Electromagnetic Interference (EMI) Shielding Effectiveness (SE) of Unsaturated Polyester Resin with Carbon Black Fillers

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***Abstract*— This paper presents the electromagnetic interference (EMI) shielding effectiveness (SE) investigation of carbon black filled polyester composites. The composition of the polymer composite ranging from 4, 6, 8 and 10wt % of carbon black to unsaturated polyester resin was prepared. Two types of carbon black were used in this project, carbon black derived from water hyacinth and commercially available activated carbon black. The S (scattering)-parameters (S11 and S21) of polyester composites were measured and compared between the two types of carbon black; carbon black derived from water hyacinth and activated carbon black. The shielding effectiveness was determined from measured S11 and S21 parameters. It was observed that the shielding effectiveness of the composites is frequency dependent and filler loading dependent. According to the results, the contribution of absorption to shielding effectiveness of both carbon blacks is greater than 83 % at 3 GHz. The analyzed results showed that the percentage of shielding effectiveness of polyester composite reinforced with naturally derived carbon black is similar to those with activated carbon black. The result also showed that the contribution of absorption to the shielding effectiveness was larger than that of reflection. This research suggests that polyester composite with carbon black derived naturally from water hyacinth can be used as a replacement for the commercially available activated carbon black as a shielding material in medical applications.**

***Index Terms*— Carbon black; Electromagnetic interference shielding (EMI); Polymer composites; Percolation; Unsaturated polyester resin.**

I. Introduction

Polymer-based conducting composites have such a broad interest in electronic applications due to their unique properties such as low density, ability to form complex shapes, versatile electrical characteristic and low manufacturing cost. As all polymers exhibit Dielectric behavior, it is also considered in applications for insulation, isolation and microelectronics. The electrical conductivity of insulating polymers materials can be enhanced by incorporating some conducting carbon black filler in the polymer matrix.

Electrically conductive polymer composite generated above a reliable filler content known as percolation threshold where a continuous path of conductive particles is formed [1]. The electrical properties of polymer composite depend on the conductive fillers distribution among polymer matrix and as a result of the method of filling [2].

Conductive polyester composite potentially can be used as electromagnetic interference (EMI) shielding for a protection purpose. Research on several aspects of the conductive polyester composite such as high anti-corrosion property, high-temperature resistance and controlled conductivity which are being studied for the future direction in research and technology of electromagnetic interference (EMI) shielding [3-10].

The study of physical properties of the carbon black filled polyester composites such as shielding effectiveness and their dependence on fillers content, and AC conductivity provides researcher more information on composites and their biomedical application [11-14]. Therefore, this paper presents the preparation of polyester composite and investigation about the effect of composition and electrical properties on the shielding efficiency of the composites.

II. Experimental Method

A. Preparation of Polyester Composite

The In this study, the polymer matrix used as doping medium is unsaturated polyester resin. Doping is a process of adding conductive carbon black filler in unsaturated polyester resin to form a conductive polymer composite. Two types of carbon black were used as a filler; carbon synthesized from water hyacinth and activated carbon black. In order to achieve a better polymerization for this polyester resin, the catalyst Methyl Ethyl Ketone Peroxide (MEKP) is added with the percentage of 0.5% for each 100ml of polyester resin. The density of polyester resin is 1.20 g/cm^3 were predetermined using density meter.

B. Mixing process using water shaker

The mixture of polymer matrix was done with various percentages (4, 6, 8 and 10) % of carbon black. After preparation of polyester resin with the required content of carbon black filler, the mixture was left out in the water bath shaker for a duration of 2 hours at 40ºC with 125rpm as a constant speed throughout the process. In order to increase the rate of polymerization, MEKP with a proportion of 0.5% for 100ml of polyester resin was added at the end of doping process. After the mixing process, the mixture was poured into a dumb-bell shaped mold. The mold was shaped used computer numerical control (CNC) machine, and the sizes are in accordance with the American Standard Test Method (ASTM). The mold was placed in an oven with 80ºC for the 1-hour duration to ensure the mixture is completely cured.

