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Research article

The Effect of Aluminum Addition Ratio as Filling Material of PLA Toward PLA Filament Electrical Conductivity on 3D Printing Applications

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A B S T R A C T

The electronic waste of daily electronic goods evokes environmental pollution because electronic waste is difficult to decompose in nature and it is also toxic to the environment and humans. The way to minimize environmental pollution from electronic waste is by making polymer composites for conductive material purposes. Polylactic acid (PLA) has the potential as a polymer matrix. PLA has a non-toxic advantage and it is easily decomposed in nature because PLA is made from organic material.

The extruder machine is used to make PLA filament with aluminum filling. When made the filaments, the ratio of each mixture was varied to obtain a filament with a mixture ratio that produced the best conductivity. The four-point probe test tool is used to measure the resistivity of each specimen to find out which specimen with the mixture ratio has the best conductivity value.

The electrical conductivity obtained from the ratio of 10% Al is 6.78 S/m; 20% Al is 10 S/m; 30% Al is 31.44 S/m; 40% Al is 24.15 S/m. The best electrical conductivity results were obtained in the 70% PLA and 30% Al mixture ratio with an electrical conductivity value is 31.44 S/m while the lowest electrical conductivity was obtained in the 90% PLA and 10% Al mixture ratio with an electrical conductivity value is 6.67 S/m

1. INTRODUCTION

The electronic waste or the remaining use of daily electronic goods evokes environmental pollution because electronic waste is difficult to decompose in nature and also toxic to the environment and humans [1]. The way to minimize environmental pollution from electronic waste is by making conductive polymer composites for conductive material purposes with PLA as its matrix and aluminum as its reinforcement.

The electric conductivity is an important indicator of material for conductive material purposes [2]. PLA has a low electric conductivity value, but PLA has the advantage of being non-toxic and easily decomposed in nature because PLA is made from organic materials [3]. To increase PLA electric conductivity, aluminum is used as a reinforcement.

1.1 PLA

Polylactic Acid (PLA) is a biocompatible, biodegradable, non-toxic, and non-carcinogenic polymer for the human body and it is derived from renewable resources, making it excellent for medical applications and food packaging. PLA can be obtained from lactic acid derived from sugar,

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starch, cellulose, and glycerin from biodiesel residues [4]. The PLA granule is shown in Figure 1.

Figure 1. PLA Granule [4]

Several technologies such as annealing, adding nucleating agents, forming composites with fibers or nanoparticles, chain elongation, and cross-linked structures have been used to improve the mechanical properties of PLA polymers [5]. Polylactic acid can be processed like most thermoplastics into fibers (for example, using conventional melt-spinning processes) and films. The mechanical properties of PLA are quite good, but not good enough in electrical conductivity and the continuous use of maximum temperature. On moderately hot surfaces, PLA has good printability and it is makes PLA widely used in 3D printing [6]. The electrical conductivity of PLA 3,32 x 10-13 S/mm and the electrical resistivity is 3,01 x 1010 Ωmm [7].

1.2 Aluminum

Aluminum is the third most abundant element in nature (after oxygen and silicon), and the most abundant metal in the earth's crust. Aluminum accounts for about 8% of the earth's weight. Aluminum is a relatively soft, durable, lightweight, ductile metal, resistant to corrosion, has high conductivity and itis malleable. The physical appearance of aluminum varies from silvery to dull gray depending on the surface roughness. The strength of pure aluminum is 7-11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa [8]. Several uses of aluminum are:

1. The automotive industry sector, to make truck bodies and motor vehicle components.
2. Making airplane bodies.
3. Residential construction sector, for door and window frames.
4. The food industry sector, for packaging various types of products.
5. Other sectors, for electrical cables, household furniture, and handicrafts.

Aluminum has the fourth lowest resistivity or fourth highest conductivity (after silver, copper, and gold). Copper is more expensive than aluminum and has a higher electrical conductivity, but since aluminum is lighter than copper, using aluminum wires proved to be a very good idea [9]. Aluminum has a resistivity varying from 2.65-2.82×10-8Ωm. Aluminum can be combined with other metals to make it stronger. The non-magnetic nature of aluminum allows it to work anywhere (even in a storm). Aluminum can be easily transported that making aluminum the best choice for high-power and long-distance power lines [8]. The aluminum powder shown in Figure 2.

