

Effect of Carbon Black Loading on Electrical Conductivity and Thermal Degradation of Poly (Vinyl Chloride)/Poly (Ethylene Oxide) Conductive Films

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Abstract – *In this paper, the effect of carbon black loading on the electrical conductivity and thermal degradation was studied. Conductive polymer films based on carbon black filled PVC/PEO (50/50 wt/wt %) were prepared by solution casting technique. The result shows that the electrical conductivity increased with the increase of carbon black loading. The analysis of thermal degradation of the PVC/PEO conductive blends was performed using thermogravimetric analysis (TGA). The data from TGA indicates that the addition of carbon black into the blend has improved the thermal stability of the PVC/PEO blends. Copyright © 2014 Penerbit Akademia Baru - All rights reserved.*

Keywords: Carbon black, Poly (vinyl chloride), Poly (ethylene oxide), Electrical conductivity

1.0 INTRODUCTION

A widespread attention has been growing in the manufacturing of polymeric materials, particularly for conductive material that does not compromise the enviable mechanical and processing properties [1]. Polymeric materials are naturally insulators, and the conductivity of composite materials depends on the content and properties of the filler, such as the size and shape of the filler particles, the distribution matrix, as well as the interaction between the filler surface and polymeric matrix [2].

Poly (vinyl chloride) is preferred as a polymer matrix because of its broad range of application, low cost, chemically stable, biocompatibility and sterilizability. However, PVC has low thermal stability, which hinders some of its applications [3]. Poly (ethylene oxide) (PEO), also referred to as polyethylene glycol (PEG), is known as polyols with molecular weight below about 20,000, which is contrary to PEO that refers to higher molecular weight polymers. PEO consists of epoxide ring where the two corners of the molecule consist of $-CH_2$ linkages and the third corner is linked oxygen [4]. Carbon black (CB), which is commonly used in industry to produce conductive polymer composites due to its low cost and abundant supply, exhibits the particle shape at relatively low concentration and supermolecular structures at relatively high concentration [5]. Carbon black is widely used as conductive fillers in order to make the polymers with insulating nature into electrically conductive polymers due to its easy processability and lighter than other metallic particles [6]. The most broadly used material to

improve conductivity is carbon black. Carbon black is composed about 97–99% elemental carbon. Other major constituents are hydrogen and oxygen. Hydrogen is distributed as hydrocarbon throughout the CB. These atoms are set into several organic functional groups such as -OH (hydroxyl) and -COOH (carboxyl) on its surface [7].

According to Phua et al., [8] the electrical properties of recycled copper filled epoxy/unsaturated polyester composites increased gradually with the increase of recycled copper powder loading. The conductivity of the composites showed the improvement from $1\text{E}-10$ to $1\text{E}-6 \text{ cm}^{-1} \Omega^{-1}$ with percolated recycled copper powder loading at 30 vol%.

An important objective of the research is to study the effect of conductive filler and its loading on the properties of PVC/PEO films. Therefore, this research reports an investigation on the electrical conductivity properties and thermal degradation of PVC/PEO filled carbon black conductive film by varying carbon black loading.

2.0 METHODOLOGY

Materials. Polyvinyl chloride (PVC) with M.W $\approx 220\,000$ and polyethylene oxide (PEO) with M.W $\approx 100\,000$ were used as the basic polymeric matrix. Carbon black (CB) with mean particle size $< 177 \mu\text{m}$ was used as the conductive filler in the conductive polymer blend. Dioctyl terephthalate (DOTP) with M.W ≈ 390.56 was used as a plasticizer.

Sample preparation. The PVC and PEO conductive films were prepared using solution cast technique. The required amount of PVC and PEO were dissolved in tetrahydrofuran (THF) by using stirrer at the speed of 600 rpm. The solution was prepared at room temperature. After incorporating the required amount of DOTP as the plasticizer, carbon black was suspended in the PVC/PEO blends. The mixture was stirred continuously for 4 h until a homogeneous mixture was obtained. Then, the mixture was cast onto a glass mould and allowed to evaporate slowly inside a fume cupboard at room temperature. The same methods were repeated to produce samples with different carbon black loading.

