

Research Article

Enhancement of Electrical and Mechanical Properties of Polycarbonate/Poly(Ethylene Oxide) and Carbon Black Composite

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Abstract

Electrically conducting composites consisting of polycarbonate/poly(ethylene oxide) (PC/PEO) and carbon black (CB) were prepared by solution method. Results showed that the dispersion of CB in the blend matrix was uniform due to interaction between the blend components (PC/PEO) and CB particles. Scanning electron microscopic (SEM) images showed fine dispersion of connected granular CB composite particles. The electrical conductivity and mechanical properties of PC/PEO/CB 1-10 composites were strongly dependent on the filler content. The yield strength of the composites increased from 41-71 MPa compared with neat blend (27 MPa). The electrical conductivity of PC/PEO/CB 1-10 was in the range of 1.1×10^{-2} to 1.1 Scm^{-1} relative to neat blend ($10^{-12} \text{ Scm}^{-1}$).

Keywords: Polycarbonate; poly(ethylene oxide); carbon black; yield strength; electrical conductivity

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1. Introduction

Polycarbonate (PC) is one of the most widely applied engineering thermoplastic having excellent electrical insulation, mechanical properties, transparency, thermal stability, and capability to be processed *via* usual machinery [1]. In spite of its outstanding physical and optical features, poor tribological characteristics have seriously restricted its relevance and working life [2]. Consequently, alteration is essential for PC-based materials. Presently, the polymeric nanoparticle-strengthened coatings have gained significant attention owing to the enhancement in a variety of properties including abrasion resistance, scratch resistance, heat stability as well as other mechanical features [3, 4]. In recent years, one of the extensively employed techniques for the assessment of tribological and mechanical properties of ceramics, metals, polymers and films at ultra-microscopic level, is the nanoindentation and nanoscratch tests employing depth-sensing method [5, 6]. Moreover, up to now, research regarding the tribological behavior at the micro/nano-scale of PC-based nanocomposites have been discussed. Most of the known polymeric materials are electrically insulating due to their small values of dielectric constants. Nevertheless, some level of electrical conductivity is essential for semiconductive or antistatic applications. Although some essentially conductive polymers such as polyaniline present preferred conductivity, their applications are restricted by high cost and deficient mechanical strength [7]. Polymers are usually combined with conductive fillers such as graphite particles, metal powder or fibers, and carbon nanotube [8, 9]. Carbon black (CB) with its chemical stability and low cost is one of the most common fillers for increasing the electrical conductivity [10]. However, several desirable properties such as tensile strength of the matrix are either compromised or vanished with greater CB content. Therefore the reduction in percolation threshold is a huge challenge. Many reports displayed that at lower CB content, the development of a perfect conductive network in single-component polymer matrix is essential to achieve desired conductivity [9]. The percolation threshold was significantly reduced to 1 vol.% CB in the electric field of 500 V/mm. A segregated structure was produced with the mechanical mixing of polymethyl methacrylate particles producing faceted grains with CB particles [9, 10]. This microstructure allowed the occurrence of percolation at a low volume fraction of 0.26 vol.% CB. Up to now, one of the most common ways, for reduction of the electrical resistivity and percolation threshold at a comparatively low CB content, is to utilize two-component polymer blends conductivity. In such immiscible blends, the percolation of CB depends on CB-rich phase and the continuity of CB-rich phase or the interface [11-14]. By the special localization of CB particles in a special region, such as a phase of a double continuous phase blend or interface between two phases, the efficient CB content was considerably superior than its supposed value. Hence the percolation threshold was significantly compacted [15, 16]. The generation of co-continuous polystyrene (PS) and polyethylene (PE) composites with a low percolation threshold (3 wt.% CB particles) was carried out [17-19]. Another common *double percolation* approach for the reduction of percolation threshold is construction of a continuous conductive association at the interfaces of immiscible multi-phase polymer blends. The conductive micro-fibrillar of polyethylene terephthalate (PET)/PE/CB composite having lower percolation threshold has been fabricated [20]. In this effort an electrical conductive cocontinuous polycarbonate (PC), poly(ethylene oxide) (PEO) and carbon black (CB) composite was prepared. Here PC/PEO blend was prepared and reinforced with 1-10 wt.% nanofiller content. Afterwards the electrical, morphological, and mechanical studies were performed to explore the composite structure.

2. Experimental

2.1. Materials

Polycarbonate (PC, $M_w \sim 50,000$), poly(ethylene oxide) (PEO, average M_v 100,000, powder), carbon black (CB, <200 nm) and N,N-dimethylformamide (DMF, anhydrous, 99.8%) were purchased from Aldrich.

