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Material properties

Development of porous polymer pressure sensors incorporating graphene platelets

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ABSTRACT

Electrically conductive polymer composites (ECPCs) based on porous polymeric matrices of PEBA 4033 incorporating different types of graphene platelets were prepared and tested. PEBA 4033 polymer was mixed with different graphene platelets: grade H5, grade MX and grade C–750. Porous morphology was obtained for the ECPCs prepared with graphene platelets grade MX and H5, while for the grade C–750 only a dense ECPCs was obtained. The porous ECPC loaded with 15 vol.% of graphene M5 exhibited a linear piezoresistive response oin a log-log plot. Some limitations were detected for this ECPC, namely hysteresis and drift due to the poor mechanical properties. The porous ECPC loaded with 15 vol.% M5 was further crosslinked, which improved its mechanical properties but the piezoresistive effect became negligible. The incorporation of carbon black in this ECPC formulation was shown to be much more efficient than crosslinking to improve mechanical properties, but the piezoresistive response became poor.

1. Introduction

In recent years, there has been an increasing interest in the use of carbon based materials in many applications as sensors and composites materials [1–2]. The discovery of graphene, the elementary structure of graphite, made a revolutionary change in scientific and technological applications and has earned Kostya S. Novoselov and Andre K. Geim the Physics Nobel Prize in 2010. Graphene is a single layer of sp^2 bonded carbon atoms patterned in a hexagonal lattice that has unique properties such as high electrical conductivity and mechanical strength that can be used in electrically conductive polymer composites (ECPCs) [2–4]. Graphene is classified by the number of stacked layers: single layer, few-layer (2–10 layers) and multi-layer (thin graphite); the number of layers needed for the properties of graphene to fully match those of bulk graphite is over 100 [4]. Recently, some studies reported the preparation of polymer-graphene/expanded graphite composites [3,5–9]. Some authors studied different methods of preparation of the polymer matrix incorporating graphene platelets and their effects on the mechanical and electrical properties. They concluded that the graphene dispersion influences the electrical response of ECPCs [3,5–10]. Chandrasekaran et al. [3], for example, employed two mixing methods, three-roll milling and sonication combined with high speed shear mixing, and they concluded that the three-roll milling method improved electrical conductivity 5 orders of magnitude at 0.3 wt.%. On the other hand, polymer composites incorporating graphene platelets showed a low percolation threshold [3,9] and promote an improvement in the mechanical properties that increases the storage modulus (E') and stiffness of the material [3,7–8,10]. However, the diameter of graphene platelets influences mechanical properties. Kalaitzidou et al. [7], for example,

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fabricated polypropylene containing exfoliated graphite platelets, xGnP, (graphene sheets 10 nm thickness) by melt mixing and injection molding. The addition of xGnP − 1 (~1 μm diameter) promotes greater improvement in the mechanical properties than adding carbon black. However, the addition of xGnP - 15 (~15 μm diameter) led to poor mechanical properties due to the difficulty of dispersing it, and resulted in a non-homogeneous composite.

The present work targets for the first time the development and characterization of porous ECPCs prepared loaded with graphene platelets of different geometries (length, surface area and thickness). The piezoresistive response and mechanical properties were also evaluated.

2. Experimental

2.1. Materials

PEBAX polymer (polyether block amide) was supplied by Atofina Chemicals. Ethanol, hexane, 2, 4 - toluyene diisocyanate (TDI), n-methyl-2-pyrrolidone (NMP) and acetone were purchased from Sigma Aldrich. Distilled water was also used as non-solvent. Carbon black powder (Vulcan® XC72R) was purchased from Cabot Corporation. Graphene platelets (GNP) grade C-750, M5, M15, M25 and H5, were purchased from XG Sciences. These materials have following characteristics: M type-maximum length of 5 μm, 15 μm and 25 μm, respectively M5, M15 and M25, average thickness of 6–8 nm and surface area between 120 $m^2\ g^{-1}$ and 150 $m^2\ g^{-1}$; H5-maximum length 5 μm, average thickness of 15 nm and surface area between 50 $m^2\ g^{-1}$ and 80 $m^2\ g^{-1}$ and C-750 maximum length 1–2 μm, average thickness of 2 nm and average surface area of 750 $m^2\ g^{-1}$.

2.2. Preparation of porous ECPCs by immersion precipitation method based on PEBA 4033

Different weight fractions of GNPs were dispersed in NMP by sonication for 15 minutes. Polyether block amide (PEBA) 4033 was dissolved in NMP to form a polymer solution that was added to a previously prepared NMP suspension of conductive particles. When the polymer solution became homogeneous, it was poured onto a glass plate. ECPCs were prepared by the immersion precipitation method. Briefly, the film was then exposed to room temperature before immersion in the non-solvent at room temperature. After that, the film was washed under running water and then kept overnight in a water bath.

Table 1
Porous ECPCs based on PEBA 4033 incorporating graphene.

Films	Non-solvent	Type of graphene	Concentration of graphene (vol.%)	Concentration of carbon black (vol.%)
a	water	M5	5.5	–
b	ethanol	M5	5.5	–
c	hexane/acetone	M5	5.5	–
d	hexane/acetone	C-750	15	–
e	hexane/acetone	H5	15	–
f	hexane/acetone	M5	15	–
g	hexane/acetone	M15	15	–
h	hexane/acetone	M25	15	–
i	hexane/acetone	M5	18	–
j	hexane/acetone	M5	13	2
k	hexane/acetone	M5	10	5
l	hexane/acetone	M5	8	2

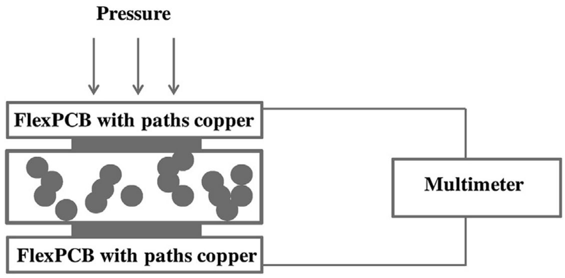

Fig. 2. Experimental set-up for measuring of the electrical resistance of the ECPCs.

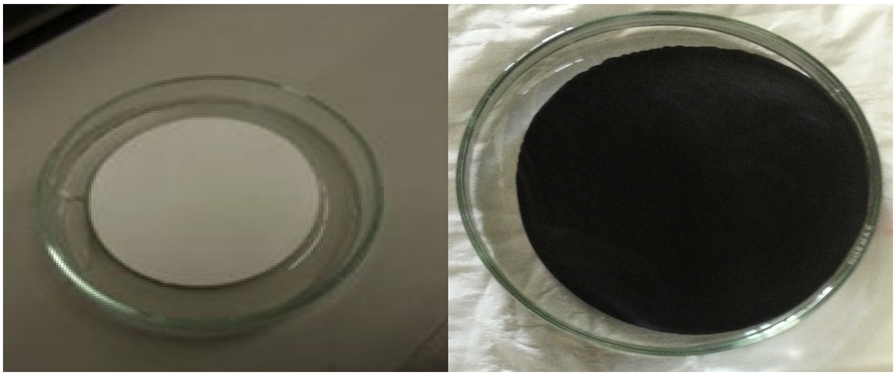

Fig. 1. PEBA 4033 films obtained after the immersion precipitation method (left image: porous plain PEBA 4033 film, right image: porous PEBA 4033 film incorporating graphene platelets).