3.0 RESULTS AND DISCUSSION

Fig. 1 shows the relation between the electrical conductivity of PVC/PEO/CB conductive film and carbon black loading. From the Fig. 1, it can be seen that the electrical conductivity of the PVC/PEO conductive films increased with the increase of carbon black loading. This is due to the incorporation of carbon black loading that improves the conductivity of the film. Jie Chen et al. [9] determined that the electrical resistivity of composites decreased slightly at CB content smaller than 3.0 wt%, and later decreased for CB content higher than 3.0 wt%.

Fig. 2 shows TGA thermograms as a function of temperature in the range from 30°C to 650°C for PVC/PEO blend with different composition of carbon black. As shown in Fig. 2, all samples have three decomposition steps. The first step occurs between the temperatures of 200°C – 280°C , which involves the melting point of PEO due to the splitting of small molecule and evaporation of moisture [10]. The second decomposition stage involves the decomposition of PVC. The latter processes in the graph show the main decomposition step where the most significant weight loss was observed. From Table 1, the temperature at 5% weight loss ($T_{-5 \text{ wt\%}}$), the final decomposition temperature and the residual mass of PVC/PEO/CB blend increased with an increase in filler loading. The result shows that higher filler loading produces

PVC/PEO/CB blends with higher thermal stability than lower filler loading. Xin Wen et al. [11] reported that the thermal decomposition temperature for PP/CB nanocomposites shifted significantly to a higher temperature range than for neat PP, which indicates an improvement of thermal stability. Both $T_{5\text{ wt\%}}$ and $T_{10\text{ wt\%}}$ increased with the increase of CB content. This is due to the formation of three-dimensional filler network structure by CB in PP, which is responsible for the improvement in thermal stability.

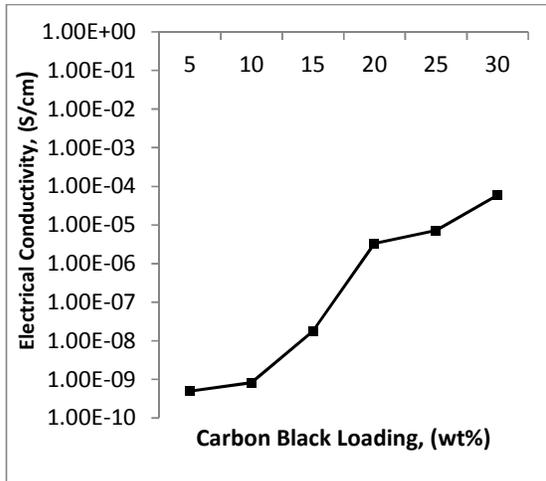


Figure 1: Electrical conductivity vs. carbon black loading of PVC/PEO with different carbon black loading.

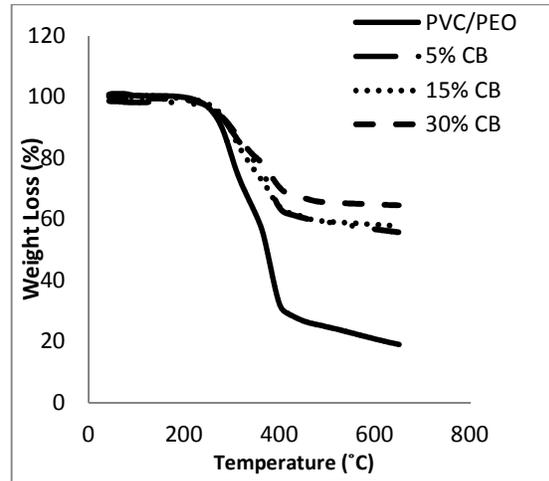


Figure 2: TGA thermogram of PVC/PEO/CB blends with different filler loading.

