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Research paper



The Effect of Nanoparticles Composition on Tensile and Thermal Properties of Polystyrene Reinforced with Graphene Nanoplatelets

Baharom M.H.[1], Mat Desa M.S.Z.[1]*, Izhab I.[1], Yusop M.[2*], Kasnan N.Z.[1], Ab Ghani N.F.[1]

[1]Faculty of Chemical & Natural Resources Engineering, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[2]Department of Physics, Faculty of Sciences, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru,, Johor, Malaysia
**Corresponding Author: shaiful@ump.edu.my*

Abstract

This study presents the reinforcement effect of graphene nanoplatelets (GNP) on tensile and thermal properties of polystyrene/graphene nanoplatelets (PS/GNP) nanocomposites. The PLA/GNP nanocomposites were prepared by melt-blending method with the GNP contents varied at 0.5, 1.0, and 1.5 wt %. The tensile properties of PS/GNP nanocomposites were analysed by using universal testing machine, the thermal properties were investigated by thermal gravimetric analysis (TGA), and thermal conductivity analysis, while the morphology were characterized by Transmission Electron Microscopy (TEM) and X-Ray Diffraction (XRD) measurement. Steady improvement of tensile strength and Young's Modulus was observed as the composition of GNP increased. The study also showed that the thermal stability and thermal conductivity of PS/GNP nanocomposites increase with increasing content of GNP. This study indicates strong influence of GNP contents on reinforcement effect and thermal properties of PS/GNP nanocomposites.

Keywords: *Graphene nanoplatelets; polystyrene; tensile properties; thermal properties*

1. Introduction

Polystyrene (PS) is versatile petroleum based polymers with wide application in insulation and packaging industries. It is an amorphous thermoplastic polymer produced by polymerization of styrene monomer, with good mechanical rigidity, low thermal conductivity, and easy processing. However its brittle character and poor thermal stability are considered as the main drawback of PS which limits its potential for wider industrial application [1]. One of the promising strategy to overcome this problem is through the development of nanocomposites system, where the use of graphene nanoplatelets (GNP) as reinforcement nanofillers in PS has increasingly attract attention from researchers [2].

GNP is essentially a two dimensional single layer carbon allotrope with extraordinary mechanical strength [3]. It possesses extremely high Young's modulus, tensile strength, thermal conductivity and electrical conductivity. Several earlier works showed that the polystyrene/graphene nanoplatelets (PS/GNP) nanocomposites exhibit superior mechanical, and flame retardant properties than the pristine PS [4-6]. Successful development of PS/GNP nanocomposites may offer wider application of PS, hence replace its conventional use as food container which is the main contributors of solid waste.

Although several works had been done to develop PS/GNP nanocomposites, review of previous research works also revealed that minimal attempt were made to investigate the effect of GNP contents towards the overall tensile and thermal properties of PS/GNP nanocomposites. Therefore, the aim of this study is to determine the suitable formulation to produce PS/GNP nanocomposites with the best mechanical and thermal properties.

2. Methodology

2.1. Materials

PS was purchased from Titan Chemicals (M) Sd. Bhd., while GNP (purity > 95wt%, thickness: 3.4-7.0 nm, electrical conductivity: 10^5 S/m, sulphur content: 0.5%, layers 6-10) was purchased from Soochow Henqiu Graphene Technology Ltd.

2.2. Nanocomposites preparation

The PS/GNP nanocomposites were prepared by melt blending method in a counter rotating twin screw extruder at the rotor rate of 45 rpm for 12 min at 220°C in the feed section and decreasing to 60°C at the die. The content of GNP in PS matrix was varied at 0.5, 1.0, and 1.5 wt%. The extruded samples were pelletized and hot pressed into test specimens for further thermal analysis.

2.3. Tensile testing

Tensile tests were carried out according to ASTM D638 using a Universal Testing Machine under ambient conditions. The tests were performed at constant loading speed of 0.5 mm min^{-1} with the 2 kN load cell at room temperature. The specimen was in dog bone shape with dimension of 6mm x 20mm x 115mm. At least three specimens of each formulation will be test and the average value was report. Tensile strength, young modulus and ductility of materials were determined.

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2.4. Thermal properties testing

The thermogravimetric analysis (TGA) of the polystyrene/graphene nanocomposites will be conducted by using Mettler Toledo TGA Thermogravimetric analyser from room temperature to 600ºC under a nitrogen flow which is 40 mL/min. TGA is used to analyse the thermal stabilities of PS/GNP nanocomposites. Only one specimens of each formulation will be test.
Thermal conductivity test will be carry out according to ASTM E1530 using a Hot Disk (Sweden TPS 2500S instrument). The sample dimensions were 5 cm × 2.5 cm with thicknesses of 0.5 cm. The thermal conductivities of PS/GNP nanocomposites will be determined.

2.5. Morphology observations

Morphological study was investigated by the X-ray diffraction (XRD), and Transmission Electron Microscopy (TEM). X-ray diffraction (XRD) measurements were obtained on a Benchtop X-ray diffraction (XRD) instrument with fixed monochromator. The samples were analysed in powder form at room temperature. The polymeric microstructure was determined at operating condition of 30 kV and 15 mA. The interlayer spacing of graphene is derived from the peak position in XRD diffractograms according to Bragg's law. TEM provides visually the details about internal composition and to examine the dispersion of graphene fillers in composites.

