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A Study on Contact Angle and Surface Tension on Copper-ABS for FDM Feedstock

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Abstract. This paper presents the development of a new Copper-ABS feedstock material by the 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 metal filled ABS and binder content on the contact angle and surface tension was investigated experimentally. The detailed formulations of compounding ratio with various combinations of a new Copper-ABS feedstock was done by volume percentage (vol. %). Based on the result obtained, an increment by vol. % of copper filler in ABS effected on contact angle and surface tension results. With highly filled copper content in ABS composites increase the surface tension value. It can be observed that, the tendency of the liquid surface that allow to resist an external force in PMC material through an injection molding process.

Introduction

ABS material has become a widely used in rapid prototyping technology, especially in fused deposition modeling(FDM) and it was developed by Stratasys Inc., This technology offering a wide-range application in prototype development by layered deposition of polymer plastic on the platform in three dimensional object. The process involves a layer by a layer deposition of extruded material through the nozzle using feedstock filaments from a spool. Normally, the FDM machine involved with either acrylonitrile butadiene styrene (ABS) plastic material [1,2,3,4,5,6,7,8] and Nylon [9,10]. Currently, the most common composites material used in layer by layer deposition are HDPE-steatite ceramic[11], ABS-Iron[2,3,9,10,12] and ABS-copper [13].Development of composite material in wire form needs a lubricant or surfactant for surface-free energy and smoothest fluid flow. Surfactant powder is normally an organic compound as a lubricant agent used in polymer matrix composite. It consists of both hydrophobic groups (tails) and hydrophilic groups (heads). The surfactant contains a water-soluble component, and it will diffuse into water and absorb at interfaces between air and water. By adding the surfactant in the polymer matrix will modify the surface properties with good interconnection bonding and concentration. Surfactant also reduces the surface tension of water by adsorbing at the liquids-vapor interface. The value of surface tension is referred on the force per unit length, and it depends on the contact angle (Θ) value, when deposition water on the specimen or material. Equation (Eq. 1) and (Eq. 2) shows the basic calculation of contact angle and surface tension for the surface-free energy of PMC material [14, 15].

$$cos\Phi = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}} \quad (1)$$

$$\gamma SV - \gamma SL = \gamma LV \cos \Theta \quad (2)$$

Where:

$\cos \Theta$ = Contact angle

γSV = Solid/vapour interfacial tension

γSL = Solid/liquid interfacial tension

γLV = Liquid/vapour interfacial tension

Nowadays, the application of conductive composite in layer by a layer offers an alternative process in rapid manufacturing technology. Pure metal is unsuitable to deposit through the heated liquefied nozzle by FDM machine because of higher melting temperature and viscosity[9,12,13]. Nevertheless, there are limited data/research dealing with layered deposition polymer composites (LDPC) focuses on free surface energy or surface tension. The aim of this study is to develop the composite feedstock with copper, ABS, binder and surfactant powder with proper formulation and mixture procedure of constituent materials for obtaining the FDM feedstock with free surface energy or surface tension.

Experimental Methods

Materials

ABS material density was 1.03 g/cm^3 and melting temperature 266 °C. Figure 1 show the ABS material for injection process. 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 ~ 150μm respectively with melting temperature 1080 °C, boiling point 2324°C and specific gravity 8.94 g/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% to85% 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 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 °C. 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[12].

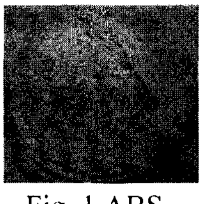

Fig. 1 ABS

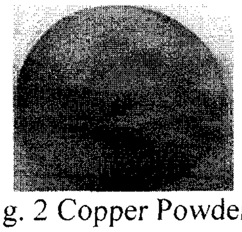

Fig. 2 Copper Powder

Fig. 3 Brabender Mixer

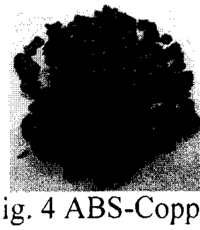

Fig. 4 ABS-Copper

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 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 mm x 80 mm x 4 mm approximately. Table 2 shows the volume percentage of ABS, copper, binder and surfactant materials in the experimental.

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

Components	Melt Temperature (°C)	Density (g/cm^3)
Copper	1080	8.94
ABS	266	1.03
Binder	155	3.54
Surfactant	80	0.891

