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MELT FLOW RATE (MFR) OF ABS-COPPER COMPOSITE FILAMENT BY FUSED DEPOSITION MODELING (FDM)

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ABSTRACT

This paper presents the melt flow rate (MFR) of an *acrylonitrile butadiene styrene* ABS-Copper filament wire for Fused Deposition Modelling (FDM) machine. In this study, the effect MFR of 70 % copper filled in 30 % ABS filament material was investigated experimentally based on the melting temperature, feed rate and different size of FDM nozzle diameter. The melt flow index (MFI) and mechanical properties of ABS-Copper filament through the injection molding machine and Melt Flow Indexer Machine was investigated in the experimental for highest value of the mechanical properties and MFI. Based on the result obtained, it was found that, increment of 75% copper filled in ABS filament material in weight percentage (wt. %) increase the MFR, velocity and length of PMC wire filament material. It can be conclude that, highest temperature and federate is needed to extrude polymer matrix composite (PMC) filament compared to ABS polymer filament material in FDM machine.

Keywords: layered manufacturing, fused deposition modeling, ABS, ABS-copper filament.

INTRODUCTION

The algorithm can be categorized into many classifications, one of its deterministic or stochastic. Deterministic algorithm is an algorithm that produce on the given input, and it will produce same result by following the same computational steps. Deterministic algorithm is quite efficient in finding local optima because of it will do local search.

Additive Layered Manufacturing (ALM) is an evolution of the part fabrication processes where the part is built in layers-by-layer process by addition material into platform. There are several names used for ALM such as solid freeform fabrication (SFF), additive fabrication (AF), rapid prototyping (RP), 3D-printing (3DP), freeform fabrication (FF) and additive manufacturing (AM) [Petrovic, *et al.*, 2011]. Traditionally, the LM process have been able to fabricate parts either from the solid, liquid and powder materials by different technology and techniques of laser, heated head and drop on demand binder. Currently, LM process involved with either plastic, wax, metal, metal matrix composite (MMC), polymer matrix composite (PMC) and ceramic matrix composite (CMC) material. There are several RP machines are available in the market such as Stereo Lithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), 3-D Printing and Laminated Object Manufacturing (LOM). The FDM machine was available in the online market with variety's plastic material in filament form with 1.7 mm ~ 3.0 mm in wire diameter. The varieties FDM machine brand in the market was Stratasys, Object, Makerbot, Vagler, UP Plus, Prusa I3, EASY3DMAKER, DIY. Normally, the FDM machine involved with plastic material such as acrylonitrile butadiene styrene (ABS) [Lee *et al.* (2005), Nikzad, *et al.* (2009, 2011) Tyberg and Bohn (1999), Sood, *et al.* (2009), Masood, *et al.* (1996), Bellini and Bertoldi (2004)] and nylon material [Masood and Song, (2004, 2005)].

Currently, metal filled in the polymer matrix has become an alternative material used in FDM machine. Some researcher used a mix material of ABS-Iron [Nikzad *et al.* (2009, 2011), Masood and Song (2004, 2005), Sa'ude *et al.* (2014] and ABS-copper [Sa'ude *et al.* (20013, 2014], Carbon fiber reinforced plastic (CIRP) [Ning *et al.* , 2015]. In FDM, a solid plastic filament wire or feedstock wire form from spool, were extrude through the heated liquefied head and nozzle and deposited into platform in layer-by- layer process. A shift from prototyping to manufacturing of the final product necessitates broadening of the material choice, improvement of the surface quality, dimensional stability, and achieving the necessary mechanical properties to meet the part performance in various application. The basic principle and operation of the FDM process offers a great potential for a range of other materials, including metals and composites to be developed and used in the FDM process as long as the new material can be produced in feedstock filament form of required size, strength and properties. Currently; application of FDM material required enhanced material, higher mechanical properties and conductive material toward layered processes. The fabrication of ABS-Iron filament wire for FDM machine has been done by Masood *et al.* (2004, 2005), Nikzad *et al.* (2009, 2011), Sa'ude *et al.* (2013, 2014) with proper formulation and mixing processes. They mentioned that the critical properties' requirements for high-quality composite are depending on the desired viscosity, strength and modulus.

