Preliminary investigation on the correlation between mechanical properties and conductivity of low-density polyethylene/carbon black (LDPE/CB) conductive polymer composite (CPC)

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Abstract. The insulating nature of a polymer can be changed to electrically conductive by incorporating conductive fillers within the polymer matrix to form a conductive polymer composite (CPC). One of the potential application of CPCs are in the area of flexible electronic interconnect application. Nevertheless, the correlation between the electrical conductivity and mechanical properties of CPCs such as tensile was found to be limited. Therefore, this paper is aimed to report the preliminary investigation on the correlation between conductivity and mechanical properties of a low-density polyethylene (LDPE) incorporation with conductive filler which is carbon black (CB). It was observed that the tensile strength was decreased by up to 29.4% and the elongation of break was decreased by up to 90.6% at higher CB loading compared to pure LDPE. Nonetheless, the modulus of elasticity and the electrical conductivity of the composites were increased by up to 150.5% and 16.4% at higher CB loading respectively. Moreover, it was found that the effect of CB additions on the tensile modulus was greater compared to the conductivity of the CPCs.

1 Introduction

Polymer composites that are conductive can be utilised in many areas such as the electronic area where it can be applied as self-regulating heaters, over-current and over-temperature protection devices, antistatic and electromagnetic radiation shielding materials [1]. Generally development of conductive polymer composites (CPCs) are developed by using polymer
Flexible CPCs had gained interest in electronic interconnect applications due to their unique properties where electric current able to flow under bending, stretching, or twisting. The crucial parts of flexible CPCs are it needs to be highly conductive and able to retain their conductivity during the mechanical deformation [3]. However, the challenge in fabrication of the flexible CPCs become more crucial in term of dispersion and distribution of conductive filler into polymer material. Conductive filler must be dispersed and distribute well in polymer matrix to form the conductive pathways, filler particle must be aligned to allow the current to flow in the composites. Properties of conductive filler such as particle size, surface area and also matrix-filler interactions play main role in electrical properties of [4].

Percolation threshold in CPCs known as the critical concentration of conductive filler that transforms composite from insulating to the conductive state where it depends on the type of filler, shape and particle size of filler, distribution and dispersion of filler into matrix and processing condition of the CPCs [5]. According to A J Marsden [6], S-shaped curve are form due to the conductivity of the composites that rise as the filler loading increase and reached the percolation threshold. S-shape curve is the graph of conductivity versus filler loading and it shows three regions which is insulating, percolating, and conductive region.

In this study, the correlation between the mechanical properties and conductivity of a CPC will be reported based on the preliminary data obtained from tensile testing and 4-point probe. A low-density polyethylene and CB were selected as the main polymer material and conductive filler, respectively. LDPE are widely known in many industries such as packaging, automobile, and household industry and it is made up from free-radical polymerization process is characterized by its low molecular weight resulting from the presence of long-chain branches in the polymer [7].

CB is one of the popular conductive filler that applied in the processing of CPCs but it is easily agglomerate due to the Van der Waals force and lead to higher percolation threshold content to achieve conductive network [8]. A higher concentration of CB loading tends to increase the conductivity of CPCs and it lead to the formation of a conductive network path inside the composites [9-10]. Furthermore, addition of CB in will also resulted in an increased in tensile modulus such as reported by D. Xiang et. Al [11], where the tensile modulus of a high density polyethylene (HDPE) was increased by 30% when adding CB at low loading within HDPE matrix.

2 Experimental Set-up

In this study, the main polymer material used was low-density polyethylene (LDPE) produced by Lotte Chemical Titan (M) Sdn. Bhd., Pasir Gudang, Johor purchased from Adv. Dynamic, Kulim, Kedah. The conductive filler which is carbon black was obtained from A.R. Alatan Sains (K) Sdn. Bhd, Alor Setar Kedah with the grade of CB was N330.