C. AC Conductivity Measurement

AC conductivity is one of the studies done on polymer composites to obtain information on electrical properties of materials and their interference with electronically conductive electrodes. The electrical conductivity of polyester composites was measured using Precision LCR Meter shown in Fig. 1(a). Testing frequency is ranging from 50 Hz to 1MHz. The pellet of the polyester composite sample was placed between two probes as shown in Figure 1(b) which have been coated with gold materials on both surfaces with leads connected to an LCR meter interfaced to a computer for conductivity measurements. The measured conductance G, from 50 Hz to 1 MHz is used to calculate AC conductivity, σ (ac) using the following expression:

$$\sigma\ (ac) = G\ d/A \tag{1}$$

where the thickness, d is 2.12 mm and cross-sectional area, A is 10.61 mm^2 of the electrode.

(a)

(b)

Figure1: Photographs of (a) LCR meter and (b) experiment setup for testing samples

D. Shielding Effectiveness Measurement

The EMI shielding effectiveness of carbon black-polyester composites is the most important parameter that was measured in this experiment. This measurement system should prove that the polyester composites are capable of acting as a shielding material for electromagnetic interference (EMI) and radio frequency interference (RFI). The shielding effectiveness of polyester composites was measured using Mini-Circuit Voltage Controlled Oscillators (VCOs) as shown in Figure 2. The absolute maximum supply voltage (V_{cc}) used for this measurement was 7 Volt. The frequency is ranging from 1200 MHz to 3000 MHz with 20 data point. Also, the maximum tuning voltage (V_{tune}) used was 25 Volt, where the V_{tune} varies according to the frequency level. The system consists of a pair of lens probes (transmit and receive probes), a VCOs with co-axial cables and a computer for data acquisition.

Figure 2: Voltage Controlled Oscillator (VCOs)

1) Reflection Coefficient Measurement (S_{11})

The setup of the experimental arrangement is shown in Figure 3. For each measurement, incident power was measured without a load between transmit and receive probes, then the reflected power measured with a load between transmit and receive probes. In addition, the reflected power was measured on at least five load samples, and finally, the average of the reflected power was calculated.

Figure 3: Experimental setup for measuring S_{11}

According to the ratio of the incident wave, P_I to the reflected wave, P_R, the reflection coefficient (R) can be calculated using the following formula:

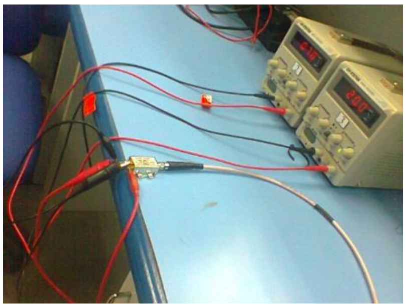
$$R = |S_{11}|^2 = |P_R/P_I|^2 \tag{2}$$

2) Transmission Coefficient Measurement (S_{21})

The transmission coefficient of polyester composites was measured based on the setup as shown in Figure 4 (a), the VCOs was connected to two power supply where one of the power supply act as a V_{CC} and the other one act as V_{TUNE}. According to Figure 4 (b), for each measurement of the data point, the incident was measured without load between transmit and receive probes then there was no gap between both probes when the incident power reading was taken. The transmitted power was measured on five load samples, and the average of the transmitted power was calculated to obtain an accurate reading.

The transmission coefficient (T) is defined as the ratio of the transmitted power, P_T to that of the incident power, P_I and can be expressed in term of scattering parameter, S_{21}:

$$T = |S_{21}|^2 = |P_T/P_I|^2 \tag{3}$$



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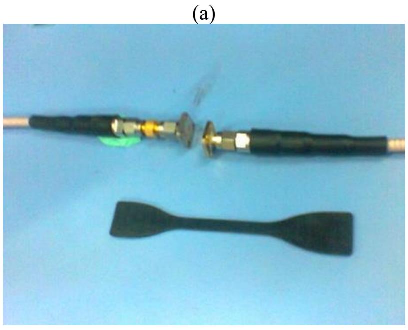


(b)

Figure 4: Photographs of(a) Voltage supply to VCOs and (b) Testing of pellets using transmit and receive probes