Layered of rapid deposition polymer composites (RDPC) with highly filled metal powder in the polymer matrix may offer the possibility of introducing new composite material in FDM [Sa'ude, *et al*., 2013]. The

intention of this study is to investigate the mechanical properties, deposited material temperature on platform, feeding speed, and melt flow rate of a new PMC filament feedstock material through the heated liquefied nozzle. The research focuses on optimum temperature selection of deposited of copper filled in ABS filament material through the heated liquefied head and nozzle diameter of 0.4 mm and 0.6 mm in diameter. The proper formulation, mixing and compounding procedure shall be followed for obtaining the homogeneous feedstock. The main outcome of this study is to produce a strong, flexible and smooth flow of a new conductive filament feedstock with a high mechanical properties and melt flow rate of wire filament in LM process by FDM machine. After that, tested sample from the highest mechanical properties and melt flow index was used in wire filament development by single screw extruder machine.

EXPERIMENTAL

Materials

ABS material density was 1.03 g/cm^3 with melting temperature 266 ºC and copper powder obtained from the Saintifik Bersatu Sdn Bhd (Johor, Malaysia) with composition is 99.9 % pure and the particles size distribution is 50 μm ~ 150 μm respectively with melting temperature 1080 °C, boiling point 2324 °C and specific gravity 8.94 g/cm^3. Figure-1 and Figure-2 shows copper powder for the preparation specimen. Table-1 shows the characteristic of compounding ABS, copper, binder and surfactant material. The distribution's composition of the copper powder, ABS, binder and surfactant are 11% to 45% ABS, 46% to 81% copper powder, 3 % to 14% binder and 0.2 % to 0.8% surfactant by weight percentage (wt. %). The binder and surfactant material is based on wax, and it was added as the release agent for smoother flow of mixture of materials in the extrusion process.

Method

Firstly, ABS wire materials were chopped into 1mm – 5mm pallet size and put into the Brabender Plastograph mixer, type W50 for the compounding and the temperature range was between 180 - 185 ºC. Then the sieved copper powder approximately 50 μm - 100 μm in size was added into ABS for melt compounding. In order to achieve a homogeneous, the mixing of copper powder, ABS, binder and surfactant was mixed in 1-3 hours with similar setting for each compounding [11,12].

Figure-1. ABS (Sa'ude, 2013).

Figure-2. Copper powder (Sa'ude, 2014].

Secondly, the feedstock was crushed by machine and the final material output from the mixer was the feedstock pallet with a length of 1mm -5 mm approximately. Figure-3 and Figure-4 shows the Brabender mixer and ABS-copper materials. Table-2 shows the weight percentage (wt. %) of copper, ABS, binder and surfactant materials in the experimental.

Figure-3. Brabender mixer (Sa'ude, 2013, 2014).

Figure-4. ABS-copper (Sa'ude, 2013, 2014).

Table-1. Characteristic of compounding ABS, copper, binder and surfactant material.

Components	Melt Temperature (°C)	Density (g/cm³)
Copper	1080	8.94
ABS	266	1.03
Binder	155	3.54
Surfactant	80	0.891

Preparation of ABS-copper composite by injection machine for mechanical properties test

The mechanical properties test is done by injection molding process. The injection machine specification with screw diameter 19 mm, injection capacity 14 cm³, injection rate 50 cm³/second and injection pressure 161 MPa. Standard test specimens were prepared based on DIN EN ISO 527-2 for tensile test and ASTM D2240 for hardness test. Zone temperatures consist of 6 areas, where the nozzle temperature was 185 ºC, front and middle were set to 185 ºC and 180 ºC, while for rear 2 and rear 1 was 135 ºC and 145 ºC. The feeding temperatures were set to 70 ºC with the cooling time is 8 second. Figure-5 show the schematic diagram of injection molding machine for ABS-Copper material.

Table-2. Weight percentage (wt. %) of copper, ABS, binder and surfactant material.

