

Review

Modernizations of graphene nanocomposites using synthesis strategies— State-of-the-art

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Abstract: Graphene has been ranked among one of the most remarkable nanostructure of the carbon world. Graphene modification and nanocomposite formation have been used to expand the practical potential of graphene nanostructure. The overview is an effort to highpoint the indispensable synthesis strategies towards the formation of graphene nanocomposites. Consequently, graphene has been combined with useful matrices (thermoplastic, conducting, or others) to attain the desired end material. Common fabrication approaches like in-situ method, solution processing, and melt extrusion have been widely involved to form the graphene nanocomposites. Moreover, advanced sophisticated methods such as three or four dimensional printing, electrospinning, and others have been used to synthesize the graphene nanocomposites. Focus of all synthesis strategies has remained with the standardized graphene dispersion, physical properties, and applications. However, continuous future efforts are required to resolve the challenges in synthesis strategies and optimization of the parameters behind each technique. As the graphene nanocomposite design and properties directly depend upon the fabrication techniques used, there is obvious need for the development of advanced methods having better control over process parameters. Here, main challenging factors may involve the precise parameter control of the advanced techniques used for graphene nanocomposite manufacturing. Hence, there is not only need of current and future research to resolve the field challenges related to material fabrication but also reporting compiled review articles can be useful for interested field researchers towards challenge solving and future developments in graphene manufacturing.

Keywords: graphene; nanocomposite; synthesis; technique; in situ; melt extrusion

1. Introduction

Due to technical utilizations of graphene nanostructures, considerable literature has been reported on the structure and synthesis methods [1]. Particularly, matrix-nanofiller compatibility has been found important to enhance the optical, electronic, thermal, mechanical, and other important properties of the graphene nanocomposites [2,3]. Consequently, the miscibility effects in the nanocomposite nanostructure resulted in synergistic property improvements in the high-tech nanomaterial [4]. The interfacial interactions in the matrix-nanofiller system greatly depend on the synthesis strategies used [5]. In this context, choice of an appropriate synthesis method may lead to advanced nanocomposite with superior physical features [6]. Traditional methods used to form the polymer/graphene nanocomposites include the in situ, solution, and melt methods [7]. In addition, various efficient advanced processes have been used to form the graphene nanocomposites like printing, spinning lithography, and several

others [8,9]. Consequently, thermoplasts, thermosets, and conjugated matrices have been filled with graphene nanoparticles to attain superior properties and applications [10–12]. The resulting graphene nanocomposites have enhanced physical properties due to suitable processing techniques applied to gain improved interfacial aspects of these nanomaterials [13].

Hence, noteworthy chemical and physical properties, graphene has been widely inspected by the researchers over past decades. Graphene has been used in numerous potential fields due to high surface area, excellent electrical, mechanical, thermal, and other structural and physical characteristics. Consequently, graphene has been found applicable for the energy devices, electronics, sensors, nanocomposites, and biomedical devices, drug delivery, and tissue engineering. To enhance the practical use of graphene nanocomposite in technical fields, it has been found important to fabricate the graphene based materials by opting appropriate synthesis strategies. Advanced fabrication techniques have well controlled parameters to attain specific properties of graphene nanocomposites for desired end application.

This review focuses on the designs and synthesis strategies for the high performance graphene nanocomposites. According to analysis, this article is novel to present manufacturing approaches of novel graphene derived nanocomposites. For graphene nanocomposites, various traditional and modified methods have been used. Developments in the synthesis techniques of graphene nanocomposites can enhanced the technical potential of these nanomaterials. Consequently, the designing, features, and appropriate processes for the graphene nanocomposites have been explained here. Literature research reports so far have been observed on the fabrication of graphene based nanomaterials using appropriate synthesis strategies. However, no compiled review article is seen on technical fabrication techniques and comprehensive debates towards structural developments using modified methods and controlled parameters. Aim or objective of this review is to develop a comprehensive article on the most frequently used methods for graphene nanomaterial synthesis. Accordingly, the resulting graphene nanocomposites have been discussed under numerous categories of solution, melt, and other fabrication techniques, in this article. Then, the design, characteristics, and applications of the nanocomposites have been explained with respect to the fabrication methods used. Thus, such specific overview on graphene nanocomposite fabrication has not seen in literature before with well explained recent literature and outline. Despite the advancements so far, devoted future research efforts are still required on the fabrication of high performance nanocomposite, to overcome the related design and parameter control challenges.

2. Graphene

Graphene is a two dimensional single nanosheet of sp^2 hybridized carbons [14]. Detection of graphene is linked back to 2004 [15]. Graphene has been formed using many technical approaches like exfoliation approaches, laser method, chemical vapor deposition, and chemical synthesis approaches [16]. Graphene has been explored for range of structural and physical features [17]. Graphene has countless enhanced features including very high Young's modulus of 1 TPa, electron mobilization of 3000–5000 W/mK, and thermal conductivity of around 200,000 $cm^2V^{-1}s^{-1}$ [18].

Essential properties of graphene has been found dependent on the graphene nanostructure [19]. Owing to van der Waals forces, the nanosheet displays wrinkling effects [20]. To augment the structural features of graphene, the nanosheet has been functionalized to introduce oxygen bearing groups on surface [21]. Such surface functional graphene nanosheet with hydroxyl, carbonyl, epoxide, carboxylic acid, etc. groups has been often termed as graphene oxide. Graphene and some linked nanostructures are shown in **Figure 1**. Graphene and derivative nanostructures own fine electronic, mechanical, thermal, and chemical characters [22]. Consequently, applications of graphene has been observed towards the electronics as well as energy devices and countless other technological sectors [23,24].

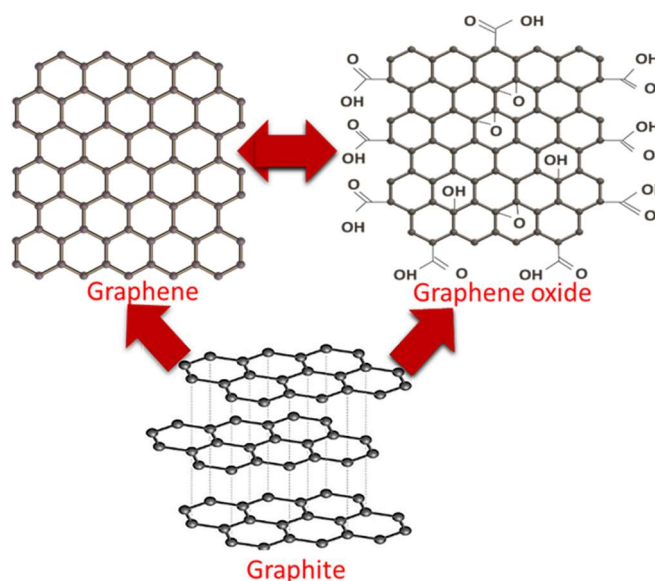


Figure 1. Graphite to graphene and graphene oxide and interconversions.

