxide for its application in epoxy nanocomposites. *Polymer*, 54(23), 6437–6446.

[96] Jacob G.J, Bandyopadhyay A., Bhowmick A.K. (2008). New generation layered nanocomposites derived from ethylene-co-vinyl acetate and naturally occurring graphite. *Journal of Applied Polymer Science*, 108(3), 1603–1616.