Samples	Weight Percentage (wt. %)				
	copper	abs	binder	surfactant	Total
1	46.56	45.60	7.37	0.46	100
2	45.39	43.15	10.78	0.68	100
3	44.28	40.81	14.03	0.88	100
4	65.95	28.49	5.22	0.33	100
5	64.77	27.05	7.69	0.48	100
6	63.63	25.66	10.08	0.63	100
7	76.58	19.12	4.04	0.25	100
8	75.52	18.13	5.98	0.38	100
9	74.48	17.16	7.86	0.49	100
10	83.30	13.20	3.30	0.21	100
11	82.35	12.45	4.89	0.31	100
12	81.42	11.73	6.45	0.41	100

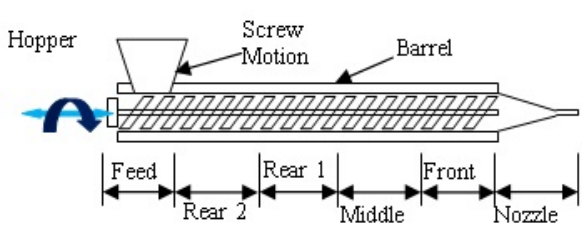

Figure-5. Schematic diagram of injection molding machine for ABS-copper material.

Due to a breakdown of the tempering system, the blends made of the certain ratio could not be processed at identical settings. The material was burned inside the barrel screw for homogeneous mixing two types of materials. In order to prevent the melt from sticking at the screw, the barrel temperature was started from low to high temperature. There was twelve (12) types of compositions used with ABS, copper and surfactant material for the flexural strength specimens made by in the injection molding machine. Figure-6 shows the flexural strength specimen (a) ABS from injection molding, (b) Copper filled in ABS by injection molding. In order to prevent the melt from sticking at the screw, the barrel temperature was started from low to high temperature.

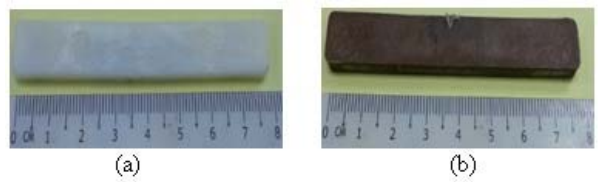

Figure-6. The flexural strength specimen (a) ABS from injection molding, (b) Copper filled in ABS by injection molding.

Fabrication of ABS-copper filament composite by single screw extruder

The single screw extruder machine specification with screw diameter 20 mm, barrel pressure 700 bars, temperature capability up to 300 ºC to 450 ºC, adjustable motor speed is approximately 500 revolutions per minutes (rpm) and maximum output approximately 2 to 15 kgs per hour. The material was burned inside the barrel screw for homogeneous mixing of new PMC materials. In order to prevent the melt from sticking at the screw, the barrel temperature was started from low to high temperature. Figure-7 shows the single screw extruder machine for ABS-Copper filament wire fabrication.

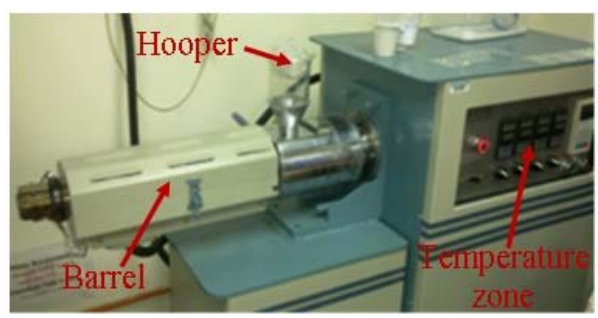

Figure-7. Single screw extruder machine for ABS-copper filament wire fabrication.

