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CHARACTERISATION OF COPPER FILLED IN ABS MATERIAL FOR FREEFORM FABRICATION

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ABSTRACT

This paper presents Polymer Matrix Composite (PMC) as feedstock used in Fused Deposition Modeling (FDM) machine. This study discussed the development of a new polymer matrix composite (PMC) material for use in injection molding machine. The material consists of copper powder filled in an acrylonitrile butadiene styrene (ABS), binder and surfactant material. In this study, the effect of copper powder was investigated as a filler material in polymer matrix composite and ABS was chosen as a matrix material. The detailed formulations of mixing ratio with various combinations of the new PMC are investigated experimentally. Based on the result obtained, it was found that, the weight percentage increment of copper filler affected the viscosity, temperature, velocity, melt flow index and surface tension.

Keywords: FDM, ABS, PMC feedstock, melt flow index, surface tension.

INTRODUCTION

The fused deposition modeling (FDM) is one the most extensively used rapid prototyping technology for an assortment of applications in engineering (Mostafa *et al.* 2009). The FDM rapid prototyping systems, industrial by Stratasys Inc., can construct parts in a range of materials together with elastomers, acrylonitrile-butadiene-styrene (ABS) and investment casting wax with the layer-by-layer deposition of extruded material all the way 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. New materials for FDM progression are needed 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 to be industrial and used in the FDM progression as long as the new material can be created in feedstock filament form of required size, strength, and properties (Song 1998). In order to forecast the achievement or failure of the flow of newly developed composite materials in the FDM process, it is necessary to investigate the main flow parameters namely temperature, velocity, and pressure drop on the flow performance of the composite in the liquefier head (Mostafa *et al.* 2009).

Presently the presented material engross in injection molding only starting plastic material. Some degree of material for relevance in injection molding process needs a new invention of the materials (Mostafa, Syed *et al.* 2009). Integration of plastic and metal material resolve vary the melting point temperature for the duration of injection molding course. The variety of a material for creating injection-molded parts is not exclusively based further on the measured crucial characteristics of the concluding part. Despite the fact that each material has dissimilar properties that determination affects the strength and purpose of the concluding part, these properties also utter the parameters worn in dealing out these materials.

The most advantageous setting of the screw speed, pressure, barrel and nozzle temperature will effect on the mechanical properties of Polymer Matrix Composite part. In the intervening time, in Fused Deposition Modeling (FDM) process, a plastic or wax material is extruded through that traces the parts cross sectional geometry layer by layer. Referring to the earlier research, the finest powder loading for the mixing ratio of the material will work out the problem where restricted material in FDM process. Above and beyond that, there are numerous applications where electrically conductive plastic patterns are compulsory. The largely usual way to formulate electrically conductive patterns is coating a plastic part by a thin layer of metal. Although this aim requires complex process and time expense, however it can reduce the cost of machining processes, which include tooling, cutting tools, power and more. (Wu *et al.* 2002).

LITERATURE REVIEW

Processing of polymer determination increasing apply of polymer, which is light, tough, corrosion resistant and cheap. More to the point that, processing of solid polymer also incorporated the polymer heated to the melt state, shaped under high pressure and cooled down to room temperature (below T_g or T_m) to conserve its shape, and shaping involves shear, bulk and elongation deformations of the polymer melt, which enclose dissimilar viscoelastic description. In polymer process, such as extrusion (films and sheets, fibers and filaments, pipes, tubing, profiles and wire coating), injection moulding, thermoforming, blow moulding, compression and transfer moulding (Wu *et al.* 2002). The material undergoes a complex record in which it melts, flows throughout complex geometries, deforms to take the form of the cavity, and cools along and solidifies interested in the final product. In all these processes, the properties of molded products are needy on the material from which it

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is manufactured and the processing parameters used. Above and beyond that, temperature is a very significant parameter that influences process description such as cycle times, crystallization rates, degree of crystalline, melt flow properties and molded product intrinsic worth.

Development associated with new FDM materials based on metals and polymer matrix composites (PMC) become a hard task from the catered requirement with combination two or more PMC material as feed stock filament. In the present work, the almost all common composites material taken through FDM method deposition are generally Zirconia (Grida & Evans 2003), ABS-Iron composite (Mostafa *et al.* 2009), Iron/nylon matrix (Masood & Song 2004), Nylon-Fe and AL-Alumina (Kumar & Kruth 2010), ABS with short glass fiber reinforced (Zhong *et al.* 2001).

