Graphene-Based Polymer Nanocomposites Preparation and Their Advantages

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Graphene and its derivatives have attracted the attention of researchers since its discovery due to its surprising properties. Since then, scientists have been trying to improve the processes that allow the incorporation of this material into polymeric matrices, to improve them, through the development of graphene-based polymeric nanocomposites. This review study reviewed these methods meticulously. Furthermore, it has already been cataloged that adding small amounts of graphene nano-fillers tends to improve the polymers' mechanical, electrical, and thermal properties.

Keywords: Graphene. Nanocomposites. Polymers. Preparation Methods.

Introduction

Approximately 70 years ago, studies on graphene began, so-called then as "2D graphite". This name was given because its fine two-dimensional structure, resembling a honeycomb, which serves as a basis for other materials composed of graphite [1]. Nevertheless, what drew the most attention to this one, so far, new material, was its exceptional properties. With a specific strength of 48,000 kN m kg^{-1}, a characteristic suitable for improving the mechanical properties of polymers, together with Young's modulus of 1 TPa and fracture resistance of 130 GPa, graphene is considered one of the most robust material today [2].

Graphene oxide (GO), a product of the chemical oxidation and exfoliation of graphite, has, unlike graphene, hydroxy, and epoxy groups, which allows GO to have excellent solubility in water [3,4]. Furthermore, among the graphene derivatives (GO and rGO), graphene oxide has the highest interaction energy with polar polymer matrices, which makes it the most suitable polymer of this classification (Figure 1) [5].

Presenting intermediate properties to graphene and GO, such as good thermal and chemical stability and excellent electrical conductivity [6,7], reduced graphene oxide (rGO) comes from the reduction of oxygen in graphene oxide through a chemical or thermal process [5].

In order to improve the bond between the polymer and the graphene-based filler, the material is subjected to some processes, which allow graphene oxide to improve the properties of the polymer matrix, depending on the desired result with the mixture [5,8]. This surface functionalization process can be characterized into 2 types: covalent and non-covalent functionalization.

Because of the hydrophilic character of GO, due to the hydroxy and epoxy groups on its surface, small functional groups are covalently bonded to it, allowing the use of graphene oxide as a nanofiller [5]. This bond can usually be made by an aqueous solution [9]. In turn, the methods of covalent functionalization can be divided into 2 groups concerning how the covalent molecules will be integrated into the final compound.

The polymeric chains can be sintered before and then grafted onto graphene oxide through radical addition, nitrene chemistry, and amidation reaction, along with others [5]. It can also occur through the ATRP and RAFT methods, where macroinitiators are positioned on the surface, initiating the polymerization of the monomers (Figure 2) [5].

Unlike covalent functionalization, the non-covalent method has certain advantages regarding

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Figure 1. Process of transforming graphene into GO and rGO [5].

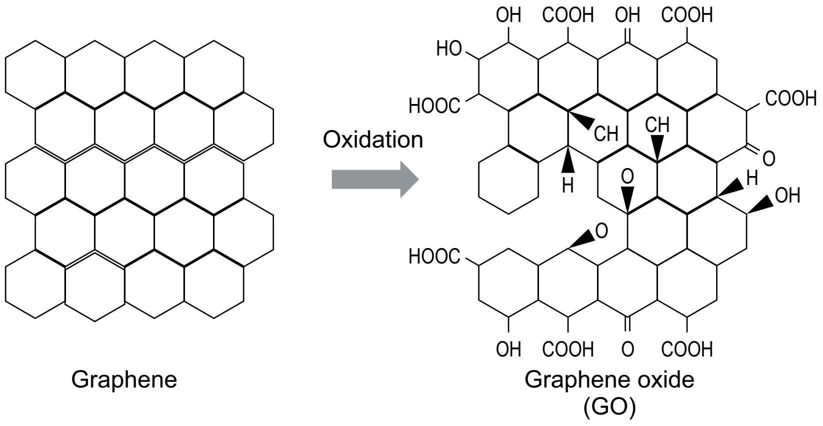
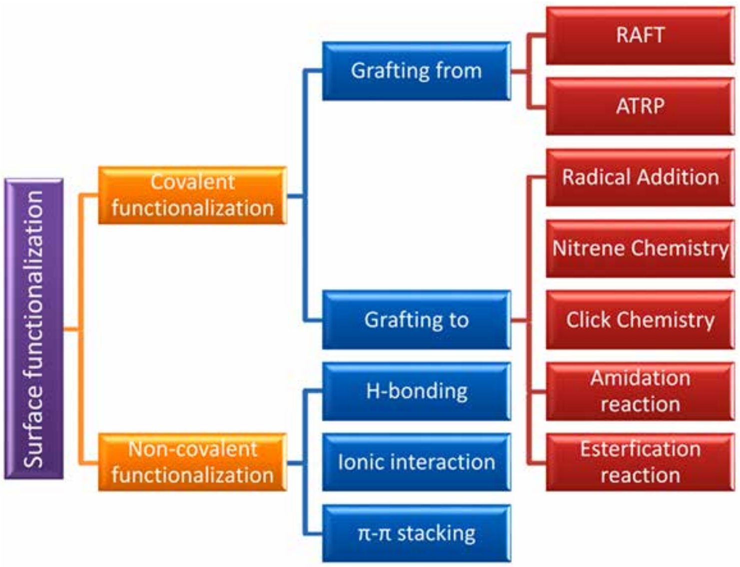


