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The electrical properties of composite fabricated of carbon-phenol formaldehyde

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Abstract: This research aimed to create composites of carbon-phenol formaldehyde (PF) using carbonated rice husks as fillers. The composites showed electrical conductivity that increased with carbon content and decreased electrical resistance. The composites were evaluated for their physical, and electrical properties. The results showed that increasing PF content resulted in higher density but lower porosity, making the composites heavier. Specimens with 80% carbon weight and 20% PF weight produce an electrical conductivity of 0.055 [S/cm], while those with 70% carbon weight and 30% PF weight produce an electrical conductivity of 0.039 [S/cm]. Specimens with 60% carbon weight and 40% PF weight generate an electrical conductivity of 0.013 [S/cm].

Keywords: Rice husks carbon; Carbon-phenol formaldehyde (PF) composite; Polymer electrically conductive; electrical properties.

Citation:. Pramono, A. E., Patrick, Y. P., Belyamin, & Indayaningsih, N. I. (2023). The electrical properties of composite fabricated of carbon-phenol formaldehyde. Recent in Engineering Science and Technology, 1(04). Retrieved from https://www.mbi-journals.com/index.php/riestech/article/view/29

Academic Editor: Iwan Susanto

Received: 26 September 2023
Accepted: 23 Oktober 2023
Published: 26 Oktober 2023

1. Introduction

The study aimed to engineer the properties of composites made from rice husks carbon and phenol formaldehyde (PF) matrix. The study focused on developing electrically conductive parts using carbon - PF composites. Composite engineering research with polymer matrices and carbon fillers has been widely studied by researchers for decades.