Each composition of LDPE and CB as tabulated in Table 1 was mixed in a plastic bag before being fed into an internal mixer for the compounding process. The speed of the rotor was set at 15rpm and temperature of 140°C. Then, the composite was weighed for the next
process. The composite was compressed at 140°C with a pressure of 15 MPa in a rectangular mould with the thickness of the specimen in 1mm. The time taken for one complete cycle of the compression process was 11 min.

| Composite Compositions | LDPE (wt.%) | CB (wt.%) |
|------------------------|-------------|-----------|
| 0                      | 100         | 0         |
| 2                      | 98          | 2         |
| 4                      | 96          | 4         |
| 6                      | 94          | 6         |
| 8                      | 92          | 8         |

All compositions of LDPE/CB were subjected to tensile testing by using the Instron machine according to ASTM D3039. The specimen was cut into dumbbell shape with the dimension of 114mm × 7mm × 1mm (length × width × thickness). For each composition, 5 specimens were tested to obtain the average data for tensile modulus, tensile strength, and elongation at break of each composition.

4-point probe test was used to measure the conductivity of the specimen. The model of the machine was Keithley Model 6221. The specimens were cut into a circular shape with the dimension 25mm of diameter and 1mm of thickness. A number of 3 measurements were taken for each sample at various scanning points to take the average of conductivity for each sample. The electrical conductivity of the CPCs was calculated by Equation 1 [12]:

\[
\sigma = \frac{L}{RA}
\]

\(\sigma\) is denote as conductivity of the composites (Scm\(^{-1}\)), \(R\) is the resistance of composites (Ω), \(L\) indicate the thickness of the specimen (cm) and \(A\) represent the area of the specimen (cm\(^2\)).

3 Results and Discussion

3.1 Tensile Properties

Effect of CB addition on the tensile modulus, tensile strength and elongation at break are shown in Fig. 1, 2, and 3 where the data is tabulated in Table 2. It can be seen from Fig. 1 that tensile modulus value of 38.83 MPa for pure LDPE was recorded. At 2 wt.% of CB loading, the modulus was increased approximately by 117.7% than pure LDPE. At higher loading of CB at 8 wt.%, the tensile modulus was increased approximately by 150.5% compared to pure LDPE. It shows that the inclusion of CB filler in LDPE had increase the tensile modulus of CPCs due to CB that has higher stiffness and it make the composites become stiffer. As reported by T. Gong et. al [13], addition of CB into polypropylene (PP) matrix had decreased the tensile strength and tensile modulus of the PP/CB composites. This is due to the agglomeration of the CB particles and the weak interfacial adhesion between CB and the PP matrix. Nonetheless, M. Sabet et. al [14] stated that increasing of graphene (Gr) loading in LDPE had created a mechanically stable network within the LDPE and high storage modulus of LDPE/Gr that lead to increase of tensile modulus of the nanocomposite.
Fig. 1 Effect of different loading of CB in modulus elasticity of LDPE/CB.

| CB filler loading, wt.% | Tensile modulus, MPa | Tensile strength, MPa | Elongation at break, % |
|------------------------|----------------------|-----------------------|------------------------|
| 0                      | 38.83 ±0.275         | 8.36±0.013            | 160.64±17.890          |
| 2                      | 84.52±0.598          | 8.17±0.196            | 36.26±9.744            |
| 4                      | 87.62±1.692          | 7.83±0.251            | 16.49±7.286            |
| 6                      | 91.23±0.324          | 6.03±0.743            | 15.72±0.562            |
| 8                      | 97.25±0.484          | 5.90±0.473            | 15.12±0.245            |

From the graph shown in Fig. 2, addition of CB into LDPE had resulted in a decrease in the tensile strength LDPE. For pure LDPE, the tensile strength was 8.36 MPa. The addition of 2wt.% of the CB had slightly decreased the tensile strength by 2.3% compared by pure LDPE. Further addition of CB in higher loading in particular 8 wt.% resulted a further decreased in the tensile strength by 29.4% than pure LDPE and the composites becomes more brittle. A higher filler loading normally will be lowering the mechanical properties of the composites. According to S. Paszkiewicz [15], nanocomposites with CB nanoparticles had slightly lowered the tensile strength and strain at break of the composite when comparing with pure LDPE.
Elongation at break is one of the important parameters to indicate the ductility or fracture toughness of materials [16]. From Fig. 3, the elongation at break of LDPE/CB was decreased when the CB loading was increased. For pure LDPE, the elongation at break of the matrix was 160.64%. The addition of 2 wt.% of CB into the LDPE had decreased the elongation at break of the CPCs at 77.4% than pure LDPE. Further addition of the CB in CPCs at 8 wt.% resulted in a further decrease of the elongation at break of CPCs by approximately 90.6%. A decrease in the elongation at break had been also reported by Jing Lang C. et. al [17] where it was observed that the increasing in filler content leading to inferior values of elongation at break when investigating LDPE composite with CB and oil palm empty fruit bunch (OPEFB).
3.2 Electrical conductivity