2.2. Instrumentation

Infrared spectroscopy (IR) spectra were taken at room temperature with a resolution of 4 cm^{-1} using Excalibur Series FTIR Spectrometer, Model No. FTSW 300 MX manufactured by BIO-RAD. The scanning electron microscopic (SEM) images were obtained by Scanning Electron Microscope S-4700 (Japan Hitachi Co. Ltd.). Stress-strain behavior was examined using a universal testing machine (Instron 4466) with a strain rate of 5 mm/min at $25 \text{ }^\circ\text{C}$ according to ASTM D638 standard method. The electrical conductivity of thin films was measured at room temperature and ambient atmosphere using the four-point method (Keithley 2401).

2.3. Preparation of PC/PEO blend system

A dispersion of 0.1 g PEO was prepared in 2 mL of DMF with sonication of 4h. 1g of PC was separately dissolved in 10 mL DMF using 6 h sonication. The dispersed PEO solution was then added to the PC solution. The blend mixture was allowed to sonicate for further 4 h. The scheme for the formation of blend is given in Fig. 1. FTIR (cm^{-1}): 3054 (Ar C–H stretching vibrations), 2901, 2899 (aliphatic C–H stretching vibrations), 1688 (C=O stretching vibrations), 1277 (C–O stretching vibrations).

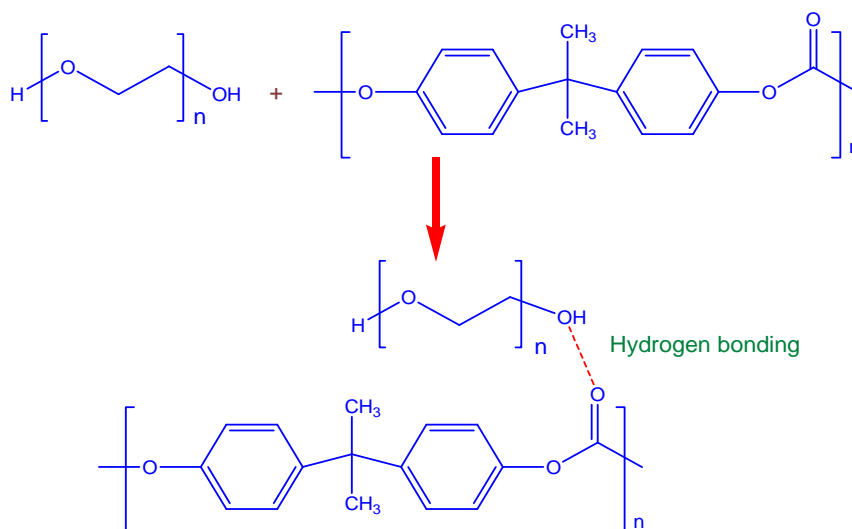


Fig. 1 PC/PEO blend formation.

2.4. Preparation of PC/PEO/CB composite films

All PC/PEO/CB composite with different CB loadings were prepared by solution blending method. A dispersion of CB (1-10 wt. %) was prepared in 5 mL DMF with sonication of 3 h. The dispersed solution was then added to the above prepared PC/PEO blend mixture. The mixture was sonicated for additional 2 h. The PC/PEO/CB mixture was then poured onto a glass plate and then a doctor blade was used to prepare film. The solvent was slowly evaporated at 80 °C. Finally, the film was thoroughly dried under high vacuum at 60 °C for 24 h [21]. Fig. 2 depicts the formation of PC/PEO/CB composite and development of interaction between blend matrix and filler.