3) *Absorption Coefficient and EMI Shielding Effectiveness (SE) Measurement*

The absorption coefficient (A) and shielding effectiveness (SE) of the polyester composites could be calculated from the measurement of S-parameters. Using the Mini-Circuit VCOs, the S-parameters, S_{11} and S_{21}were calculated. The absorption coefficient (A) can be derived from the following relation:

$$T + R + A = 1 \quad (4)$$

$$A = 1 - T - R \quad (5)$$

Since reflection coefficient (R) and transmission coefficient (T) are defined as R=$|S_{11}|^2$ and T=$|S_{21}|^2$ then the absorption coefficient (A) can be written as:

$$\mathrm{A} = 1 - |\mathrm{S}_{21}|^2 - |\mathrm{S}_{11}|^2 \quad (6)$$

The EMI shielding is the summation of reflection, absorption and multiple internal reflection losses at the interface of the shielding material. The overall EMI shielding effectiveness can be derived as:

$$SE_T = SE_R + SE_A + SE_{MIR} \quad (7)$$

Moreover, since the absorbance loss (SE_A) is greater than 10 dB, then the multiple internal reflection loss (SE_{MIR}) is negligible. Therefore, the earlier relation is then modified into the simple equation as below:

$$SE_T = SE_R + SE_A \quad (8)$$

$$SE_T = -10log(1 - R) - 10\ log\left(\frac{T}{1-R}\right) \quad (9)$$

$$SE_T = -10\left[log(1 - R) + log\left(\frac{T}{1-R}\right)\right] \quad (10)$$

$$SE_T = -10\ log\left[(1 - R) \times \left(\frac{T}{1-R}\right)\right] \quad (11)$$

After the simplification of the above equation, the following expression is obtained for the total shielding effectiveness (SE):

$$SE_T = -10 \log T \quad (12)$$

III. Results And Discussion

A. *Conductivity of Two Different Types of Conductive Carbon Black-Polyester Composites*

The variations of the AC conductivity of the polyester composite with respect to % of carbon black (CB) to the polyester resin at 1MHz frequency are shown in Fig. 5. According to the obtained results, the AC conductivity shows weak dependent on both CB contents up to 6% CB and then the AC electrical conductivity of polyester composite with activated carbon black starts to increases linearly with respect to the CB contents. The AC electrical conductivity between activated carbon black and carbon black from water hyacinth shows drastic changes starting from 6% CB and upwards as shown in Table 1.

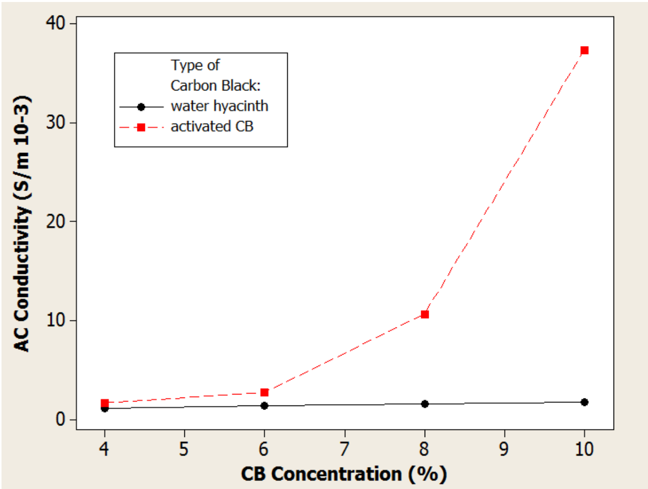


Figure 5: AC conductivity versus black carbon concentration in two types of polyester composites

Based on the result, in term of AC conductivity measurement of two different types of polyester composites, the activated carbon black based polyester composite shows higher conductivity compare to the water hyacinth carbon black based polyester composite. This result showed similar function in different experiments on polymer composites [9]. For example, with same amount filler loading (10%) in both polyester composites at 2 cm distance, the AC electrical conductivity of activated carbon black-polyester composite is 37.34 S/m 10^{-3} which are higher compared to the water hyacinth carbon-polyester composite which is only 1.71 S/m 10^{-3}. It can be concluded that, in order to reduce the electromagnetic field in spacing, the use of activated carbon black filler is proven as a better conductivity for the polyester composite as a shielding material rather than using the water hyacinth carbon filler [15-17].

