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Melt Flow Behavior of Metal Filled in Polymer Matrix for Fused Deposition Modeling (FDM) Filament

N.Sa'ude[1,b], M.Ibrahim[2,a], M. H. I. Ibrahim[3,c]

[1] Department of Manufacturing and Industrial Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.

[2] Department of Manufacturing and Industrial Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.

[3] Department of Engineering Mechanics, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.

[a]nasuha@uthm.edu.my, [b]mustaffa@uthm.edu.my, [c]mdhalim@uthm.edu.my

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Abstract. This paper presents the melt flow behavior (MFB) of an acrylonitrile butadiene styrene (ABS), Polyproplene (PP), Polylactic Acid (PLA), ABS mix 10% Copper and ABS mix 10% Iron in the simulation. In this study, the effect MFB of ABS mix with 10% Iron and 10% Copper material was investigated based on the viscosity, density, thermal conductivity, melting temperature and specific heat of material properties. The MFB of metal filled in polymer matrix composite(PMC) through the FDM nozzle was investigated using Finite-Element Analysis (ANSYS CFX 12). Based on the result obtained, pressure outlet of mix ABS copper and ABS iron in extruder nozzle was higher value compared with others plastic material. The velocity was increased since the nozzle diameter is smaller than the entrance diameter. It can be observed that, the melt flow behavior of metal filled in PMC are affected on pressure drop, velocity and the nozzle size at the exit nozzle.

INTRODUCTION

Nowadays, customer needs and demand on the product customization for low cost product and time savings have generated a renewed interest in rapid manufacturing (RM) and rapid prototyping (RP) technologies. Among various RP technologies available today, Fused Deposition Modelling (FDM) is one of the technology uses a filament plastic based material. The filament plastic was heated into semi molten state and deposited on the machine platform for the part fabrication in layer by layer process. Normally, the FDM machine involved with either acrylonitrile butadiene styrene (ABS) plastic material [1,2,3,4,5,6,7] material. Currently, the most common polymer matrix composites(PMC) material used in FDM are ABS-Iron[1,7,8,9]. In various research work, some researcher focuses on the optimal process parameters by taguchi method[10,11,12]. In order to predict the behavior of new ABS based composite materials during FDM process, it is necessary to investigate the flow of the composite material in the liquefier head [1]. M. Nikzad et al has mentioned that, the flow behavior of the melts flow channel is affected by the pressure drop, velocity, and the geometrical dimension at the exit. H.S. Ramanath, et al (2007) was investigate the melt flow behavior (MFB) physical properties of poly caprolactone (PCL) such as the melting temperature, thermal conductivity, rheology and specific heat. The contribution of the process parameters and material properties data of conductive PMC by ANSYS CFX simulation will give a good information and less error to produce a wire filament by extruder machine. The rapid deposition of polymer composite (RDPC) with conductive wire filament through the heated liquefied head in layer by a layer process may offer a great potential in rapid manufacturing and rapid prototyping. The intension of this study is to find out a proper material that will use in

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makerbot replicator machine. This study is focused on the parameter that involved along the melt flow behaviour of plastics filament and combination ABS-10%Iron and ABS-10% copper in the melt flow nozzle of the makerbot replicator machine by Finite Element Analysis using ANSYS 12 software. The parameters that have been investigated are thermal behaviour, pressure drops and the velocity gradient along melt flow channel. The flow considered as a steady state and there is no change in flow profile at the time implying a laminar flow. Temperature in the extruder nozzle stays constant as the working chamber is isolated. Velocity components at the wall of the channel are zero as the melt is assumed to be adhering to it. Two modes were employ to study the flow behaviour, which is by theoretical modelling and Finite element analysis (FEA). The result of FEA will be analyze from the melt flow behavior of polymer composites in the FDM simulation to obtain the best condition to produce a wire filement by the extruder machine.