Figure 2. Classification of surface functionalization [5].



material properties, as it preserves the π-conjugation and the electronic characteristics of graphene oxide [5,9]. Furthermore, because it can be carried out in aqueous solutions at a temperature environment (mild conditions), the structure of the aromatic ring is preserved, in addition to preserving the GO nanosheets [9]. Non-covalent functionalization can occur through π-π interactions, ionic interactions, and hydrogen bonds [5].

Because of the current importance of graphene's properties, this work reviews the development of graphene-based polymeric nanocomposites.

Materials and Methods

For the development of the article, the Science Direct and Google Scholar tools were widely used to contribute to the selection of data used in the current review. In order to present current data, articles were meticulously searched using the following filters: texts published between 2012 and 2022, texts in English and present in review articles, scientific journals, and research articles.

Results and Discussion

Some methods aim to enable the synthesis of graphene-based polymer nanocomposites. For them to happen correctly, it is expected that the dispersion of graphene in the composite is as homogeneous as possible [5]. Each processing route has advantages and often presents different characteristics in the final product. Table 1 presents the primary methods found in the literature.

Over the decades, there has been an advance in the methods of synthesizing graphene-based polymer nanocomposites in terms of technologies and processes.

Developing these composites presents excellent advantages for the scientific society as a whole, as it guarantees a possibility of significant improvement of materials such as polymers through small additions of graphene and its derivatives (Table 2).

Just as the addition of graphene changes the nanocomposite's properties, the method used for this mixture also plays an essential role in the final product (Table 3).

Due to the significant improvement in the mechanical properties of the material, in addition to the cost-effectiveness for mass production, the

Table 1. Processing route of graphene-based polymer nanocomposites.

Processing Route	Procedure	Ref.
Dip-coating	It occurs when the substrate is immersed in a precursor solution composed of the polymer in a liquid state with graphene. In this way, the solution's components adhere to the surface of the immersed substrate, forming thin layers.	[5,12]
Casting	Graphene nano-filler fills a mold, adding the polymer to the entire filler. Then, heat is added to start the polymerization process when a uniform mixture is obtained.	[5]
Melt mixing	This process is done by pouring the graphene nano-filler and molten state polymer into a mixer, causing both to be homogeneously incorporated, producing graphene-based nanocomposite polymers.	[13]

Table 2. Properties of graphene-based polymer nanocomposites.

Polymer	Graphene (wt%)	Results	Ref.
Epoxy resin	0.5	Young's modulus and tensile strength increased by 13% and 83%, respectively.	[10]
PVP	2.0	Decreased tensile strength and high increase in Young's modulus.	[11]
Silicone rubber (SR)	0.5	Tensile strength increased by 175%. Also, the melting point (Tm) decreased, and the glass transition temperature (Tg) increased.	[11]
Cyanate ester resin	1.0	Flexural and impact strength increased.	[11]
Unsaturated polyester resin	10	Stiffness enhanced and a 55% increase in flexural properties.	[11]

Table 3. Advantages of processing routes.

Processing Route	Advantages	Ref.
Dip-coating	Used for polymers in a liquid state, homogeneous results cheaply.	[5,12]
Casting	Simple and inexpensive method; good thermal and electrical properties.	[14]
Melt mixing	Advantageous for large-scale production; improvement in mechanical properties (Young's modulus, tensile strength, storage modulus).	[15]

melt mixing method is the one that presents the most advantages to the product consumer.

Conclusion

Technological advances made possible by implementing graphene and its derivatives in the composites industry are increasingly observed. After showing improvements from the initial to the end phase, graphene-based polymer nanocomposites have been well-seen as the future material due to their impressive properties in several aspects.

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