Additive Manufacturing of Copper-ABS Filament by Fused Deposition Modeling (FDM)

N Sa'ude, M Ibrahim, MHI Ibrahim, MS Wahab, R Haq, OMF Marwah, RK Khirotdin*
Advanced Manufacturing and Material Centre (AMMC),
Additive Manufacturing Research Group (ADDMAN),
Universiti Tun Hussein Onn Malaysia,
Faculty of Mechanical and Manufacturing Engineering,
86400 Parit Raja, Batu Pahat, Johor, Malaysia.

**nasuha@uthm.edu.my*

ABSTRACT

Highly copper filled in an acrylonitrile butadiene styrene (ABS) matrix will provide a brittles filament in the layered manufacturing process. This paper aims to investigate the optimum composition of metal filler, binder and surfactant material of copper-ABS filament on the melt temperature and federate in layered manufacturing (LM) process. The compounding of copper-ABS feedstock was accomplish by the Brabender Plastograph Mixer in weight percentage (wt.%). The copper-ABS filament was fabricated by single screw extruder machine with different material composition, melting temperature and deposited material on the FDM Machine(Model: Prusa I3) in a layer by a layer processes with appropriate setting on melt temperature and the feed rate. Based on the result obtained, it was found that, increment of 75% copper filled in ABS matrix in weight percentage (wt. %) increase the Melt Flow Rate (MFR) filament in layered manufacturing process. It can be observed that, highest temperature and federate is needed to extrude polymer matrix composite (PMC) wire filament compare to ABS polymer filament material in FDM machine. The deposition of copper-ABS filament on the FDM platform will create a new paradigm on polymer matrix composites material in the Rapid Manufacturing (RM) process

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-01-12
Accepted for publication: 2017-09-26
Published: 2018-03-15

Keywords: *Additive Manufacturing (AM), Rapid Prototyping (RP), Layered Manufacturing (LM), Fused Deposition Modeling (FDM), PMC Filament,*

Introduction

Layered manufacturing (LM) or additive manufacturing (AM) technologies is an evolution of rapid prototyping (RP) techniques, where a part is built in a layered process on the heated platform. AM is defined by the American Society for Testing and Material (ASTM) as the process of joining materials to make object from 3D model data in a layer by a layer process [9]. There are several names used for LM such as solid freeform fabrication (SFF), additive fabrication (AF), rapid prototyping (RP), rapid manufacturing, 3D-printing (3DP) and freeform fabrication (FF) [10]. Currently, others available technologies in part fabrication or manufacturing process involving with high cost of tooling, mold making some of those technology is required the secondary process in finished part such as machining, injection molding, casting, forming and extrusion processes. All those technologies are "subtractive" techniques and each process involving with removing material and waste material was occur during fabrication process [2].

Among of AM technologies is the fused deposition modeling (FDM) have been able to deposit only thermoplastic filament in a layer by a layer process as long as the material can be made in filament wire. The filaments or wire from spool will flow through the heated liquefied head and nozzle and the melt material will deposited on the FDM heated platform or bed. These technology was developed by S. Scott Crump since 1980s and it was commercialized in early 1990 [9]. FDM and others related printing technology in layered manufacturing could be used in direct PMC part fabrication and rapid manufacturing process. These technologies will offer a possibility combination of varieties material from ceramic and metallic material for continues improvement on internal structure, mechanical and thermal properties, as long as the material in a filament wire. Continued growth on a new PMC filament will enhance the mechanical properties, smoothest material flow on conductive and functional graded material deposition on the printed platform through the heated liquefied head and nozzle tips in layered manufacturing processes. Noort, (2012), was mentioned that, the available material and the transition from prototypes to functional devices will begin to play a much bigger role. A similarly statement was mentioned by Diegel, et al., a new possibility to print directly the complex parts with conductive electronic track by layered deposition process. Furthermore, the limitation of open source metal 3D printer development in layered manufacturing because of high capital investment [1].

The basic principle of FDM process offers a great potential for a range of other materials, including metals and composites to be developed.

