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Mechanical Properties of Highly Filled Iron-ABS Composites in Injection Molding for FDM wire Filament

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Abstract. This paper presents the development of a new polymer matrix composite (PMC) material for use in injection molding machine. The material consists of iron powder filled in an acrylonitrile butadiene styrene (ABS) and surfactant powder material. In this study, the effect of iron powder was investigated as a filler material in polymer matrix composite and ABS was chosen as a matrix material. The detailed formulations of compounding ratio by volume percentage (vol. %) with various combinations of the new PMC are investigated experimentally. Based on the result obtained, it was found that, vol. % increment of iron filler effected on the hardness, tensile and flexural strength. With highly filled iron content in ABS composites increase the hardness and tensile strength of PMC material through an injection molding process.

Introduction

Layer Manufacturing Technology (LMT), is based on the principle of adding material in two dimensional (2D) layers to build a complete 3D-model. There are several names of layer manufacturing such as Rapid prototyping (RP), 3D-printing, solid freeform fabrication (SFF), freeform fabrication (FF) and additive manufacturing. Traditionally, the LM systems have been able to fabricate parts either from the solid, liquids or powder material. Currently, Each LM process involved with either plastic, wax, metal, metal matrix composite(MMC), polymer matrix composite(PMC) and ceramic matrix composite (CMC) material. Material plays an important factor to produce an economic part or component by LM processes. Among the LM, process is the fused deposition modeling (FDM) process, which is involved with plastic filament wire or feedstock wire form, and the fabrication wire is from the extrusion machine. The process involves a layer-by layer deposition of extruded material through a liquefied nozzle using feedstock filaments from a spool. In the present work, the most common composites' material used in injection moulding are basalt-LDPE[1], iron-HDPE[2,19], iron, nickel-HDPE[4], zirconia-PE[10], copper-PE[11], stainless steel-PE[12,19], stainless steel-PEG, PMMA[13,16], EVA[19] and stainless steel-EVA[26]. However, there are limited data/research available particularly dealing with the deposition of PMC through the heated liquefied nozzle. Currently, the most common composites' material used in layer by layer deposition are HDPE-steatite ceramic[6], wax-alloys[3], ABS-Iron[14,15,22,23], fibre glass[17] and stainless steel-ECG2[34]. Pure metal is unsatisfied with deposit by FDM machine because of higher melting temperature and viscosity. Existing FDM systems have been able to deposit(layer by layer) only in thermoplastic's filament with limited mechanical properties through the heated liquefied nozzle.

Currently, application of FDM required an enhanced and higher mechanical properties toward rapid manufacturing. Nevertheless, there are limited data/research available particularly dealing with the deposition of PMC through the heated liquefied nozzle. Layered of rapid deposition polymer composites (RPDC) with highly filled metal powder in the polymer matrix may offer the possibility of introducing new composite material in FDM. The intention of this study is to develop composite filament wire with ABS and Iron powder for FDM process at Universiti Tun Hussein Onn Malaysia (UTHM). The research focuses on developing a proper formulation and mixture procedure of constituent materials for obtaining the homogeneous condition to produce the filament wire form for use in the FDM machine. The main outcome of this study is to produce a strong, flexible, smooth and conductive feed stock produce by extrusion machine. At the early stage, the optimum composition of mixing ratio of constituent material was made by an injection molding process for tensile, flexural and hardness tests. The influence of the process parameters in injection molding and extrusion wire filament for FDM process will contribute a new knowledge on mechanical properties and material performance of PMC material. 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 stiffness and suitable material for extrusion process. **Figure 1** shows the ABS pallet material for injection process. The other constituent material is an iron with particle size approximately 30μm ~ 40μm. Table I show the characteristic of compounding iron, ABS and surfactant materials. Results will be presented for mechanical properties, including, tensile and flexural strength, hardness. The iron particle was mixed with the ABS material as binder content to form the composite in mixer machine. An important issue is a viscosity of the composite material through the extrusion process. Due to the high powder loading of iron in the ABS matrix, the viscosity of the composite increases perpendicular with an increment of iron powder. Therefore, additive's material is needed in order to control the melts flow behavior during an extrusion process.