3. In situ technique towards graphene nanocomposites

One of the simple and efficient method for the formation of graphene nanocomposites is the in situ polymerization or in situ method [25]. This synthesis strategy has been found effective for better graphene dispersion [26]. Fine nanoparticle scattering in turn generated better interactions in matrix-nanofiller phases [27]. Main benefits of in situ synthesis strategy include the environmental friendliness, use of non-toxic solvent, room temperature processing, and one step processes involved to form the graphene nanocomposites [28]. Subsequently, countless graphene nanocomposite designs have been reported using the in situ synthesis strategy [29]. In situ technique is a facile, low cost, and environmentally benign method to physically or covalently functionalize graphene nanosheets. In this method, monomers are in situ polymerized in the presence of graphene or graphene oxide to form the nanocomposites. In situ polymerization has been used as a common method for the polymerization of ϵ -caprolactam monomer to form the polyamide 6 backbone [30]. Adding 1–2 vol.% graphene contents along with ϵ -caprolactam monomer during in situ polymerization resulted in reasonable electrical conductivity of $\sim 0.028 \text{ Sm}^{-1}$. In addition, the resulting in situ polymerized polyamide 6/graphene nanocomposites have revealed the superior thermal conductivity of around $0.27 \text{ Wm}^{-1}\text{K}^{-1}$ [31,32]. In situ synthesis strategy has

also led to enhanced mechanical properties of the polyamide 6/graphene nanocomposites [33]. Elevated tensile strength and Young's modulus were found with 0.1 wt.% graphene nanofiller addition. The improved properties were accredited to the mutual interactions between the matrix and nanofillers leading to compatibility effects. Xu et al. [33] synthesized the polyamide 6 and graphene derived nanocomposites using in situ polymerization method. The caprolactam monomer was in situ polymerized by the ring-opening polymerization reaction [34]. The reaction was carried out in the presence of graphene oxide nanoparticles to follow the in situ process (**Figure 2**). This method involved the use of 6 aminocaproic acid for an in situ process. This technique caused fine dispersion of monomers as well as graphene nanoparticles in solvent medium, followed by the in situ polymerization to form the polyamide 6/graphene nanocomposite. **Figure 3** displays the stress strain curves of unfilled polyamide 6 as well as 0.01 and 0.1 wt.% nano-additive reinforced graphene nanocomposites. The 0.01 and 0.1 wt.% graphene loaded nanocomposite had tensile strength of 84 and 123 MPa, respectively, relative to neat matrix (56 MPa). Hereafter, the mechanical properties of the nanocomposites were found more than 50% higher than the unfilled matrix. Hence, this method has been suggested to minimize the nanoparticle dispersion responsible for improved features of the nanomaterials.

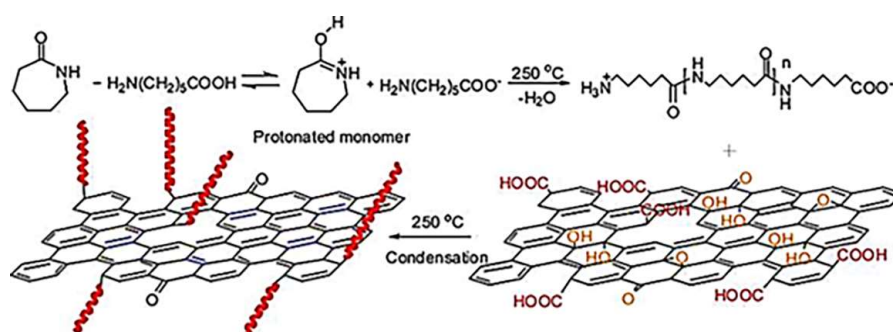


Figure 2. In situ synthesis strategy of graphene nanocomposite by in situ ring opening polymerization of caprolactam occurring in the presence of graphene oxide [33]. Reproduced with permission from ACS.

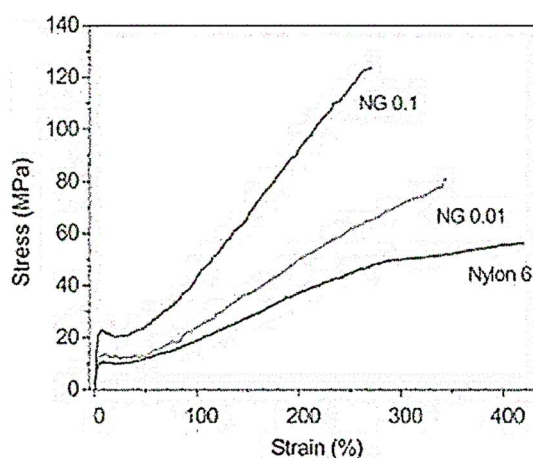


Figure 3. Stress strain curves of neat polyamide 6 and nano-graphene (NG) nanocomposites with 0.01 and 0.1 wt.% graphene additions [33]. Reproduced with permission from ACS.

Polystyrene, another commodity thermoplastic, has also been polymerized by in situ technique [35,36]. In the presence styrene monomer and graphene dispersion, in situ polymerization method is applied using surfactants [37,38]. Styrene monomer is absorbed on graphene surface and then polymerized leading to fine dispersion of nanoparticles and compatibility with the matrix [39,40]. In this way, in situ produced nanocomposite had fine interactions leading to high electron conduction, heat stabilization, glass transition, and other improved properties [41,42]. Poly(methyl methacrylate) and graphene derived nanocomposites have also been formed using in situ method and polymerizing the methyl methacrylate monomers [43,44]. Physical as well as covalent bindings have been observed between the poly(methyl methacrylate) and graphene nanoparticles [45]. Reports on waterborne polyurethane and graphene based in situ formed nanomaterials have also been found in literature [46,47]. Here again, interfacial interactions between matrix and nanofiller led to enhanced performance, so depicting the efficiency of in situ technique [48].

4. Solution strategies for graphene nanocomposites

Another common synthesis strategy to form graphene nanocomposites is the solution casting or solution synthesis or solvent based processing approaches [49,50]. Solvent method is a facile and low cost for the formation of graphene nanocomposites [51]. In this technique, polymer is dissolved in a suitable solvent and graphene nanosheets are also dispersed in an appropriate solvent [52]. Both the dispersions are mixed and stirred to form a homogeneous nanocomposite mixture (**Figure 4**). The nanocomposite formation occurs through the solvent evaporation step. Numerous thermoplastic polymers have been successfully formed by solution technique [53,54]. For example, polystyrene and graphene based nanocomposites have been prepared using the solution processing [55]. N-methyl-2-pyrrolidinone was used as a solvent to dissolve polystyrene and disperse graphene nanoparticles. Addition of 10 wt.% nanofiller enhanced the electrical conductivity of polystyrene matrix to $1.5 \times 10^{-7} \text{ Sm}^{-1}$ [56]. In this concern, the microstructure and matrix-nanofiller interactions in solution formed nanomaterials have been investigated [57].

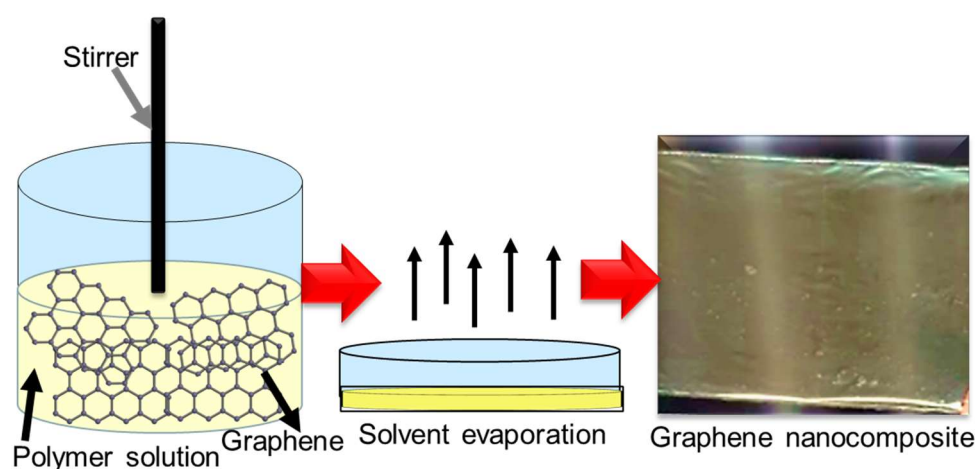


Figure 4. A simple route of solution method.