Firstly, the extruder machine should be heated around 10 to 20 minutes for establish the barrel temperature approximately 180 to 200 °C. Then the new ABS-Copper mixture pallet was fed into the hopper in certain amount, and the material flows from top to bottom by a gravity concept. The extruder screw will compress the ABS-copper pallet material from feeding area to middle, front and die area. Four areas of temperature zone and the extruder screw speed will be adjusted by manually in order to maintain the feedstock filament diameter. The die diameter was 2.9 mm and the targeting

diameter of the feedstock filament in approximately 3.00 mm to 3.20 mm. In order to minimize the swelling during the fabrication filament, the screw speed was started from low to higher speed. Feedstock filament will flow using environment temperature without waterbed cooling system. These ABS-Copper filament wire will be used in layered manufacturing by fused deposition modelling machine (Prusa I3). Figure-8 show the ABS-Copper filament by single screw extruder machine.

Figure-8. ABS-copper filament by single screw extruder machine.

Melt flow rate of ABS-copper composite by melt indexer machine for melt flow index (MFI)

In this study, the experiment was done by melt indexer machine (MIM) which is a common equipment used for the melt flow index (MFI) or melt flow rate (MFR). Three (3) samples with different compounding of copper filled in ABS matrix from Brabender mixer was used in MFR. The selection melting temperature was 180 ^{o}C and standard load is 5kg. Firstly, pre heated the MIM about 30 minutes for maintain the temperature and standardize preheating time. Then insert 5g – 8g compounding of ABS-copper in heated and barrel compartment for pre heated process in 5 minutes at 180 ^{o}C approximately. Piston load of 5 kg was placed on the piston rod, and the reading of MFR was made by stop watch. The length of MFR reading was 25.4 mm and a wire filament form is produced according to gravity flow in vertical direction. The calculation of MFI is based on the formula (1) and (2).

Calculation for Melt Flow Index:-

$$MFI = \frac{427 \times L \times d}{t} \quad (1)$$

where :-

L= Timed piston stroke (25.4mm)
d= Material density (g/cm^3)
t = Time for L (second)

$$d = \frac{w}{v} \quad (2)$$

where :-

w= Weight of the extruded material for L (g)
d= Density material (g/cm^3)
v= Extruded volume for travel L (1.804 cm^3)

A high MFR will indicate an easier flow material through the dies and knows as low viscosity fluid, while a low MFR indicates a high viscosity fluid. Figure-9 shows the melt indexer machine (MIM) used in the experiment and Figure-10 was a ABS-Copper composite filament wire by MIM.

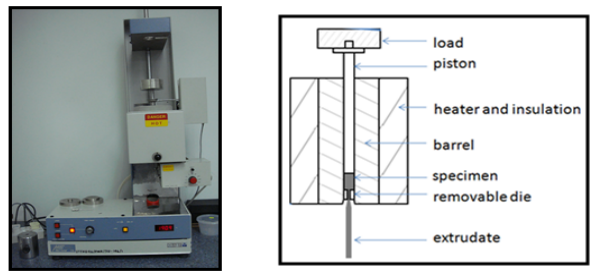

Figure-9. Melt indexer machine.

Figure-10. ABS-copper filament wire.

RESULTS AND DISCUSSIONS

Mechanical properties test

Flexural testing machine used in this study was Shimadzu AG-I. The maximum load capacity is 10 KN. From the results obtained, it found that the highest flexural strength of original ABS is 53 MPa. The maximum flexural strength was 37.44 MPa for sample 7 with 76.58 % copper filled in 19.12% ABS material by weight percentage (wt. %). It was concluded that, an increment of 76 % by wt. % of copper filled in ABS was increases the flexural strength value. When add more copper up to 83 % by weight percentage it was reduce the flexural strength result compared with 76 % copper filled in ABS material. (refer to Table-3). Figure-11. Show the weight percentage versus flexural strength result

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Table-3. Flexural strength results on maximum stress, force and displacement.

Sample	ABS (wt.%)	Copper (wt.%)	Binder (wt.%)	Max Stress (MPa)
ABS	100.00	-	-	53.83
1	45.60	46.56	7.37	29.05
2	43.15	45.39	10.78	29.32
3	40.81	44.28	14.03	25.12
4	28.49	65.95	5.22	35.77
5	27.05	64.77	7.69	29.13
6	25.66	63.63	10.08	22.90
7	19.12	76.58	4.04	37.44
8	18.13	75.52	5.98	32.76
9	17.16	74.48	7.86	23.72
10	13.20	83.30	3.30	22.80
11	12.45	82.35	4.89	25.58
12	11.73	81.42	6.45	18.77

Melt flow index (MFI) test

There were twelve (12) mixed copper, ABS, binder and surfactant material by weight percentage (wt. %) in the melt flow rate analysis. The percentage weight of compounding between a copper, ABS, binder and surfactant were 46% ~ 81% copper, 11% ~ 46% ABS and 3% ~ 14% binder. The detail compounding material by percentage weight shows in Table-4.

