Effect of graphite loading on the electrical and mechanical properties of Poly (Ethylene Oxide)/Poly (Vinyl Chloride) polymer films

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Abstract: In this study, films consisting of a blend of poly (ethylene oxide)/ poly (vinyl chloride) (PEO/PVC) and a conductive filler, graphite were prepared and characterized for their mechanical and electrical properties. Solid polymer blend films based on PEO/PVC (50/50 wt%/wt%) with different graphite loading were prepared by using solution casting technique. Electrical conductivity results discovered the conductivity increased with increasing of filler loading. However, increasing amount of graphite loading led to a decreased in tensile strength and young’s modulus of PEO/PVC/Graphite polymer films. The dispersion of graphite and mechanism of conductive path in the polymer films were also investigated by scanning electron microscopy (SEM). The morphology of the PEO/PVC/Graphite polymer films shows that agglomeration occurred to complete the connection of conductive path, thus improving the conductivity behavior of the polymer films.

Keywords: Poly (vinyl chloride), Poly (ethylene oxide), graphite, electrical conductivity, mechanical testing

1. Introduction

Conductive polymer composites can be fabricated to achieve the desired properties for specific applications. It has been extensively used in various engineering applications including conductive adhesives, electromagnetic interference shields and electronic devices [1-3]. The choice of conductive fillers is the important criteria to produce highly conductive polymer composites since different conductive fillers have their own unique properties. Numerous types of carbon based fillers have been studied including graphite, carbon black and carbon fiber [4].

PEO is crystalline polymer which has solvating characteristics and commonly applied in polymer electrolytes system. The major problem of using PEO is the high degree of crystallization when used as single matrix in conductive polymer composites. This problem can be overcome by blending or mixing with another polymer such as PVC and PMMA. PVC has chlorine atom which containing lone pair electrons and inorganic salts able to be dissolved in electrolyte systems [5]. The PVC are inexpensive, able to form homogenous hybrid film and marketable. In this study, PVC forms miscible blend together
with PEO due to its unique characteristic which is easy processability and compatible with various plasticizers. The PEO/PVC blends have been broadly used as a matrix in polymer electrolytes.

Graphite is crystal form of a pure carbon much resembling of mica-sheets of strongly linked atoms, with very weak bonds between the sheets. Graphite generally used as electronically conducting filler because it is economical and abundant naturally [6]. In this study, the electrical properties, morphology and mechanical properties of PEO/PVC blends containing graphite filler were investigated.

2. Experimental

2.1 Materials
PVC powder with molecular weight of 220 000 g/mol and PEO powder with molecular weight of 100 000 g/mol as the matrix for conductive polymer film was supplied by AR Alatan Sdn. Bhd., Alor Star, Malaysia. Graphite with molecular weight of 12.02 g/mol and particle size of <50 µm was supplied by R&M Chemicals. Plasticizer used in this research was Diocetyl terephthalate with molecular weight of 390 g/mol and tetrahydrofuran with molecular weight of 72.11 g/mol was provided from AR Alatan Sdn. Bhd.

![Figure 1. Morphology of graphite particle](image)

2.2 Composites Preparation
The PEO/PVC/Graphite polymer films were processed by solution casting method. Initially, PEO and PVC are dissolved in tetrahydrofuran solution (THF) and were blended together to get homogeneous solution. The DOTP as was incorporated at the same amount for all composition. After that, conductive filler were added in the solution. The PEO/PVC/Graphite polymer films solutions were poured and casted on a glass mould after 4 hours and let it to evaporate in a fume cupboard at room temperature. The PEO/PVC/Graphite polymer films were formed when THF are fully dried. The same process was repeated to produce films which consist of different graphite content.
2.3 Tensile Test
This testing was conducted using Universal Testing Machine Instron 5569 by following to ASTM D638. Five rectangular samples were used for each film composition and were tested with crosshead speed of 10 mm/min. The tensile strength and young’s modulus of each of the films were obtained.

2.4 Scanning Electron Microscopy (SEM)
The morphology of PEO/PVC/Graphite polymer films was examined by scanning electron microscope, JEOL JSM-6460 LA. The sample surfaces were coated by auto fine coater, JEOL JFC 1600.