Currently, several researcher focuses on optimal method parameter (Lee *et al.* 2005), (Anitha *et al.* 2001) and (Wu *et al.* 2002), modeling and dynamics of bond formation (Bellehumeur *et al.* 2004), investigation of melt flow behavior (Mostafa *et al.* 2009), developing a great proper formulation and also mixture (Nikzad *et al.* 2007) , (Vayena *et al.* 2005), (Masood & Song 2004), (Kumar & Kruth 2010), (Ma *et al.* 2007) and to improve the mechanical properties (Grida & Evans 2003), (Thivillon *et al.* 2009), (Zhong *et al.* 2001).

EXPERIMENTAL METHODS

Materials

The ABS material was supplied by Dutatek Sdn Bhd (Selangor, Malaysia). The density of ABS was 1.03 g/cm^3 and melting temperature 266 ºC. 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).

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

The chemical composition is 99.9 % pure and the particles size distribution is 50 μm ~ 150μm respectively with melting temperature 1080 °C, boiling point 2324 °C and specific gravity 8.94 g/cm^3. 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 ºC for compounding temperature. In order to achieve a homogeneous, the mixing of the powder and binder was carried out in 1– 3 hours.

Injection molding

The injection machine specification with screw diameter of 19 mm, injection capacity 14 cm³, injection rate 50 cm³/second and injection pressure of 161 MPa. Standard test specimens were prepared based on heat flow for differential scanning calorimeter-thermo gravimetric analysis test and ASTM D2240 for hardness test. Zone temperatures consist of five areas, where the nozzle temperature was 180 ºC, front and middle were set to 180 ºC and 180 ºC, while for rear 2 and rear 1 was 130 ºC and 180 ºC. The feeding temperatures were set to 70 ºC 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. Figure-1 and Figure-2 shows, the injection molding machine and the zone temperature in injection molding machine.

Figure-1. Injection molding machine.

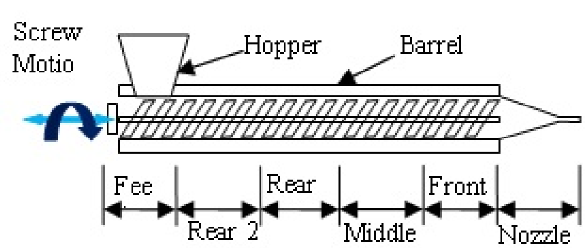

Figure-2. Zone temperature in injection molding machine.

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Figure-3. PMC specimen (example for sample 1-6)

EXPERIMENTAL RESULT

Flexural test ISO 178

In this testing, the specimen or shape that used is plate. The thickness for this specimen is 4.2 mm, width 10 mm and the lower support for this testing is 60mm. Each specimen testing was done three times or three specimen every each of same sample. This is because, to get the more accurate result, and the result is an average taken.

The result in the Figure-5 shows that, sample 7 shows the highest value for maximum force 73.376 N, sample 1 shows the highest value for maximum displacement, which is 2.749 mm, and for the break force sample 7 shows the highest value, which is 72.941 N. The Figure-4 below shows the test geometry for ISO 178 Specimen of 1/8" x 1/2" x 5" is placed on two supports and a load is applied at the center. The load at yield is the sample material's flexural strength. The analogous test to measure flexural strength in the ISO system is ISO 178. The values reported in the ASTM D790 and ISO 178 tests seldom differ significantly.

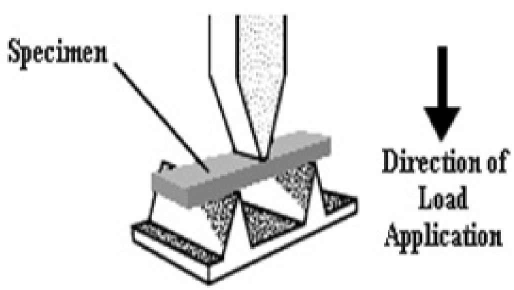
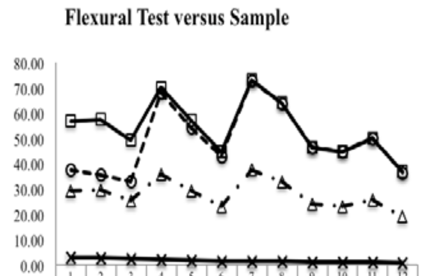


Figure-4. Test geometry for ISO 178.