Figure 2. Aluminum Powder [8]

1.3 Electrical Conductivity

Electrical conductivity is the ability of a substance or material to allow the flow of electric current and transport electrons [2]. Electrical conductivity is the opposite of electrical resistivity. Electrical conductivity varies according to temperature, the atomic, and the molecular structure of the substance or material. There are two main objects with high electrical conductivity, that is metals and

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electrolytes. The material with high electrical conductivity are usually high heat conductivity as well as seen in most metals. The temperature of a material can affects electrical conductivity. In conductor materials, an increase in temperature generally decreases the conductivity [6]. The electrical conductivity of a material can be obtained by the equation:

$$\sigma = 1/\rho \tag{1.1}$$

Description:

σ = Electrical Conductivity (S/m)

ρ = Electrical Resistivity (Ωm)

The electrical resistivity is measured in ohm meter (Ωm), while electrical conductivity is measured in siemens per meter (S/m). The electrical conductivity is the inverse of the unit for electrical resistivity. The electrical conductivity and electrical resistivity of a material is an immutable property that does not change based on size or shape of the material [6].

2. METHODOLOGY

2.1 PLA/Aluminum Filament Fabrication.

PLA and aluminum are crushed and fed into the extruder machine. Ratio of each admixture PLA/Aluminum are varied that is 10%Al, 20%Al, 30%Al, and 40%Al. Figure 3 shows the extruder machine ready to operate.

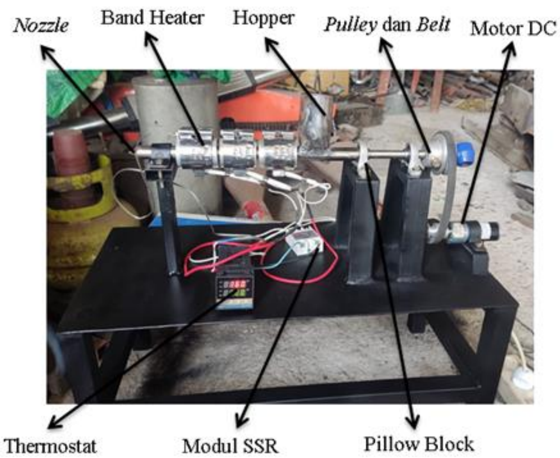


Figure 3. Extruder Machine

The output of extruder machine is PLA/Aluminum Filament with ±1 mm diameter. The average powder size of PLA is 300 microns, while the size of aluminum powder is 50 microns. The resulting filament from the extruder machine has a diameter of ±1 mm. Figure 4 shows the output filament PLA/aluminum from extruder machine.

Figure 4. Output Filament of Extruder Machine

2.2 Specimen Isolation

The output filament from the extruder machine must be printed onto the isolator section of the PCB to isolate electrical noise for the data to be valid. The PLA/aluminum filament on the PCB insulator part is shown in Figure 5.

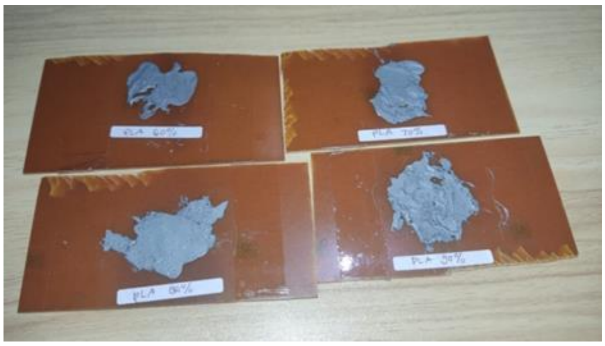


Figure 5. PLA/Aluminum on isolator part of PCB (a) 40%Al, (b) 30%Al, (c) 20%Al, (d) 10%Al

2.3 Four Point Probe Method

Four point-probe method involves four probes touched to the specimen material to measure its resistance, where 2 probes are tipped as inlet current sources and the 2 probes inside are output voltage values and the distance between the probes(s) is made equal [10]. The modeling of the four-point probe is shown in Figure 6.