This article explores the use of CFRP composites with a resin matrix modified by acrylonitrile nano rubber. The study demonstrates that incorporating nano rubber improves the fracture toughness and interlaminar shear strength of CFRP composites. SEM analysis indicates that these enhancements result from nano rubber debonding, crack path deflection, and fiber bridging [1]. This article explores the synthesis of PPy/CuZnFe2O4 nanocomposites and their impact on physical, mechanical, and electrical properties. Using in-situ polymerization with Ammonium Persulphate as the oxidizing agent, the research reveals that incorporating nanoparticles alters the structure and conductivity of the composite. This highlights their potential as excellent insulation materials for electrical and electronic applications [2]. This article explores carbon-quartz fiber-reinforced phenolic-silica aerogel nanocomposites (C-QF/PSi) for lightweight thermal protection. They offer strong compression resistance, low thermal conductivity, and excellent thermal ablation and insulation properties. These nanocomposites have promising applications in aerospace and other thermal protection fields [3]. This study develops PA66/CF composites with a hybrid filler of AGO and CNTs. The 2:1 ratio of AGO to CNTs improves interfacial shear strength, tensile strength, and storage modulus significantly compared to the control sample. The composite also exhibits high damping properties and strong CF-PA66 bonding due to hydrogen bonding, good dispersion, and the mechanical effects of the AGO-CNT hybrid [4]. This article explores electrically conductive polymer composites with fillers like GR, CNTs, and CB in a PC/ABS matrix. CNTs show superior electrical and mechanical performance compared to other carbon-based fillers [5]. This research modifies high modulus carbon fibers (HMCF) using anodization and electrochemical grafting. The surface treatment with NH4HCO3 electrolyte enhances DETA grafting, while (NH4)2SO4 increases oxygen groups. These modifications greatly improve the interfacial performance of the HMCF/epoxy composite, boosting interlaminar shear strength by 257.1%. Valuable for high-performance applications utilizing modified HMCF [6]. This study introduces a homogenization model to analyze the processing of carbon-DCPD composites via frontal polymerization. The model identifies two distinct processing regimes based on the fiber volume fraction. Experimental validation of the model's predictions is performed on carbon-DCPD composite panels [7]. This study analyzes the failure of CFRP composites under fiber-aligned compression. Compressive strength is influenced by fiber and matrix properties, with shear stress playing a crucial role. Improving properties or reducing fiber misalignment enhances compressive strength by up to 3.38%. Matrix elasticity has the greatest influence, followed by fiber alignment and matrix plasticity [8]. This study compares carbon/carbon (C/C) composites with different carbon matrix development methods. Composites with PyCN matrix show the highest strength and toughness, while those with asphalt-derived carbon matrix have lower strength. PyCX matrix exhibits the highest thermal conductivity [9]. This research develops High Temperature Low-Sag (HTLS) conductors for high-temperature power transmission. Tests on carbon and glass fiber composite rods reveal that excessive compressive stress in the carbon region causes failure. Natural fiber deviation also impacts bending strength and damage initiation [10]. This research examines the mechanical properties of the matrix in carbon fiber-reinforced plastic composites (CFRP) to study stress concentration at the fiber-matrix interface caused by adjacent fiber fractures. The results reveal a linear correlation between crack tip opening displacement (CTOD) and stress concentration factor (SCF), informing the development of stronger CFRP materials [11]. This research investigates thermoplastic composites and their welding process with short durations. An experimental setup is devised to assess the adhesion of carbon-PEKK composites within time intervals ranging from 1 second to 1 hour. The findings identify three distinct bonding stages and shed light on the healing kinetics at the interface [12]. This research proposes an eco-friendly method to enhance the adhesion of carbon fiber-polymer composites using carboxymethyl cellulose (CMC) and graphene oxide (GO). The CMC and GO significantly improve the interfacial and interlayer shear strength of the composite, offering potential for enhancing its performance with natural cellulose fibers [13]. This study analyzes failures related to water in the polymer matrix and interfaces of composites and nanocomposites used in marine construction. By using experimental and simulation methods, the study investigates damages in polymer-based carbon nanotube (CNT) composites. The findings reveal the mechanisms of damage and highlight improvements in the water resistance properties of nanocomposites [14]. In this study, we examined thermoplastic overmolding methods on thermoset composites using epoxy resin and PA6. Factors investigated included fiber type, molding temperature, and peel-ply usage. Peel-ply, higher temperature, and carbon fiber reinforcement improved adhesion. Mechanical analysis and imaging techniques supported the findings [15]. This research explores the impact of temperature and relative humidity on the electrical resistance of carbon fibers in polymer composites. The findings emphasize the importance of considering these effects in carbon fiber resistance measurements for health monitoring purposes. It highlights the suitability of carbon fibers for diverse applications [16]. This research investigates the impact of surface treatment and sizing type on carbon fibers in polymer composites. PA6 pellets reinforced with short fibers were produced and analyzed. The results show that surface treatment and sizing type affect the modulus and flexural strength of the composite [17]. This research compares the mechanical performance of recycled sheet materials using different methods. Sandwich panels show potential for upcycling, achieving properties similar to monolithic laminates. The recycling method also produces flat sheets without wrinkles, comparable to new materials [18]. This study developed a ceramifiable electroconductive polymer composite using glass powder, mica powder, organically modified montmorillonite, and short carbon fibers in EVA. The composite shows excellent EMI shielding and high-temperature resistance [19].

This new research project focuses on the engineering of carbon-phenol formaldehyde composites for electrical conductivity properties. The density, porosity, and morphology of the composite are also investigated.

2. Materials and Experiment Methods

2. 1 Sample Preparation

We produced this composite by combining carbon from rice husks and a phenol-formaldehyde (PF) matrix. The rice husks were carbonized at 950°C with a heating rate of 2°C/minute. Carbon was milled to a 150-mesh size, while PF powder was sieved through a 350-mesh sieve. Varying weight ratios (60:40, 70:30, and 80:20) of carbon and PF were mixed and heat-compacted at 120°C and 200 bars pressure for 15 minutes using a hydraulic press.

