Anisotropic Dispersal of Carbon Elements Lowers Electrical Resistance in Carbon-LLDPE Composites

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Abstract: This article is about the electrical resistance generated by composite materials fabricated from rice husk carbon and LLDPE polymers. The higher the weight content of carbon weights the lower the electrical resistance of carbon-LLDPE composites. At the carbon-LLDPE composition ratio of 50:50 % wt., generating electrical resistance R = 1506 Ω, at the ratio composition of carbon: LLDPE 60:40%wt., at a compaction temperature of 150 degrees Celsius, it produces an electrical resistance of R= 237 Ω. Meanwhile, the lowest electrical resistance of 57 Ω is generated by the composition of C7-3LLDPE, with a composition ratio of carbon: LLDPE 70:30 % wt. This fact also occurs in other compaction temperature variants, namely 120 degrees Celsius, and 135 degrees Celsius. The distribution of weight of carbon elements in composites 49; 66; and 55% wt., respectively at C5-5LLDPE; C6-4LLDPE; C7-3LLDPE. Through testing with SEM EDX, elements inside the composite can be identified. At a compaction temperature of 120 degrees Celsius, the distribution of weight of carbon elements is 49% wt., the electrical resistance R shows 622.8 Ω, at the distribution of weight of carbon elements 66.5% wt., the electrical resistance decreases to 349.2 Ω, and when distribution of the weight of carbon elements at 55.4% wt. of the electricity resistance decreases to 94.5 Ω.

1 INTRODUCTION

This paper describes the electrical resistance properties of carbon-LLDPE composite materials. In this study, carbon produced from organic waste produced low electrical resistance properties, and this carbon serves as a composite filler with a matrix of Linear low-density polyethylene (LLDPE). The carbon elements dispersal in the LLDPE matrix in this study was studied from the elemental distribution map with SEM EDS. The content of other elements carried in composites also affects the electrical resistance properties of composites. Anisotropic carbon materials such as carbon nanotubes (CNTs) and carbon fibre show very high thermal conductivity (TC). However, due to their high electrical conductivity, they have not been used in applications requiring high TC and electrical insulation (Morishita & Matsushita, 2021). The study examined the influence of different carbon-based fillers on the composite performance of electrically conductive polymer mixtures. Specifically, the study examined

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and compared the effects of graphene (GR), carbon nanotubes (CNTs) and black carbon (CB) on the PC/ABS matrix with morphological investigation, electrical and physical-mechanical characterization (dal Lago et al., 2020). Electrically conductive polymer composite (CPC) with bendable and stretchable deformation. Fabrication composites demonstrate comprehensively increased mechanical modulus, thermal conductivity, and electrical conductivity. The cut graphene is then applied as a filler to make composites (Jiang et al., 2021). The addition of ionic fluid (IL) to black conductive styrene-butadiene-carbon rubber composites (CB) can increase electrical conductivity and flexibility, thus enabling use in applications such as small strain sensors and stretchable conductors (Narongthong et al., 2019). Experimental testing and analytical modelling revealed that orthogonally conductive filament-z weaving in the direction of thickness through carbon-epoxy composites increased electrical conductivity by creating interconnected pathways for current flow (Abbasi et al., 2020). Rubber-based conductive polymer composites are shape-shifting and flexible, with different dimension carbon fillers, including carbon black, single-dimensional carbon nanotubes, two-dimensional graphene, and their combination, into isoprene rubber (IR) to create flexible EMI protective composites. Both electrical, mechanical, and EMI shield properties investigated (Wang et al., 2020). The study investigated how temperature and relative humidity affect the electrical resistance of strengthening carbon fibre in polymer composites. The study describes the use of hybrid composites in which the tight circumference of carbon fibre is laminated inside epoxy specimens reinforced by glass fibres. The electrical resistance of carbon fibre is monitored continuously, while the temperature or relative humidity varies (Forintos & Czigany, 2020). Structural changes were investigated using simultaneous electrical rheological measurements at shear deformations specified in conductive polymer composites containing carbon fibre or carbon black. This work presents a systematic study of the electrical behaviour of composites with anisotropic micro fillers under deformation in a liquid state. It was found that composite electrical conductivity with carbon fibre reacts very sensitively to mechanical deformation (Starý & Krückel, 2018). Electrically conductive composites are prepared by dispersing various amounts of PPy-coated PPF in a polyurethane matrix derived from castor oil. Polyurethane/PPy-coated PPF composite (PU/PPF-PPy) shows higher electrical conductivity than PU/PPy mixture with similar filling content (Merlini et al., 2017). Carbon-based composites are widely used in applications such as in polymer composite bipolar plates. The study was conducted to investigate the potential use of milled carbon fibre as a conductive filler in composites and adapt the General Effective Media (GEM) model to predict the electrical conductivity of polymer composites produced (Mohd Radzuan et al., 2017). Mixed polypropylene/polyamide 6 (PA6) melts, and multiwalled carbon nanotubes (CNTs) are formed by compression, injection, and interval injection moulding. The PA phase exists as an isolated dispersed phase in a sea-island system with different phase orientations and degrees of dispersion. Conductive line can be formed without considering phase morphology, when the CNTs content is high enough. When the CNT content is low, the scattered PA forms a non-elongated structure, which is beneficial for electrical conductivity (Mi et al., 2021).

