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Evaluation of mechanical, thermal and electrical properties of graphite base nanocomposites

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Abstract

The postulate for lightweight, good performance and high mechanical strength, thermal stable and electrical conductor materials for usage in military, aerospace and electronics device is ever increasing in both industrial and transportation sectors. High performance graphite nanocomposites require the use of advanced bipolar plates with high electrical conductivity and good mechanical strength. This can be achieved by using high performance polymer composites reinforced with graphite platelet. Expanded graphite (EG) and graphite nanoplatelets having large aspect ratio, high electrical and thermal conductivity. This research presents a short review for the mechanical, thermal and electrical properties of graphite nanocomposites designed for using in high performance industries. From this research, it is concluded addition of a small fraction of graphite nanoplatelet to polymer resins improve the mechanical properties, thermal and electrical conductivity of manufactured composites.

Review Article

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INTRODUCTION

Demanding for advanced materials with best properties to meet new necessities or to substitute existing materials is increased. The high performance of fiber reinforced polymer matrix composites is well known and attested. Nevertheless, these composites have some weaknesses related to the matrix dominated properties which frequently limit their broad application and necessity to develop new types of composite materials. Carbon materials attract significant attention of researchers because many of them have a very advantageous combination of high mechanical characteristics and low density[1]. Carbon based fillers have an extremely large strength/density ratio [2].

Graphite is one of the carbon's allotrope and is the stiffest material found in nature (Young's Modulus = 1060 MPa), having a modulus several times that of clay, but also with excellent electrical and thermal conductivity. On the other hand the graphite crystal lattice consists of graphene layers formed by sp^2 hybridized carbon atoms, whereas the carbon sheets are bounded by weak van der Waals forces with each other [2].

The key to utilizing graphite as a platelet nano reinforcement is in the ability to exfoliate this material [3]. Addition of graphite particulate to a polymer is a common method to improve these types of weaknesses. This improves not only mechanical, thermal, electrical and magnetic properties of polymer but also increases of hardness, toughness, thermal stability. Furthermore addition of these particles is caused to enhance the glass transition temperature, storage modulus, less modulus and other thermal properties like heat distortion temperature and mold shrinkage. Increasing of thermal and electrical conductivity of polymers is one of the other effects of method. On the other hand using this method reduces the processing cost significantly. However the meliorated physical properties, such as surface smoothness and fair barrier properties cannot be attained

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by using conventional micron sized particles. Hence, in recent year's nanoparticle based composites have drawn significant attention. For instance polymer/graphite nanoplatelet composites[3], polymer/clay nanocomposites[4] polymer/carbon nanotube composites [5] and polymer graphene nanocomposites. In general, natural graphite is exfoliated by a combination of chemical and thermal treatments [6].

Graphite is intercalated by an acid treatment followed by exfoliation by a thermal shock at an elevated temperature. Such a process can generate exfoliated graphite platelets. [7]. It is of interest to mention that graphite particles show a layered structure by nature and possess high aspect ratios that caused to intercalate or exfoliate by chemical processes[8]. Carbon nanotubes also exhibit prodigious mechanical, thermal and electrical properties. But usage of these fillers because of high cost of manufacturing of these fillers is extremely limited. It is also reported that graphite platelets, about 500 times less expensive than carbon nanotubes, that be exfoliated and compounded in a conventional way[9], whereas the nanotube-based composites require development of processing techniques with regard to dispersion, waviness and alignment of nanotubes. Therefore, graphite platelets are a potential alternative to carbon nanotubes with regard to cost and desired properties[10].The objective of this research is investigate the mechanical, thermal and electrical properties of graphite based nanocomposites.

Effect of Graphite on Mechanical Properties

Graphite is well known to be a layered material with high electrical conductivity high mechanical strength [11]. Filling the graphite particles in polymer materials improves mechanical properties of these materials. The improvement of mechanical and other properties of such composites that produced from these polymers depends strongly on the particle content, particle shape and size, surface characteristics and degree of dispersion.[12]. Accordingly, the toughening of these composites rises with increasing number of mechanisms such as crack-tip pinning, crack-surface bridging, deboning/micro-cracking, and crack deflection[13].

The mechanical properties of composites filled with micron-sized filler particles are inferior to those filled with nanoparticles of the same filler such as graphene nanoparticle[14]. Because of containing a very low amount of filler about 1-5 wet% compared to conventional particulate composites where the usual filler content is in the range of 10–20 wt % , these nanocomposites are quasi-isotropic and can be processed by formal means compared to thecomposites reinforced with continuous fibers. With the proper surface treatment, the graphite nanoplatelets in polymeric matrixes also showed better flexural strength than composites with other carbon materials[15].

Furthermore an appropriate surface treatment was established for the new material, which produced a nanographite that increased the mechanical properties of an epoxy system better than some commercially available carbon materials at the same volume percentage[16].

