

## **A Study on Melt Flow Index on Copper-ABS for Fused Deposition Modeling (FDM) Feedstock**

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**Keywords:** FDM, ABS, ABS-Copper, PMC Filament, Melt flow index

**Abstract.** This paper presents of Polymer Matrix Composite (PMC) as feedstock used in Fused Deposition Modelling (FDM) machine. This study discussed on the development of a new PMC material by the injection molding machine. The materials consist of copper powder filled in an acrylonitrile butadiene styrene (ABS), binder and surfactant material. The effect of metal filled in ABS and binder content was investigated experimentally by the Melt Flow Index (MFI) machine. Based on the result obtained, an increment of copper filled in ABS by volume percentage (vol. %) affected on melt flow index results. With highly filled copper in PMC composites increase the melt flow index results. It was concluded that, the propensity of the melt flow allow an internal force in PMC material through the injection molding and FDM machine.

### **Introduction**

The fused deposition modelling (FDM) is one the most significantly used in rapid prototyping technology for an assortment of engineering applications. The FDM rapid prototyping systems by Stratasys Inc., can construct parts in a range of materials such as elastomers, acrylonitrile-butadiene-styrene (ABS) and Polyactic Acid (PLA) with layer by layer deposition of extruded material through a nozzle using feedstock filaments from a spool. Most of the parts fabricated in these materials can be used for design substantiation, form and fit examination and patterns for casting processes and medical purpose. Normally, the FDM machine involved with either acrylonitrile butadiene styrene (ABS) plastic material [1] or Nylon [2]. At present, the most frequent composites material used in layer by layer deposition are HDPE-steatite ceramic [3], ABS-Iron [4] and ABS-copper [5]. New materials for FDM progression are considered necessary to increase its purpose domain especially in rapid tooling and rapid manufacturing areas. The basic theory of operation of the FDM process offers grand approaching for a range of other materials including metals, ceramics, and composites as long as the new material can be created in feedstock filament form of required size, strength, and properties [6]. One of the most important issues in composite material development is determine the material viscosity. The intention of this study is to investigate the melt flow rate and density of the PMC material by Melt Flow Index (MFI) machine. The requirement material flow through a small capillary nozzle is measure in gram(g), standard load of 5kg in 10 minutes time approximately for each experiment. The value obtained through the melt flow index test is a single datapoint. Normally, a higher MFI indicates a lower material viscosity. This means that, the material easier to flow in the nozzle area during experimental process. The calculation of MFI is based on the formula (1) and (2). Melt flow index information from different materials and material grades may be used for a rough comparison of flow characteristics for different materials.

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

where :-

L = Timed piston stroke (25.4mm = 2.54 cm) (cm)  
 d = Material density (at least temperature) ( $\text{g}/\text{cm}^3$ )  
 t = Time for L (s)

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

where :-

w = Weight of the extruded material for L (g)  
 d = Density (at least temperature) ( $\text{g}/\text{cm}^3$ )  
 v = Extruded volume for travel L ( $1.804 \text{ cm}^3$ ) ( $\text{cm}^3$ )

## Experimental Methods

### Materials

The ABS material was supplied by Dutatek Sdn Bhd (Selangor, Malaysia). The density of ABS was  $1.03 \text{ g}/\text{cm}^3$  and melting temperature  $266^\circ\text{C}$ . ABS materials are an environmental friendly material because they are completely recyclable. Figure 1 show the ABS material for injection process. Copper powder obtained from the Saintifik Bersatu Sdn Bhd (Johor, Malaysia). The chemical composition is 99.9 % pure and the particles size distribution is  $50 \mu\text{m} \sim 150 \mu\text{m}$  respectively with melting temperature  $1080^\circ\text{C}$ , boiling point  $2324^\circ\text{C}$  and specific gravity  $8.94 \text{ g}/\text{cm}^3$ . Figure 2 shows the copper powder for the preparation specimen. The distribution's composition of the copper powder, ABS, binder and surfactant are 70% to 85% ABS, 10% to 20 % copper powder, 4 % to 8% binder and 1 % to 2% surfactant by volume percentage (vol. %) in (Table 1). Binder and surfactant material is based on wax was added as the release agent for smoother flow of mixture of materials in the extrusion process. Firstly, ABS material was chopped into 1 – 5 mm pallet size and put into the Brabender Plastograph mixer type W50 at range  $180 - 185^\circ\text{C}$  for compounding temperature. In order to achieve a homogeneous, the mixing of the powder and binder was carried out in 1– 3 hours of mixing.