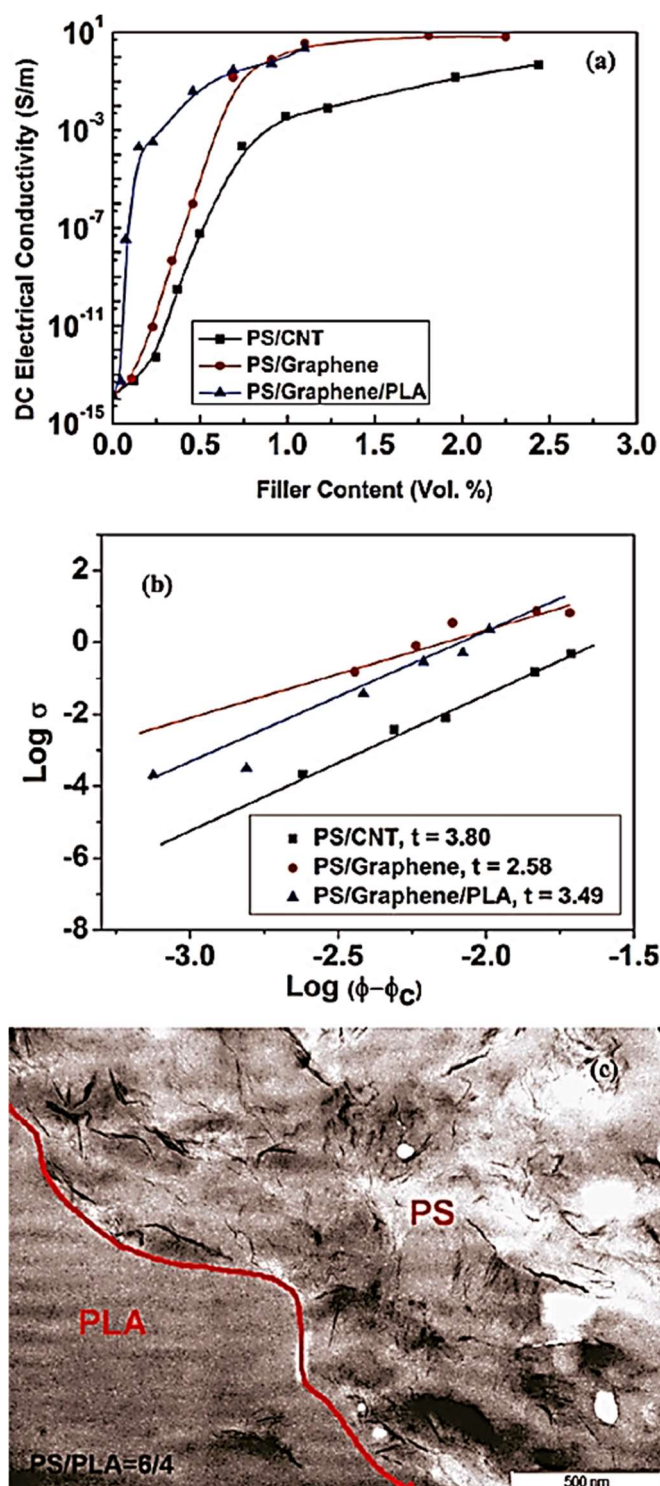


Figure 5. (a) Electrical conductivity versus filler content for neat polystyrene (PS) and its nanocomposites; (b) Double-logarithmic plot of electrical conductivity versus $\phi - \phi_c$, where ϕ is the filler volume fraction and ϕ_c is the percolation threshold; and (c) Transmission electron microscopy image of PS:PLA (6:4) composite with ~ 0.46 vol.% (~ 1.0 wt.%) graphene additives. The selective localization of graphene in the polystyrene region is evident from the image [58]. PS/CNT = polystyrene/carbon nanotube; PS = polystyrene; PLA = poly (lactic acid); PS/PLA = polystyrene/poly (lactic acid). Reproduced with permission from ACS.

Qi et al. [58] synthesized polystyrene/graphene, polystyrene/graphene/poly(lactic acid), and polystyrene/carbon nanotube nanocomposites using solution strategy. **Figure 5** demonstrates increase in the electrical conductivity of the polystyrene/graphene nanocomposites with the addition of 0.1 to 0.69 vol.% nanofiller. High electrical conductivity of 3.49 Sm^{-1} was observed with 1.1 vol.% graphene contents. Nanoparticle dispersion formed conducting network in the matrix to improve the electrical conductivity values at percolation threshold. Furthermore, double-logarithmic plots of the polystyrene/graphene (0.33 vol.%) and polystyrene/carbon nanotube (0.50 vol.%) nanocomposites depicted values at 3.80 and 2.58, respectively. Transmission electron microscopy image of polystyrene/poly(lactic acid) blend showed two phase morphology. Graphene nanoparticles can be seen dispersed in the polystyrene matrix.

Poly (methyl methacrylate) and graphene based nanocomposites have been reported using the solution technique [59]. These nanomaterials have been studied for morphology, electrical conductivity, and mechanical characters [60]. The poly (methyl methacrylate) filled with 2.0 wt.% graphene contents had high electrical conductivity of 0.04 Sm^{-1} . Enhancement in electrical conductivity was attributed to the formation of interlinked graphene network in the matrix [61]. Polyethylene and graphene based nanocomposites were also formed using the solution method [62,63]. Similarly, poly(vinyl alcohol) and graphene based nanomaterials have been developed using solvent method [64]. Inclusion of 6.5 vol.% graphene to the matrix led to high conductivity of 0.06 Scm^{-1} . In addition, the Young's modulus of poly(vinyl alcohol) was enhanced by 58 % [65]. Consequently, the low cost, simple, and ecofriendly solution technique has been applied on variety of thermoplastics and graphene nanofillers. The resulting high performance nanocomposites have superior dispersion, electrical and thermal conductivity, glass transition temperature, thermal stability, and mechanical strength performances [66,67].

5. Melt strategy for graphene nanocomposites

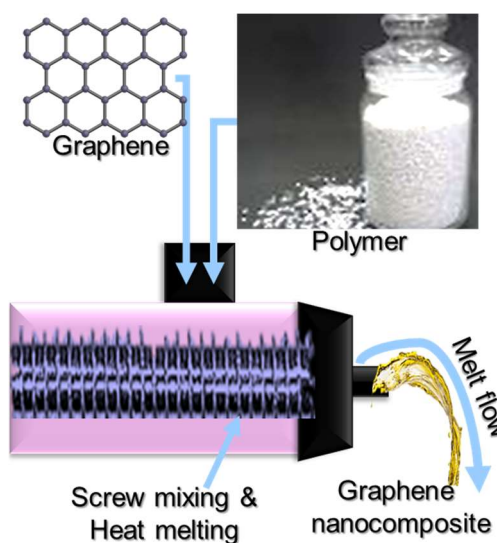


Figure 6. Schematic of melt strategy.

Melt strategy or melt extrusion technique has also been widely used for the

formation of polymer/graphene nanocomposites [68,69]. In this process, polymer as well as graphene are filled in an extruder using high temperature and shear rate conditions for melt processing (**Figure 6**). Melt technique has been used for better dispersal and chain alignment processes [70,71]. Commonly used polymers include polyamide matrices [72]. The polyamide 12 and graphene derived nanocomposites have been formed by melt compounding method [73]. Including 1.38 vol.% graphene loading enhanced the electrical conductivity to $6.7 \times 10^{-2} \text{ Sm}^{-1}$ [74].

Subsequently, numerous thermoplastic matrices have been melt processed with graphene nanoparticles [75]. Polystyrene and graphene based nanocomposites have been developed using melt blending [76,77]. These nanomaterials have revealed fine dispersion and electron conduction features. Shen and colleagues [78] industrialized the polystyrene and graphene derivatives nanocomposites through melt blending. **Figure 7** shows a schematic for the development of π - π stacking interactions in melt blending of polystyrene/graphene nanomaterials. Due to high shear forces, polymer chains are inserted between the graphene nanosheets. **Figure 8** reveals the thermogravimetric analysis of the polystyrene/functional graphene nanocomposites. Inclusion of 5 to 60 wt.% nanofiller considerably boosted the thermal stability of the polystyrene matrix.