2 EXPERIMENTS

2.1 Material Preparation

Rice husks are carbonized at a temperature of 950°C at a rate of 2°C/min resulting in electrically conductive carbon. Carbon is ground and filtered to obtain mesh particle size of 150, as a composite filler, and LLDPE powder with mesh of 60 as matrix is obtained from the commercial market. Note, based on ISO 3146, melting point LLDPE 124°C.

2.2 Sample Fabrication

Carbon and LLDPE are mixed evenly at a ratio of 50/50; 60/40; and 70/30% wt., compacted heat in mould at temperature of 120°C; 135°C; and 150°C, generated electrical resistance test samples in square form with a size of ± 10 × 10 × 5 mm.

2.3 Electrical Resistance Testing

Electrical resistance testing was conducted with Keithley Instruments tool, The 2450 Source Meter® Instrument, at BRIN physics laboratory, Serpong, Indonesia. Electrical resistance testing is performed by a four-point probe method following ASTM D257 standards (Julia A. King et al., 2007) (Sherman et al., 2019). Each variant was tested for 5 specimens. The number of test specimens is indicated in Table 1.

Table 1: Number of specimens.

Composition ratio, % wt.	Specimen code	Hot compaction temperature, °C		
		120	135	150
		Number of Specimen		
50/50	C5-5LLDPE	5	5	5
60/40	C6-4LLDPE	5	5	5
70/30	C7-3LLDPE	5	5	5

2.4 SEM-EDS Testing

This test was conducted to observe the microstructures and elements contained in the carbon-LLDPE composite. The test was conducted with microscopic scanning electron Hitachi SU 3500, at brin physics laboratory, Serpong, Banten, Indonesia.

3 RESULTS AND DISCUSSIONS

3.1 Electrical Resistance

Electrical resistance testing is intended to determine the value of electrical resistance experienced by carbon-LLDPE composites. The tendency that occurs indicates that the higher the distribution content of carbon particles, the lower the electrical resistance.

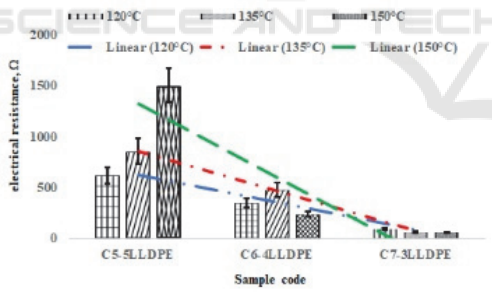

Figure 1: Electrical resistance and deviation.