Other previous research has shown that the carbonization process results in highly conductive carbon (99.9%) [9]. Researchers and authors of this article have done carbonization of organic waste with the same technique before, but for different research [20].

2. 2 Material characteristics

The carbon structure is an amorphous structure with an irregular arrangement of atoms, and the peak intensity observed at 2θ = 24.25°. The carbon density was found to be 1.3794 ± 0.12 grams/cm^3. Another study showed a carbon fiber density of 1.76 g/cm^3. PAN-based carbon fiber without size agents (average diameter seven μm, density1. 78 g/cm^3) supplied by Heng Shen Industries, Inc. (Jiangsu, China) [13]. Sigrafil CT24-5.0/270-E100 carbon fibres 1.79 [g/cm^3] [16].

2. 3 Composite density-porosity tests

The density of carbon composites is determined follow the Archimedes method, based on the DIN-51097 standard to conduct the experiment [21, 22]. Porosity is defined as the percentage of the open pore volume in a specimen relative to its total exterior volume.

2. 4 Testing of electrical properties

The ASTM D4496 standard was followed to test the electrical conductivity using the four-point probe method. The Keithley Instruments' 2450 Source Meter® Instrument was used for the testing, which was conducted at the Research Centre for Physics, National Research, and Innovation Agency (BRIN), Indonesia. Similar methods have been used in other studies. Samples with electrical conductivity higher than 10^{-8} [S/cm] were tested using a 2400-meter source (Keithley, USA) and the standard four-probe method was used to record the results [19].

3. Results and Discussion

3.1. Composite density

The density of the composite material studied can be seen in Figure 1. The incorporation of more carbon in the composite led to a decrease in density, making the composite material lighter. This finding provides evidence that carbon is lighter than phenol-formaldehyde after undergoing hot compaction at 120 °C, compaction of 200 bars, and holding time of 15 minutes. Specifically, the carbon-PF composite sample with code C8-2PF (80% by weight of carbon and 20% by weight of phenol-formaldehyde) exhibited a density of 1.11 [grams/cm^3]. On the other hand, increasing the PF content resulted in a higher composite density, as demonstrated by the sample code C6-4PF (60% carbon weight and 40% PF weight) with a density of 1.42 [grams/cm^3]. The study conducted a comparison with other materials, revealing that the density of pp-GF virgin monolithic was 1.65 [grams/cm^3] and PA6-CF SMC coarse was 1.41 [grams/cm^3] [18]. C-QF/PSi results in density in the range of 0. 460 to 0. 515 [g/cm^3] [3].

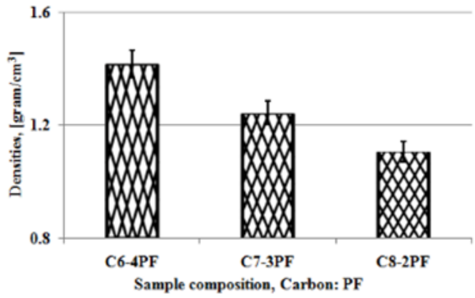

Figure 1. Densities of carbon-PF composite

3.2. Composite porosity

The heat compaction process of 120°C and 200 bar pressure is not sufficient to eliminate porosity in the carbon-PF composite bulk, as shown in Figure 2. Specifically, the samples with the code C8-2PF (80% by weight of carbon and 20% by weight of phenol-formaldehyde), which contained 80% carbon by weight, exhibited porosity levels of up to 0.8%. However, increasing the PF content in the composites can lead to a reduction in porosity. This is demonstrated by composites with sample code C6-4PF(60% carbon weight and 40% PF weight), which had a PF weight content of 40% and a porosity level of only 0.16%. It is important to note that the porosity of the CFRP samples in the other study was found to be less than 3% [8].