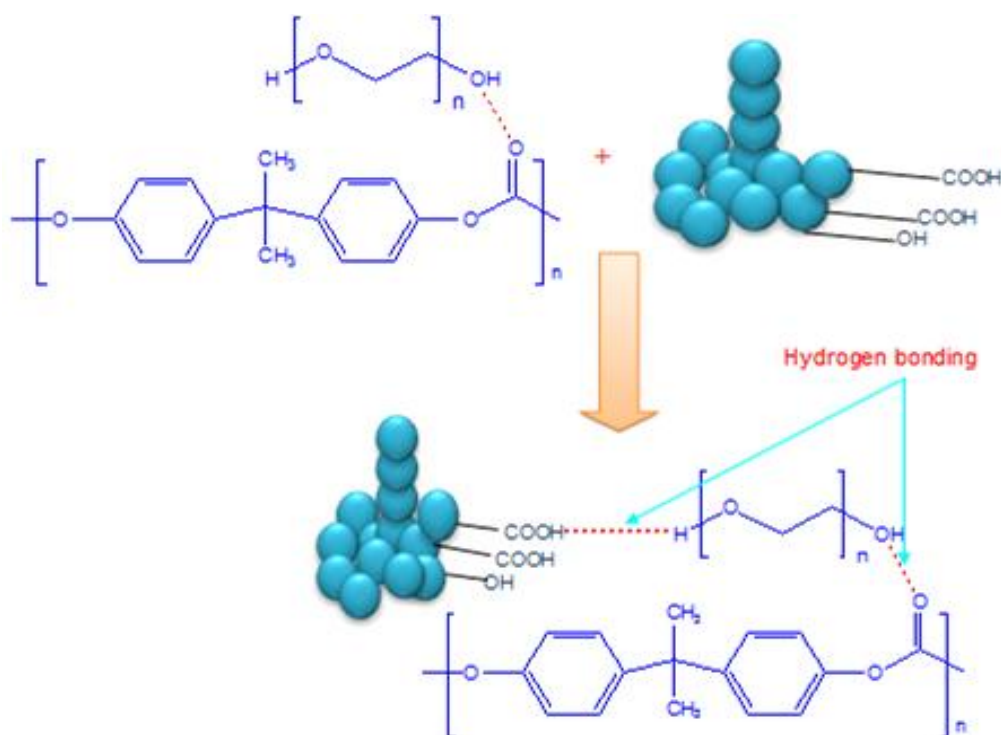


Fig. 2 Formation of PC/PEO/CB composite.

3. Results and Discussion

3.1. Morphology study

The morphology of PC/PEO/CB 1, PC/PEO/CB 5, and PC/PEO/CB 10 composite films are given in Fig. 3. In PC/PEO/CB 1 composite (Fig. 3A), fine composite domains with smaller size polymer wrapped carbon black particles were visible. Afterwards the higher loading of CB content brought about some change in composite morphology. In PC/PEO/CB 5 and PC/PEO/CB 10 composites relatively larger size gravely separated composite particles were observed (Fig. 3B & C). However homogeneity in the CB dispersion was clearly observed in all the composites prepared. Morphological results depicted that there

existed fine interaction between the blend and CB particles. The composite particles were not aggregated; nevertheless CB particles were in contact with each other to form network structure. This network formation was also observed in the form of enhanced electrical property of the PC/PEO/CB composites.