Fig. 4 illustrated the electrical conductivity of the pure LDPE and various loading of CB into LDPE. In general, addition of CB at higher loading had increased the electrical conductivity of LDPE/CB composites. The conductivity value of $4.25 \times 10^{-5}$ S cm$^{-1}$ for pure LDPE was recorded using the 4-point probe. At the addition of 2 wt.% of CB filler, the conductivity of the CPCs was slightly decreased by approximately 4% compared to pure LDPE. It may be due to the poor dispersion of the CB filler in LDPE. However, at 6 wt.% of CB filler loading, the conductivity was increased marginally from $4.09 \times 10^{-5}$ to $4.19 \times 10^{-5}$ S cm$^{-1}$ compared to composite with 2 wt.% of CB. At the higher loading of CB which is at 8 wt.%, the conductivity of the CPCs approximately increased by 16.4% when comparing with the conductivity of pure LDPE. Previous work done by Yongsi Y. et al [18], it was reported that the addition of CB filler in LDPE matrix recorded a value of $1.93 \times 10^{-7}$ S cm$^{-1}$ for composite with 13 wt.%, CB loading. Furthermore, Bahaa H. [19] and Iftekharul I. et. al [4] stated that with the increasing of conductive filler loading, the conductivity was also increased due to the increasing of charge carriers in the composite with increased filler contact. H. Yang et. al [20] had reported that the addition of 5 wt.% of CB into PP had increased conductivity to $2.7 \times 10^{-4}$ S/m. This due the formation of network path structures in composites matrix. S. Azizi et. al [21] found that the incorporation of CB into LDPE had increased the conductivity by 11 orders of magnitude than pure LDPE alone due to the concentration of filler that reached the percolation in the range of 20-25 wt.% of CB. Nevertheless, compared to metal particles incorporated with polymer matrix, CB tends to aggregates and formed an agglomerated structure in the matrix for several of carbon black/ polyethylene (CB/PE) composite systems depending on the processing technique utilised [1].

![Fig. 4 Conductivity of LDPE with various loading of CB](image)

3.3 Correlation between tensile modulus and electrical conductivity

Fig. 5 shows the graph of the correlation between tensile modulus and conductivity of LDPE/CB. It shows that the modulus of elasticity increases with conductivity. At 0 wt.% of CB, which is pure LDPE, the conductivity value of $4.25 \times 10^{-5}$ S cm$^{-1}$ and 38.83 MPa for the tensile modulus of CPCs were recorded. The addition of CB in 2wt.% had increased the tensile modulus about 117.7% compared to pure LDPE but the conductivity of the LDPE was slightly decreased. However, the conductivity of CPCs and tensile modulus at 6 wt.% of CB
filler loading were found to slightly increased compared to pure LDPE. At higher filler loading which is at 8wt.%, the conductivity was increased, and the tensile modulus of CPCs was higher compared to pure LDPE. According to Yasar M. et al [22], the agglomeration of the conductive filler leads to the increasing of elastic modulus. Further, previous work done by Leonardo Nishiguti S. et. al [23], they found that addition of CB can enhanced the elastic modulus of composites.

![Graph](image.png)

**Fig. 5** Relationship of modulus of elasticity with conductivity of LDPE/CB

## 4 Conclusion

In this preliminary research work, it was observed that when CB filler loading were increase, the tensile strength and elongation at break were decreased. This may probably be due to poor dispersion which leads to CB particle agglomeration within the matrix and because of poor interaction between the matrix and filler. Nonetheless, the tensile modulus was increased due to the stiffening effect because of CB addition. The addition of CB in LDPE had also increased the conductivity of the CPC at higher filler loading. At low filler loading, marginal decrease in conductivity was observed which may be due to the poor distribution of CB in the composite. The correlation between the tensile modulus and conductivity indicates that the effect of CB addition on the composite tensile modulus was greater compared to the conductivity of the CPC.

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