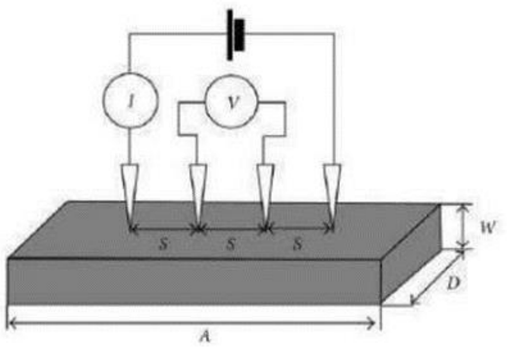


Figure 6. Four Point Probe Method [10]

Specimen resistivity value can be determined by equations (1.2) and (1.3):

$$\rho = 2\pi s \frac{V}{I}, t > s \qquad (1.2)$$

$$\rho = \frac{\pi t}{ln2} \frac{V}{I}, t < s \qquad (1.3)$$

Description:

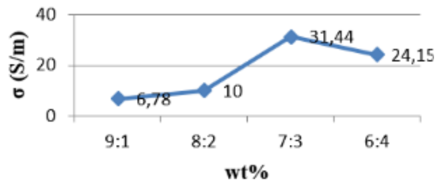
ρ = Resistivity(Ωmm)
s = Distance between probes (mm)
t = specimen thickness (mm)
V = Voltage (Volt)
σ = Electrical conductivity (S/mm)
I = Ampere (A)

3. RESULTS AND DISCUSSION

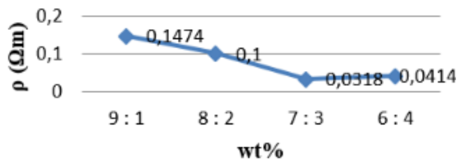
The output of FPP measurement is voltage, and then the voltage was converted to electrical resistivity using equation (1.3) and then to electrical conductivity using equation (1.1). The measurement results using four point probes are shown in Table 2 and Figure 7.

Table 2. Data Experiment

PLA : Al (wt%)	Voltage (mv)	Electrical Resistivity (Ωmm)	Electrical Conductivity (S/mm)
6 : 4	9.2	4.14×10^{-2}	24.15
7 : 3	15.9	3.18×10^{-2}	31.44
8 : 2	44.7	1×10^{-1}	10
9 : 1	73.7	14.74×10^{-2}	6.78



(a) Conductivity



(b) Resistivity

Figure 7. Electrical Conductivity and Resistivity Value of filament PLA/Al

Table 2 shows the measurement results obtained from the four-point probe. When the aluminum ratio was increased, the voltage results also increased but it was not applied to the electrical conductivity and resistivity. The electrical resistivity was decreased when the voltage was increased but at a ratio of 60%PLA and 40%Al the electrical resistivity was increased. This occurs because the specimen was not well formed and it was indicated that the filaments produced have low printability.

Figure 7 clarifies the difference in results between electrical conductivity and electrical resistivity. The electrical conductivity increases at the ratio of 90%PLA and 10%Al to the ratio of 70%PLA and 30%Al, and decreases at the ratio of 60%PLA and 40%Al, where the values obtained are 6.78 S/m, 10 S/m, 31.44 S/m, 24.15 S/m. While the electrical resistivity decreased at a ratio of 90%PLA and 10%Al to 70%PLA and 30%Al and increased at a ratio of 60% and 40%. The values obtained were 0.1474 Ωm, 0.1 Ωm, 0.0316 Ωm, 0.0414 Ωm.

This study showed that the admixture ratio and electrical conductivity have an effect on the printability of the resulting PLA/Aluminum filaments. As the aluminum ratio increased, the printability of the filament decreased.

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4. CONCLUSION

Polylactic acid is used as the polymer matrix because it is biodegradable and non-toxic. Aluminum is added to PLA/Aluminum filaments to improve the electrical conductivity of PLA filaments. Thus, filaments with higher electrical conductivity and non-toxicity can be made. The highest electrical conductivity was obtained at a ratio of 70% PLA and 30% Al, which was 31.44 S/m. In contrast, the lowest electrical conductivity was obtained at a ratio of 90% PLA and 10% Al at 6.78 S/m. Theoretically, the more aluminum added, the more electrical conductivity will increase. However, in this study, the electrical conductivity value decreased at a ratio of 60% PLA and 40% Al. It was indicated that the ratio of 60%PLA and 40%Al has low printability, and this ratio cannot be used for 3D printing applications.

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