EXPERIMENTAL

This study conduct remodel the heated melt flow extruder for fused deposition modeling feedstocks by the simulation ANSYS software. Five types of materials were used in these studies which are ABS, PP, PLA, combination of 10% Iron-ABS and 10%Copper-ABS material. Two dimension(2D) finite-element analysis of the melts flow behavior will be conducted in Computational Fluid Dynamic (CFD), which are embedded module in the latest release of the ANSYS Workbench. Material data was selected from the previous research such as HDPE and PP[14], ABS-10%Iron[2]. There are five main properties for each materials should used in the simulation. The properties are a density, thermal conductivity, specific heat, viscosity and melting temperature. There are five steps has been done in simulation to complete the ANSYS CFX analyses which are geometry modeling, meshing, setup, solution and results. The internal geometry modeling of extruder nozzle shows in Figure I and the CAD data file was import from the solidwork software.

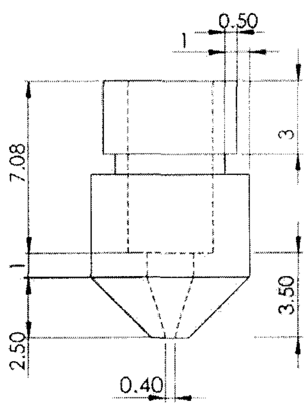

Fig. I Extruder nozzle for the FDM head

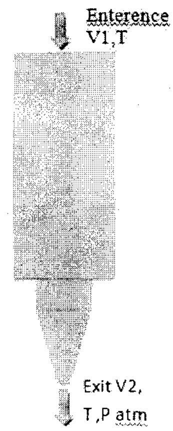

Fig. II Boundary condition

Table I Properties of ABS

ITEMS	ABS
Specific heat (J/kgK)	2080
Thermal conductivity (W/mK)	0.177
Mass density (kg/m³)	1050
Initial temperature of melt (℃)	266
Viscosity (Pa s)	1E4

Table II Properties of PP

ITEMS	PP
Specific heat (J/kgK)	1900
Thermal conductivity (W/mK)	0.16
Mass density (kg/m³)	904
Initial temperature of melt (℃)	165
Viscosity (Pa s)	1E7

From simulation, the distribution of velocity, pressure and temperature along the melt flow channel will be analysed for a new wire FDM feedstocks. In the simulation setup, correct inserted data is needed to avoid error during the simulation and the input data was the material properties and boundary condition setting (refer Figure II). In order to achieve the optimum results, a combination of tetrahedral, pyramid and prism shaped element is applied in CFX meshing. An assumptions was made in the simulation, where the temperature distribution is similar along the nozzle channel in entrance and exit flow. Table I until Table V shows the different properties of polymer materials.

Table III Properties of PLA

ITEMS	PLA
Specific heat (J/kgK)	2114
Thermal conductivity (W/mK)	0.195
Mass density (kg/m³)	950
Initial temperature of melt (℃)	230
Viscosity (Pa s)	20.8E6

Table IV Properties of ABS-Iron

ITEMS	ABS-Iron
Specific heat (J/kgK)	1040
Thermal conductivity (W/mK)	0.258
Mass density (kg/m³)	1776
Initial temperature of melt (℃)	270
Viscosity (Pa s)	2600

Table V Properties of ABS-Copper

ITEMS	ABS-Copper
Specific heat (J/kgK)	1010
Thermal conductivity (W/mK)	0.235
Mass density (kg/m³)	1660
Initial temperature of melt (℃)	260
Viscosity (Pa s)	2700

EXPERIMENTAL RESULT

Experimental results was coved the pressure drop, velocity and temperature along the melt flow channel in the heated nozzle. Five different materials was studied the melt flow behavior in the simulation such as ABS, PP, PLA, ABS-10% Iron and ABS-10% copper.