This tendency is generated by all variations in the temperature of the compaction process of the carbon-LLDPE composite, as shown in Figure 1. At the composition ratio of carbon-LLDPE of 50:50 % wt. and at compaction temperature of 150°C indicates the value of electrical resistance R = 1506 Ω. At the composition ratio of carbon: LLDPE 60:40% wt., at a compaction temperature of 150°C, it produces an electrical resistance of R= 237 Ω. Meanwhile, the lowest electrical resistance of 57 Ω is generated by the composition of C7-3LLDPE, with a composition ratio of carbon: LLDPE of 70:30 %wt. This fact also occurs in other compaction temperature variants, namely 120°C, and 135°C, as shown in Figure 2. So, this study shows that the nature of the electricity resistance that is getting down is a contribution from carbon, while also pointing to the electrical conductivity properties of carbon. Variations in heat compaction temperature have a significant effect on the composition of C5-5LLDPE which shows an increase in electrical resistance when the temperature reaches 150°C. In the composition of C7-3LLDPE it shows a decrease in electrical resistance when the compaction temperature reaches 150°C. The temperature of LLDPE plastic melting according to the standard at 124°C, while in the melting study at 120°C, 135°C to 150°C only affected rheology which serves as a matrix of bonds between carbon particles. Figure 2 shows, the higher the volume of LLDPE weight, the higher the electrical resistance of the composite. In the composition of C7-3LLDPE the highest electrical resistance is indicated at the compaction temperature of 120°C, at the composition of C6-4LLDPE the highest electrical resistance is indicated at the compaction temperature of 135°C, and the composition of C5-5LLDPE the highest electrical resistance is indicated at the compaction temperature of 150°C. Some articles indicate the study of electrical resistance inside polymer composites, for example, (Abbasi et al., 2020), (Hayashida & Tanaka, 2012), (Sherman et al., 2019), (dal Lago et al., 2020), (Morishita & Matsushita, 2021), (Bai et al., 2021), (Luo et al., 2021).

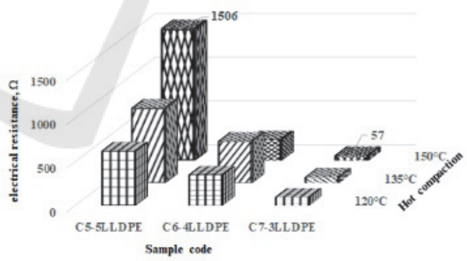

Figure 2: Sample code vs. compaction temperature vs. electrical resistance.

3.2 Dispersal of Composite Carbon Element

The distribution of carbon elements weights in this study was investigated with SEM-EDX. The purpose of observing the content of this element is to ascertain what percentage of the weight of the carbon element in the composite. The results of the investigation showed the weight of the carbon element dominated the carbon-LLDPE composite, as shown in Figure 3.

The weight of the dispersal of carbon elements in composites is 49; 66; and 55 % wt., respectively C5-5LLDPE; C6-4LLDPE; C7-3LLDPE. The content of the next sequence element is the oxygen element which is thought to contribute to lowering the electrical resistance of the composite in this study. Another element, Si, is also present in the composite, but it is not thought to contribute to the decrease in electrical resistance, because Si is more insulator. In this composite study there are also other elements with a small percentage of weight, <10% wt., namely Mg, Al, P, Cl, K, Fe, Cu, Zn, Na, It, Ca, Mn, and Ni. The elements are scattered unevenly within the carbon-LLDPE composite. The higher the volume weight of carbon elements in composites is shown to be able to lower the electrical resistance of composites, this fact occurs in all composition ratios and all compaction temperatures, as shown in Figure 4. At a compaction temperature of 120°C, the weight of the carbon element distribution is 49%, the electrical resistance R shows 622.8 Ω, at the carbon element distribution weight of 66.5%, the electrical resistance decreases to 349.2 Ω, and when the weight of the carbon element distribution at 55.4% the electric resistance decreases to 94.5 Ω.