Fig. 1 ABS Pallet Fig. 2 Copper Powder Fig. 3 Brabender Mixer Fig. 4 Compounding ABS-Copper

Secondly, the feedstock was crushed by crusher machine and the final material output from the mixer was the feedstock pallet with a length of 1-5 mm approximately. Figure 3 and Figure 4 shows the Brabender mixer and the compounding of ABS and copper materials. The feedstock pallet was injection molded on a horizontal NP7-1F molding machine of bar size in  $10 \text{ mm} \times 80 \text{ mm} \times 4 \text{ mm}$  approximately. The injection machine specification with screw diameter of 19 mm, injection capacity  $14 \text{ cm}^3$ , injection rate  $50 \text{ cm}^3/\text{second}$  and injection pressure of 161 MPa. Standard test specimens were prepared based on heat flow for differential scanning calorimeter-thermogravimetric analysis test and ASTM D2240 for hardness test. Zone temperatures consist of five areas, where the nozzle temperature was  $200^\circ\text{C}$ , front and middle were set to  $190^\circ\text{C}$  and  $180^\circ\text{C}$ .

°C, while for rear 2 and rear 1 was 155 °C and 165 °C. The feeding temperatures were set to 50 °C with the cooling time is 10 second. 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. Table 1 shows the volume percentage of ABS, copper, binder and surfactant materials in the experimental.

Table 1 Volume Percentage of ABS, Copper, binder and surfactant materials

Sample	Volume Percentage (vol. %)				
	Vcopper	Vabs	Vb	Vs	Vtotal
1	10	85.0	4.0	1.0	100
2	10	82.5	6.0	1.5	100
3	10	80.0	8.0	2.0	100
4	20	75.0	4.0	1.0	100
5	20	72.5	6.0	1.5	100
6	20	70.1	8.0	2.0	100
7	30	65.0	4.0	1.0	100
8	30	62.5	6.0	1.5	100
9	30	60.0	8.0	2.0	100
10	40	55.0	4.0	1.0	100
11	40	52.5	6.0	1.5	100
12	40	50.0	8.0	2.0	100

## Methods

The melt flow index, more appropriately known as melt flow rate (MFR). Melt flow index or MFI is a measure of the ease of flow of polymer melts. A high MFR indicates easy flow or low viscosity fluid, while a low MFR indicates a slow flow or high viscosity fluid. This test is primarily used as mean of measuring the uniformity of the flow rate of the material. The reported melt index values help to distinguish between the different grades of polymer.

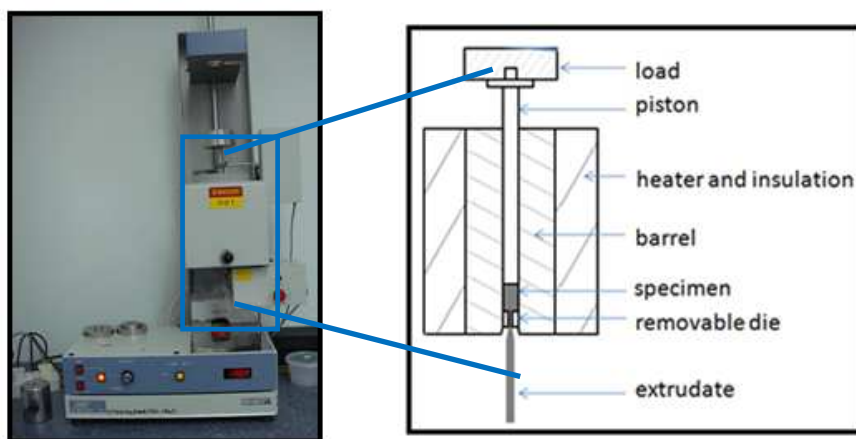


Fig 5 Melt Indexer Schematic Diagram

The MFI test procedure is as follow, weighted new material (compounding ABS-copper) granules about 5 gram according to table provided from melt flow manual instruction. After that, the melt flow machine was turn on and switched on the heating system by pressed the heating switch and the pilot light was checked which is on the switch. Then, die locker knob was pushed in until its stop. After that, the die was taken from tool container and inserted it from the top of the extruder barrel.

