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Research Article

Flexural Properties of Copper-ABS in Metal Injection Molding Process For FDM Feedstock

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Abstract

This paper aims to investigate the flexural strength and hardness of acrylonitrile butadiene styrene (ABS) and five different samples of copper filled in ABS parts made by injection molding process for fused deposition modeling (FDM) feedstock wire. In this study, the effect of copper powder was investigated as a filler material in polymer matrix composite (PMC) and ABS was chosen as a matrix material. The detailed formulations of compounding ratio by weight percentage with various combinations of the new PMC are investigated experimentally. Based on the result obtained, it was found that, increment of 71% to 75% copper filler affected the flexural strength, and hardness values. The highly filled copper content in ABS composites increases the mechanical properties and density of PMC material through the injection molding process. The potential of development of a new composite material with metal loading in the PMC will be explored for the FDM rapid prototyping process.

Keywords: *Polymer Matrix Composites, Injection Moulding, Flexural Strength, Hardness.*

1. Introduction

Metal injection molding (MIM) technology is an alternative technique in the manufacturing process for making parts in polymer matrix composite (PMC) by the injection process. Normal application of injection molding process deals with plastic material for building plastic products for various industries such as automotive, aerospace, medical, electrical devices, consumer product, fitting and testing. Customer need and continued demand of end used product with the high mechanical properties and low cost has generated a renewed interest in MIM. A shift from prototyping to manufacturing of the final product will give an alternative selection with different material choice, low cost part fabrication and achieving the necessary mechanical properties. Various kinds of metal material used in injection molding process include nickel (Huang, B et al 2003), alloys (Hartwig, T et al 1998), copper (Moballegh, L et al 2005), iron (Gungor, A. 2007), (Huang, B et al 2003), (Sa'ude, N et al 2013), and stainless steel (Omar, M. A et al 2010), (Amin, S. Y. M et al 2009), (Ahn, S et al 2009), (Hartwig, T et al 1998). Fig. 1 shows the schematic diagram of the injection molding machine for PMC material. In the published work, the most common composites' material used in injection molding are basalt-LDPE (Akinci A. et al 2009), iron-HDPE (Gungor, A. 2007; Kumar S. et al,2010), iron-ABS(Sa'ude, N et al 2013), nickel-HDPE (Huang, B et al 2003), zirconia-PE (Merz, L et al 2002), copper-PE (Moballegh, L et al 2005), stainless steel-PE (Omar, M. A, 2010;Kumar S. et al, 2010), stainless steel-PEG, PMMA(Amin, S. Y. M et al,2009; Gungor, A. 2007), iron-PP, EVA (Kumar S et al 2010) and stainless steel-EVA (Li, Y et al 2007). Moballegh et al. (Moballegh, L et al 2005) concluded that the thermal degradation properties of copper feedstock with 95 wt%, degrading of paraffin wax occur from 170 °C to 350 °C and 350 °C – 500 °C for polyethylene. The binder degradation will start at 171 °C. The temperature on mixing and injection molding process must be lower than the binder degradation temperature. Gungor et al. (Gungor, A. 2007) studied the mechanical properties of Fe powder fillers in the HDPE polymer matrix based on vol. % (5,10,15 vol. %). They concluded that an additional 5 vol. % of Fe reduced the impact strength of HDPE 40% and reduced 90% of elongation respectively. When vol. % of Fe increase of 10 vol. % and 15 vol. %, the impact strength and % elongation values decrease proportionally. For additional 5 vol. % Fe composite in HDPE, the modulus of elasticity was 31% higher than unfilled HDPE.

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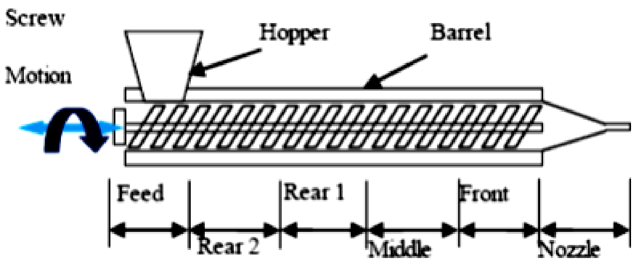


Fig.1 Schematic diagram of the injection molding machine for PMC material

The fabrication of ABS-Iron filament wire by extruder machine has been done by Masood et al. and Nikzad et al. with proper formulation and mixing processes. They mention that the critical properties' requirements for high-quality composite are depending on the desired viscosity, strength and modulus. High iron powder loading in the ABS and Nylon will lead to dispersion issues, and the viscosity will increase perpendicular with increment of metal powder in PMC material. Nowadays, application of MIM material requires enhanced and higher mechanical properties of the extrusion process. Pure metal is unsatisfied with deposit through the extrusion mould because of higher melting temperature and viscosity. Nevertheless, there are limited data/research available particularly dealing with the MIM of the PMC copper through the extrusion process. MIM with highly filled metal powder in the polymer matrix may offer the possibility of introducing new composite material in the extrusion process. Fig.1 shown the schematic diagram of the injection moulding machine for PMC material. The aim of this study is to investigate the characteristic of flexural properties of the copper-ABS composite parts produced by the injection molding process. The research focuses on developing a proper formulation and mixture procedure of constituent materials for obtaining the homogeneous condition. The optimum composition of mixing ratio of constituent material was made by an injection molding process for flexural and hardness tests.

