



Preparation and characterization of highly electrically and thermally conductive polymeric nanocomposites

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ABSTRACT

Purpose: The conducting polymers and polymeric composites have attracted considerable attention in recent years because of their potential applications in advanced technologies, for example, in antistatic coatings, electromagnetic shielding.

Design/methodology/approach: In this study the conductive fillers were expanded graphite (EG) and untreated graphite (UG), the base material was ethylene- vinyl acetate copolymer (EVA). Nanocomposites containing up to 30 volume % of filler material were prepared by mixing them in a Brabender Plasticorder.

Findings: The increase in thermal conductivity was more pronounced for EVA-UG nanocomposites than EVA-EG nanocomposites.

Practical implications: The recent advancement of nano-scale compounding technique enables the preparation of highly electrically conductive polymeric nanocomposites with very low loading of conductive fillers. Compared with traditional composites, nanocomposites may offer enhanced physical features such as increased stiffness, strength, barrier properties and heat resistance, without loss of impact strength in a very broad range of common synthetic or natural polymers.

Originality/value: The introduction of electrically conductive fillers such as graphite, carbon black, metal and metal oxide powders into the polymeric matrix is a promising approach to fabricate electrically conductive polymeric materials.

Keywords: Nanocomposite; EVA; Graphite; Thermal conductivity

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MATERIALS

1. Introduction

Polymer based nanocomposites are used more and more in the industry due to the fact that dispersing only small quantities of nanoscopic clay particles in polymer matrices enhances significantly thermal and mechanical properties [7]. In their work, [4] investigated the mechanical properties of nylon-6 clay hybrid, mechanical properties showed significant improvement at a loading of only 4.2 wt % clay, the modulus doubled, and the increase in strength was more than 50%.

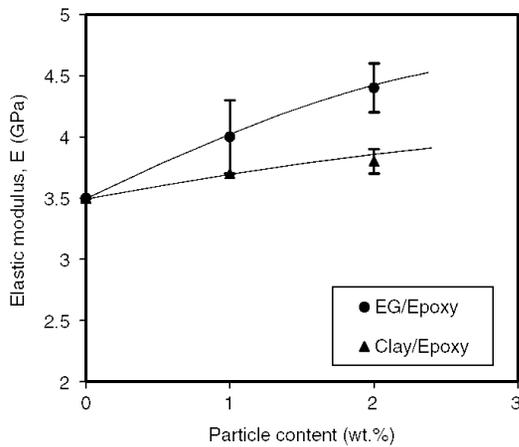


Fig. 1. Variation of elastic modulus as a function of particle content [9]

By adding a graphite platelet in polystyrene, the electrical conductivity was improved significantly, there is a sharp transition of the polymer from an electrical insulator to an electrical semiconductor with the addition of a graphite nanoplatelet [2]. The percolation threshold value of the conducting composite (with 1.8wt% of expanded graphite) was much lower than that of conventional composites [1, 2, 3, 6] investigated the effect on mechanical, thermal, and electrical properties of graphite platelet nanocomposites reinforcement in both epoxy and PP systems. They showed better flexural and tensile properties of chemically functionalized graphite nanoplatelet in the epoxy matrix. In addition they achieved lower CTE (coefficient of thermal expansion) and electrical resistivity compared to other carbon materials like carbon fibre, carbon black, etc. These properties of graphite nanoplatelet combined with low cost make it useful in electromagnetic interference (EMI) shields, thermal conductors, etc. Graphite is well known for its stiffness and excellent thermal and electrical conductivity, which are absent in clay materials. (Yasmin et al., 2006) used both graphite/epoxy and clay/epoxy nanocomposites to investigate the performance of reinforcement and they found that graphite/epoxy has a higher (16% for 2wt% particle content) elastic modulus compared to the clay/epoxy for the same particle content (Figure 1).

In their paper [8] studied the electrical and mechanical properties of high-density polyethylene (HDPE) reinforced with

expanded and untreated graphite prepared by a melt-compounding process. Viscosity increased upon addition of graphite phase, with the expanded graphite (EG) showing more pronounced rise than the untreated graphite (UG) in viscosity, Figure 2. The increase in viscosity was attributed to the increased surface-to-volume ratio for the EG filler after acid treatment. Electrical conductivity also increased from that of an electrical insulator to one characteristic of a semiconductor, Figure 3. The EG composite showed a lower percolation threshold for transition in conductivity compared to that in the UG composite. DSC results indicated that the fillers acted as a nucleating agent in inducing the crystallization of HDPE in the composites. Mechanical properties improved as a function of filler content but the overall enhancement was not very big, Figure 4. It was estimated that the filler-matrix interface was not optimized in the melt-mixing process. However, the role of EG as a reinforcement phase for both electrical and mechanical properties was unambiguously established. The EG composites demonstrated potentially useful attributes for antistatic, barrier, mechanical, electrical, and cost-effective applications.