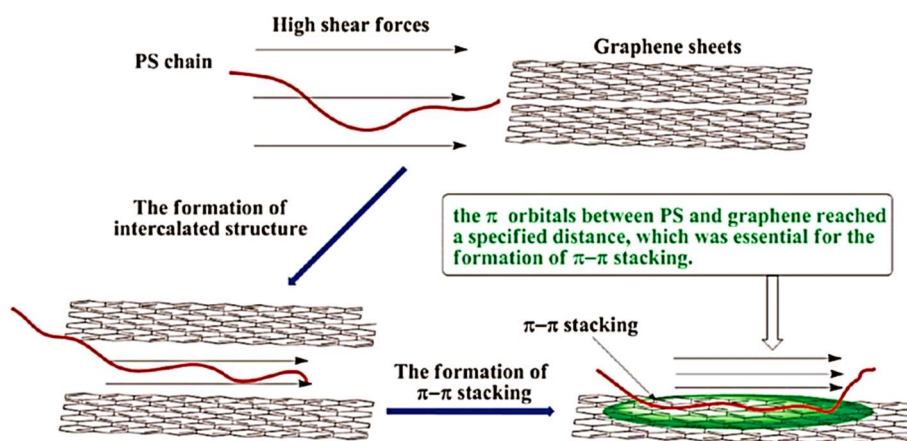


Figure 7. Schematic for the formation of π - π stacking during melt blending [78]. PS = polystyrene. Reproduced with permission from ACS.

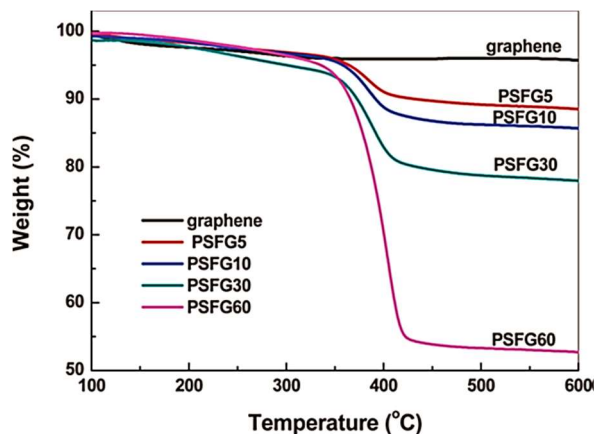


Figure 8. Thermogravimetric analysis curves of nanocomposites. PSFG = polystyrene/functional graphene. 5, 10, 30, 60 = nanofiller contents in designations [78]. Reproduced with permission from ACS.

The graphene filled polypropylene nanocomposites were processed using melt blending technique for enhanced electrical, thermal, and mechanical features [79]. The elevated performance was attributed to the interfacial interactions in the matrix-nanofiller [80]. Melt processed graphene filled polyethylene and polyethylene terephthalate nanocomposites have been developed with elevated strength features [81,82]. The poly(methyl methacrylate) nanocomposites with graphene have also been prepared through melt blending practice [83]. Melt strategy has been found facile, low cost, and large scale processable [84,85]. By controlling the reaction temperature, time, and shear and extrusion rate may define fine dispersion in the polymeric matrices [86,87].

6. More synthesis strategies

For graphene nanocomposites, solution approaches have been applied as effective methods, however, complex post treatments must be used for solvent evaporation [88]. Range of other synthesis strategies have been found effective for the formation of graphene nanocomposites. Essential processing techniques include three or four dimensional printing approaches [89]. Among printing methods, stereolithography [90], inkjet printing [91], selective laser sintering [92], direct ink writing [93], fused deposition modeling [94], and others have been used. Printing techniques have been used to enhance the dispersion as well as end properties and performances of the graphene nanomaterials [95,96]. Choice of a particular printing technique has been found critical to form the desired material and properties. Accordingly, the performance of printed material relies on the polymer type, nanoparticle dispersion, interactions, and printing parameters. The direct three dimensional printing involves the extrusion of viscous material from the pressurized syringe to form the three dimensional shapes. The fused deposition modeling printing performs with controlled filament extrusion. By controlling the printing parameters, product quality can be managed. The selective laser sintering uses high power lasers to fuse the powder and product resolution depends upon the powder specifications, laser power and scan speed. Electrospinning has also been adopted as an efficient and sophisticated method to form the high-tech nanomaterials [97,98]. By using electrospinning, finely reinforced graphene nanocomposites have been designed [98,99]. This technique may include a syringe, spinneret, collector, and voltage based system [100,101]. Resulting electrospun graphene nanocomposite nanofibers have been tested for high electrical, mechanical, thermal, and other advanced technical features [102]. **Table 1** displays essential details of some literature reported graphene filled nanocomposite designs formed using the efficient synthesis strategies. Hence, the manufacturing technique relies on the inherent features of graphene nanomaterials.

Table 1. Specs of graphene nanocomposites thru various synthesis strategies.

Matrices	Nanofiller	Manufacturing	Ref.
Polystyrene	Graphene	In situ polymerization	[35]
Polyamide 6	Graphene	In situ polymerization	[31]
Polyamide 6	Graphene	In situ polymerization	[32]
Polystyrene	Graphene	Solution method	[56]

Table 1. (Continued).

Matrices	Nanofiller	Manufacturing	Ref.
Poly (methyl methacrylate)	Graphene	Solution method	[60]
Poly (methyl methacrylate)	Graphene	Solution method	[61]
Poly (vinyl alcohol)	Graphene	Solution method	[64]
Polystyrene, polycarbonate, polypropylene, high density polyethylene, low density polyethylene	Graphene	Melt compounding	[75]
Poly (methyl methacrylate), polystyrene, polybutyl acrylate	Graphene	Atom transfer radical polymerization	[103]
Polystyrene, poly (methyl methacrylate), poly (vinyl fluoride)	Graphene	Colloid method	[104]

7. Scenarios and conclusions

Graphene nanocomposites have been designed using several simple and sophisticated synthesis strategies (**Figure 9**) [105]. Choice of a particular technique always relies on the cost, ease of processing, and opportunities for the large scale production [106,107]. Accordingly, graphene dispersion, matrix-nanofiller interactions, and interface developments were influenced. Consequently, suitable synthesis technique has been found important to improve the nanocomposite features and end uses of the graphene nanocomposites [108]. Here, each synthesis method owns relevant advantages and disadvantages towards the formation of graphene nanomaterials [109].

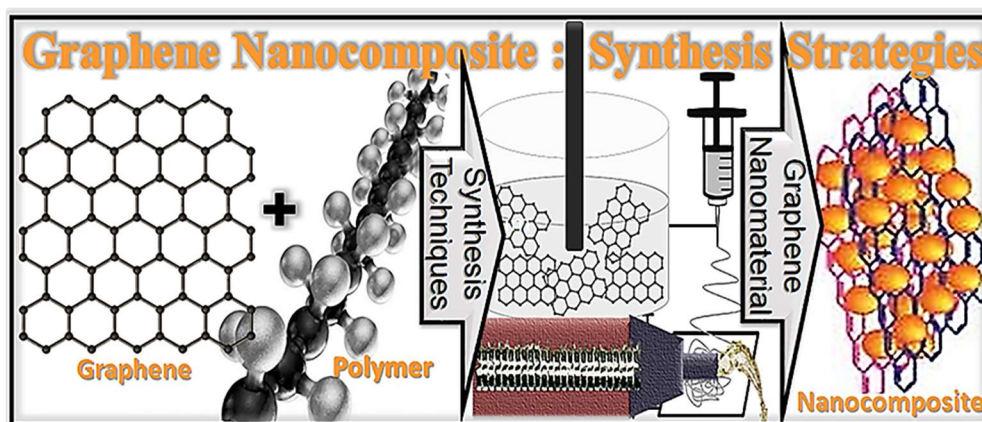


Figure 9. Synthesis strategies for graphene nanocomposites.