Experimental

Material Preparation

The ABS material, which is supplied by Dutatek Sdn Bhd (Selangor, Malaysia). The density of ABS was 1.1 g/cm^3 and melting temperature 266 °C. ABS materials are an environmental friendly material because they are completely recyclable. Fig. 1 show the ABS material for injection process. The iron powder, which is supplied by Saintifik Bersatu Sdn Bhd (Johor, Malaysia). The chemical composition is 99.9 % iron powder, and the particles size distribution is 30 μm ~ 40μm respectively with melting temperature 1539 °C, boiling point 2745 °C and specific gravity 7.86 g/cm^3. **Figure 2** shows the iron material for injection process. The distributions of the iron powder and binder composition are 19% to 20% ABS, 70% to 75 % iron powder and 7 % to 9% surfactant by weight percentage (wt%). A binder material based on ABS plastic, the palm stearin (PS) and paraffin wax (PW) powder was added as the surfactant agent for smoothest flow of mixture of materials. Firstly, ABS material was crushed and sieved in approximately 1 mm - 5 mm particles size to eliminate the impurities' content. In order to achieve a homogeneous, the mixing of the powder and binder was carried out by Brabender Plastograph mixer, type W50 at 185 °C to get the feedstock. The maximum volume of the mixer is 55 cm^3 per mix approximately and one hour mixing time. **Figure 3** shows (a) the Brabender mixer, (b) compounding of ABS and iron materials. Secondly, the feedstock was crushed by machine to form the pallet with similar size approximately. The feedstock pallet was injection molded on a horizontal NP7-1F molding machine for tensile strength and hardness test specimens. Table II shows the weight percentage ratio of ABS, iron and surfactant material.

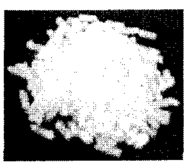

Fig. 1 ABS Pallet

Fig. 2 Iron Powder

Results and Discussion

Tensile Strength Test Result

There were five specimens of each mixing material done in the tensile strength tests, where each specimen covered for three readings per sample. The tensile strength specimen of original and mix ABS-Iron are shown in **Figure 6**. The result shows that, the higher value for max stress and break stress of ABS-palm stearin are 9.22 MPa and 8.72 MPa with percentage volume of ABS 46%, Iron 29%, 25% surfactant(sample 3). The higher value for max stress and break stress of ABS-paraffin wax are 12.80 MPa and 12.62 MPa with percentage volume of ABS 50%, Iron 24%, 26% surfactant (sample 1). Therefore, an increasing of ABS-iron and palm stearin binder increase the max and break stress of PMC material. The overall tensile strength test results are shown in Table III and **Figure 7** to **Figure 10**.

(a) (b)

Fig. 3(a) Brabender Mixer (b) Compounding of Iron-ABS Material

Table I. Characteristic of compounding ABS, iron and surfactant material

Components	Melt Temperature (°C)	Density (g/cm^3)
Iron	1539	7.86
ABS	266	1.1
Surfactant	100	0.891

Fig. 4 Injection molding machine

Table II. Volume Percentage of ABS, Iron and surfactant materials

Sample	ABS, Iron and Surfactant (vol. %)		
	Wiron (gm)	Wabs (gm)	Ws (gm)
1	24.056	49.666	26.278
2	25.915	48.450	25.635
3	28.725	46.613	24.663

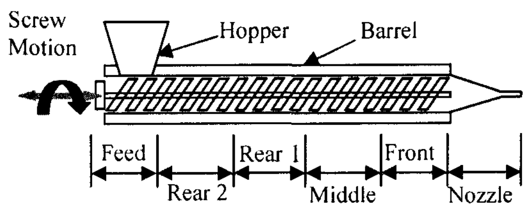

Fig. 5 Zone temperature

Hardness Test Result

There were three mixed ABS, iron and surfactant material for the flexural and hardness specimens done in an injection molding machine. The percentage weight of mixing ratio between the ABS, iron and surfactant are (ABS 50%, Iron 24%, 26% surfactant), (ABS 48%, Iron 26%, 26% surfactant) and (ABS 46%, Iron 29%, 25% surfactant). From the results obtained, it found that the hardness value is not much different between an original ABS and mix ABS-Iron material. However, higher flexural force was reduced perpendicularly with increment of iron content in ABS material. **Figure 11** shows the flexural strength and hardness results of various constituents for different volume percentage of ABS, iron and surfactant material.