General properties

Dissimilar to several lamellar silicate solids, whose exfoliation can be achieved by ion exchange reactions, exfoliation of graphite cannot be achieved in the same way because it does not bear any net charge. Nevertheless, due to the weak van der Waals interaction among graphene layers, some appropriate atoms or molecules, known as intercalating agents, can penetrate graphite by diffusion through edge planes to form layered crystals. The resulting products composed of guest intercalants and host graphite are called graphite intercalation compounds[17]. Graphite is a layered-structure material and more than 100 kinds of intercalated graphite compounds[18]. Nanosheets of these materials (GNs) have gained great interest because of their high flexibility, large surface area, and lower cost compared with other carbon nanofillers such as nanotubes and nanowires[19]. When natural graphite is intercalated by small molecules such as sulfuric acid the spacing between graphite nanolayers is increased and the resulting product is called graphite intercalated compound (GIC)[20]. The main challenge for the application of graphite nanosheets is their uniform dispersion in insulating media as matrixes. The aspect ratio of these particles, because of their large surface area is higher than other filler particles and this specific property make the GNs difficult to be stably dispersed in either organic or aqueous solvents[21]. A new process for the dispersion of graphite in the form of nanosheets in a polymer matrix was developed via in situ polymerization of monomer at the presence of sonicated expanded graphite during sonication[22].The experimental results shows the weight of nanocomposite (polymer after addition of graphite particles) more than neat polymer(without nano particles).This discrepancy may be due to the occasional presence of inclusions in the graphite particles, which becomes more pronounced as the graphite content increases. However, it can be suggested that the increase in density due to the addition of graphite platelets in pure epoxy is still negligible[10].

Effect of Graphite on Thermal Properties

The experimental results have shown that the thermal conductivity of polymer increase by addition of graphite particles [23]. The coefficient of thermal expansion is an important issue for polymers in engineering applications [24]. A low thermal expansion coefficient is often desirable to achieve dimensional stability and can be achieved by incorporation of a rigid and low CTE filler material[25]. The experimental results show the CTE of polymer matrix nanocomposites is dropped by addition of graphite nanoparticles. The lowering of CTE can be attributed to the fine dispersion and rigidity of graphite platelets in the epoxy matrix, which can inhibit the expansion of polymer chains as the temperature is raised[10].It can also be seen that the T_g (glass transition temperature) of pure epoxy increased slightly with the incorporation of graphite platelets[26].In general, the increase in T_g is attributed to the good adhesion between the polymer and the reinforced particles[27]. It can be suggested that the graphite content influences the thermal behavior of the

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composites significantly[28]. The effects of processing techniques as well as the orientation and aspect ratio of platelet materials can also influence the thermal expansion behavior of composites significantly[29]. On the other hand addition of graphite particles increases the thermal stability of polymer composites. Therefore, the incorporation of the graphite platelet resulted in pronounced improvement in thermal properties[30].

Effect of Graphite on Electrical Properties

Conducting polymer composites have been extensively studied because of their potential applications in batteries, antistatic, electromagnetic shielding, electrorheological fluids, and other applications[31].Thus many researchers have investigated the electrical conductivity of composites that contain randomly dispersed conducting particles in an insulating polymer matrix [32]. Since natural graphite (NG) has high electrical conductivity, it has been considered an ideal candidate for manufacturing conductive polymer composites[33]. Graphite is a good electrical conductor with an electrical conductivity in the range of 10^4 S/m at room temperature[34]. These materials, which is naturally abundant, has been widely used as an electronically conducting filler for preparing conducting polymer composites in the last decades[35]. The electrical and dielectric properties of these composites are mainly dependent on the filler content [36]. When the filler content reaches a certain critical value, the so-called percolation threshold, an insulator-to-conductor transition in the conductivity of the composites occurs [37]. Simultaneously, there is a sharp transition in the dielectric properties of the composites [38]. On the other hand the infiltration threshold for the electrical conductivity depends too much on the geometry of the conducting filler. Fillers having elongated geometry such as fibers or sheets can be used to achieve a very low percolation threshold value, due to the fact that fibers or sheets with higher aspect ratios have greater advantage over spherical or elliptical fillers in forming conducting networks in polymer matrices[39]. The electrical conductivity of the nanocomposites is greatly influenced by filler morphology [40].

CONCLUSION

The nanocomposites with graphite platelets show additional excellent electrical and thermal conductivity. The improvement in strength and modulus of graphite nanaoplatelet composites are be attributed to the high strength and high aspect ratio of graphite platelets as well as to the uniform distribution and good interfacial adhesion between the platelets and the polymer matrix. All these characters provide good load transfer from the matrix to the platelets and causing to restriction of stress concentration. Usage of graphite particles as a filler not only increase the thermal conductivity and thermal stability, but also decrease the CTE of polymers. Results of this review shows that the electrical conductivity of polymer composites increases with addition of graphite fillers.

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