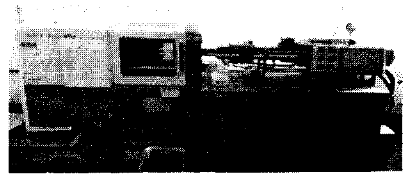

Fig. 5 Injection molding machine

Table 2 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

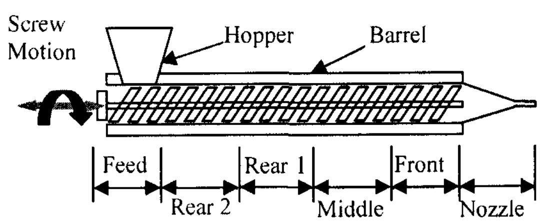

Fig. 6 Temperature zone in Injection

Methods

The injection machine specification consists of screw diameter of 19 mm, injection capacity 14 cm^3, injection rate 50 cm^3/second and injection pressure of 180 MPa. Standard test specimens were prepared based on ISO 178 for flexural strength. The specific dimension is 80 mm(L) x 10 mm(W) x 4 mm(H). Zone temperatures consist of five areas, where the nozzle temperature was 185 °C, front and middle were set to 185 °C and 180 °C, while for rear 2 and rear 1 was 135 °C and 145 °C. The feeding temperatures were set to 70 °C with the cooling time is 8 second. Figure 5 and Figure 6 shows, the injection molding machine and the zone temperature in injection molding machine. Then, the contact angle was measured by up-to-date technology in UTHM. The measurement of copper filler in ABS composites in solid surface was done by a simple apparatus which is eight(8) type of liquid was used to measure the contact angle. The liquid consists of Isopropyl alcohol(IPA), Acetone, Methyl-methacrylate(MMA), Mineral Oil(MO), Dimethyl Sulfoxide(DMSO), Ethylene Glycol(EG), Glycerol(GR) and Distilled Water(DW). Table 3 show standard of surface tension with variety's liquid. In order to measure the contact angle and surface tension, eight(8) type of liquid in a different syringe was deposited on a new PMC bar (10 mm x 80 mm x 4 mm) and 30 seconds in constant time was given for each deposition liquid on the specimen. Each measurement was repeated three times for each specimen for an accurate measurement. Figure 7 and Figure 8 shows the PMC specimen and contact angle measurement.

Fig. 7 PMC Specimen for surface tension

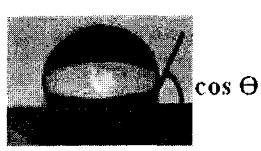

Fig. 8 Contact angle measurement

Table 3 StandardSurface Tension with Varieties Liquid

Types of Liquid	Interfacial Tension (mN/m)
Isopropyl alcohol(IPA)	21.79
Acetone(AT)	23.00
Methyl-methacrylate(MMA)	30.60
Mineral Oil(MO)	35.00
Dimethyl Sulfoxide(DMSO)	42.90
Ethylene Glycol(EG)	47.30
Glycerol(GR)	64.00
Distilled Water(DW)	72.80

Table 4 Critical Surface Tension of PMC Samples by Distiller Water by Vol. %.

Sample	Contact Angle (Θ)	Surface Tension (mN/m)
10Co,85Abs,4B,1S	85.68	25.12
10Co,82.5Abs,6B,1.5S	64.25	24.16
10Co,80Abs,8B,2S	75.94	21.67
20Co,75Abs,4B,1S	79.65	24.57
20Co,72.5Abs,6B,1.5S	71.61	21.50
20Co,70Abs,8B,2S	65.20	22.50

EXPERIMENTAL RESULT

Surface Tension

From the results obtained, it was found that each of liquids has own fluid surface tension. In this experiment, we found that the contact angles of PMC compounding are dropped with increment of copper filled in ABS material, and this result can be observed in Table 4. The contact angle value is determined by the molecular interactions across the liquid/vapor. According to the Fox and Zisman theory, the critical surface tension corresponds to the minimum value of the liquid surface tension data set and crossing with the extrapolation of the best fitted regression line at cos Θ = 1 [16,17]. Complete wetting is only reached if the substrate itself becomes wettable (Θ = 0) [18]. According to Table 4 with 10% Copper filled in 85% ABS material was determined the highest value of critical surface tension with 25.12mN/m. Second highest value of critical surface tension with 20% copper filled in 75% ABS was determined at 24.57mN/m. An increment of binder and surfactant material in PMC was reduced the critical surface tension results. The critical surface tensions for all samples are shown in Figure 9 and example critical surface tension of sample 1 in Figure 10. From the result obtained, it was concluded that, with lower surface tension value the surface stress or surface free energy was reduced. Meaning that, surface tension was contractive tendency of the liquid surface that allows to resist an external force in melt flow behavior.