Table 1
AC Conductivity of Different Filler Loading in Both Polyester Composites

Concentration of Carbon Black in Composite (%)	Carbon Black from Water Hyacinth (S/m 10^{-3})	Activated Carbon Black (S/m 10^{-3})
4	1.1092	1.6377
6	1.3258	2.7126
8	1.5648	10.6337
10	1.7091	37.3380

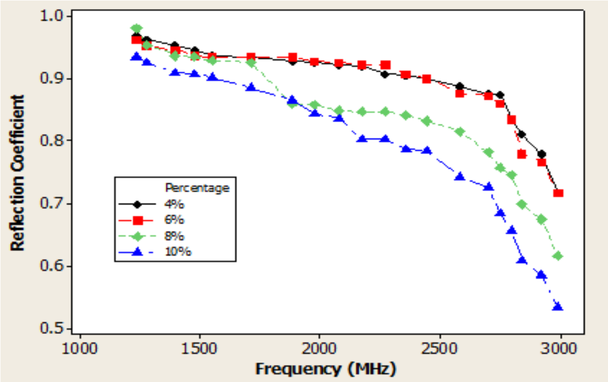
B. EMI Shielding Effectiveness Comparison between Two Different Types of Conductive Carbon Black-Polyester Composites

The higher the shielding effectiveness (SE), the lesser the microwave energy passes through the specimen. All measured SE is the combination of reflection from the sample's surface, absorption of the electromagnetic energy and multiple internal reflections of the EM radiation. The variation of the reflection coefficient of water hyacinth carbon black-polyester composite for different loading is given in Figure 6 (b). By comparing Figure 6 (a) and (b), the reflection is comparatively low for polyester composite with activated carbon black compared to those with carbon black derived from water hyacinth. For example, with same amount filler loading (10%) in both polyester composites at 2.99 GHz, the reflection coefficient of activated carbon black-polyester composite is only 0.53 which is lower compared to the water hyacinth carbon-polyester composite which is 0.79, due to the content of water hyacinth carbon black which is light in weight, makes the polymer matrix-filler interface more compact compared to activated carbon black filler.

Variation of the absorption coefficient of water hyacinth carbon black-polyester composite for different loading is given in Figure 7 (b). Comparing Figure 7 (a) and (b), the absorption is comparatively high for polyester composite with activated carbon black compared to those with carbon black derived from water hyacinth. The same amount of loading (10%) on both composites at 2.99 GHz, the absorption value for activated carbon black is 0.47 which is higher compared to water hyacinth carbon black which is only 0.21. This is because the size of the filler particles and the amount of activated carbon black is more favorable for the absorption compared with the water hyacinth carbon black filler [18].

Figure 8 (b) shows the variation of transmission coefficient of water hyacinth carbon black-polyester composite for different loading. By comparing Figure 8 (a) and (b), the transmission coefficient has more contribution compared to water hyacinth carbon black. Since transmission coefficient is directly dependent on the absorption in the composite, it is proven that activated carbon black based composite is highly suitable material to be used for shielding [19]. Figure 9 (a) shows the EMI shielding effectiveness over the frequency range of 1000 MHz to 3000 MHz for activated carbon black-polyester composites with various loadings. It has been observed that the shielding effectiveness of the composites is frequency dependent and increase with increasing filler loading. Maximum shielding efficiency in this composite occurs at 2.99 GHz. Therefore, it can be inferred that this material is ideal for shielding at 2.99 GHz.

Measured shielding effectiveness of the water hyacinth carbon black-polyester composites with various loading is shown in Figure 9 (b). From the comparison of Figure 9 (a) and (b), it is observed that the shielding effectiveness of the composites is frequency dependent and increases with increased filler loading. According to the results, the contribution of absorption to shielding effectiveness of both carbon blacks is greater than 83 % at 2.99 GHz. The analyzed results showed that the percentage of shielding effectiveness of polyester composite reinforced with naturally derived carbon black is similar to those with activated carbon black.