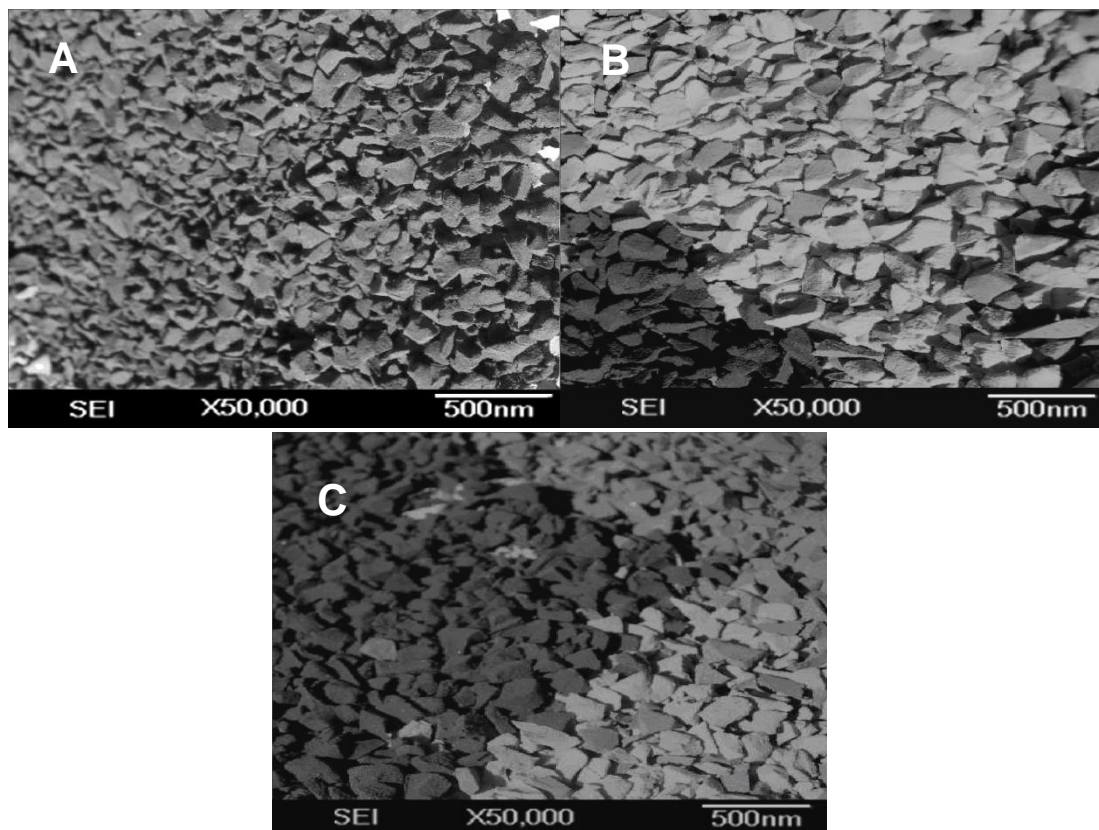


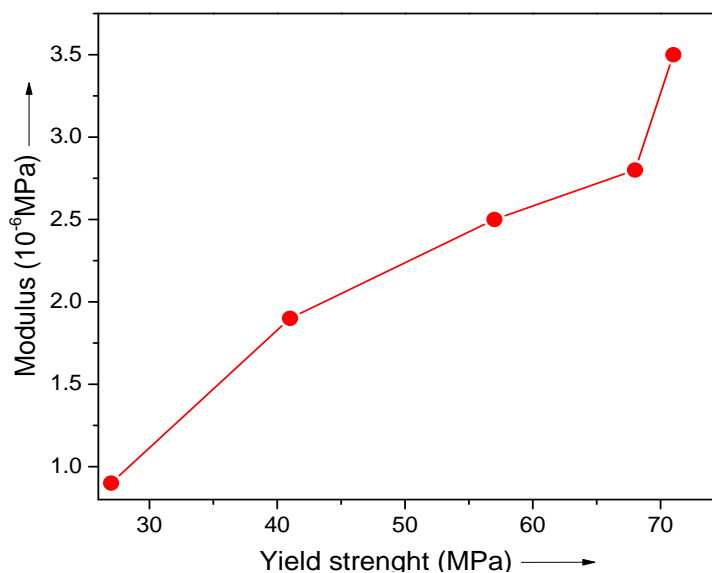
Fig. 3 SEM micrographs of (A) PC/PEO/CB 1; (B) PC/PEO/CB 5; and (C) PC/PEO/CB 10 composites.

3.2. Mechanical properties of PC/PEO/CB composite

Table 1 summarizes the mechanical properties of PC/PEO/CB composites. Fig. 4 shows the influence of CB concentration on stress-strain behavior of composites. Adding CB particles results in an increase in modulus and yield strength. The yield strength of neat PC/PEO blend is 27 MPa. The CB addition has increased the values significantly from 41 MPa (1 wt. % CB) to 71 MPa (10 wt. % CB). This is attributed to fine dispersion of CB particles in PC/PEO/CB composites and better interfacial adhesion between CB particles and PC/PEO blend. Moreover, the mechanical properties of composite are not deteriorated with the addition of higher nanofiller loading. Similarly a continuous increase in the modulus was observed from 1.9 GPa to 3.5 GPa.

Table 1 Mechanical properties of PC/PEO and PC/PEO/CB composite.

Sample	Filler content (wt.%)	Modulus (GPa)	Yield strength (MPa)
Neat PC/PEO	-	0.9	27
PC/PEO/CB 1	1	1.9	41
PC/PEO/CB 3	3	2.5	57
PC/PEO/CB 5	5	2.8	68
PC/PEO/CB 10	10	3.5	71

**Fig. 4** Plot of yield strength vs. modulus of composites.

3.3. Electrical conductivity measurement

The electrical conductivity of PC/PEO/CB composites was measured and the results are listed in Table 2. When the electrical conductivity of PC/PEO/CB 1-10 was compared, the electrical conductivity increased in an order of

$$\text{PC/PEO/CB 1} > \text{PC/PEO/CB 3} > \text{PC/PEO/CB 5} > \text{PC/PEO/CB 10}$$

The results suggested that the electrical conductivity of composite was closely related to the (i) CB particle content and (ii) dispersion of CB particle in blend matrix. In other words, the better the dispersion and content of CB, the higher the electrical conductivity of PC/PEO/CB 10 composite [23]. The electrical conductivity of PC/PEO/CB 10 was increased to 1.1 Scm^{-1} compared with neat blend ($10^{-12} \text{ Scm}^{-1}$).

Table 2 Electrical conductivity of PC/PEO and PC/PEO/CB composite.

Sample	CB content (wt.%)	Conductivity (Scm^{-1})
Neat PC/PEO	-	10^{-12}
PC/PEO/CB 1	1	1.1×10^{-2}
PC/PEO/CB 3	3	7.1×10^{-1}
PC/PEO/CB 5	5	0.99
PC/PEO/CB 10	10	1.1

4. Conclusions

Polycarbonate/poly(ethylene oxide) composites were prepared with various carbon black content. The results revealed that the solution route was effective to homogeneously disperse CB in polycarbonate-based materials. As a result, the mechanical and electrical properties of PC/PEO/CB 1-10 composites were noticeably improved with CB loading. The interaction between blend component and CB particles acted as a compatibilizer. Interestingly the properties were not deteriorated even at 10 wt. % of CB particles loading in PC/PEO matrix.

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