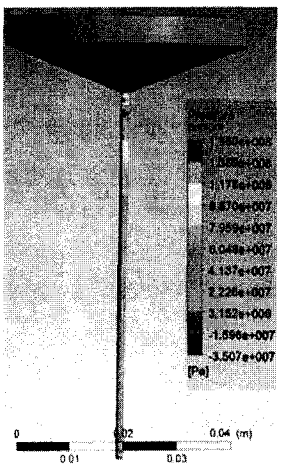

Fig. III Pressure drop for ABS

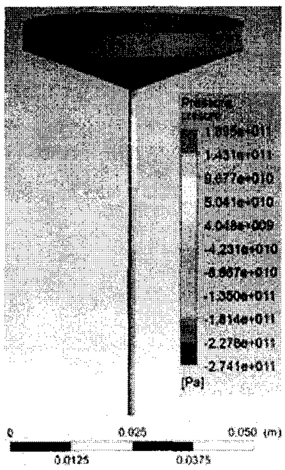

Fig. IV Pressure drop for PP

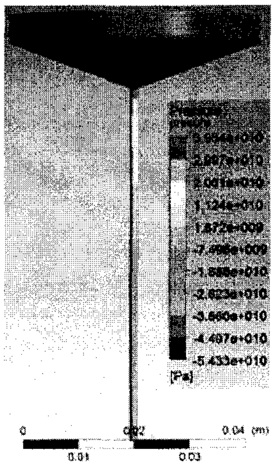

Fig. V Pressure drop for PLA

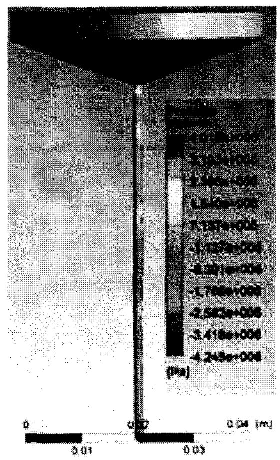

Fig. VI Pressure drop for ABS-Iron

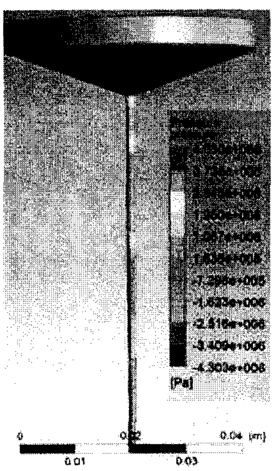

Fig. VII Pressure drop for ABS-Copper

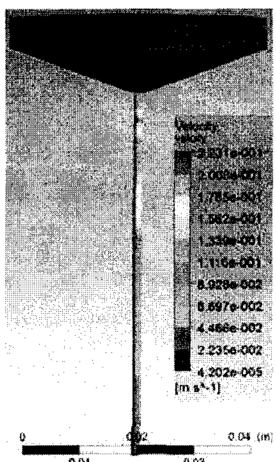

Fig. IX Velocity for ABS

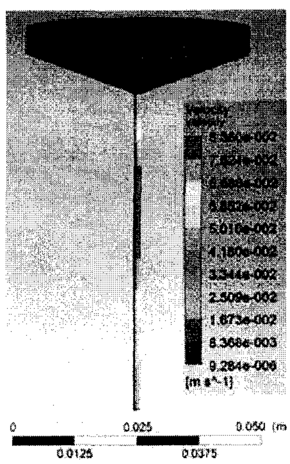

Fig. X Velocity PP

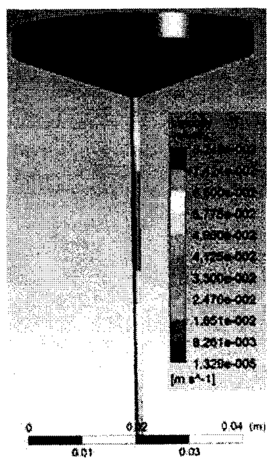

Fig. XI Velocity PLA

Pressure Drop along the Melt Flow Channel

In the simulation, there are three parameters obtained, which are velocity distribution, temperature distribution and pressure along the extruder nozzle. Five different materials was used in the simulation such as ABS, PP, PLA, ABS-10% Iron and ABS-10% copper. The result of pressure drop along the melt flow channel are shown in Figure III until Figure VI with different polymer plastic material. From the results obtained, it was found that the properties of mix materials has better than original materials. It was conclude that, the pressure outlet of mix ABS copper and ABS iron in extruder nozzle was higher value compared with others plastic material. The pressure ABS-10% iron was -1.127E+05 Pa and ABS-10% copper was -1.62E+06 Pa. The detail results of pressure drop are shown in Figure VIII.