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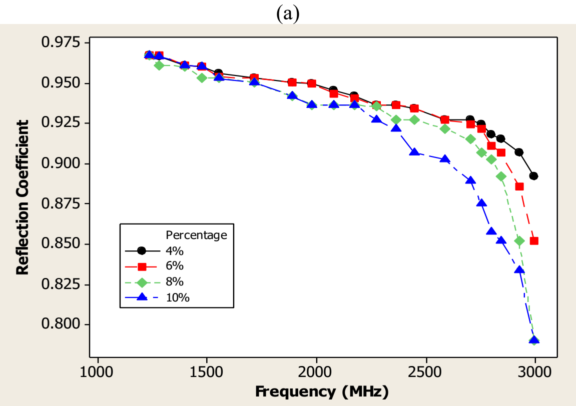
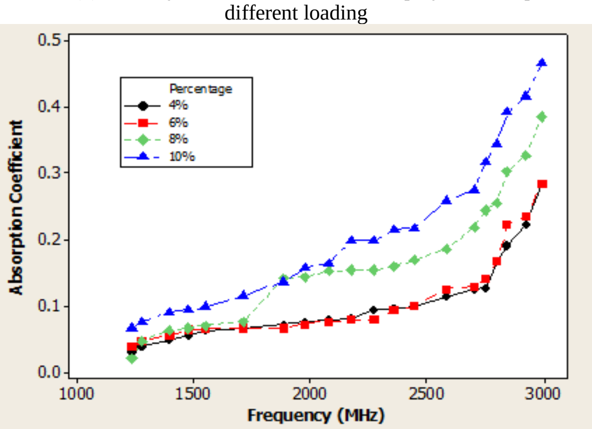


(b)

Figure 6: Variation of the reflection coefficient of the (a) activated carbon black and (b) water hyacinth carbon black based polyester composite for different loading



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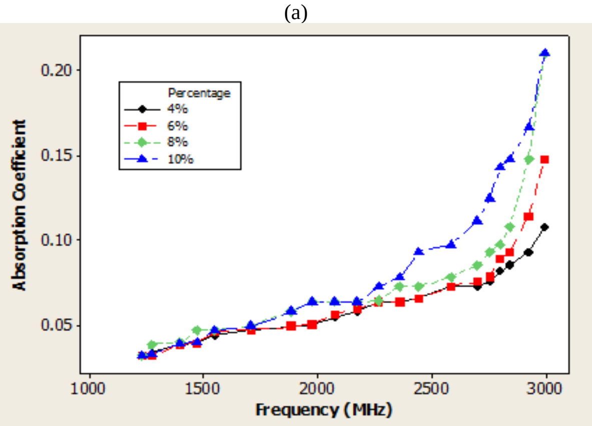
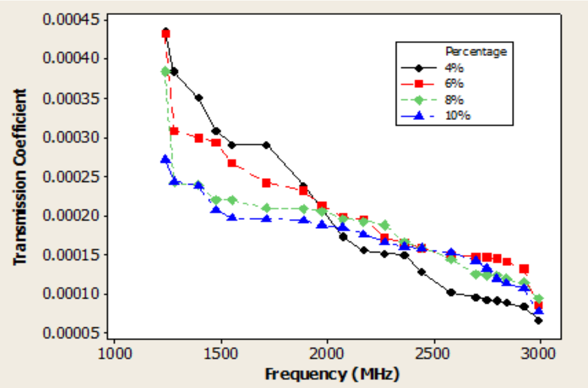


(b)

Figure 7: Variation of the absorption coefficient of the (a) activated carbon black and (b) water hyacinth carbon black based polyester composite for different loading



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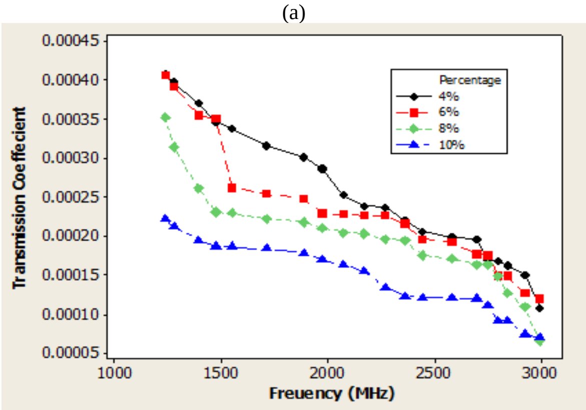

