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RESISTIVITY STUDY ON CONDUCTIVE COMPOSITE FILAMENT FOR FREEFORM FABRICATION OF FUNCTIONALITY EMBEDDED PRODUCTS

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ABSTRACT

Fused Deposition Modelling (FDM) is the technology that uses an additive manufacturing process to fabricate a product. This study aims to investigate the resistivity of both conductive composite materials through an extrusion process by FDM and calculating resistivity through a variety of tests. The study of the resistance of designing a prototype using conductive composite filaments through the AM process. This analysis more understandable when the basic equations of electricity used, which is V = IR. This equation shows the relationship between the voltage and the resistance, whereas the resistance increasing, the voltage will be decreasing. The test was done in different length, diameter, which is before and after extrusion. This study is also includes taking reading of light intensity for a functional embedded product by using a lux meter. Therefore, the resistivity by length and volume were measured for both materials, conductive ABS and protopasta- conductive filament, from the results found out that the protopasta-conductive filament is 56% more conductive than the conductive ABS.

Keywords: freeform fabrication, conductive filament, and resistivity.

INTRODUCTION

The additive manufacturing (AM) is a technique that permits freeform manufacturing without the requirement of tooling or moulds. In other hand, to the conventional reductive processes for instance milling or lathing remove materials to make a part (Muir, E., 2015). In this paper, it concentrated on Fused Deposition Modelling (FDM) and it is also known as 3D printing, is one of the method of additive manufacturing, which uses a spool of materials, such as ABS are fed through a heater and extruded from a nozzle. The material will be heated to slightly high temperature from its glass transition temperature so as to its partially molten not fully fluid (Hague, R., 2006). The partially molten materials were then printed on the platform in XY direction.

The ability of 3D printer that can operate multi-task of printing object from software occur is the technology recently. It can design the object from plastic or other material composition based on additive manufacturing process. Therefore, this technology procedure is printed the composition layer by layer, from bottom to finish. The advantage of this method is it can produce every shape, from easier to complex. Nevertheless, a duration time and costing of this 3D printer is more efficient that conventional system by 50% – 90%.

An additive manufacturing technique also known as freedom solid fabrication, automatic computerized manufacturing and layer fabrication. Whereas, from a computer model to this layer and this part was designed with added the layer with the other layers. Furthermore, to fulfil a customer demand, a manufacturer enhances the product due to 3D printing technology, whereas the combination of other functions, for example electronic sensor into 3D micro structure. Therefore, to achieve this demand, the combination of 3D printing process and functionalities material are needed.

In 3D printing, it has a concept used by Direct Write (DW), whereas a starting of DW uses an extruding of steel paint. DW is one of the technology happen with single properties and multi-layer, high resolution, conformal surface with dual-layer (Church et.al. 2011). Rather than that, DW can represented as a procedure for conductive materials. In additional, DW can produce an application with sensor manufacturing and antenna, where Casanova *et al.* designed and produced a 3-dimensional fractal antenna shown in figure 1a using conventional manufacturing and found it to improve radiation efficiency (J.J. Casanova et. Al, 2010) and gain when compared to a 2-dimensional patch antenna Optomec in figure 1b has demonstrated its ability to use the Aerosol Jet (Perez *et al.* 2013).

DW process deposit on conformal substrates, which is wearable technology such as an insert in a helmet that contain an accelerometer in it (figure 2) (Castillo et.al. 2009) and create functional antennae on AM substrates, which removes the sticky and swirling of conventional electronic fabrication. Therefore, when combined with additive manufacturing (AM), this process will be more efficient and create a perfect finished product. When electronic parts are integrated into the structure of the AM and DW can be used to produce an electronic signal path. Next, when the detectors embedded in the printing and integrated power systems in the AM structure is produced.

In this paper, we report on a resistance test of the both electrically conductive filaments. In this technology era, 3D printing must go through with the science research process, whereas it can combine other materials that have a more plastic ability due to conductive

composite material, and will be presenting inside this research.