Velocity along the Melt Flow Channel

The velocity results obtained in 3D was shows in Figure IX until Figure XIII by CFX. It was observed that an entrance velocity of wire filament is maintained along the flow channel. When melt material flow into the nozzle head, the velocity was increased since the nozzle diameter is smaller than the entrance diameter. The velocity of the melts flow was higher value at the channel centre than the walls nozzle. Table VI shows the minimum and maximum velocity of different materials in the CFX simulation. A minimum velocity value was 0.0161m/s for ABS-10% Iron and the maximum velocity was 0.2231m/s for ABS pure compared with others polymer plastic materials. The velocity of non-virgin material ABS iron and ABS copper has less velocity compared to others.

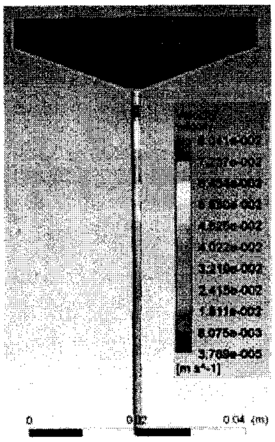

Fig.XII Velocity ABS-Iron

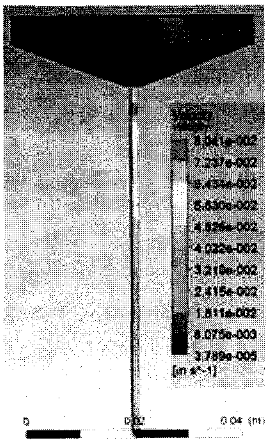

Fig. XIII Velocity ABS-Copper

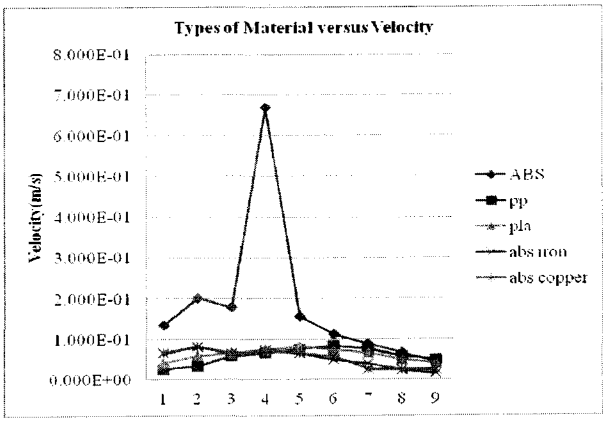

Fig. XIV Types of Materials versus Velocity

Temperature along the Melt Flow Channel

The temperature distribution from inlet to outlet along the melts flow channel was assume as similar value. From the temperature data, it was observed that the ABS-Iron had the higher temperature, which is 270 ℃ compared with original ABS approximately. The smaller temperature was PP, which is 165 ℃. The melt material temperature was shows in Table VII.

Table VI Velocity of different materials

Material	Velocity (ms^{-1})	
	Minimum	Maximum
ABS	0.0446	0.2231
PP	0.0167	0.0836
PLA	0.0165	0.0825
ABS-Iron	0.0161	0.0804
ABS-Copper	0.0611	0.0804

Fig. XIV Types of Materials versus Velocity

Material	Temperature(K)	Temperature(℃)
ABS	5.392E+002	266
PP	4.381E+002	165
PLA	5.031E+002	230
ABS-Iron	5.432E+002	270
ABS-Copper	5.332E+002	260

CONCLUSIONS

A combination of ABS mix with iron and copper material has been successfully simulate by ANSYS CFX simulation software. From the results obtained in simulation shown that, the maximum pressure of melt flow channel was at the entrance and the velocity profiles showed a smooth flow along the channel and the filaments fully melt at the higher temperatures. In the simulation, it was reduced the number of experiment trial and to optimize the varieties compounding material during the PMC wire filament fabrication by extruder machine. Suitable mixing and compounding in the simulation was used as a guidance to fabricate a new filament with metal filled in polymer matrix. This filament was used in FDM machine to fabricate a conductive part in a layer by a layer process.

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