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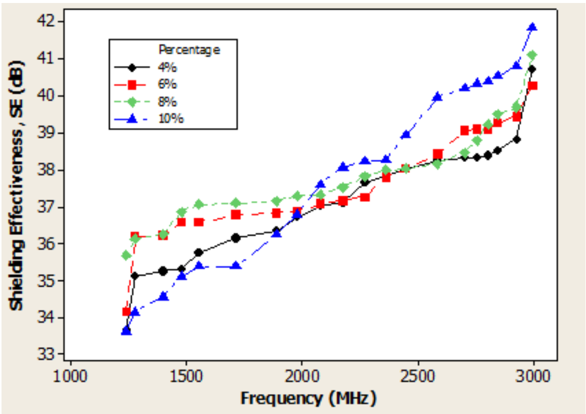
Figure 8: Variation of transmission coefficient of the (a) activated carbon black and (b) water hyacinth carbon black based polyester composite for different loading



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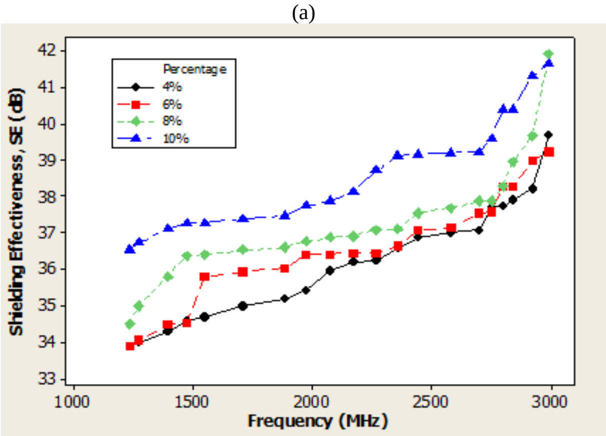

(b)

Figure 9: Measured shielding effectiveness of the (a) activated carbon black and (b) water hyacinth carbon black based polyester composites with various loading

Table 2
Contribution of Reflection and Absorption in the Overall EMI SE of Polyester Composite As A Function of CB Content at 2.99 GHz

Type of carbon black		CB content 4%	6%	8%	10%
Activated carbon black	SE_R (dB)	5.465	5.465	4.152	3.316
	SE_A (dB)	36.379	35.261	36.112	38.528
	Total EMI SE (dB)	40.73	40.27	41.08	41.84
	% EMI SE by absorption	89	87	88	92
Carbon black derived from water hyacinth	SE_R (dB)	9.666	8.300	6.780	6.780
	SE_A (dB)	30.040	30.908	35.098	34.825
	Total EMI SE (dB)	39.69	39.22	41.87	41.61
	% EMI SE by absorption	75.69	78.81	83.83	83.69

The results in Table 2 also show that shielding by reflection decreased while shielding by absorption increased with increase in filler loading. EMI shielding by absorption increased with increase in frequency because all those composites are dependent directly on the frequency [20-22]. The contribution of shielding by absorption to the overall shielding increased with increase in filler loading [23]. For instance, for activated carbon black, the contribution of EMI shielding by absorption to the overall shielding rose from 83% to 92% with increasing the CB content from 4 wt% to 10 wt%. From this, it becomes apparent that for such type of polymer composites most of the attenuation is due to absorption. Similar patterns have been reported by Horacio et al. for composites.

IV. Conclusion

According to the results and analyses, the activated carbon black has superior conductivity compared to the carbon derived from water hyacinth thus able to form a better conductive network on the polymer matrix and with a suitable amount of loading, it is able to lower and overcome the percolation threshold of the polymer. Furthermore, dispersion of both polyester composites played a significant role to obtain excellent electrical conductivity. The frequency dependence of EMI shielding effectiveness (SE) of carbon black-polyester composite has been carried out. The absorption coefficient was found to be increased with increasing frequency for both composites. According to the results, the contribution of absorption to shielding effectiveness of both carbon blacks is greater than 83 % at 3 GHz. Although water hyacinth based carbon black-polyester composite have moderate conductivity, they can still provide significant levels of EMI shielding. The analyzed results showed that the percentage of shielding effectiveness of polyester composite reinforced with naturally derived carbon black is similar to those with activated carbon black. Also, the result also showed that the contribution of absorption to the shielding effectiveness was larger than that of reflection. Therefore, in future, the use of carbon nanotube (CNT) as filler is highly encouraged for this study to enhance a better EMI shielding.

ACKNOWLEDGMENT

The authors would like to thank the School of Mechatronic Engineering, Universiti Malaysia Perlis for the financial support throughout the investigation.

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