Solution synthesis is a simple method; however, this may include drawback of using toxic solvent. The in situ technique, on the other hand, has resolved this issue by using environmental friendly solvents [110]. Melt method has also been found beneficial avoiding the use of any toxic solvent. Sometimes melt extrusion method may has drawback of poor graphene dispersion in the nanocomposites. Therefore, the nanofiller dispersion depends on the type of synthesis strategy used. Sophisticated techniques like printing and electrospinning have been found effective to form well dispersed high performance graphene nanocomposites [111]. However, these techniques have drawbacks of high cost and limitations for large scale processing [112,113]. Moreover, nanoparticle aggregation has been found challenging in sophisticated techniques like coating and prating [114]. Beside studying the

experimentally processed graphene nanocomposites, theoretical approaches like molecular dynamics or simulation must be applied for graphene nanomaterials [115]. Henceforth, research efforts have focused the use of appropriate synthesis techniques and controlled processing parameters to attain high performance graphene nanocomposites. Main application areas recognized for the well processed graphene nanocomposites include batteries, supercapacitors, solar cells, fuel cell, coatings, membranes, engineering structure, and space, automobile, and other transportation sectors.

In short, this article summarizes the synthesis strategies widely used for the formation of graphene nanocomposites. Most importantly, in situ strategy, solution processing, melt blending, printing, spinning and numerous other methods can be adopted for the development of efficient graphene filled nanomaterials. Here, opting suitable method may reveal fine graphene dispersion, matrix-nanofiller associations, and physical property enhancements. In this context, important microstructure, electrical, thermal, and mechanical features were improved with the graphene additions. Consequently, the nanocomposite performance was enhanced by controlling the parameters of synthesis strategies used. Future progress on the processing of graphene nanocomposites may lead to the development of advanced next level approaches for the formation of high-tech nanomaterials.

Conflict of interest: The authors declare no conflict of interest.

References

1. Kausar A, Ahmad I, Lam TD. High-tech graphene oxide reinforced conducting matrix nanocomposites—Current status and progress. *Characterization and Application of Nanomaterials*. 2023; 6(1). doi: 10.24294/can.v6i1.2637
2. Kausar A, Ahmad I. Graphene and nanocomposites—Imprints on environmentally sustainable production and applications based on ecological aspects. *Characterization and Application of Nanomaterials*. 2024; 7(1): 4226. doi: 10.24294/can.v7i1.4226
3. Kausar A, Ahmad I. Cutting-edge conjugated nanocomposites—Fundamentals and anti-corrosion significance. *Characterization and Application of Nanomaterials*. 2023; 6(2): 3361. doi: 10.24294/can.v6i2.3361
4. Idumah CI. Phosphorene polymeric nanocomposites for biomedical applications: a review. *International Journal of Polymeric Materials and Polymeric Biomaterials*. 2022; 73(4): 292-309. doi: 10.1080/00914037.2022.2158333
5. Cai C, Liu L, Fu Y. Processable conductive and mechanically reinforced polylactide/graphene bionanocomposites through interfacial compatibilizer. *Polymer Composites*. 2017; 40(1): 389-400. doi: 10.1002/pc.24663
6. Potts JR, Dreyer DR, Bielawski CW, et al. Graphene-based polymer nanocomposites. *Polymer*. 2011; 52(1): 5-25. doi: 10.1016/j.polymer.2010.11.042
7. Tripathy DB, Gupta A. Nanocomposites as sustainable smart materials: A review. *Journal of Reinforced Plastics and Composites*. Published online February 13, 2024. doi: 10.1177/07316844241233162
8. Yousefi N, Gudarzi MM, Zheng Q, et al. Self-alignment and high electrical conductivity of ultralarge graphene oxide-polyurethane nanocomposites. *Journal of Materials Chemistry*. 2012; 22(25): 12709. doi: 10.1039/c2jm30590a
9. Goyal M, Singh K, Bhatnagar N. Conductive polymers: A multipurpose material for protecting coating. *Progress in Organic Coatings*. 2024; 187: 108083. doi: 10.1016/j.porgcoat.2023.108083
10. Yan Y, Han M, Jiang Y, et al. Electrically Conductive Polymers for Additive Manufacturing. *ACS Applied Materials & Interfaces*. 2024; 16(5): 5337-5354. doi: 10.1021/acsami.3c13258
11. Balaji KV, Shirvanimoghaddam K, Naebe M. Multifunctional basalt fiber polymer composites enabled by carbon nanotubes and graphene. *Composites Part B: Engineering*. 2024; 268: 111070. doi: 10.1016/j.compositesb.2023.111070

12. Lee SH, Luvnish A, Su X, et al. Advancements in polymer (Nano)composites for phase change material-based thermal storage: A focus on thermoplastic matrices and ceramic/carbon fillers. *Smart Materials in Manufacturing*. 2024; 2: 100044. doi: 10.1016/j.smmf.2024.100044
13. Abbasi H, Antunes M, Velasco JI. Recent advances in carbon-based polymer nanocomposites for electromagnetic interference shielding. *Progress in Materials Science*. 2019; 103: 319-373. doi: 10.1016/j.pmatsci.2019.02.003
14. Gao Y, Zhang Y, Chen P, et al. Toward Single-Layer Uniform Hexagonal Boron Nitride–Graphene Patchworks with Zigzag Linking Edges. *Nano Letters*. 2013; 13(7): 3439-3443. doi: 10.1021/nl4021123
15. Berger C, Song Z, Li X, et al. Electronic Confinement and Coherence in Patterned Epitaxial Graphene. *Science*. 2006; 312(5777): 1191-1196. doi: 10.1126/science.1125925
16. Wei C, Negishi R, Ogawa Y, et al. Turbostratic multilayer graphene synthesis on CVD graphene template toward improving electrical performance. *Japanese Journal of Applied Physics*. 2019; 58(SI): SIIB04. doi: 10.7567/1347-4065/ab0c7b
17. Narayanam PK, Botcha VD, Ghosh M, et al. Growth and photocatalytic behavior of transparent reduced GO–ZnO nanocomposite sheets. *Nanotechnology*. 2019; 30(48): 485601. doi: 10.1088/1361-6528/ab3ced
18. Zandiatashbar A, Lee GH, An SJ, et al. Effect of defects on the intrinsic strength and stiffness of graphene. *Nature Communications*. 2014; 5(1). doi: 10.1038/ncomms4186
19. Shen X, Zeng X, Dang C. Graphene Composites. *Handbook of Graphene*. Published online June 17, 2019: 1-25. doi: 10.1002/9781119468455.ch53
20. Zhou Q, Xia G, Du M, et al. Scotch-tape-like exfoliation effect of graphene quantum dots for efficient preparation of graphene nanosheets in water. *Applied Surface Science*. 2019; 483: 52-59. doi: 10.1016/j.apsusc.2019.03.290
21. Pei S, Cheng HM. The reduction of graphene oxide. *Carbon*. 2012; 50(9): 3210-3228. doi: 10.1016/j.carbon.2011.11.010
22. Lee H, Lee KS. Interlayer distance controlled graphene, supercapacitor and method of producing the same. US20150103469A1, 26 February 2019.
23. Tang C, Titirici MM, Zhang Q. A review of nanocarbons in energy electrocatalysis: Multifunctional substrates and highly active sites. *Journal of Energy Chemistry*. 2017; 26(6): 1077-1093. doi: 10.1016/j.jechem.2017.08.008
24. Panwar N, Soehartono AM, Chan KK, et al. Nanocarbons for Biology and Medicine: Sensing, Imaging, and Drug Delivery. *Chemical Reviews*. 2019; 119(16): 9559-9656. doi: 10.1021/acs.chemrev.9b00099
25. Sen Gupta R, Mandal S, Malakar A, et al. Graphene oxide offers precise molecular sieving, structural integrity, microplastic removal, and closed-loop circularity in water-remediating membranes through a covalent adaptable network. *Journal of Materials Chemistry A*. 2024; 12(1): 321-334. doi: 10.1039/d3ta04539k
26. Owji E, Ostovari F, Keshavarz A. Influence of the chemical structure of diisocyanate on the electrical and thermal properties of in situ polymerized polyurethane–graphene composite films. *Physical Chemistry Chemical Physics*. 2022; 24(46): 28564-28576. doi: 10.1039/d2cp03826a
27. Ajaj Y, AL-Salman HNK, Hussein AM, et al. Effect and investigating of graphene nanoparticles on mechanical, physical properties of polylactic acid polymer. *Case Studies in Chemical and Environmental Engineering*. 2024; 9: 100612. doi: 10.1016/j.cscee.2024.100612
28. Yang C, Gede M, Abdulhamid MA, et al. Solvent and material selection for greener membrane manufacturing. *Current Trends and Future Developments on (Bio-) Membranes*. Published online 2024: 249-293. doi: 10.1016/b978-0-323-99311-1.00016-7
29. Itapu B, Jayatissa A. A Review in Graphene/Polymer Composites. *Chemical Science International Journal*. 2018; 23(3): 1-16. doi: 10.9734/csji/2018/41031
30. Zheng D, Tang G, Zhang HB, et al. In situ thermal reduction of graphene oxide for high electrical conductivity and low percolation threshold in polyamide 6 nanocomposites. *Composites Science and Technology*. 2012; 72(2): 284-289. doi: 10.1016/j.compscitech.2011.11.014
31. Chen J, Chen X, Meng F, et al. Super-high thermal conductivity of polyamide-6/graphene-graphene oxide composites through in situ polymerization. *High Performance Polymers*. 2016; 29(5): 585-594. doi: 10.1177/0954008316655861
32. Ding P, Su S, Song N, et al. Influence on thermal conductivity of polyamide-6 covalently-grafted graphene nanocomposites: varied grafting-structures by controllable macromolecular length. *RSC Advances*. 2014; 4(36): 18782. doi: 10.1039/c4ra00500g
33. Xu Z, Gao C. In situ Polymerization Approach to Graphene-Reinforced Nylon-6 Composites. *Macromolecules*. 2010; 43(16): 6716-6723. doi: 10.1021/ma1009337