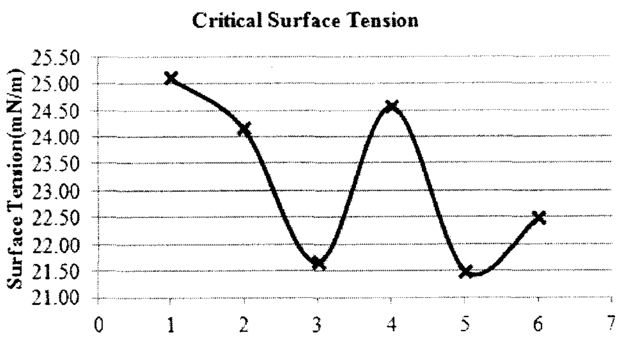

Fig 9. Critical Surface Tension

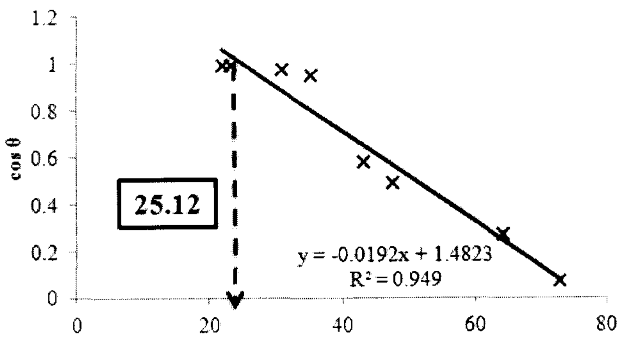

Fig 10. Surface Tension of Sample 1

Conclusions

A new PMC material with copper filled powder in ABS by the injection molding machine has been successfully produced and tested for contact angle and surface tension. An improvement of contact angle measurement and analysis was done in the experimental to determine critical surface tension based on Fox-Zisman's theory. Suitable compounding ratio of copper filled ABS, binder and surfactant will be used as a platform to fabricate the new PMC wire filament form for applying in layer by a layer deposition process.

References

[1] B. H. Lee, J. Abdullah, and Z. A. Khan, Optimization of Rapid Prototyping Parameters for Production of Flexible ABS Object, *J. of Materials Processing Technology, 169*, 2005, 54-61.

[2] M. Nidzad, S. H. Masood, I. Sbarski and A. Groth, A study of Melt Flow analysis of an ABS-Iron composite in Fused Deposition Modeling Process, *Tsinghua Science and Technology, 14(1),* 2009, 29-37.

[3] M. Nidzad, S. H. Masood, I. Sbarski, Thermo Mechanical Properties of a highly filled Polymeric Composites for Fused Deposition Modeling, *J.of Materials and Design, 32,* 2011, 3448-3456.

[4] J. Tyberg and J. H. Bohn, FDM Systems and local adaptive slicing, *J.of Materials and Design, 20,* 1999, 77-82.

[5] A. K. Sood, R. K. Ohdar and S. S. Mahapatra, Improving dimensional accuracy of Fused Deposition Modelling Processed part using grey Taguchi Method, *J.of Materials and Design, 30,* 2009, 4243–4252.

[6] S. H. Masood, Intelligent Rapid Prototyping with Fused Deposition Modelling, *Rapid Prototyping Journal, 2(1),* 1996, 24–33.

[7] A. Bellini and S. G. M. Bertoldi, Liquefier Dynamics in Fused Deposition, *J. of Manufacturing Science and Engineering, 126,* 2004, 237-246.

[8] C. Bellehum, L. Li, Q. Sun and P. Gu, Modeling of bond formation between Polymer Filaments in the Fused Deposition Modeling Process, *J. of Manufacturing Process, 6(2),* 2004, 170-178.

[9] S. H. Masood and W. Q. Song, Development of new metal/polymer materials for Rapid Tooling using Fused Deposition Modeling, *J.of Materials and Design, 25,* 2004, 587-594.

[10]S. H. Masood and W. Q. Song, Thermal Charecteristics of a new metal/polymer material for FDM Rapid Prototyping Process, Research articles: Assembly Automation 25/4, 2005, 309-315, Emerald Group Publishing Limited.

[11]C. Karatas, A. Kocer, H. I. Unal, S. Saritas, Rheological Properties of Feedstocks prepared with steatite powder and polyethylene based thermoplastic binders, J. of Materials Process. Technol.,152, pp. 77-83, (2004).

[12]N. Sa'ude, M. Ibrahim and M. H. I. Ibrahim, Mechanical Properties of Highly Filled Iron-ABS Composites in Injection Molding for FDM wire Filament, Materials Science Forum Vols. 773-774 (2014) pp 456-461.

[13]Sa'ude, N., Masood, S. H., Nikzad, M., Ibrahim, M., Ibrahim, M. H. I, Dynamic Mechanical Properties of Copper-ABS Composites for FDM Feedstock, International Journal of Engineering Research and Applications (IJERA), Vol. 3, Issue 3, (2013), pp.1257-1263.

[14]M. Zenkiewicz, Method for the calculation of surface free energy of solid, J.of Achievements in Materials and Manufacturing Engineering, 2007; 24(1), 137-145.

[15]C. F. Soon, W. I. W. Omar, N. Nayan, H. Basri, M. Narawi, K. S. Tee, A Bespoke Contact Angle Measurement Software and Experimental Setup for Determination of Surface Tension, Procedia Technology 8C (2013) 474-481.

[16]H. W. Fox and W. A. Zisman, J. Colloid. Science 1950; 5: 514.

[17]T. Thomson, Designed application of hydrophilic polyurethanes, United States: CRC Press; 2000.

[18]Jose Bico, Uwe Thiele, David Quere, Wetting of textured surfaces, J.of Colloids and Surfaces, vol. 206, 2002, pp41-46.