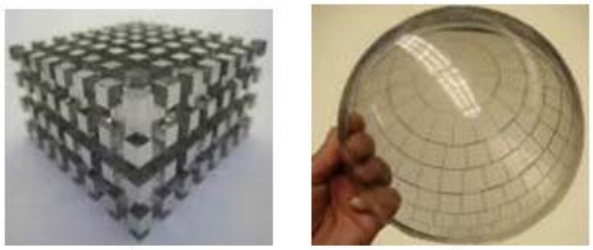

Figure-1. a) 3D fractal antenna b) Aerosol jet of conductive traces.

Figure-2. Helmet insert for detecting traumatic head injury.

Other than, this material might produce printed circuit, but in this research, we will show the ability to produce other product, for example a button on player controller the flex sensor inside hands cover and heat sensor inside a coffee mug. Material properties of this filament will be explained with another section, in this research. In this research, we go through with the experiment procedure to identify the material properties and electrical properties from existing conductive composite material, and we use the designation of functionalize structure to find simple electrical flow.

METHODOLOGY

The method to test the material's resistance were referring to the previous researcher. There are two materials which both ready in market was being used to compare between both materials. The material used are conductive ABS and Proto-pasta Conductive PLA shown in Figure-3. The conductive anti-static ABS has advantages with excellent mechanical strength, impact resistance, dimensional stability, high flow creep resistance and excellent heat and low temperature resistance. Whereas, Proto-pasta Conductive PLA contains Natureworks 4043D PLA, a dispersant and conductive carbon black. In filament form, it is quite flexible, and currently only recommended to use for low voltage and current.

By using existing this two conductive composite materials, with some advance preparation should be carried out, among which are studying the use of the printer involved, few parameters to be identified to enable to make the filament to be printed. Next, understanding the behaviour of the electrical resistance in both materials. Then, understanding the steps and methods of producing specimens and carry out laboratory testing and analysis. Finally, collecting the data, discussions and identify the better conductive material to be used.

Figure-3. a) Conductive ABS b) Proto-pasta conductive PLA.

SAMPLE PREPARATION

For sample preparation of specimens will involve the Fused Deposition modelling (FDM) which, is also known as 3D printer. In this study, we have only done taking measurement of resistance towards electric for both materials. Other than that, for a case study, we refer to various methods such as using the existing design of the test, namely capacitive interface, where it is easy circuits used to detect the input for the final case study. Therefore, this specimen will be design in the Solidwork software and kept in STL file for easy printing in 3D.

The specimens that were prepared are filament diameter of 1.75cm which cut at length of 1cm, 2cm, 3cm, 4cm, 5cm, 6cm, 7cm, 8cm, 9cm, 10cm. Next is after extruded from the 3D printer which will be 0.4cm and it also cut as the filament every centimeter from 1cm till 10cm. For the third test is for volume resistance, the specimen is a cube with the measure as 1cm x 1cm x 1cm. printed specimen. Refer to Figure-4 the sample specimens that prepared.

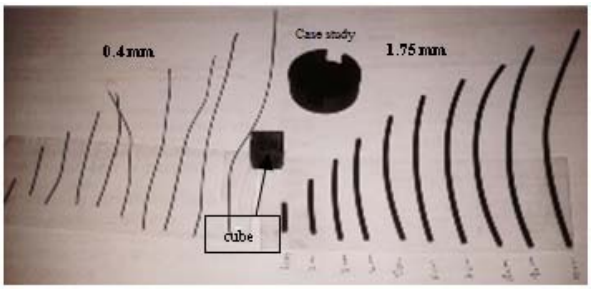

Figure-4. Sample of specimens – Proto-pasta.

METHOD USED

We use existing conductive composite filaments as the main component to analyse. The conductive ABS have 1.75 mm diameter, 0.5 kg as a weight and black in

colour. Other properties are being more than 104 ohms/cm as electric resistance in the data sheets. In addition, when extruding process, the temperature must be set as within 220°C to 260°C this varies according to printer and slow speed of printing. This filament known as brittle and hard in physical properties.

On the other hand Proto-pasta Conductive PLA have 1.75mm in diameter, only 125 grams in weight and black in colour. The hotend temperature will be around 210°C to 230°C. This filament has special advantage in Protopasta Conductive PLA with high electrical conductivity and its quite flexible than other conductive filaments.