34. Wang S, Zhang L, Zeng Q, et al. Designing Polymer Electrolytes via Ring-Opening Polymerization for Advanced Lithium Batteries. *Advanced Energy Materials*. 2023; 14(3). doi: 10.1002/aenm.202302876
35. Lu Y, Wang X, Chen D, et al. Polystyrene/graphene composite electrode fabricated by in situ polymerization for capillary electrophoretic determination of bioactive constituents in *Herba Houttuyniae*. *Electrophoresis*. 2011; 32(14): 1906-1912. doi: 10.1002/elps.201100162
36. Muthukumar J, Kandukuri VA, Chidambaram R. A critical review on various treatment, conversion, and disposal approaches of commonly used polystyrene. *Polymer Bulletin*. 2023; 81(4): 2819-2845. doi: 10.1007/s00289-023-04851-0
37. Babaie B, Najafi M, Ataefard M. Designing an optimised formulation for in situ emulsion polymerization: printing ink production by response surface methodology. *Pigment & Resin Technology*. Published online February 21, 2024. doi: 10.1108/prt-10-2023-0091
38. Wang Y, Lu Q, Xie H, et al. In-situ formation of nitrogen doped microporous carbon nanospheres derived from polystyrene as lubricant additives for anti-wear and friction reduction. *Friction*. 2023; 12(3): 439-451. doi: 10.1007/s40544-023-0766-2
39. Wang X, Hu Y, Song L, et al. In situ polymerization of graphene nanosheets and polyurethane with enhanced mechanical and thermal properties. *Journal of Materials Chemistry*. 2011; 21(12): 4222. doi: 10.1039/c0jm03710a
40. Milani MA, González D, Quijada R, et al. Polypropylene/graphene nanosheet nanocomposites by in situ polymerization: Synthesis, characterization and fundamental properties. *Composites Science and Technology*. 2013; 84: 1-7. doi: 10.1016/j.compscitech.2013.05.001
41. Patole AS, Patole SP, Kang H, et al. A facile approach to the fabrication of graphene/polystyrene nanocomposite by in situ microemulsion polymerization. *Journal of Colloid and Interface Science*. 2010; 350(2): 530-537. doi: 10.1016/j.jcis.2010.01.035
42. Hu H, Wang X, Wang J, et al. Preparation and properties of graphene nanosheets-polystyrene nanocomposites via in situ emulsion polymerization. *Chemical Physics Letters*. 2010; 484(4-6): 247-253. doi: 10.1016/j.cplett.2009.11.024
43. Wang J, Hu H, Wang X, et al. Preparation and mechanical and electrical properties of graphene nanosheets-poly(methyl methacrylate) nanocomposites via in situ suspension polymerization. *Journal of Applied Polymer Science*. 2011; 122(3): 1866-1871. doi: 10.1002/app.34284
44. Ahmed MAM, Jurczak KM, Lynn NS, et al. Rapid prototyping of PMMA-based microfluidic spheroid-on-a-chip models using micromilling and vapour-assisted thermal bonding. *Scientific Reports*. 2024; 14(1). doi: 10.1038/s41598-024-53266-y
45. Salam MA, Alsultany FH, Al-Bermamy E, et al. Impact of graphene oxide nanosheets and polymethyl methacrylate on nano/hybrid-based restoration dental filler composites: ultrasound behavior and antibacterial activity. *Journal of Ultrasound*. Published online February 7, 2024. doi: 10.1007/s40477-023-00855-8
46. Lee YR, Raghu AV, Jeong HM, et al. Properties of Waterborne Polyurethane/Functionalized Graphene Sheet Nanocomposites Prepared by an in situ Method. *Macromolecular Chemistry and Physics*. 2009; 210(15): 1247-1254. doi: 10.1002/macp.200900157
47. Yang L, Huang R, Yuan J, et al. High thermal conductive polyurethane composite films with a three-dimensional boron nitride network in-situ constructed by multi-folding and multi-laminating. *Composites Science and Technology*. 2024; 245: 110326. doi: 10.1016/j.compscitech.2023.110326
48. Mishra SK, Tripathi SN, Choudhary V, et al. SPR based fibre optic ammonia gas sensor utilizing nanocomposite film of PMMA/reduced graphene oxide prepared by in situ polymerization. *Sensors and Actuators B: Chemical*. 2014; 199: 190-200. doi: 10.1016/j.snb.2014.03.109
49. Ganguly S. Preparation/processing of polymer-graphene composites by different techniques. *Polymer Nanocomposites Containing Graphene*. Published online 2022: 45-74. doi: 10.1016/b978-0-12-821639-2.00015-x
50. D'Amore A, Ali Z, yaqoob saba, et al. Advancements in Graphene-Based Hybrid Filler Polymer Composites: A Comprehensive Survey of Processing, Properties, and Influential Factors. Published online February 26, 2024. doi: 10.20944/preprints202402.1412.v1
51. Wu K, Tan J, Liu Z, et al. Incombustible solid polymer electrolytes: A critical review and perspective. *Journal of Energy Chemistry*. 2024; 93: 264-281. doi: 10.1016/j.jechem.2024.01.013
52. Zhang J, Liang B, Long J. Preparation and characteristics of composite films with functionalized graphene/polyimide. *Journal of Applied Polymer Science*. 2023; 141(10). doi: 10.1002/app.55045
53. Hu K, Kulkarni DD, Choi I, et al. Graphene-polymer nanocomposites for structural and functional applications. *Progress in Polymer Science*. 2014; 39(11): 1934-1972. doi: 10.1016/j.progpolymsci.2014.03.001