Surface tension test

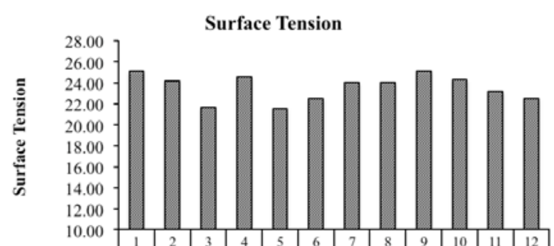
In this testing, to know the surface tension for every sample, we used eight-type liquid to investigate the contact angle. The liquid that we used are, IPA, Acetone, MMA, Mineral Oil, Dimethyl Sulfoxide, EG, Glycerol and Distilled Water. To get the accurate value for Surface Tension Test, the more type of liquid we used, the more accurate value we can get.

This testing conducted with hardware which is camera that can capture the image of the sample that put liquid at the upper of the liquid. After that, the image that already captured, we transfer the image to the software that can calculate the contact angle. The software that used in this testing is Image J. After the values of the contact angle already know, calculations for Surface Tension are needed.



	1	2	3	4	5	6	7	8	9	10	11	12
Max Force (N)	56.95	57.47	49.23	70.11	57.09	44.89	73.38	64.21	46.49	44.69	50.14	36.79
Max Displacement (mm)	2.75	2.70	2.18	1.89	1.73	1.41	1.27	1.35	0.98	0.93	0.98	0.65
Max Stress (MPa)	29.06	29.32	25.12	35.77	29.13	22.90	37.44	32.76	23.72	22.80	25.58	18.77
Break Force (N)	37.46	35.56	33.01	68.13	54.21	42.90	72.94	63.81	46.48	44.68	50.07	36.35

Figure-5. Graph of flexural test for 12 samples.



	1	2	3	4	5	6	7	8	9	10	11	12
Surface Tension	25.12	24.16	21.67	24.57	21.50	22.50	24.01	24.01	25.07	24.33	23.17	22.53

Figure-6. Graph of surface tension.

Result shows that sample 1 (Figure-6) is the highest surface tension 25.12 mN/m. For the information, copper consist in the sample 1 to 3 is 10%, sample 4 to 6 is 20%, sample 7 to 9 is 30% and sample 10 to 12 is 40%. Even sample 1 give the highest value for surface tension, the copper consists in this sample is only 10% compared to sample 7,8 and 9, which are, consists 30% copper. At the same time, the value for surface tension at the sample 7, 8 and 9 gives the second higher. Therefore, either sample 7, 8 and 9 was choosing for best result of surface tension.

Melt flow index test

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. Table-2 shows the result for Melt Flow Index test, result shows that, 156 seconds (sample 7), and at this sample the value for Melt Flow Index was the highest compared to other sample.

Table-2. Result for melt flow index test.

Sample	Rho (g/cm^3)	Stroke, L (cm)	Time(s)	MFI (g/10 min)	Density (g/cm^3)
1	1.56	2.54	187	9.06	1.49
2	1.72	2.54	193	9.69	1.39
3	1.40	2.54	126	12.09	1.49
4	1.23	2.54	86	15.46	2.02
5	1.11	2.54	122	9.90	1.95
6	1.24	2.54	98	13.67	1.86
7	8.78	2.54	156	61.04	2.51
8	5.57	2.54	141	42.84	2.69
9	5.69	2.54	165	37.40	2.63
10	5.58	2.54	256	23.64	3.24
11	5.57	2.54	226	26.73	3.22
12	5.55	2.54	269	22.38	3.17

Wire filament extrusion

Wire filament extrusion process is carried out using the Melt Flow Index (MFI) machine. Samples 7 and 8 were taken for the extrusion process, it is because the sample was the best samples for the extrusion process. For the extrusion process, the die 3.0 mm was used as the wire filament size (diameter). The weight of materials are inserted into the machine melt flow index is 9g.