EQUIPMENT USED

All the drawing were done using Computer Aided Drawing (CAD) which is Solidworks. The printer was connected directly to Makerware® software. The drawing that is drawn save in STL file, then only can be transferred to the Makerware software. From the some parameter setting will be done such as Hot-end, platform temperature, printing speed and more. Then, we will have to produce Gcode so be transfer to the printer, so that it can start the heating and printing process.

RESULTS AND DISCUSSION

This analysis draws a number of specimens in accordance with the test which was carried out as 2 test specimens for resistance test each. Even the 10 specimens for resistance test through filament length (size 1.75 mm and 0.4 mm). This test for the presence of resistance before this material given electric current. Therefore, some of the processes carried out to test it.

Table-1. Resistance value across conductive ABS filament (diameter 1.75mm).

Length (cm)	Resistance (ohm, MΩ)						MΩ/cm
	1	2	3	4	5	Average	
1	0.0581	0.0729	0.0735	0.0730	0.0716	0.0698	0.0698
2	0.0594	0.1822	0.1812	0.1810	0.1791	0.1566	0.0783
3	0.0627	0.1227	0.1126	0.1120	0.1101	0.1040	0.0347
4	0.0976	0.0876	0.0875	0.0872	0.0870	0.0894	0.0224
5	0.1044	0.2372	0.2458	0.1719	0.1635	0.1846	0.0370
6	0.1101	0.1020	0.1017	0.1013	0.1012	0.1033	0.0172
7	0.1332	0.1357	0.1362	0.1351	0.1348	0.1350	0.0193
8	0.1577	0.2248	0.2192	0.2168	0.2118	0.2061	0.0258
9	0.1591	0.1631	0.1630	0.1629	0.1630	0.1622	0.0180
10	0.2148	0.1959	0.1954	0.1950	0.1949	0.1992	0.0199

Table-2. Resistance value across conductive ABS filament (diameter 0.4mm).

Length (cm)	Resistance (ohm, MΩ)						MΩ/cm
	1	2	3	4	5	Average	
1	0.390	0.389	0.385	0.381	0.380	0.385	0.385
2	2.114	2.059	2.014	2.002	1.993	2.036	1.018
3	2.061	2.058	2.020	2.019	1.988	2.029	0.676
4	3.840	3.780	3.770	3.760	3.750	3.780	0.945
5	4.010	4.020	4.010	4.000	4.010	4.010	0.802
6	1.240	1.241	1.242	1.241	1.241	1.241	0.207
7	5.690	5.660	5.490	5.460	5.450	5.550	0.793
8	34.870	34.850	34.980	34.640	34.830	34.834	4.354
9	7.280	7.300	7.290	7.320	7.300	7.298	0.811
10	4.970	4.780	4.780	4.690	4.810	4.806	0.481

Table-3. Resistance value across proto-pasta conductive PLA filament (diameter 1.75mm).

Length (cm)	Resistance (ohm, kΩ)						kΩ/cm
	1	2	3	4	5	Average	
1	1.558	1.472	1.469	1.578	1.644	1.544	1.544
2	1.418	1.045	1.675	1.563	1.750	1.490	0.745
3	1.127	1.112	0.904	1.007	1.084	1.047	0.349
4	1.184	1.171	1.174	1.166	1.151	1.169	0.292
5	1.347	1.334	1.312	1.322	1.345	1.332	0.266
6	1.707	1.696	1.686	1.691	1.681	1.692	0.282
7	1.753	1.747	1.731	1.735	1.749	1.743	0.249
8	1.830	1.826	1.823	1.821	1.819	1.824	0.228
9	2.111	2.095	2.078	2.081	2.089	2.091	0.232
10	2.327	2.331	2.322	2.309	2.314	2.321	0.232

Table-4. Resistance value across Proto-Pasta conductive PLA filament (diameter 0.4mm).