54. Panzer F, Dyson MJ, Bakr H, et al. A Unified Picture of Aggregate Formation in a Model Polymer Semiconductor during Solution Processing. *Advanced Functional Materials*. Published online February 13, 2024. doi: 10.1002/adfm.202314729
55. He F, Lam KH, Fan J, et al. Improved dielectric properties for chemically functionalized exfoliated graphite nanoplates/syndiotactic polystyrene composites prepared by a solution-blending method. *Carbon*. 2014; 80: 496-503. doi: 10.1016/j.carbon.2014.08.089
56. Yu YH, Lin YY, Lin CH, et al. High-performance polystyrene/graphene-based nanocomposites with excellent anti-corrosion properties. *Polym Chem*. 2014; 5(2): 535-550. doi: 10.1039/c3py00825h
57. Zhao F, Zhang G, Zhao S, et al. Fabrication of pristine graphene-based conductive polystyrene composites towards high performance and light-weight. *Composites Science and Technology*. 2018; 159: 232-239. doi: 10.1016/j.compscitech.2018.02.013
58. Qi XY, Yan D, Jiang Z, et al. Enhanced Electrical Conductivity in Polystyrene Nanocomposites at Ultra-Low Graphene Content. *ACS Applied Materials & Interfaces*. 2011; 3(8): 3130-3133. doi: 10.1021/am200628c
59. Kausar A, Bocchetta P. Poly(methyl methacrylate) Nanocomposite Foams Reinforced with Carbon and Inorganic Nanoparticles—State-of-the-Art. *Journal of Composites Science*. 2022; 6(5): 129. doi: 10.3390/jcs6050129
60. Zeng X, Yang J, Yuan W. Preparation of a poly(methyl methacrylate)-reduced graphene oxide composite with enhanced properties by a solution blending method. *European Polymer Journal*. 2012; 48(10): 1674-1682. doi: 10.1016/j.eurpolymj.2012.07.011
61. Balasubramaniyan R, Pham VH, Jang J, et al. A one pot solution blending method for highly conductive poly (methyl methacrylate)-highly reduced graphene nanocomposites. *Electronic Materials Letters*. 2013; 9(6): 837-839. doi: 10.1007/s13391-013-6025-3
62. Kuila T, Bose S, Hong CE, et al. Preparation of functionalized graphene/linear low density polyethylene composites by a solution mixing method. *Carbon*. 2011; 49(3): 1033-1037. doi: 10.1016/j.carbon.2010.10.031
63. Chen M, Peng B, Guo X, et al. Polyethylene interfacial dielectric layer for organic semiconductor single crystal based field-effect transistors. *Chinese Chemical Letters*. 2024; 35(4): 109051. doi: 10.1016/j.ccllet.2023.109051
64. Vadukumpully S, Paul J, Mahanta N, et al. Flexible conductive graphene/poly(vinyl chloride) composite thin films with high mechanical strength and thermal stability. *Carbon*. 2011; 49(1): 198-205. doi: 10.1016/j.carbon.2010.09.004
65. Kausar A, Rafique I, Anwar Z, et al. Perspectives of Epoxy/Graphene Oxide Composite: Significant Features and Technical Applications. *Polymer-Plastics Technology and Engineering*. 2015; 55(7): 704-722. doi: 10.1080/03602559.2015.1098700
66. Chen W, Weimin H, Li D, et al. A critical review on the development and performance of polymer/graphene nanocomposites. *Science and Engineering of Composite Materials*. 2018; 25(6): 1059-1073. doi: 10.1515/secm-2017-0199
67. Hu T, Ye H, Luo Z, et al. Efficient exfoliation of UV-curable, high-quality graphene from graphite in common low-boiling-point organic solvents with a designer hyperbranched polyethylene copolymer and their applications in electrothermal heaters. *Journal of Colloid and Interface Science*. 2020; 569: 114-127. doi: 10.1016/j.jcis.2020.02.068
68. Gill YQ, Ehsan H, Mehmood U, et al. A novel two-step melt blending method to prepare nano-silanized-silica reinforced crosslinked polyethylene (XLPE) nanocomposites. *Polymer Bulletin*. 2022; 79(11): 10077-10093. doi: 10.1007/s00289-021-03989-z
69. Kaczor DP, Bajer K, Raszowska-Kaczor A, et al. Screw Extrusion as a Scalable Technology for Manufacturing Polylactide Composite with Graphene Filler. *Advances in Science and Technology Research Journal*. 2024; 18(2): 226-237. doi: 10.12913/22998624/184152
70. Tan B, Thomas NL. A review of the water barrier properties of polymer/clay and polymer/graphene nanocomposites. *Journal of Membrane Science*. 2016; 514: 595-612. doi: 10.1016/j.memsci.2016.05.026
71. Liu Y, Davies R, McCutcheon P, et al. Fabrication of functionalised graphene-PAEK nanocomposites for different manufacturing processes. *Virtual and Physical Prototyping*. 2023; 19(1). doi: 10.1080/17452759.2023.2283884
72. Scaffaro R, Maio A. A green method to prepare nanosilica modified graphene oxide to inhibit nanoparticles re-aggregation during melt processing. *Chemical Engineering Journal*. 2017; 308: 1034-1047. doi: 10.1016/j.cej.2016.09.131
73. Yan D, Zhang HB, Jia Y, et al. Improved Electrical Conductivity of Polyamide 12/Graphene Nanocomposites with Maleated Polyethylene-Octene Rubber Prepared by Melt Compounding. *ACS Applied Materials & Interfaces*. 2012; 4(9): 4740-4745. doi: 10.1021/am301119b
74. Kausar A. In-situ modified graphene reinforced polyamide 1010/poly(ether amide): mechanical, thermal, and barrier properties. *Materials Research Innovations*. 2017; 23(4): 191-199. doi: 10.1080/14328917.2017.1409392