Table III. Tensile Strength for Iron-ABS-Binder

Sample	ABS-Palm stearin		ABS-Paraffin wax	
	Max Stress (MPa)	Break Stress (MPa)	Max Stress (MPa)	Break Stress (MPa)
1	5.26	4.70	12.80	12.62
2	7.50	7.36	12.64	12.22
3	9.22	8.72	11.00	11.00

(a) (b)

Fig. 6 Tensile strength sample from injection molding (a) Original ABS material (b) ABS-Iron material

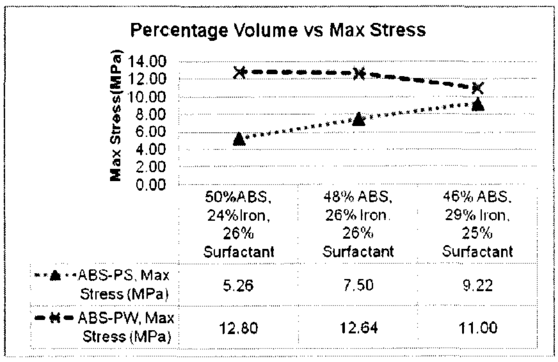

Fig. 7 Percentage volume versus maximum stress

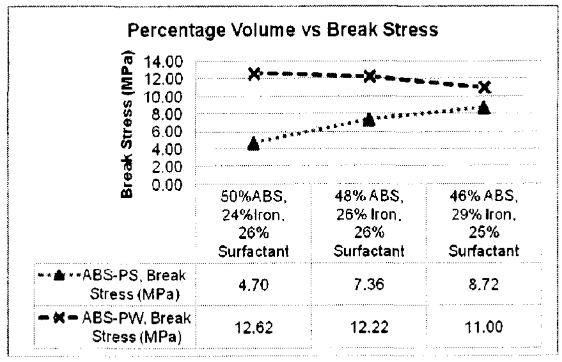

Fig. 8 Percentage volume versus break stress

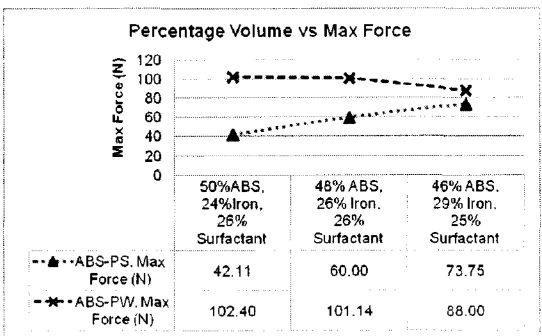

Fig. 9 Percentage volume versus maximum force

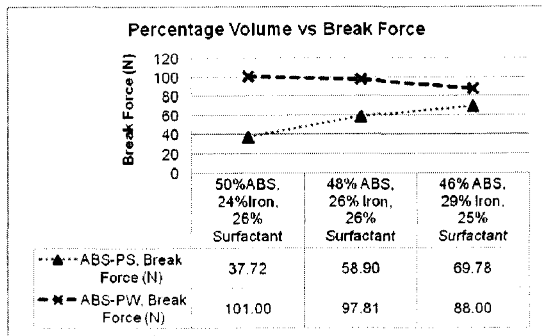

Fig. 10 Percentage volume versus break force

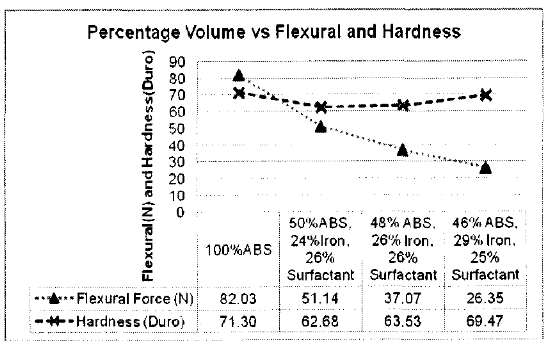

Fig. 11 Percentage volume versus break force

Conclusion

A new PMC material has been successfully produced and tested for the hardness, tensile and flexural strength by the injection molding machine. From the result obtained, it has shown that the mechanical properties of PMC material was increased with add more iron filled content 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. Metal deposition of a layer by a layer process will reduce the product development times, reduce a cost of the tool and die fabrication and reduced waste material by the rapid deposition polymer composite (RDPC) process.

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