In this study, two main types of constituent materials were used to develop the new composite material. The first material, used as the matrix, is the ABS thermoplastic powder with lower melting temperature approximately 270°C, flexible and suitable material for extrusion process. Results will be presented for mechanical properties, including, flexural strength and hardness test. The copper particle was mixed with the ABS material as binder content to form the composite in Brabender mixer machine. An important issue is a viscosity of the composite material through the extrusion process. Due to the high powder loading of copper in the ABS matrix, the viscosity of the composite increases perpendicular with an increment of iron powder. Table I show the characteristic of copper, ABS, surfactant materials and five(5) sample PMC compounding with the different density value. Therefore, additive's material is needed in order to control the melts flow behavior during an extrusion process.

Fig.2 ABS Material

Fig.3 Copper powder

(a) (b)

Fig. 4 (a) Brabender Mixer (b) Compounding process of Copper, ABS and surfactant Material

2. Experimental

The ABS material is 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 environmental friendly material because they are completely recyclable. Fig. 2 shows the ABS material used in the injection process. The copper powder is supplied by Saintifik Bersatu Sdn Bhd (Johor, Malaysia). The chemical composition is 99.9 % copper powder, and the particles size distribution is 17μm ~ 130 μm respectively with melting temperature 1080 °C and specific gravity 9.84 g/cm^3. Fig. 3 shows the copper material used in compounding process and the SEM images of pure copper powder (300x) with different grain size distribution in millimeter are shown in Fig. 6. The distributions of the copper powder, ABS and surfactant composition are 18% to 24% ABS, 71% to 75 % copper powder and 5 % to 7% surfactant by weight percentage (wt.%). A binder material based ABS plastic and surfactant (S) powder was added as the surfactant agent for smooth flow of mixture of materials. Firstly, ABS material was cut into the smallest size with approximately 2 mm - 5 mm in length. After that the ABS materials were then loaded in Brabender Plastograph mixer, type W50 at 180 ^{o}C for compounding process in constant speed. In order to achieve a homogeneous mixture, the compounding procedure will be followed. The maximum volume of the mixer is 55 cm^3 per mix approximately with one to three hour mixing time. Fig. 4 shows the (a) Brabender mixer, (b) Compounding process of ABS and copper materials. The PMC compounding were analyzed by scanning electron microscope(SEM) images to ensure a homogeneous compounding is achieved for feedstock preparation. At the end, the surfactant was added into compounding to reduce the inter particle forces and to lubricate the powder. The compounding was crushed by machine to form the pallet with 2 mm – 6 mm in size approximately. Fig. 5 shows the (a) PMC material after the Bra bender mixer and (b) PMC material after crushing process. The feedstock pellet was injection moulded on a horizontal NP7-1F molding machine to make flexural strength and hardness test specimens. Table II and Fig. 8 shows the weight percentage ratio of copper, ABS and surfactant material.

(a) (b)

Fig. 5 (a)PMC material after the brabender mixer (b) The PMC material after crushing process.

Table I. Characteristic of copper, abs and surfactant material

Components	Melt Temperature (°C)	Density (g/cm^3)
Copper	1080	8.94
ABS	270	1.03
Surfactant	100	0.891
Sample 1	-	2.229
Sample 2	-	2.34
Sample 3	-	2.395
Sample 4	-	2.429
Sample 5	-	2.515

2.1 Injection Molding

The injection machine specification with the screw diameter 19 mm, injection capacity 14 cm^3, injection rate 50 cm^3/second and injection pressure 161 MPa. Standard test specimens were prepared based on ISO 178 for flexural strength and hardness test. The specific dimension of the specimen is 80 mm(L) x 10 mm(W) x 4 mm(H). Zone temperatures consist of five areas, where the nozzle temperature was 185 ^{o}C, front and middle were set to 185 ^{o}C and 180 ^{o}C, while for rear 2 and rear 1 was 135 ^{o}C and 145 ^{o}C. The feeding temperatures were set to 70 ^{o}C with the cooling time is 8 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 started from low to high temperature. Fig. 7 shows, the injection molding machine used for MIM process.