The temperatures used for the extrusion process is started at 180 ° C. Starting temperature of 180 ° C for samples 7 and 8, because it represents the melting point for the materials and it is the same as the temperature using a mixer machine. The temperature of 180 ° C to 210 ° C for sample 7, whereas temperature for sample 8 is 180 ° C to 230 ° C. This is because after a temperature of 210 ° C for a sample 7 and a temperature of 230 ° C for 8 samples, the extrusion material will come out too melt and it self cut off. The weight data and the time data, after the extrusion process was taken for analysis. Based on Figure-7 shows that graph of time's average and weight's average for sample 7. The graph shows that, when the temperature increased the value for time was decreased. Differently for weight, when the temperature increased the value for weight also increased.

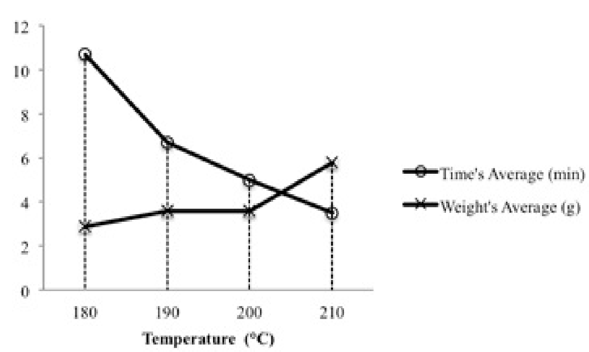


Figure-7. Graph of time's average and weight's average for sample 7.

Based on Figure-8 shows that graph of time's average and weight's average for sample 8. The graph shows that, when the temperature increased the value for time was decreased. Similarly for weight values, when the temperature decreased the value for weight also decreased.

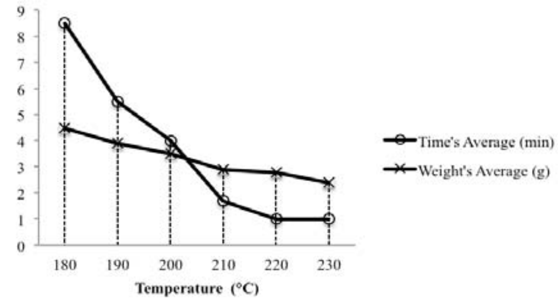


Figure-8. Graph of time's average and weight's average for sample 8.

The Figure-9 below shows that fabricated wire filament by using Melt Flow Index machine.

Figure-9. Fabricated wire filament by using MFI machine

The result in Figure-10 below, shows that the result of extrusion wire filament by using 3D printer (Prusa i3). From the result, the suitable feed rate and temperature plays an important role in ensuring that the extruded filament can exits with ease and smooth. The feed rate applied to drive the filament into the extruder head should be between 5 mm/s to 15 mm/s only the validation experiment that has been carried out shows that, selection of extrusion temperature is vital due to its effect on filament extruded diameter (part size accuracy) and selection of nozzle diameter will a effect part size accuracy and also feed rate speed.

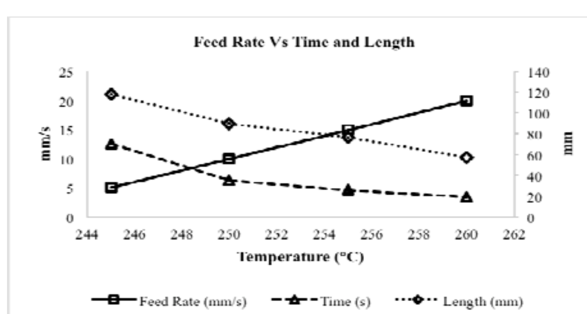


Figure-10. Graph of feed rate versue time and length.

CONCLUSIONS

A new PMC material with copper filled powder in ABS by the injection molding machine has been successfully produced and tested. According to the right selection of setting temperature in the injection molding temperature, the composition can be extruded.

The appropriate material and binder selection, mixing method and parameter setting on melting temperature, pressure and cooling time may offer great potential area for metal wire filament in the extrusion of wire filament.

In the future work, the researcher should tackle a significant issue in the extrusion process is a viscosity of the composite material to deform through the injection mold. Due to the copper powder loading in the ABS matrix, the density of the composite increases perpendicular with an increment of copper powder. Based on the observation on melt flow index machine, the diameter of the wire filament cannot define accurately based on the diameter hole die.

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