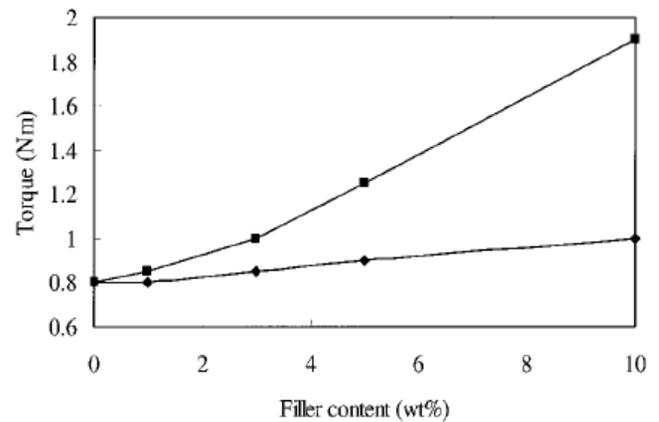


Fig. 2. Torque of unreinforced and reinforced HDPE as a function of filler content in a Haake mixer at 200°C with a screw speed of 20 rpm. (■) EG; (◆) UG [8]

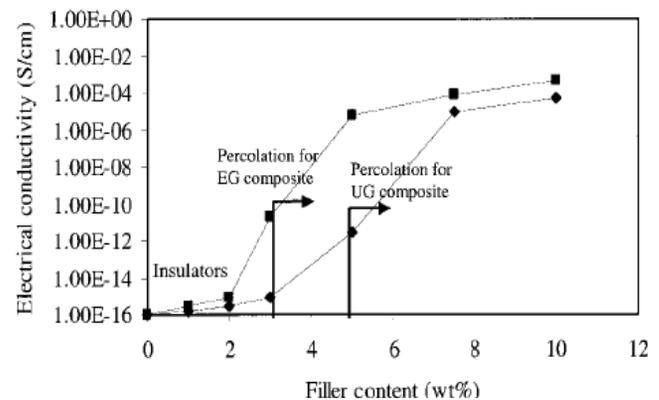


Fig. 3. Electrical conductivity of the UG- and EG-reinforced HDPE as a function of filler content (■) EG; (◆) UG [8]

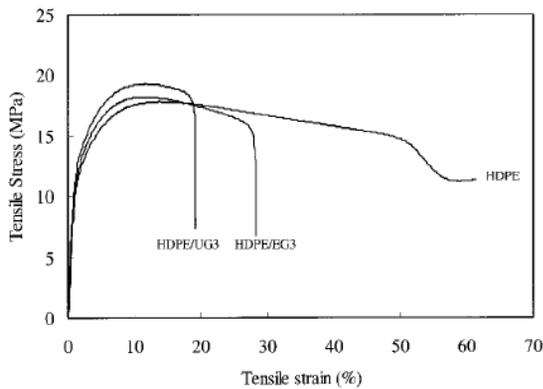


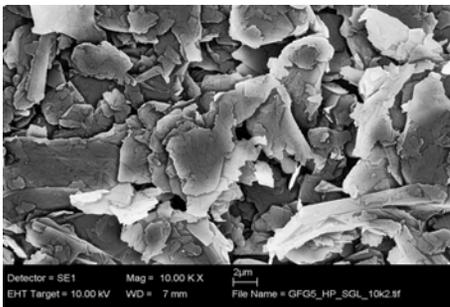
Fig. 4. Tensile stress–strain curves of unreinforced HDPE, 3 wt % UG- and EG-reinforced HDPE. The crosshead speed is 5 m/min. [8]

2. Material and method

2.1. Materials

In this study Ethylene- vinyl acetate copolymer (EVA) containing 14 wt% of vinyl acetate (VA), Miravithen® D 14010 V supplied by Leuna Polymer GmbH, Germany was used as matrix material. Its melt flow index is 9.8 g/10min (190°C/2.16 kg). The filler materials were expanded graphite (EG) and untreated graphite (UG), Figure 5.

a)



b)