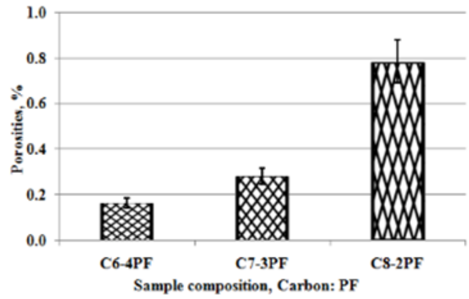

Figure 2. Porosities of carbon-PF composite

3.3. Density and porosity relationships

The relationship between density and porosity is evident, with a decrease in porosity corresponding to an increase in composite density, as shown in Figure 3. The C6-4PF composite exhibits low porosity (0.16%) and high density (1.42 g/cm³). In contrast, the C8-2PF composite has a density of 1.11 g/cm³ and a porosity of 0.8%. This suggests that increasing the carbon weight content leads to higher porosity in the composite. The performance of composite materials in rheology is influenced by factors such as interfacial adhesion between fillers and polymers, as well as the properties of densities and porosities. Additionally, particle size, distribution, shape, dispersion, and associated volume fractions can also have an impact [23].

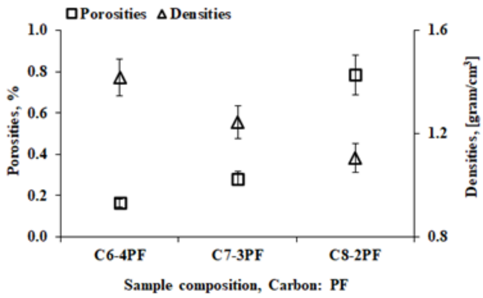

Figure 3. Densities and porossities relationship

The higher porosity observed in C8-2PF suggests that both the carbon content and rheological properties play a role in the formation of porosity. The 20% PF content, which cannot be uniformly dispersed within the composite bulk, leads to increased porosity. This likely explains the observed porosity in the composite material. There is a clear relationship between porosity and density. Porosity represents the percentage of void space in a material, while density refers to the mass per unit volume of the material. Generally, higher porosity results in lower density because porosity reduces the overall mass of the material without significantly affecting its volume. In other words, a more porous material will have a lower mass per unit volume, resulting in lower density. Sample C8-2PF exhibits the highest porosity (0.78%) and the lowest density (1.11 g/cm³). On the other hand, sample C6-4PF demonstrates the lowest porosity (0.16%) and the highest density (1.42 g/cm³). This inverse relationship between porosity and density is expected and can be used to predict the density of a material based on its porosity, or vice versa. The composite samples with higher weight percentages of carbon (C6-4PF) exhibit lower porosity and higher density compared to samples with lower weight percentages of carbon (C7-3PF and C8-2PF). This indicates that increasing the amount of carbon in the composite leads to a more compact and dense material with fewer voids or pores. While the difference in densities between the samples is relatively small, the difference in porosity is more significant. This suggests that the amount of carbon in the composite has a greater effect on porosity than on density. Factors affecting the porosity and density of composite materials can vary, as observed in this study. Porosity was influenced by the weight ratio of carbon and phenol-formaldehyde, while density remained relatively constant since the amount of resin used in the composite matrix was constant. The weight ratios of the composite materials (60:40, 70:30, and 80:20) significantly influenced the porosity of the resulting samples, as indicated by the significant difference in means. This may be attributed to differences in the packing density of the carbon and PF particles at different weight ratios, affecting the formation of voids during heat compaction.

On the other hand, the weight ratios of the composite materials did not have a significant effect on the overall density of the resulting samples, as indicated by the lack of significant difference in means. This could be due to the constant PF matrix, which is the main contributor to density, while the weight ratio of the carbon particles varied.

3.4. Current and voltage of carbon-PF composite

The purpose of this study was to measure the electrical properties of a carbon-PF composite, specifically its ability to deliver electrical current and voltage. The measurements were conducted at the Research Centre for Physics, National Research, and Innovation Agency (BRIN), Indonesia, using the four-point probe method. A voltage speed of 0.16 V/second was set, ranging from -4 Volts to +4 Volts, to generate an electric current in Ampere, as shown in Figure 4.