New material can be produced in feed stock filament form of required size, strength and properties. Zhong et al., (2001) was mentioned that, the key mechanical properties of the filament material must have a good strength, stiffness, ductility and flexible. In order to achieve a good flexibility of the filament wire in the matrix material, the composition mush have a binder or surfactant material for better flowability. The function of flexible filament is an easier to flow from the spool through the heated liquified head during deposition process on the machine platform [6 – 8]. The polymeric binder systems have several advantages over wax/polymer binders, including improved flow properties, mechanical properties and better shape retention after debinding process. The binder acts as a temporary vehicle for homogeneously packing a powder into desired shape and holding the particles in that shape until the beginning of debinding and sintering method [10].

There are three (3) major issues in these research which are (1) The mixing or compounding (2) The fabrication filament via extruder machine (3) Layered Manufacturing of Polymer Matrix Composite (PMC) via FDM machine. Firstly, the major issues in mixing material are the homogeneous compounding material and bonding. The degradation on the material will occur when the temperature selection over the melting temperature and some of the material weight will be reduced and vaporize. Moballegh et al., (2005), conclude that the thermal degradation properties of copper feedstock with 95 wt%, degrading of paraffin wax occur from 170 to 350 °C and 350 – 500 °C for polyethylene. Secondly, the material selection and method of compounding process to produce the filament are most important for enhance the material performance and application in the FDM. Thirdly, the major limitation of AM are speed, accuracy, material properties and system cost [2]. A significant issue in the layered manufacturing is the federate and melt temperature of composite wire filament in layered process on FDM platform. Due to the highly metal filled in polymer matrix, will be effected on the feed rate of the composite filament during melt flow extrusion by FDM machine. It was expected that, this need some of knowledge, methods, material transition phase and behavior from solid to semi solid and effect of temperature, melt flow and the feed rate during deposition material in layer by a layer manufacturing process. The intention of this study is to expand the composite feedstock and filament with copper filled in ABS polymer via layered manufacturing processes by FDM machine. A suitable binder and surfactant material has been added as lubricant agent for smoothest melt flow of composites materials in wire filament form for used in FDM machine in layered manufacturing process.

DEVELOPMENT OF A NEW ABS-COPPER FILAMENT COMPOSITES FOR FUSED DEPOSITION MODELING (FDM)

Acrylonitrile butadiene styrene (ABS) is one of the most successful engineering thermoplastics material with high performance in the engineering application. ABS has a desirable properties which is good mechanical properties, chemical resistance and easy processing characteristic [13]. ABS has a good mechanical properties and fluidity, desirable flexibility and stiffness [7-8]. The selection of materials are consists of the matrix polymer, metal filler, binder and surfactant material in the filament wire part fabrication. The ABS polymer as a matrix material and metal copper powder as a filler material in the main matrix. The characteristics of each materials in compounding process are shown in Table I.

Table I Characteristic of compounding Copper, ABS and surfactant

Components	**Melt Temperature (°C)**	**Degradation Temperature (°C)**	**Density (g/cm³)**
Copper Powder	1080	-	8.94
ABS Polymer	266	366	1.03
Calcium Stearate	155	265	3.54
Palm Stearin	50 - 55	255	0.891

Table II Mixing ratio of Copper, ABS, Calcium Stearate and Palm Stearin material by volume percentage (vol. %)

Sample	Vcopper (%)	Vabs (%)	Vcs (%)	Vps (%)	Total V (Vol. %)
1	10	85.0	4	1.0	100
2	10	82.5	6	1.5	100
3	10	80.0	8	2	100
4	20	75.0	4	1.0	100
5	20	72.5	6	1.5	100
6	20	70.0	8	2	100
7	30	65.0	4	1.0	100
8	30	62.5	6	1.5	100
9	30	60.0	8	2	100
10	40	55.0	4	1.0	100
11	40	52.5	6	1.5	100

There are three stages required in the processing and compounding must be followed in the experimental. Firstly, the compounding of the feedstock was accomplished using Brabender Plastograph Mixer. Secondly, feedstock wire has to produce by the single screw extruder. All pieces of equipment are described first. The material compounding ratios in the experimental is based on volume percentage (vol. %). Table II shows the mixing ratio of Copper, ABS, Calcium Stearate and Palm Stearin material by volume fraction percentage (vol. %). ABS filament wire materials were chopped into 1 mm – 5 mm pallet size and put into the Brabender Plastograph mixer, type W50 for the compounding and the selection of melting temperature of 180 ^{o}C approximately. The selection of temperature is based on the melting point of ABS material from the TGA and degradation analysis test. Then the sieved copper powder approximately 50 μm - 100 μm in size was added into ABS polymer for the melt compounding process. When the distribution compounding of copper powder and ABS polymer is mix well with homogenous in color, some of binder and surfactant will be added into the ABS-Copper mix material in 1-3 hours Figure 1 shown the Brabender Plastograph Mixer used in the mixing and compounding PMC material [12].