Length (cm)	Resistance (ohm, kΩ)						kΩ/cm
	1	2	3	4	5	average	
1	1.873	1.737	1.857	1.750	1.770	8.987	8.987
2	3.001	2.993	2.986	2.991	2.990	2.992	1.496
3	4.46	4.43	4.42	4.44	4.45	4.44	1.48
4	6.34	6.31	6.33	6.33	6.30	6.322	1.581
5	8.08	8.00	7.99	8.06	8.01	8.028	1.606
6	13.15	13.11	13.12	13.13	13.11	13.124	2.187
7	14.45	14.52	14.50	14.54	14.57	14.516	2.074
8	13.96	13.97	14.01	13.98	13.97	13.978	1.747
9	14.44	14.43	14.47	14.46	14.45	14.45	1.606
10	19.69	19.70	19.76	19.82	19.84	19.762	1.976

RESISTANCE THROUGH FILAMENT LENGTH

The resistance was measured with a standard which is taking measurements from a calibrated multimeter (fluke 87-V Digital Multimeter). The value of resistance for the conductive ABS filament before extrude (1.75mm) is between 17.2 kΩ / cm up to 78.3 kΩ / cm, meanwhile, the resistance measured at 0.4 mm diameter is flawed at the resistance at 8 cm spans of 4.354 MΩ / cm. Therefore, the probability occurs at the filament, there is a defect due to part of the filament was broken, then the existence of the resistance intact. This is because its diameter is small and easy to break.

For Proto-pasta conductive PLA filament the reading is quite consistence between 0.2 kΩ/cm to 0.3 kΩ/cm only reading for 1cm is higher. This is due irregular diameter of the filament and the carbon mixture at the initial part of the filament. In other hand, the after extrude filament is measured to be same consistence between 1.4 kΩ/cm to 2.2 kΩ/cm, the same fluctuation happens at 1cm this due to the temperature at the starting of printing might be higher.

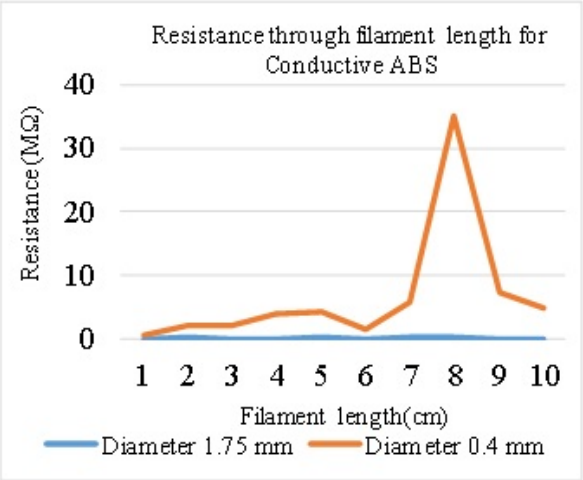

Figure-5. Resistance vs length in conductive ABS.

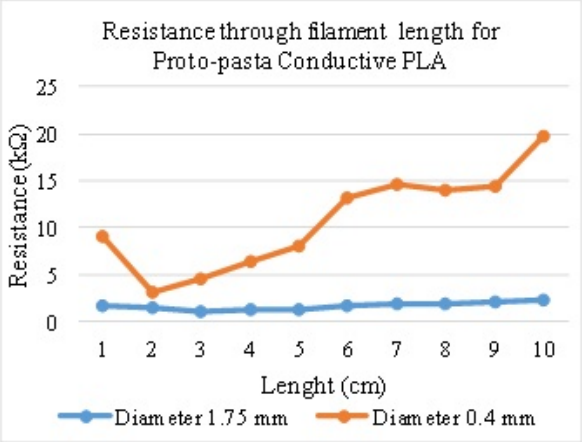

Figure-6. Resistance vs length in Proto-Pasta conductive PLA.

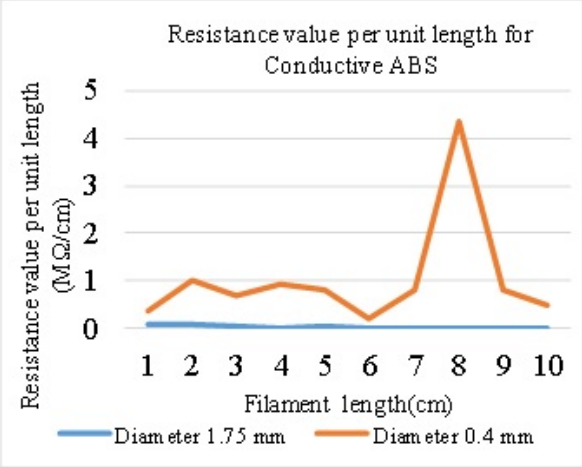

Figure-7. Resistance per unit length vs length in conductive ABS.