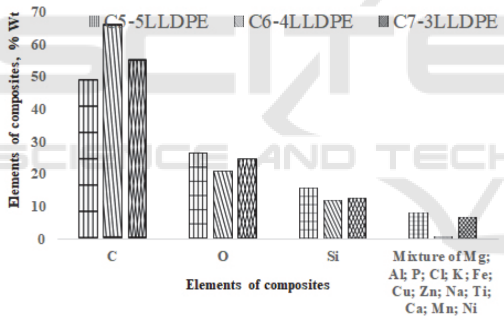

Figure 3: Elements of composites.

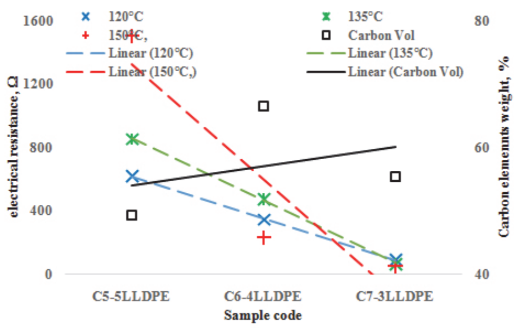

Figure 4: Elect. Resistivity vs. carbon elements.

The same fact occurs also in composites with a compaction temperature of 135°C, when the weight of the carbon element is at 49.3%, the electrical resistance is at 855 Ω, when the weight of the carbon element is at 66.5%, the electrical resistance becomes 477.8 Ω, and when the weight of the carbon element is at 55.5%, the electrical resistance at this compaction temperature shows 65.9 Ω. The same fact subsequently occurs at a compaction temperature of 150°C, at the weight of the same carbon element sequentially resulting in a decreased electrical resistance that is, from 1506.3; 237; and 57 Ω. The fact shows that the higher the weight of anisotropic dispersal of the carbon elements in the composite with LLDPE matrix can lower the electrical resistance of the composite of this study.

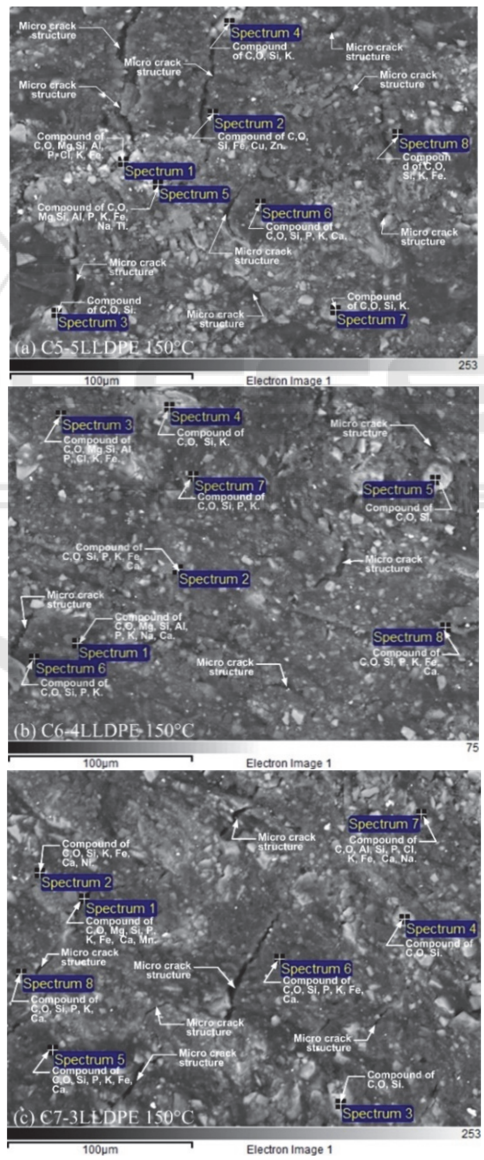

Figure 5: Elements dispersal and composite microstructure.