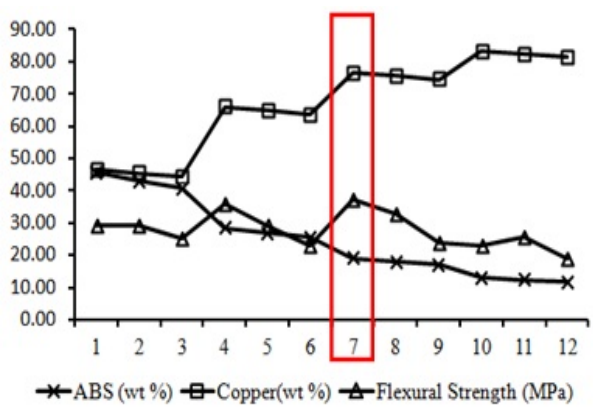

Figure-11. Weight percentage versus flexural strength result.

Table-4. Melt flow index test.

Samples	ABS (wt.%)	Copper (wt.%)	Binder (wt.%)	MFI (g/10min)
1	45.60	46.56	7.37	4.35
2	43.15	45.39	10.78	6.83
3	40.81	44.28	14.03	10.55
4	28.49	65.95	5.22	22.60
5	27.05	64.77	7.69	18.09
6	25.66	63.63	10.08	16.45
7	19.12	76.58	4.04	23.36
8	18.13	75.52	5.98	42.71
9	17.16	74.48	7.86	37.30
10	13.20	83.30	3.30	23.59
11	12.45	82.35	4.89	26.65
12	11.73	81.42	6.45	22.32

From the results obtained, it was found that, the decreasing of ABS material increased the MFI in the experimental. The higher value of MFI was in sample 8 with 42.71 g/10 min approximately. An increment of 74% ~ 76% by weight percentage of copper filled in ABS increase the MFI value, but additional up to 83% by weight percentage of copper was reduced the MFI value. It can be concluded that the maximum copper filled in ABS material was 75% by weight percentage. The detail correlation between copper, ABS, binder and surfactant are shown in Figure-12.

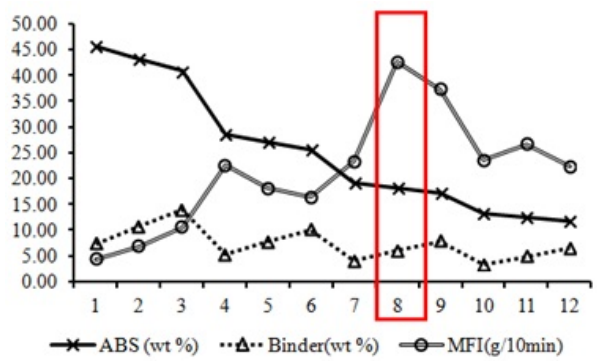

Figure-12. Melt flow index based on weight of percentage (wt. %) copper and binder materials.

CONCLUSIONS

A new PMC filament with copper filled in ABS material has been successfully produced by single screw extruder and melt indexer machine for flexural strength, melt flow rate test. From the twelve (12) different compounding materials, it can be concluded that, the flexural strength of injected parts are great influenced by weight percentage of copper 76.58 % and ABS 19.12% with the higher flexural strength was 37.44 MPa in sample 7. However, the maximum result on MFI was in sample 8 with 42.71 g/10min. From the both results obtained, it shown that, the mechanical properties and MFI of PMC

material are greatly affected with adding more copper in ABS material by weight percentage. This filament was used in FDM machine to fabricate a conductive part in a layer by a layer process.

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