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REVIEW

Influence of graphene oxide on mechanical, morphological, barrier, and electrical properties of polymer membranes

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Abstract This paper expresses a short review of research on the effects of graphene oxide (GO) as a nanocomposite element on polymer morphology and resulting property modifications including mechanical, barrier, and electrical conductivity. The effects on mechanical enhancement related to stress measurements in particular are a focus of this review. To first order, varying levels of aggregation of GO in different polymer matrices as a result of their weak inter-particle attractive interactions mainly affect the nanocomposite mechanical properties. The near surface dispersion of GO in polymer/GO nanocomposites can be investigated by studying the surface morphology of these nanocomposites using scanning probe microscopy such as atomic force microscope (AFM) and scanning electron microscope (SEM). In the bulk, GO dispersion can be studied by wide-angle X-ray scattering (WAXD) by analyzing the diffraction peaks corresponding to the undispersed GO fraction in the polymer matrix. In terms of an application, we review how the hydrophilicity of graphene oxide and its hydrogen bonding potential can enhance water flux of these nanocomposite materials in membrane applications. Likewise, the electrical conductivity of polymer films and bulk polymers can be advantageously enhanced via the percolative dispersion of GO nanoparticles, but this typically requires some additional chemical treatment of the GO nanoparticles to transform it to reduced GO.

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Contents

1. Introduction

It is well known that blending in well-dispersed additives and fillers to polymers can substantially improve the mechanical and physical properties of the polymer composites (Liu et al., 2014). We examine a nanomaterial of much recent interest, graphene oxide (GO) in this context in forming polymer nanocomposites. Graphene oxide GO is produced by introducing graphite to oxidation agents that add oxygenated functionalities to the graphite structure and exfoliates the layers, thereby improving its dispersion in water. Recently, GO has emerged as one of the most attractive nanofiller in polymer nanocomposite technology due to the notable improvement and enhancement of mechanical, thermal, and electrical properties of many nanocomposites, improvements that could lead to innovative solutions for many applications (Zhu et al., 2010; Gómez-Navarro et al., 2007; Liu et al., 2009; Dikin et al., 2007; Lei et al., 2012; Sun et al., 2008; Marcano et al., 2010; Satti et al., 2010; Park et al., 2009; Venugopal et al., 2012; Wang et al., 2010; Hu et al., 2010; Zinadini et al., 2014; Jin et al., 2015; Gudarzi and Sharif, 2012; Dreyer et al., 2010; Compton et al., 2012). For instance, in water filtration applications, GO could potentially solve the serious obstacle of polymer membrane fouling by biological species. GO can play the role of anti-biofouling of nanocomposite membranes because it can alter the smoothness of the membrane surface, and also due to its hydrophilicity and electrostatic repulsion characteristics, all of which can disfavor bio-adsorption or even induce bio-degradation (Lee et al., 2013). While GO is highly attractive as a nanofiller material, there are other nanoparticles in this family of graphitic nanomaterials that lend themselves to enhancing properties of nanocomposites in general. In this regard as examples, graphene, graphene oxide and reduced graphene oxide nanosheets and nanotubes can have different interactions with many polymers at high loading due to the differences of their surface functional group. For example, reduction of graphene oxide to its "r-GO" form is one of the interesting nanoparticles due to its similar electrical properties to graphene. r-GO is produced by removing (reducing) functional group of GO using chemical or thermal treatments (Pei and Cheng, 2012). However, the dispersion of r-GO in polymeric and other materials is a notable challenge, hence it is typically reduced in situ, while GO is conveniently dispersed in water and other hydrogen bonding polar solvents. Note also that GO has largely insulating properties. GO improves the performance of hydrogen, H_2 and oxygen, O_2 permeability and also increases the proton conductivity of polyimides (PI) membranes due to the interaction between sulfonic functional group and GO (Jiang et al., 2012). GO has also been shown to have useful properties as nanosheets for bio-nanotechnology applications such as drug delivery, anti-bacteria, and DNA sensors (Wang et al., 2010; Ma et al., 2011).

As mentioned, polymeric membranes in various water treatment applications have different types of fouling problems, most commonly due to the natural organic materials. The hydrophilicity modification of these membranes by adding GO is considered to be a viable solution to this problem (Forati et al., 2014). One of the most commonly used polymers for water filtration is Polysulfone, PSf due of its resistance to high pH, and harsh chemicals. In addition to enhanced transport barrier, PSf has good mechanical and thermal properties, which preserves the membrane for a longer lifetime thereby reducing its lifetime cost in applications (Ganesh et al., 2013; Ionita et al., 2014; Zhao et al., 2013). However, PSf is a naturally hydrophobic material, so that dispersing graphene oxide in PSf to form GO/PSf nanocomposite membranes could be a key to changing the surface properties of Polysulfone and making it more hydrophilic (Yang et al., 2006). In contrast, the addition of carbon nanotubes, CNTs to Polysulfone can also improve the properties of these membranes for enhanced mechanical and thermal properties, but the high cost of CNTs compared to GO limits their uses (Voicu et al., 2013). Furthermore, CNTs have weak dispersion in solvents and polymers while GO has good dispersion in organic solvents and polymers compared to CNTs (Zhu et al., 2012; Wang et al., 2011).

Another interesting polymer that can be used as a commercial or laboratory ultrafiltration membranes is Polyethersulfone (PES). Like many polymers, it however has a fouling problem due to a lack of hydrophilicity, which adversely impacts its water permeability properties. However, the addition of GO into PES matrix improves the hydrophilicity of the membrane leading to better water permeability (Zinadini et al., 2014). Furthermore, polyvinylidene fluoride (PVDF) is also used as a nanofiltration membrane due to its thermal stability and easy to control surface structure (morphology). Similar to PES polymer, PVDF has the same fouling difficulty and likewise, with adding GO it can be improved (Xu et al., 2014).

In the chemical industry, aromatic/aliphatic separations are usually done by traditional separation like distillation, that however cost a lot of energy. Polymer membranes such as Poly(vinyl alcohol) PVA has the possibility to make these