Fig. 1 Brabender Plastograph Mixer [12]

Fig. 2 ABS-copper feedstock composites

Secondly, when the binder and surfactant material added were in dry condition and the mixing of PMC material in homogenous distribution, the compounding process will be stop immediately. Figure 2 shows the ABS-copper feedstock composited produced by the Brabender Mixer. After that, the feedstock material were crushed to form into a pallet form with similar size approximately. The feedstock material will be sieved in a room temperature to achieve the constant pallet size in length of 1 mm to 5 mm approximately. Figure 3 show feedstock after crushed in a pallet form.

Thirdly, the fabrication of the feedstock filament wire by single screw extruder machine needs to be specify the wire diameter size, melting temperature, density, viscosity and mechanical properties. The extruder machine should be heated around 10 to 20 minutes for establish the barrel temperature of 180 °C approximately. Then the new PMC mixture pallet is fed into the hopper in certain amount, and the material flows from top to bottom by a gravity concept. The extruder screw will compress the PMC material from feeding area, middle, front and die. Four areas of temperature zone and the extruder screw speed will be adjusted by manually in order to maintain the feedstock filament diameter. The die diameter was 2.5 mm and 3.0 mm. The targeting diameter of the feedstock filament in approximately 2.5 mm to 3.00 mm. In order to minimize the swelling during the fabrication, the filament will flow in waterbed cooling with a constant spool feeder and suitable temperature selection. Figure 4 show the feedstock filament by wire extruder machine (Sa’ude, et al., 2016).

Fig. 3 The feedstock after crushed in a pallet form [12]

Fig. 4 Copper ABS Wire Filament by Single Screw Extruder Machine [12]

The temperature setting and screw speed has a most important parameter in experimental during wire filament fabrication. An increment of temperature in die zone was lead a material in slurry material and it difficult to form the material in filament form. When the temperature reduce on die zone, the material didn’t melt properly and the buckling was occurred during wire filament fabrication. The justification using a different temperature is to optimize the diameter of filament with desired shape. In order to fabricate a constant diameter and smoothest flow of wire filament of 3.00 mm, the best temperature setting in four zones was 170 ºC in feeding, middle 205 ºC, front 215 ºC, die 180 ºC and screw speed 4 hz.

RESULTS & DISCUSSIONS

In the deposition ABS-Copper filament material on the FDM heated platform, two type of ABS and ABS-Copper filament material with size 3 mm in diameter has been selected for extrusion by FDM machine. The selection of melt temperature range of ABS was tested from 230°C until 250°C and ABS-Copper from 180 °C to 260 °C. The consistency of the filament length, time and velocity in diameter of ABS and ABS-Copper filament was investigated during extrusion process. Furthermore, the selection of extruder motor speed are 5 mm/s, 10 mm/s, 15 mm/s, 20 mm/s, and 25 mm/s respectively.

The measurement of ABS filament length by FDM machine are shown in Figure 5. The results indicates that, an increment of melting temperature and feed rate will increased the ABS filament length with different size of the nozzle diameter. Therefore, the ABS filament length increase proportionally an increment of temperature and federate in extrusion process by FDM machine. The best selection of temperature and federate for ABS filament length are 260 °C and 10 mm/s in extrusion process.