Then, it was pushed it down until it comes in contact with the locker. Temperature was set to 200°C and waits until it reaches the temperature by knowing that both of pilot lights will flash some time as shown in Fig 5. Piston was placed in the extruder barrel, let it pre-heated about 30 minutes. The piston was introduced which acts as the medium that causes extrusion of the molten new material (compounding ABS-copper). At the same time, two reference marks identified to locate the piston. Then, piston was removed and fills the barrel with the new material (compounding ABS-copper) granules and the piston was put it back in the barrel. Make sure that new material (compounding ABS-copper) was packed properly inside the extruder barrel to avoid formation of air pockets. Let the new material (compounding ABS-copper) granules pre-heated about 5 minutes at 200°C as to give a time for sample undergoing pre-melting process. 5.0 kg of mass is placed over the piston. The weight exerts a force on the molten new material (compounding ABS-copper) and it straight away starts flowing through the die. By this condition, new material (compounding ABS-copper) was extruded through the die. Once one of the two references marks on the piston become aligned with the upper insulating plate of the heating system, the stopwatch was reset and the extruded new material (compounding ABS-copper) was cut with a sharp rotation on the cutting device handle. New material (compounding ABS-copper) flow through the die for the required time (time collected in between of references marks) then the extruded new material (compounding ABS-copper) was cut again using the cutting device and collects it. The new material (compounding ABS-copper) extruded was weighted and melt index values are calculated in grams per 10 min.

## Experimental Result

From the results obtained, it was found that the highest values for Melt Flow Index are at sample 8. The reason why we make this testing are, we can know which sample or ratio of the material will produce good timing for extrusion the wire filament for this composite. In this testing we want to know about the time for finish the extruded. From the result obtained, it was shows that the sample 8 finished the 5 gram of composition in the time 141 seconds. It was concluded that, with the higher melt flow index value the more viscous of the material. The material or sample with higher value of MFI easier than a material or sample with a lower value of MFI.

Table 2 Result for MFI test

Sample	MFI(g/10min)	Time(s)
1	4.354	383
2	6.834	251
3	10.553	158
4	22.600	112
5	18.086	130
6	16.452	140
7	23.356	132
8	42.709	141
9	37.297	165
10	23.594	256
11	26.646	226
12	22.320	269

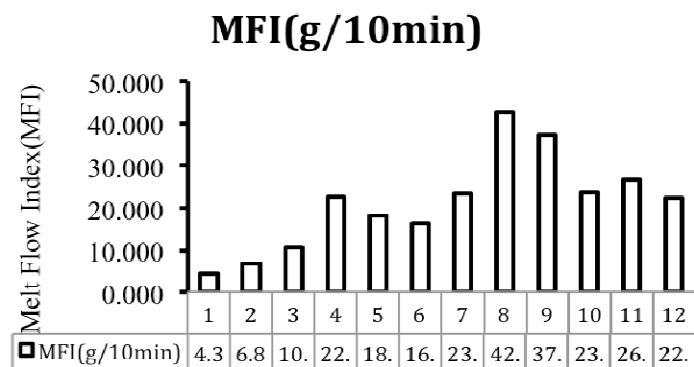


Fig 6 Bar chart of Melt Flow Index result

## Conclusions

A new PMC material with copper filled powder in ABS by the injection-molding machine has been successfully produced and tested for melt flow index. An improvement of melt flow index and analysis was done in the experimental to determine the highest melt flow index based on experiment and calculation. The suitable material and binder selection, mixing method and

parameter setting on melting temperature, pressure and cooling time may offer great potential area for metal feedstock in the extrusion of wire filament through the extruder machine.

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