3. Results and Discussion.

3.1. Tensile properties analysis

Table 1 shows that the tensile strength slightly increases with increasing of GNP content in PS/GNP nanocomposites. Compared to pure PS, the tensile strength of PS/GNP increased by 1.6%, 44% and 50% with additional of 0.5wt% and 1wt% GNP respectively. The Young Modulus of GPS nanocomposite had risen up 25%, 63%, and 71% with 0.5wt%, 1.0wt% and 1.5wt% addition of GNP respectively when compared with pure PS. This is in similar with the pronounced mechanical enhancements observed by Fang et al [7]. The profound increment of tensile strength indicates the well distribution of GNP particles among PS matrix hence contribute to efficient load transfer between GNP and the PS matrix [8]. The steady increment of Young's modulus is expected due to the presence of stiff GNP particles in PS matrix. The drastic decline of elongation at break as shown in Table 1, reaffirm the propagation of stiffness of PS/GNP nanocomposites.

Table 1: Tensile properties of PS and PS/GNP nanocomposites

Specimen	Tensile Strength (MPa)	Young's Modulus (GPa)	Elobngation at Break (%)
PS	17.63±0.13	1.47±0.02	0.75±0.01
PS/GNP(0.5wt%)	17.91±0.22	1.84±0.12	0.63±0.02
PS/GNP(1.0wt%)	25.39±0.18	2.40±0.02	0.46±0.02
PS/GNP(1.5wt%)	26.45±0.42	2.51±0.23	0.42±0.02

3.2. Thermal properties analysis

Thermal degradation behaviour of all samples were analysed by thermal gravimetric analysis (TGA). Fig. 1 shows the TGA thermograms, while Table 2 shows the detail thermal degradation profile of different PS/GNP nanocomposites formulations as compared to pure PS. It can be noted from Table 2, that $T_{10\%}$ and T_{peak} is increase with increasing contents of GNP. The $T_{10\%}$ indicates temperature at early degradation profile of PS/GNP, while T_{peak} indicates the temperature at which the PS/GNP has maximum rate of degradation. The increasing of these two parameters clearly shows the ability of GNP to enhance the thermal stability of PS. The enhanced thermal stability of PS/GNP nanocomposites can be credited to the dispersion of the GNP sheets and their boundary impact which prevent thermal degradation at molecular level [5]. The char residue also shows increasing value with the increase of GNP contents. The increase in char residue is an indication of the GNP presence that can withstand degradation at high temperature.

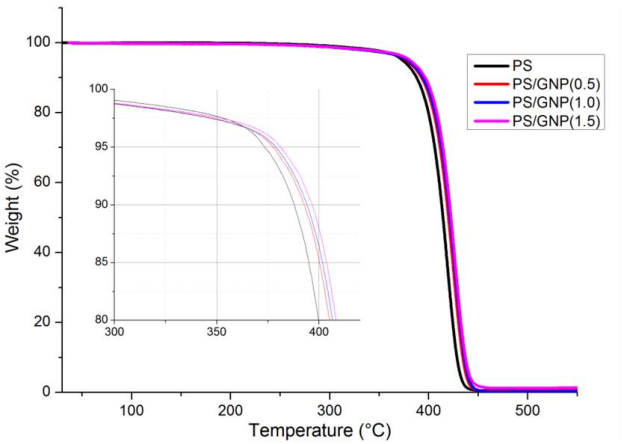

Fig. 1: TGA thermograms of PA and PS/GNP nanocomposites

Table 2: $T_{10\%}$, T_{peak}, and char reside value of PS and PS/GNP nanocomposites

Specimen	$T_{10\%}$(ºC)	T_{peak} (ºC)	Char Residue (%)
PS	385.63	418.47	0.5712
PS/GNP(0.5wt%)	386.64	418.71	0.7540
PS/GNP(1.0wt%)	387.86	418.84	1.2630
PS/GNP(1.5wt%)	388.06	418.90	1.4500

The thermal conductivity analysis was conducted by using Lee's disc method. As depicted in Fig. 2, the thermal conductivity character of PS/GNP nanocomposites shows an increasing trend with increasing content of GNP nanofiller. PS/GNP with 1.5 wt% of GNP contents exhibit the highest thermal conductivity of 1.028 × 10^{-3} $W.m^{-1}K^{-1}$, which is 24 % higher than the thermal conductivity of pure PS. The high thermal conductivity of all PS/GNP nanocomposites as compared to pure PS is attributed to the well dispersion of GNP among PS matrix that enable effective ability of GNP to conduct heat through the nanocomposites' mass.