2.5 Electrical Conductivity Testing
The conductivity measurement of PEO/PVC/Graphite polymer films was conducted using I-V measurement systems. The conductivity was tested by Keithley Model 4200 Semiconductor Characterization System. The samples were conducted with voltage varied from 0 V to 10 V. The electrical conductivity was determined using its relationship with resistivity and conductivity as shown in Equation 1 and Equation 2 below:

\[
\rho = R \left( \frac{w \times t}{l} \right) \tag{1}
\]

Where \( R \) = resistance of the films, \( w \) = width, \( t \) = thickness, \( l \) = length between the probe contact.

\[
\sigma = \frac{1}{\rho} \tag{2}
\]

3. Discussion

3.1 Electrical Conductivity
The dependency of the electrical conductivity of PEO/PVC filled with graphite polymer films on the filler content is shown in Figure 2. The results illustrate that the electrical conductivity of PEO/PVC/Graphite polymer films increased with increasing in filler loading. When the graphite content in polymer films increased, the electrical conductivity of PEO/PVC/Graphite polymer films also increased. The graphite fillers act as mediums for the electron or electrical charge to flow. This allows the electrons free to flow through the graphite fillers and matrix. Electrical conducting paths and networks are formed in films with increasing filler concentration. It can be observed that about 15 wt% of the graphite content, the increase of electrical conductivity was observed. In this condition, infinite cluster of graphite particles is built within the polymer matrix. These infinite clusters go through to the sample and represent a conductive path for electrons to move throughout the sample [7]. Huang et al. (2015) have investigated the effect of graphene loading on the properties of polypropylene (PP). The result shows that an increasing amount of graphene in the PP results in a more complete conductive path thus contributed higher conductivity [8].
3.2 Morphology analysis

Figure 3 shows the surface morphology of pure PEO/PVC and PEO/PVC/Graphite polymer films with different filler loading varied from 5 wt% to 25 wt%. Figure 3(a) shows the surface morphology of the pure PEO/PVC polymer films without addition of graphite filler at x200 magnification. A flat surface was observed on the surface of pure PEO/PVC polymer films due to the miscibility between PVC and PEO blends.

Figure 3(b) shows the surface morphology of PEO/PVC polymer films with incorporation of 5 wt% of graphite loading. It can be observed that the graphite particles are distributed far because only a small amount was added into the blend. Figure 3(c) and Figure 3(d) shows the surface morphology of PEO/PVC polymer films with a graphite filler of 15 wt% and 25 wt% respectively. The distributions of filler particle are clearly uniform, but there is agglomeration of graphite on the surface of the sample at high filler loading. At 25 wt% of graphite filler, the filler are adequate to have intimate contact, thus conductive path is formed. This was convinced that by increasing amount of graphite in PEO/PVC polymer films has led to the high electrical conductivity behavior. The filler matrix interaction at higher filler content is substituted by the domination of filler-filler interaction.
3.3 Tensile properties

The mechanical properties of polymer composites are particularly corresponded with the filler content, dispersion of fillers in the matrix, and the properties of the polymer matrix and the interaction between polymer matrix and filler. The results of tensile strength and young’s modulus for pure PEO/PVC polymer films and PEO/PVC/Graphite polymer films containing various graphite loading are presented in Figure 4 and 5 respectively. By comparing to the tensile properties of pure PEO/PVC polymer films, the PEO/PVC/Graphite polymer films containing 5 wt% of graphite have 23 % lower tensile strength and 39 % lower young’s modulus and the tensile properties of the polymer films are decreased continuously with addition of loading level of graphite. The addition of graphite fillers attributes a restrictive effect over the PEO/PVC polymer films by deformation of their molecular chains and restricting the motion [8].

Figure 4. Tensile strength of PVC/PEO/Graphite polymer films at different graphite loading.
4. Conclusion
In this study, the electrical and mechanical properties of PEO/PVC/Graphite polymer films were investigated. The addition of graphite filler to PEO/PVC blends induced an increased in electrical conductivity. It was observed that increasing amount of graphite filler has led to a decreased in tensile strength and young’s modulus of the PEO/PVC/Graphite polymer films.

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6. References
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