Table 1: Data for $T_{-5\text{ wt\%}}$, final decomposition temperature and residual mass of PVC/PEO/CB at different carbon black loading.

Blend composition	$T_{-5\text{ wt\%}}$ (°C)	Final decomposition temperature, FDT (°C)	Residual mass (%)
PVC/PEO	260.36	551.95	22.74
PVC/PEO/5% CB	267.64	565.65	57.54
PVC/PEO/15% CB	268.32	591.17	58.37
PVC/PEO/30% CB	269.78	604.84	64.82

The importance of infrared spectroscopy analysis is to determine the chemical functional groups in the PVC/PEO/CB conductive polymer blend. Different functional group absorbs different characteristic frequencies of infrared. From the result in Fig. 3, the wavenumber

observed for spectrum absorption intensity peaks at 3423 cm^{-1} corresponds to the N-H groups. Besides that, Fig. 3 shows a strong absorption peak at 3182 cm^{-1} , which represents the O-H (hydroxyl) groups. The peaks at 2995 cm^{-1} and 2637 cm^{-1} correspond to the $-\text{CH}_2$ bending from PVC and PEO structures. The vibration of CN group at 2362 cm^{-1} is from the plasticizer, whereas the peak at 1710 cm^{-1} signifies the C=O stretching of the DOTP structure and the peak at 1520 cm^{-1} is the vibration from N-H. The peaks at 627 cm^{-1} and 616 cm^{-1} show the C-Cl stretching of polyvinyl chloride.

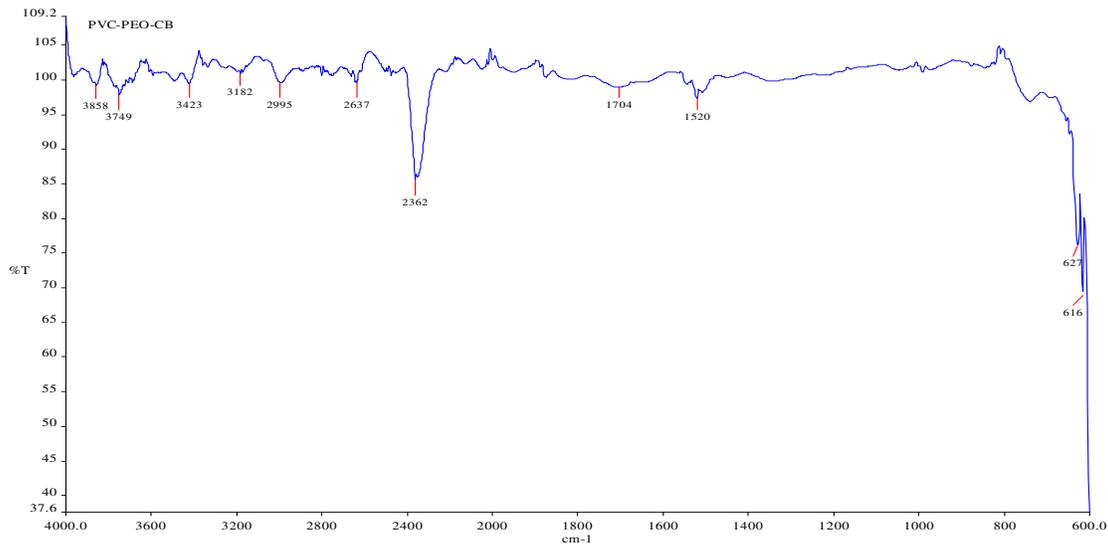


Figure 3: FTIR spectrum of PVC/PEO/CB conductive polymer film

4.0 CONCLUSION

The electrical conductivity of the PVC/PEO/CB conductive polymer blends increased with the increase of carbon black loading. Also, the addition of high carbon black loading improves the thermal stability of PVC/PEO/CB conductive polymer blends.

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