3.3 Dispersal of Elements and Micro-Structures

Figure 5 shows the dispersal of the elements inside the carbon-LLDPE composite. The image also shows micro cracks of the composite.

This fact indicates the presence of porosity in the composite. The spectrum inside the image are observation points with the EDX SEM test, which are taken randomly based on the appearance of a unique feature. Spectral features indicate different compound elements, but all spectral points indicate the presence of a dominant carbon content. The percentage of the elements weight of the three sample variants is shown in Table 2, with different element weights at each point of the observation spectrum. This fact indicates an uneven dispersal of the elements (also carbon), and results in a different degree of decrease in electrical resistance. Figure 5(a) is a composite with 50% carbon weight and 50 LLDPE weights, with a carbon element content of 49.3% wt., and at all points of the observation spectrum there is carbon content. Composites with a carbon content of 60% wt. and LLDPE 40% wt., the distribution of elements shown in Figure 5(b), shows a carbon element content of 66.6% wt. and all observation points indicate the presence of carbon elements. Meanwhile, the composition of 70% wt. of carbon, and 30% wt. of LLDPE, the results of observations at all spectral points show a carbon element with a value of 55.4% wt. Observational facts at spectral points also indicate the presence of silica elements as the dominant element of the third order after carbon, and oxygen. The presence of silica in composites is suspected because the carbon material comes from rice husk waste that contains a lot of silica. Silica is more insulator. Meanwhile, carbon from organic waste rice husks, with a pyrolysis process of 950°C can produce carbon with low electrical resistance.

Table 2: Percent weight of elements.

Elements	C5-5LLDPE	C6-4LLDPE	C7-3LLDPE
C	49.27	66.46	55.41
O	26.46	20.96	25.02
Mg	0.04	0.01	0.01
Al	1.09	0.12	0.09
Si	15.95	11.84	12.83
P	0.28	0.11	0.09
Cl	0.01	0.01	0.01
K	1.61	0.31	0.17
Fe	0.22	0.12	4.31
Cu	3.11	-	-
Zn	1.90	-	-
Na	0.03	0.01	0.05
Ti	0.02	-	-
Ca	0.01	0.06	1.36
Mn	-	-	0.06
Ni	-	-	0.60
% Wt.	100	100	100

4 CONCLUSIONS

This study has successfully fabricated carbon-LLDPE composites with lower electrical resistance properties when the volume of carbon weight is increased, and so that these composites will also be able to conduct electric current. The study also showed pyrolysis at 950°C produces carbon with low electrical resistance. The study also showed the results of composite engineering that unites basic materials with opposite electrical properties into materials that can lower electrical resistance. At the composition ratio of carbon-LLDPE of 50:50 %wt., produces an electrical resistance of R = 1506 Ω. At the composition ratio of carbon: LLDPE 60:40% wt., at a compaction temperature of 150°C, it produces an electrical resistance of R = 237 Ω. Meanwhile, the lowest electrical resistance of 57 Ω is generated by the composition of C7-3LLDPE, with a composition ratio of carbon: LLDPE of 70:30 %wt. This fact also occurs in other compaction temperature variants, namely 120°C, and 135°C. The dispersal weight of carbon elements in composites ranges from 49; 66; and 55 % wt., respectively at C5-5LLDPE; C6-4LLDPE; C7-3LLDPE. At a compaction temperature of 120°C, the dispersal weight of the carbon element is 49%, the electrical resistance R shows 622.8 Ω, at the distribution weight of carbon element of 66.5%, the electrical resistance decreases to 349.2 Ω, and when the dispersal weight of the carbon element at 55.4% the electric resistance decreases to 94.5 Ω.

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