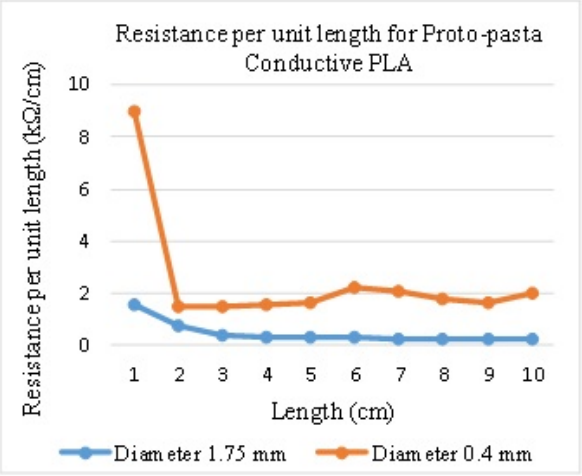

Figure-8. Resistance per unit length vs length in Proto-Pasta conductive ABS.

RESISTANCE THROUGH FILAMENT LAYER (VOLUME)

There are 3 types of test for this analysis. Therefore, the resistance involving these volumes is defined as the electrical resistance of the conductive composite material of ohms per cubic centimetre. It is printed with the dimensions of 10 mm x 10 mm x 10 mm. Thus, the experiments carried out on conductive ABS found that, where the odds of this specimen went to more than 10 MΩ/mm3, whereas the Conductive PLA gave reading around 3.548 Ω/mm3. For conductive ABS reading is much higher because the voltage applied is not enough match the resistance of the specimen being printed. In addition, to differentiate between printed and heating specimen, it comes out with this analysis, the required specimens through this procedure failed. Firstly, heating temperature of ABS is more than melting temperature of about 220°C. The results of this experiment are disturbing by air convection specimen melting process resulting filaments but not through a direct melting phase through the combustion process. Therefore, the existing composite in conductive filaments, it is a mixture of ABS/PLA and carbon, the air convection conditions that interfere with the carbon particles. Based on additive manufacturing technology, it able to exceed its ability, as shown in the testing by case study. It has ability to flow current through the conductive composite filament. Therefore, this material shows it can be improved with existing functions are able to emulate the function itself.

CASE STUDY

In this study, we have designed and printed a sample of functional product, which shows the usability of the filament. During the testing we have seen there are differences in brightness of the LED light, this is due to the resistivity of the materials, refer Figure-9. Therefore, a reading of the light intensity value was taken to show the comparison in numerical form. The measuring equipment that used is the Lux meter, which measure the luminous flux per unit area.

The reading is taken 10cm away from the LED light and in a dark environment. Other than that, the lux will be 45° from from the light source this is to get the accurate reading.

Figure-9. Difference between the brightness of LED regarding to conductive composite filament.

The result taken from the Lux meter is as below in the Table-5. From the table shown that the sample of that printed using Proto-pasta gave the higher reading then the conductive ABS where 7.51 Lux in 9V for Proto-pasta compared to just 0.93 Lux in 9V for conductive ABS. From this, we can know that the Proto-pasta is more conductive and can be used in industry through embedded circuits.

Table-5. Light intensity reading from Lux meter.

Voltage (V)	With Proto-pasta (lux)	With Conductive ABS (lux)	Direct connection (lux)
3	1.26	0.77	1.67
6	4.18	0.79	5.12
9	7.51	0.93	8.46

CONCLUSIONS

This study shows that Proto-pasta Conductive PLA is resistance to electricity, which means has a high electric conductivity than the conductive ABS filament. These filaments can use to increase the production of various products in the rapid manufacturing with embed circuit. Therefore, a various preliminary analysis needs to be done every time for enhances this new creation. As it was done in this research, such as the analysis and testing of electrical resistance tests were conducted could increase the potential of this new invention. From the data that has been analysed, we found that the presence of the resistance in the conductive composite filament a high and it requires a high voltage to maintain the current.

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