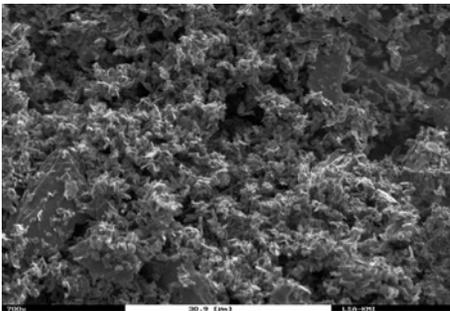


Fig. 5. SEM photographs of materials used in the preparation of nanocomposites (a) untreated graphite (UG); (b) expanded graphite (EG)

a)



b)

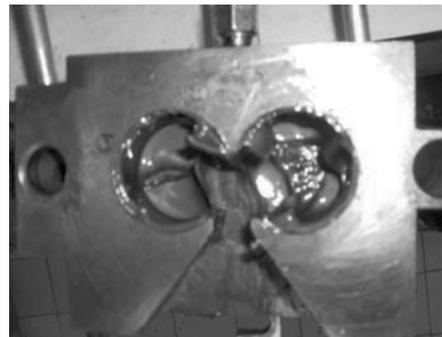
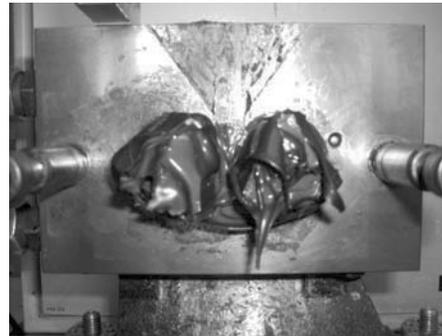


Fig. 6. (a) General view Brabender Plasticorder PLE 331 (b) The mixing chamber and the rotors after the mixing process of the composite

2.2. Preparation of nanocomposites

Ethylene- vinyl acetate copolymer (EVA) – graphite mixtures were prepared in a Brabender Plasticorder PLE 331 internal mixer

at 150°C for a total mixing time of 10 min, the mixing chamber capacity being 30 ml, Figure 6. The rotors turned at 35 rpm in a counter-rotating fashion with a speed ratio of 1.1. After 10 minutes, the mixing chamber of the Brabender apparatus is opened and the resulting mixture is taken out, then after passing through the rollers the mixture is solidified. The resultant mixture is then put in a compression moulding die, Figure 7, and compressed in a compression molding press at 120°C, under 40 kP pressure for one minute to obtain samples in the form of sheets of 1mm in thickness, Figure 8.

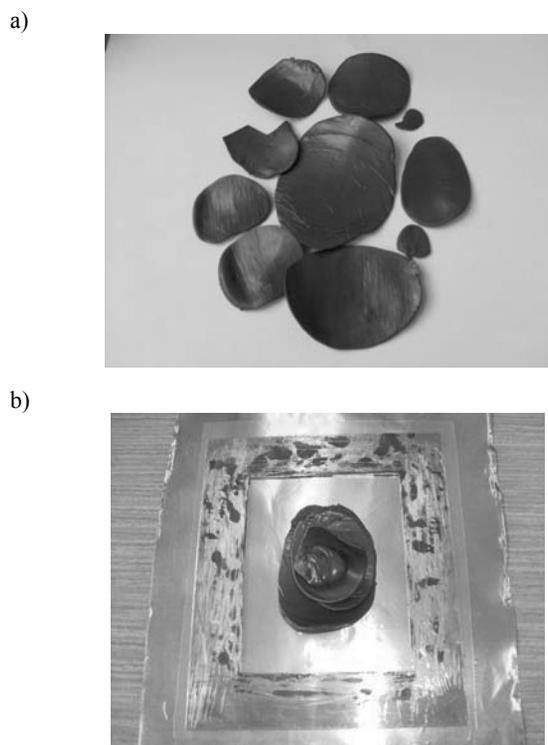


Fig. 7. (a) EVA-Graphite composite solidified after passing through the rollers (b) Composite in the compression moulding die



Fig. 8. Hot press for preparation of plate nanocomposite samples

3. Results and discussion

Thermal conductivities of EVA-UG and EVA-EG samples prepared up to 7.5% volume fraction were measured by a periodical method at room temperature. In this method a plate composite sample is placed between two metallic plates, one made of copper and the other of brass, the front side of the copper plate is heated periodically, the brass plate is cooled on the side which is not in contact with the sample, the evolution of the temperatures with respect to time of both plates are measured by thermocouples and unrecorded in a computer for further treatment, more detailed information on the method is given in the publication by [5]. The increase in thermal conductivity with volume fraction of filler was more for EVA+UG nanocomposites (87% increase for 7.5% volume fraction of UG) than EVA+EG nanocomposites (70% increase for 7.5% volume fraction of EG). Electrical conductivity also increased from that of an electrical insulator to one characteristic of a semiconductor, Figure 10. The EG nanocomposite showed a lower percolation threshold, about 5% of volume fraction of filler, for transition in conductivity compared to that in the UG nanocomposite, about 15% of volume fraction of filler (Figs. 9,10).