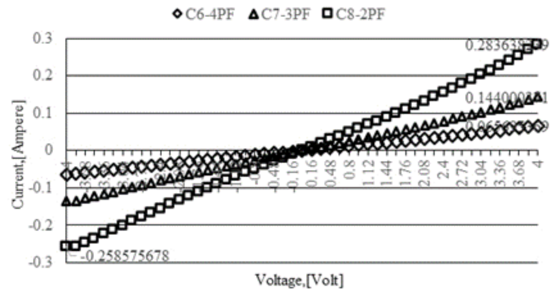

Figure 4. Electric current vs. voltage

For instance, in the case of specimen C8-2PF, a voltage value of 4 V allowed an electric current flow of 0.284 Ampere on the composite. The amount of electrical current decreased with a decrease in the carbon content of the composite. For example, specimen C7-3PF produced a current flow of 0.144 A at a voltage of 4 V, while specimen C6-4PF conducted an electric current of 0.065 A at the same voltage.

3. 5. Relationship between conductivity and electrical resistance

Simultaneously with the measurement of electric current by voltage setting, the electrical resistance value is also measured using the four-point probe method. Figure 5 shows that the electrical resistance value of a carbon-PF composite decreases with an increase in the volume of carbon content.

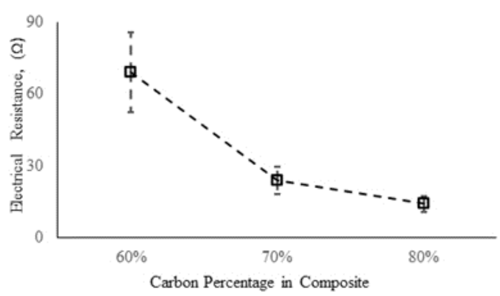

Figure 5. Electrical resistance vs. carbon content

For instance, specimens with a weight volume of 80% carbon exhibit an electrical resistance value of 14 Ω, while specimens with a weight volume of 70% carbon display a resistance value of 24 Ω. On the other hand, specimens with a weight volume of 60% carbon demonstrate a resistance of 69 Ω. These findings demonstrate that higher carbon content in the composite leads to a lower electrical resistance value, indicating that the carbon content can conduct electricity. This study of engineered materials provides evidence that increasing the carbon content results in a lower electrical resistance. The findings reveal that the volume resistivity decreases with an increase in the content of carbon-based fillers. This suggests that the addition of carbon-based fillers enhances the electrical conductivity of the PC/ABS composite material [5]. Figure 6 shows that the electrical conductivity of carbon-PF composites increases as the electrical resistance decreases. For instance, specimens coded as C8-2PF with 80% carbon weight volume and 20% PF weight produce an electrical conductivity of 0.055 [S/cm], while those coded as C7-3PF with 70% carbon weight volume and 30% PF weight produce an electrical conductivity of 0.039 [S/cm].