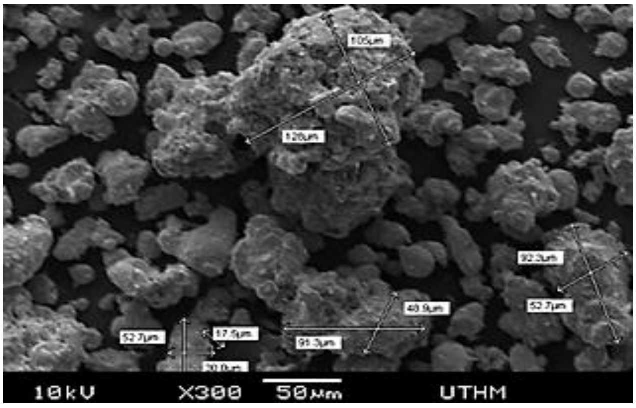


Fig. 6 SEM Image of pure copper powder (300x)

Fig. 7 Injection molding machine

Table II. Weight Percentage of PMC compounding

Sample	copper, ABS and surfactant (wt. %)		
	copper	ABS	surfactant
1	71	24	5
2	72	22.5	5.5
3	73	21	6
4	74	19.5	6.5
5	75	18	7

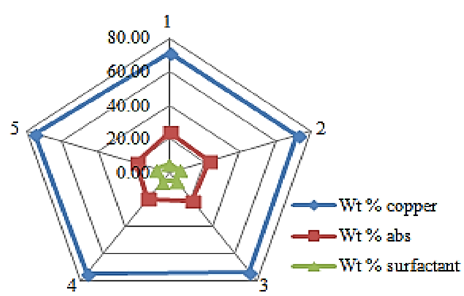


Fig. 8 Distribution of weight percentage of copper, ABS and surfactant materials.

3. Results and Discussion

3.1 Flexural Strength

Flexural testing machine used in this study was Shimadzu AG-I. The maximum load capacity is 10 KN (Refer to Fig.9). There was five types of compositions used with ABS, copper and surfactant material for the flexural strength specimens made by in the injection moulding machine. Fig. 10 shows the flexural strength specimen (a) ABS from injection molding, (b) Copper filled in ABS by injection moulding. From the results obtained, it was found that the highest flexural strength of original ABS is 57 MPa. The mixing of 71% copper filled in ABS reduced the flexural strength to 29 MPa. It was concluded that, an increment of copper filled in ABS reduced the flexural strength value. The flexural strength result is shown in Fig. 11. Furthermore, the maximum displacement of ABS is 7.19 mm and the maximum displacement of copper filled in ABS is from 1.78 mm to 2.56 mm approximately. An increment of copper filled in ABS was not much different in maximum displacement(refer to Fig. 12). However, increment of 71 % - 73% copper filled in ABS increased the break stress value up to 14 MPa – 22 MPa. Furthermore, the maximum strain (%) of ABS material is 4.2% and the maximum strain (%) of copper filled ABS is in range 1.0% to 1.7%. Fig. 13 shown the flexural strength result on maximum strain (%). The detail flexural strength results are shown in Table III with different compounding ratio by weight percentage of ABS, copper and surfactant material.

Table III Flexural strength results on maximum stress, strain, break stress and maximum displacement.

Sample	Max Stress (MPa)	Max Strain (%)	Break Stress (MPa)	Max Disp (mm)
ABS	57.08	4.21	6.98	7.19
Co71%, Abs 29%	27.67	1.5	21.53	2.56
Co72%, Abs 28%	25.46	1.72	19.89	2.94
Co73%, Abs27%	21.58	1.35	13.51	2.3
Co74%, Abs26%	14.16	1.35	6.02	2.31
Co75%, Abs25%	14.13	1.04	6.37	1.78

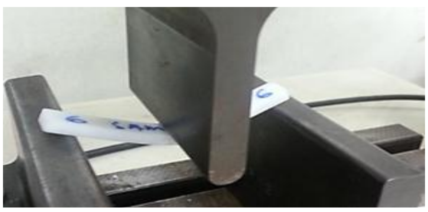
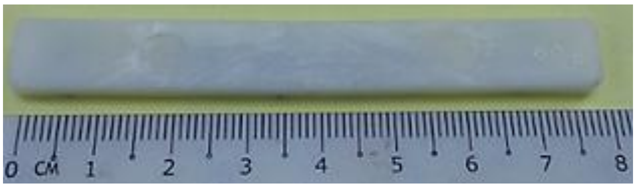


Fig. 9 The Flexural strength test by universal testing machine



(a)

(b)

Fig. 10 The Flexural strength specimen (a) ABS from injection molding, (b) Copper filled in ABS by injection molding