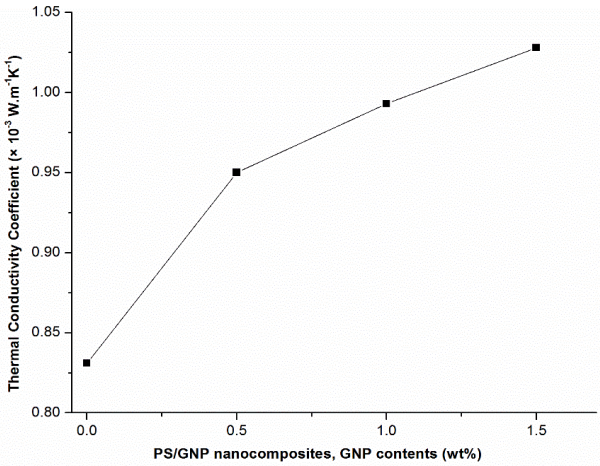

Fig. 2: Thermal conductivity coeffient of PS and PS/GNP at various GNP contents

In overall, this study shows that PS/GNP nanocomposites with 1.5wt% GNP contents, displayed the best improvement of thermal stability and thermal conductivity as compared to other formulations.

3.3. Morphology analysis

The morphological structures of a PS/GNP nanocomposites at 5 wt% GNP contents were studied by TEM as shown in Fig. 3. Observation in Fig. 4 shows the continuous light region which represent PS matrix and the discrete dark spot represent the GNP particles dispersed in the polymer matrix. GNP were found to exhibit good dispersions within the polymer matrix with particle size ranging from 10 to 12 nm, indicating successful processing method. The good dispersion of GNP also explains the higher tensile strength observed in all PS/GNP nanocomposites as compared to pure PS, which is due to efficient load transfer of isolated particles with its surrounding matrix [9 and 10].

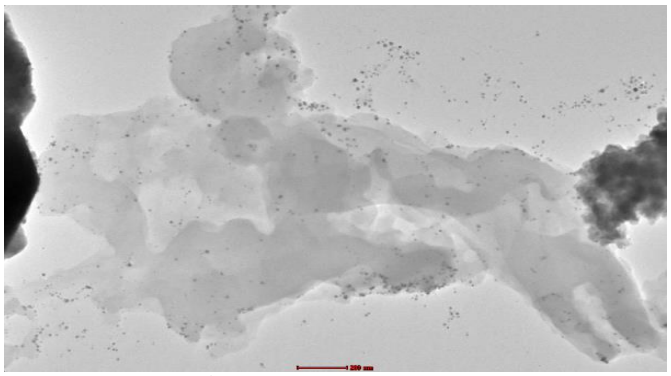

Fig. 3: TEM image of PS/G nanocomposites at 0.5 wt% GNP contents

Fig. 4 shows the X-ray diffraction data for neat PS and various contents of GPS nanocomposites. The neat PS profile is related to it's a monoclinic modification, exhibiting the three main diffraction peaks of this crystalline lattice corresponding to the (110), (310) and (240) planes, in order of increasing angles. Moreover, the PS diffractogram has a strong peak at $2\theta \approx 19.38^{o}$. For various contents of PS/GNP nanocomposites, the strong peaks were located near the 19.38^{o} for each composition. This indicates complete exfoliation and good dispersion of graphene in the composite especially for 0.5wt% and 1.0wt% of graphene content. However, for 1.5wt% of graphene content, the characteristic PS/GNP peak appears not only at three main planes but also an appearance of a new basal reflection at 26.46^{o}. These features peak determine that graphene was dispersed in the polymer but not completely exfoliated. The intensity of the crystalline peak decreases with increasing content of graphene. The intensity of the peak indicates that the crystallinity of PS/GNP nanocomposites is greater than the crystallinity of neat PS.

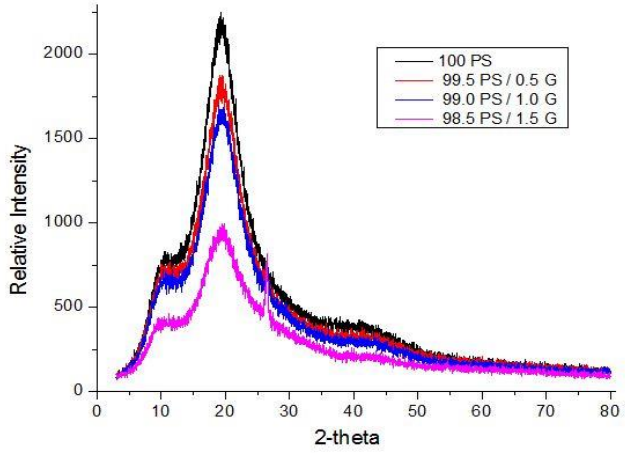

Fig. 4: XRD of PS neat and GPS nanocomposite at different Graphene content 3.4. Figures and tables

4. Conclusion

PS reinforced with GNP by melt blending method is potentially good reinforcement agent in PS and maintaining its stiffness. Moreover, this study also shows that the thermal degradation behaviour and thermal conductivity properties of PS/GNP nanocomposites were also increased with increasing content of GNP. These results may strongly relate to the morphology and good dispersion of GNP in PS matrix as shown by TEM and XRD analysis. In overall, among all studied formulations, PS/GNP nanocomposites with 1.5 wt% GNP exhibit the best tensile and thermal properties among all studied formulations.

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