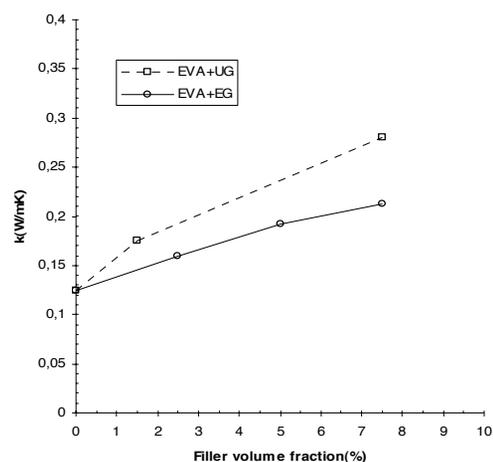


Fig. 9. Thermal conductivity of the EVA-UG, EVA-EG nanocomposites as a function of filler content

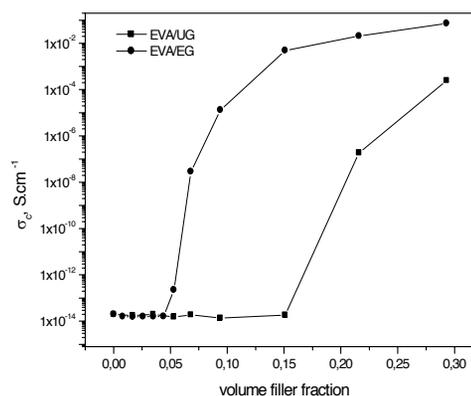


Fig. 10. Electrical conductivity of the EVA-UG, EVA-EG nanocomposites as a function of filler content

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Additional information

The paper was published also in the Archives of Materials Science.

References

- [1] A. Celzard, G. Furdin, J. Mareche, E. McRae, Anisotropic Percolation in an Epoxy-Graphite Disc Composite, *Solid State Communications* 92/5 (1994) 377-383.
- [2] G.H. Chen, D.J. Wu, W.G. Weng, Preparation of Polymer/Graphite conducting Nanocomposite by Intercalation Polymerization, *Journal of Applied Polymer Science* 82 (2001) 2506-2513.
- [3] K. Kalaitzidou, H. Fukushima, L. Drazal, Graphite Nanoplatelets as Nanoreinforcements for Polymers: Comparison between a Thermoset and a thermoplastic matrix, *Proceedings of the 14th International Conference "Composite Materials" ICCM-14, San Diego, 2003*, 541.
- [4] Y. Kozima, A. Usuki, M. Kawasumi, A. Okada, Y. Fukushima, T. Kurauchi, O.J. Kamigaito, Mechanical Properties of Nylon-6 Clay Hybrid, *Journal of Materials Research* 8 (1993) 1185-1189.
- [5] I. Krupa, A. Boudenne, L. Ibos, Thermophysical properties of polyethylene filled with metal coated polyamide particles, *European Polymer Journal* 43/6 (2007) 2443-2452.
- [6] Y.X. Pan, Z. Yu, Y. Ou, G. Hu, A New Process of Fabricating Electrically Conducting Nylon 6/Graphite Nanocomposites Via Intercalation Polymerization, *Journal of Polymer Science Part B: Polymer Physics* 38 (2000) 1626-1633.
- [7] A. Usuki, Y. Kojima, M. Kawasumi, A. Okada, Y. Fukushima, T. Kurauchi, O. Kamigaito, Synthesis of nylon 6-clay hybrid, *Journal of Materials Research* 81 (1993) 1179-1184.
- [8] Z. Wenge, L. Xuehong, W. Shing-Chung, Electrical and mechanical properties of expanded graphite-reinforced high-density polyethylene, *Journal of Applied Polymer Science* 91 (2004) 2781-2788.
- [9] A. Yasmin, J. Luo, I.M. Daniel, Processing of Expanded Graphite Reinforced Polymer Nanocomposites, *Composites Science and Technology* 66/9 (2006) 1182-1189.