75. Mittal V, Chaudhry AU. Polymer – graphene nanocomposites: effect of polymer matrix and filler amount on properties. *Macromolecular Materials and Engineering*. 2015; 300(5): 510-521. doi: 10.1002/mame.201400392
76. Shen B, Zhai W, Tao M, et al. Enhanced interfacial interaction between polycarbonate and thermally reduced graphene induced by melt blending. *Composites Science and Technology*. 2013; 86: 109-116. doi: 10.1016/j.compscitech.2013.07.007
77. Mohammadsalih ZG, Uddin Siddiqui V, Sapuan SM. The role of organic solvent and nano-additives loading in preparing and characterizing graphene oxide based polystyrene nanocomposites. *Polymer-Plastics Technology and Materials*. 2024; 1-12. doi: 10.1080/25740881.2024.2325431
78. Shen B, Zhai W, Chen C, et al. Melt Blending In situ Enhances the Interaction between Polystyrene and Graphene through π - π Stacking. *ACS Applied Materials & Interfaces*. 2011; 3(8): 3103-3109. doi: 10.1021/am200612z
79. El Achaby M, Arrakhiz F, Vaudreuil S, et al. Mechanical, thermal, and rheological properties of graphene-based polypropylene nanocomposites prepared by melt mixing. *Polymer Composites*. 2012; 33(5): 733-744. doi: 10.1002/pc.22198
80. Ryu SH, Shanmugaraj AM. Influence of hexamethylene diamine functionalized graphene oxide on the melt crystallization and properties of polypropylene nanocomposites. *Materials Chemistry and Physics*. 2014; 146(3): 478-486. doi: 10.1016/j.matchemphys.2014.03.056
81. Istrate OM, Paton KR, Khan U, et al. Reinforcement in melt-processed polymer–graphene composites at extremely low graphene loading level. *Carbon*. 2014; 78: 243-249. doi: 10.1016/j.carbon.2014.06.077
82. Maiti S, Suin S, Shrivastava NK, et al. Low percolation threshold in polycarbonate/multiwalled carbon nanotubes nanocomposites through melt blending with poly(butylene terephthalate). *Journal of Applied Polymer Science*. 2013; 130(1): 543-553. doi: 10.1002/app.39168
83. Jiang S, Gui Z, Bao C, et al. Preparation of functionalized graphene by simultaneous reduction and surface modification and its polymethyl methacrylate composites through latex technology and melt blending. *Chemical Engineering Journal*. 2013; 226: 326-335. doi: 10.1016/j.cej.2013.04.068
84. Anwar Z, Kausar A, Rafique I, et al. Advances in Epoxy/Graphene Nanoplatelet Composite with Enhanced Physical Properties: A Review. *Polymer-Plastics Technology and Engineering*. 2015; 55(6): 643-662. doi: 10.1080/03602559.2015.1098695
85. Papageorgiou DG, Kinloch IA, Young RJ. Mechanical properties of graphene and graphene-based nanocomposites. *Progress in Materials Science*. 2017; 90: 75-127. doi: 10.1016/j.pmatsci.2017.07.004
86. Mittal V. Functional Polymer Nanocomposites with Graphene: A Review. *Macromolecular Materials and Engineering*. 2014; 299(8): 906-931. doi: 10.1002/mame.201300394
87. Du J, Cheng H. The Fabrication, Properties, and Uses of Graphene/Polymer Composites. *Macromolecular Chemistry and Physics*. 2012; 213(10-11): 1060-1077. doi: 10.1002/macp.201200029
88. Diniz FLJ, Lima TBS, Araujo ES, et al. Graphene-Based Flexible and Eco-Friendly Wearable Electronics and Humidity Sensors. *Materials Research*. 2024; 27. doi: 10.1590/1980-5373-mr-2023-0480
89. Wu JJ, Huang LM, Zhao Q, et al. 4D Printing: History and Recent Progress. *Chinese Journal of Polymer Science*. 2017; 36(5): 563-575. doi: 10.1007/s10118-018-2089-8
90. Kafle A, Luis E, Silwal R, et al. 3D/4D Printing of Polymers: Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA). *Polymers*. 2021; 13(18): 3101. doi: 10.3390/polym13183101
91. Guo Y, Patanwala HS, Bogner B, et al. Inkjet and inkjet-based 3D printing: connecting fluid properties and printing performance. *Rapid Prototyping Journal*. 2017; 23(3): 562-576. doi: 10.1108/rpj-05-2016-0076
92. Shirazi SFS, Gharekhani S, Mehrali M, et al. A review on powder-based additive manufacturing for tissue engineering: selective laser sintering and inkjet 3D printing. *Science and Technology of Advanced Materials*. 2015; 16(3): 033502. doi: 10.1088/1468-6996/16/3/033502
93. Wan X, Luo L, Liu Y, et al. Direct Ink Writing Based 4D Printing of Materials and Their Applications. *Advanced Science*. 2020; 7(16). doi: 10.1002/advs.202001000
94. Ponnamma D, Yin Y, Salim N, et al. Recent progress and multifunctional applications of 3D printed graphene nanocomposites. *Composites Part B: Engineering*. 2021; 204: 108493. doi: 10.1016/j.compositesb.2020.108493
95. Ul Hassan R, Sharipov M, Ryu W. Electrohydrodynamic (EHD) printing of nanomaterial composite inks and their applications. *Micro and Nano Systems Letters*. 2024; 12(1). doi: 10.1186/s40486-023-00194-7

96. Park SS, Park Y, Repo E, et al. Three-dimensionally printed scaffold coated with graphene oxide for enhanced heavy metal adsorption: Batch and fixed-bed column studies. *Journal of Water Process Engineering*. 2024; 57: 104658. doi: 10.1016/j.jwpe.2023.104658
97. Che H, Yuan J. Recent advances in electrospinning supramolecular systems. *Journal of Materials Chemistry B*. 2022; 10(1): 8-19. doi: 10.1039/d1tb02304g
98. Tiwari SK, Sahoo S, Wang N, et al. *Electrospinning of Graphene*. Springer International Publishing; 2021. doi: 10.1007/978-3-030-75456-3
99. Han Z, Wang J, Liu S, et al. Electrospinning of Neat Graphene Nanofibers. *Advanced Fiber Materials*. 2021; 4(2): 268-279. doi: 10.1007/s42765-021-00105-8
100. Li Y, Dong T, Li Z, et al. Review of advances in electrospinning-based strategies for spinal cord regeneration. *Materials Today Chemistry*. 2022; 24: 100944. doi: 10.1016/j.mtchem.2022.100944
101. Reneker DH, Yarin AL. Electrospinning jets and polymer nanofibers. *Polymer*. 2008; 49(10): 2387-2425. doi: 10.1016/j.polymer.2008.02.002
102. Gopiraman M, Fujimori K, Zeeshan K, et al. Structural and mechanical properties of cellulose acetate/graphene hybrid nanofibers: Spectroscopic investigations. *Express Polymer Letters*. 2013; 7(6): 554-563. doi: 10.3144/expresspolymlett.2013.52
103. Lee SH, Dreyer DR, An J, et al. Polymer Brushes via Controlled, Surface-Initiated Atom Transfer Radical Polymerization (ATRP) from Graphene Oxide. *Macromolecular Rapid Communications*. 2010; 31(3): 281-288. doi: 10.1002/marc.200900641
104. Zhao W, Wu F, Wu H, et al. Preparation of Colloidal Dispersions of Graphene Sheets in Organic Solvents by Using Ball Milling. *Journal of Nanomaterials*. 2010; 2010: 1-5. doi: 10.1155/2010/528235
105. Ganesan V, Jayaraman A. Theory and simulation studies of effective interactions, phase behavior and morphology in polymer nanocomposites. *Soft Matter*. 2014; 10(1): 13-38. doi: 10.1039/c3sm51864g
106. Gupta T, Ratandeeep, Dutt M, et al. Graphene-based nanomaterials as potential candidates for environmental mitigation of pesticides. *Talanta*. 2024; 272: 125748. doi: 10.1016/j.talanta.2024.125748
107. Banglani TH, Chandio I, Khilji MUN, et al. Graphene-based nanocomposites for gas sensors: challenges and opportunities. *Reviews in Inorganic Chemistry*. 2024; 0(0). doi: 10.1515/revic-2023-0033
108. Saeed M, Haq RSU, Ahmed S, et al. Recent advances in carbon nanotubes, graphene and carbon fibers-based microwave absorbers. *Journal of Alloys and Compounds*. 2024; 970: 172625. doi: 10.1016/j.jallcom.2023.172625
109. Wypych G. *Graphene: Important results and applications*. ChemTec Publishing; 2019.
110. Seyedjamali H, Pirisedigh A. Well-dispersed polyimide/TiO₂ nanocomposites: in situ sol-gel fabrication and morphological study. *Colloid and Polymer Science*. 2012; 290(7): 653-659. doi: 10.1007/s00396-012-2599-9
111. Wang B, Chen X, Ahmad Z, et al. 3D electrohydrodynamic printing of highly aligned dual-core graphene composite matrices. *Carbon*. 2019; 153: 285-297. doi: 10.1016/j.carbon.2019.07.030
112. Levchenko I, Ostrikov K, Zheng J, et al. Scalable graphene production: perspectives and challenges of plasma applications. *Nanoscale*. 2016; 8(20): 10511-10527. doi: 10.1039/c5nr06537b
113. Zhong YL, Tian Z, Simon GP, et al. Scalable production of graphene via wet chemistry: progress and challenges. *Materials Today*. 2015; 18(2): 73-78. doi: 10.1016/j.mattod.2014.08.019
114. Yan H, Tao X, Yang Z, et al. Effects of the oxidation degree of graphene oxide on the adsorption of methylene blue. *Journal of Hazardous Materials*. 2014; 268: 191-198. doi: 10.1016/j.jhazmat.2014.01.015
115. Rissanou A, Power A, Harmandaris V. Structural and Dynamical Properties of Polyethylene/Graphene Nanocomposites through Molecular Dynamics Simulations. *Polymers*. 2015; 7(3): 390-417. doi: 10.3390/polym7030390