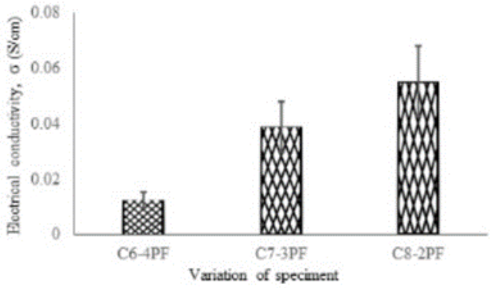

Figure 6. Electrical conductivity

Similarly, specimens with 60% carbon weight volume and 40% PF weight generate an electrical conductivity of 0.013 [S/cm], as seen in Figure 7. Thus, increasing the carbon weight volume leads to higher electrical conductivity in the carbon-PF composites of this study. In contrast, other studies have reported different electrical conductivity values for composite materials. For instance, the conductivity of Ethylene-vinyl acetate, Carbon fiber, organo-modified montmorillonite (EVA/CF/OMMT) composite is 4.44×10^{-15} S/cm, which is considered a typical insulating material. However, when short carbon fiber (SCF) is added to the EVA/CF/OMMT composite, the conductivity increases significantly. In the case of EVA/CF/OMMT/SCF 5(5%) composite, the conductivity rises to 4.74×10^{-9} S/cm [19]. Decreased electrical resistance leads to an increase in electrical conductivity. For instance, specimens with 60% carbon weight volume have a resistance of 69 Ω and an electrical conductivity of 0.013 [S/cm].

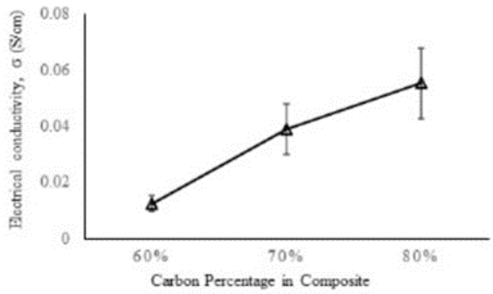

Figure 7. Electrical conductivity vs carbon content

Meanwhile, specimens with 70% carbon weight volume have a resistance of 24 Ω and an electrical conductivity of 0.039 [S/cm]. Specimens with 80% carbon weight volume have an electrical conductivity of 0.055 [S/cm] and a resistance of 14 Ω. Figure 8 demonstrates that there is a positive correlation between the volume of carbon weight and electrical conductivity, as well as a negative correlation between carbon volume and electrical resistance in the studied carbon-PF composite.

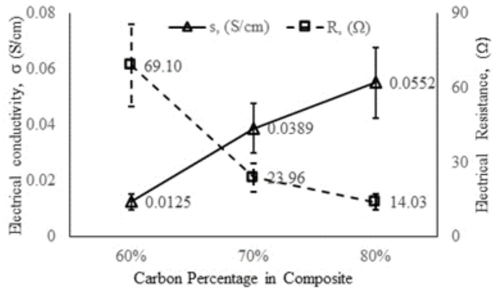

Figure 8. Carbon content vs. electrical conductivity vs. electrical resistance

When two substrates come in contact, surface roughness can prevent immediate perfect contact. The concept of intimate contact takes into account the initial surface roughness and the subsequent evolution of physical contact between the substrates [12]. This study found that the surface characteristics of carbon particles played a role in the rheological behavior of PF, resulting in the filling of porous cavities within the composite bulk, leading to an increase in the electrical resistance to flow.

4. Conclusions

Increasing the phenol-formaldehyde (PF) content in carbon-PF composites increases density. Sample C8-2PF has a density of 1.11 g/cm^3, while sample C6-4PF has a density of 1.42 g/cm^3. Higher carbon content results in lower density, making the composite lighter. Lower carbon content leads to weaker electrical conductivity. For example, specimen C8-2PF conducts 0.284 A of current at 4 V, while specimen C7-3PF conducts 0.144 A and specimen C6-4PF conducts 0.065 A at the same voltage. Sample C8-2PF (80% carbon, 20% PF) has an electrical conductivity of 0.055 S/cm, C7-3PF (70% carbon, 30% PF) has a conductivity of 0.039 S/cm, and samples with 60% carbon and 40% PF exhibit a conductivity of 0.013 S/cm.

Acknowledgment

Scheme of Leading Research of Product Innovation of DIPA of Politeknik Negeri Jakarta has funded this research, Contract Number: B.265/PL3.B/PN.00.03/2021, dated July 7, 2021. The author would like to thank UP2M, Politeknik Negeri Jakarta.

The authors acknowledge the facilities, scientific and technical support from Advanced Characterization Laboratories Serpong, National Research and Innovation Agency through E-Layanan Sains, Badan Riset dan Inovasi Nasional (BRIN).

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