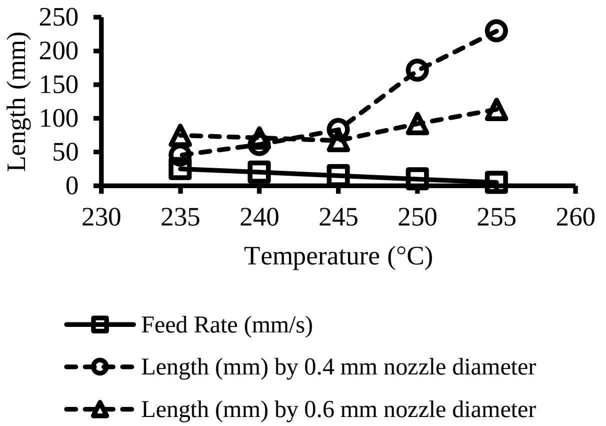

Fig.5 Length (mm) of ABS Filament by Different Nozzle Diameter

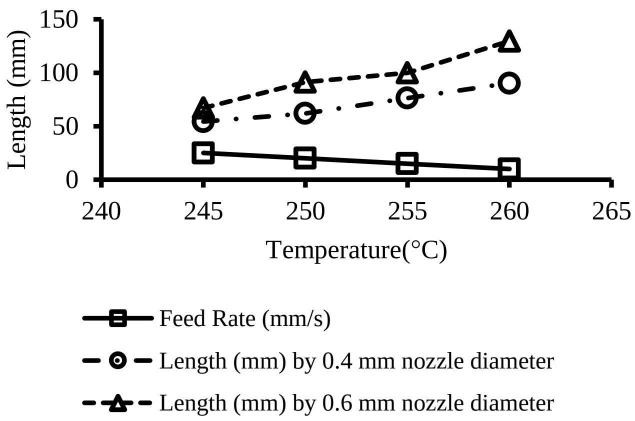

Fig.6 Length (mm) of ABS-Copper Filament by Different Nozzle Diameter

The results of ABS-copper filament length by FDM machine in Figure 6 indicates that, an increment of melting temperature with lower feed rate will increased the ABS filament length with different size of the nozzle diameter. The best selection of temperature and federate for ABS-copper filament length are 260 °C and 10 mm/s in extrusion process. Therefore, with 0.6 mm size of the nozzle diameter give a better length of 129 mm approximately, when to extrude the ABS-copper filament in FDM machine.

There were four (4) reading temperature and federate used in the experimental by FDM machine. Table III show the different variables of temperature from 245 ºC ~ 260 ºC and the feed rate of 10 mm/s ~ 25 mm/s were selected and examined by 0.3 mm ABS and ABS-Copper filament.

Table III Comparison length of ABS and ABS-Copper filament based on varieties temperature and feed rate value with different size of nozzle diameter

Temperature (°C)	Feedrate (mm/s)	ABS Filament length (mm) Diameter Nozzle(mm)		ABS-Copper Filament length (mm) Diameter Nozzle(mm)	
		0.4	0.6	0.4	0.6
245	25	63.0	67.6	54.3	67.0
250	20	85.6	77.3	62.0	91.3
255	15	150.3	83.6	76.3	100.0
260	10	166.6	103.6	90.3	129.6

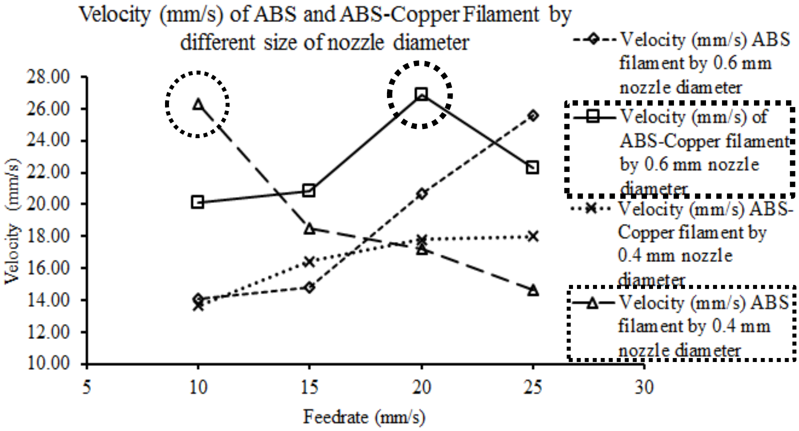

Fig. 7 Comparison velocity of ABS and ABS-Copper filament based on varieties feed rate value with different size of nozzle diameter

From the results obtained on the Figure 7, it was found that, ABS filament velocity was reduced perpendicularly on increment of federate value by the nozzle diameter of 0.4 mm approximately. A similarly observation was made by Mireles et al., (2012), mentioned that during deposition or composites material, the deposition velocity and flow rate shall be slowdown with the properly liquefied temperature controlled. The best selection of ABS filament federate was 10 mm/s, temperature 260 ºC with 0.4 mm nozzle diameter by FDM machine.

ABS-Copper filament material was done to extrude through the FDM heated liquefied head and successfully deposited on the platform. The parameter setting on the melts temperature ABS-Copper are from 180°C to 260°C and the federate are from 10 mm/sec – 25 mm/sec. Figure 8, show the fabrication sample from ABS-Copper filament by FDM machine.