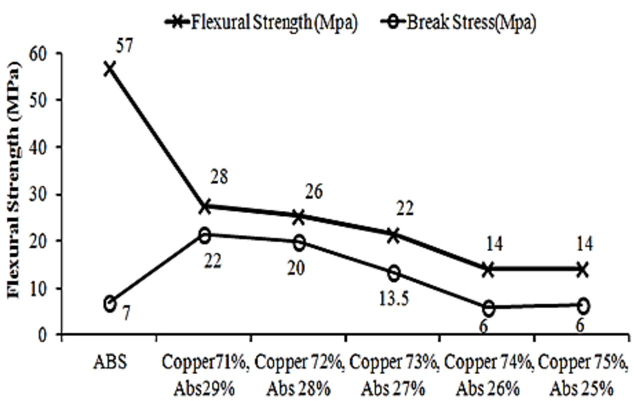


Fig. 11 Flexural strength and break stress result

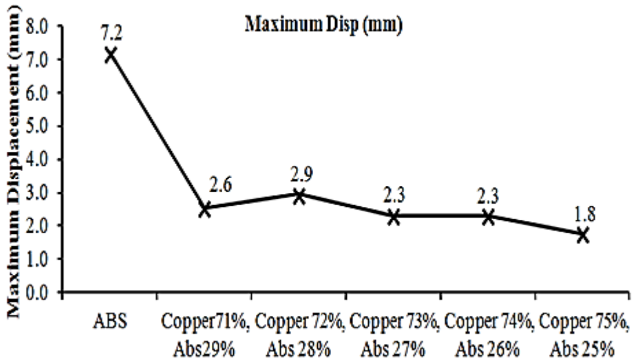


Fig. 12 Flexural strength result on maximum displacement

3.2 Hardness Test Result

Hardness equipment used in this study was Durometer Type D (ASTM D2240) from Shore Instrument and Manufacturing, New York USA. There were five compositions of mixed ABS, copper and surfactant material for the hardness specimens made by the injection

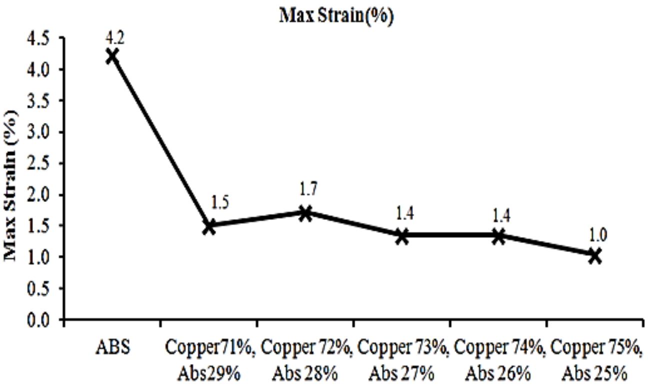


Fig. 13 Flexural strength result on maximum strain (%)

molding machine. From the results obtained, it was found that the max hardness value of pure ABS was 73 Duro. However, an addition of 72% copper filled in ABS, will give the maximum hardness value of composite material of 70 Duro. It was concluded that the hardness value decreased almost proportionally with increment of copper filled in ABS material. Fig. 14 shows the hardness results of various constituents of different weight percentage of ABS, copper and surfactant material.

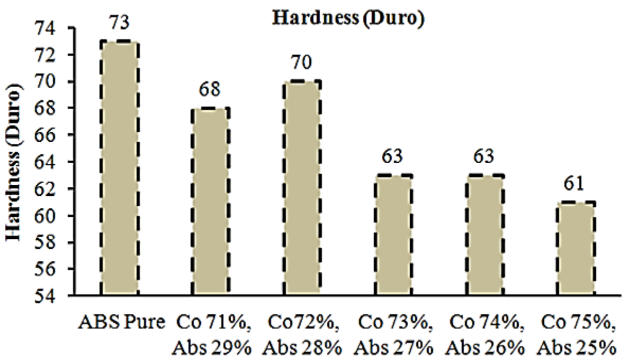


Fig. 14 Hardness result of various constituents of different

Conclusions

A new PMC material has been successfully produced by injection moulding process and tested for the flexural strength and hardness. From the different compounding of the parts made by the injection moulding process, it can be concluded that flexural properties of injected parts are greatly influenced by copper filled in ABS material. With 71% to 73% copper filled in ABS increase the break stress up to 22 MPa compared with pure ABS 7 MPa approximately. Moreover, it was observed that, 71% to 75% copper filled in ABS give 61 Duros to 70 Duros in hardness value. From the result obtained, it has shown that the mechanical properties of PMC material is affected with adding more copper filled in ABS material. The suitable material and binder selection, mixing method, parameter setting on melting temperature, pressure and cooling time may offer a great potential area for metal injection molding and the extrusion of wire filament through extruder.

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