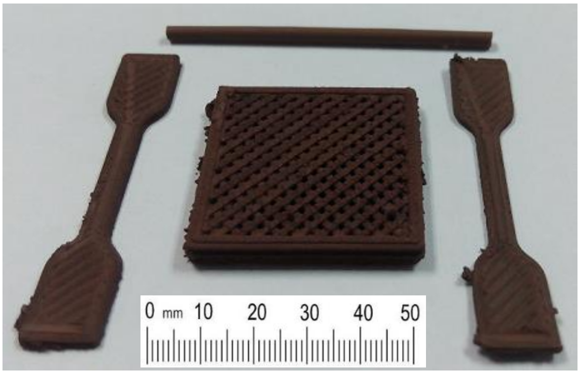

Fig. 8 The fabrication sample from ABS-Copper filament by FDM machine

CONCLUSION

The parts fabrication of a new ABS-copper filament was greatly achieved in additive manufacturing process by FDM machine. Therefore, it was concluded that, lowest federate was gave better length for both filament material during extrusion flow through heated liquefied head in layer by a layer process on FDM platform. Highest temperature and federate is needed to extrude polymer matrix composite (PMC) wire filament compare to ABS polymer wire filament material in FDM machine.

References:

[1] G. C. Anzalone, C. Zhang, B. Wijnen, P. G. Sanders, J. M. Pearce, "A low cost open source metal 3d printer" IEEE Access vol. 1, 803-810 (2013).

[2] I. Campbell, D. Bourell, I. Gibson, "Additive manufacturing: rapid prototyping come of age" Rapid Prototyping Journal 18/4, 255-258 (2012).
[3] O. Diegel, S. Singamneni, B. Huang, "The future of electronic products: Conductive 3D Printing". (Taylor & Francis, NUS Singapore, 2010), 397-402,
[4] L. Moballegh, J. Morshedian, M. Esfandeh, "Copper injection molding using a thermoplastic binder based on paraffin wax, " Materials Letters, 59(22), 2832 – 2837 (2005).
[5] J. Mireles, D. Espalin, D. Roberson, B. Zinniel, F. Medina, R. Wicker, "Fused deposition modeling of metals," SFF Symposium, 836-845 (2012).
[6] S. H. Masood, W. Q. Song, "Thermal characteristics of a new metal/polymer material for FDM rapid prototyping process," Emerald Group Publishing Limited, 25/4, 309–315 (2005).
[7] N. Mostafa, H. M. Syed, S. Igor, G. Andrew, "A study of melt flow analysis of an abs-iron composite in fused deposition modelling process," Tsinghua Science & Technology, 14, Supplement 1(0), 29 – 37 (2009).
[8] N. Mostafa, H. M. Syed, S. Igor, G. Andrew, "Thermo-mechanical properties of a highly filled polymeric composites for fused deposition modeling," Materials & Design, 32(6), 3448 – 3456 (2011).
[9] R. V. Noort, "The future of dental devices is digital," Dental Materials, 28, 3–12 (2012).
[10] M. A. Omar, I. Subuki, N. Abdullah, M. F. Ismail, "The influence of palm stearin content on the rheological behavior of 316l stainless steel mim compact," Journal of Science and Technology, 2, 1–14 (2010).
[11] V. Petrovic, J.V.H. Gonzalez, O.J. Ferrando, J.D. Gordillo, J.R.B. Puchades and L.P. Grinan, "Additive layered manufacturing: Sectors of industrial application shown through case studies," International Journal of Production Research, 49(4), 061–1079 (2011).
[12] N. Sa'ude, M. Ibrahim, M.H.I. Ibrahim, "Melt flow rate (mfr) of abs-copper composite filament by fused deposition modeling (fdm)," ARPN Journal of Engineering and Applied Sciences 11, 6562-6567 (2016).
[13] S. Wang, Y. Hu, L. Song, Z. Wang, Z. Chen, W. Fan, "Preparation and Thermal Properties of ABS/Montmorillonite Nanocomposite," Polymer Degradation and Stability 77, 423–426 (2002).
[14] W. Zhong, F. Li, Z. Zhang, L. Song, Z. Li, "Short fiber reinforced composites for fused deposition modeling," Materials Science and Engineering A301, 125-130 (2001).