VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

VERIFICATION OF FEED RATE EFFECTS ON FILAMENT EXTRUSION FOR FREEFORM FABRICATION

M. Ibrahim, N. M. A. Isa, N. Sa'ude and M. I. Ibrahim
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat Johor, Malaysia
E-Mail: mustaffa@uthm.edu.my

ABSTRACT

Fused Deposition Modelling (FDM) machine usually uses an extrusion method of plastic based material in layered manufacturing process. This study was focused on the effects of feed rate on filament flow in the extrusion process. For the first step, testing jig was built to ease the extrusion process were carried out. Testing jig was designed using the FDM extruder which are a major component in this study. Three types of filament were selected in the experimental such as Acrylonitrile Butadiene Styrene (ABS), High Impact Polystyrene (HIPS), and (ABS + Copper) by 3mm diameter size of the filament. From the results of the filament extrusion conducted, feed rate plays an important role in smoothing the extrusion process. Based on the results obtained, it was found that, the feed rate applied to drive the filament into the extruder head should be between 5 mm/s to 15 mm/s approximately. Meanwhile, the high temperature was affected on the filament extrusion flow through the different nozzle diameter of 0.4 mm and 0.6 mm in size. Therefore, the temperature range of ABS and HIPS in extrusion process was 230 °C until 250 °C and for ABS + Copper at 240 °C to 270 °C respectively.

Keywords: fused deposition modelling, feed rate, filament extrusion.

INTRODUCTION

Freeform Filament Fabrication (FFF) has been traditionally used only to rapidly prototype designs, thus there has been an insistence to use the fused deposition modeling process to manufacture final products. Recent improvements in the area of FFF has brought to the creation of inexpensive desktop based rapid prototypes such as the Replicating Rapid-Prototyper (RepRap), Fab@Home desktop, Makerbot Replicator and so on (Evan and Hod 2007). Currently, many researchers aim to develop and produce new material through FFF process. To that end, they also need to examine the flow behaviour of the filament at thermoplastic extruder, such as level of suitable temperature to melt of filament, feed rate speed of the extruder motor, the diameter size of the nozzle and so forth. If this parameters is changed, it also affects the extruded melt flow behaviour. However, Fused Deposition Modeling (FDM) extruder playing an important role in order to improve the quality of 3D printing objects especially on freeform filament extrusion. (Guohua *et al.* 2002)

Extrusion Freeforming (EF) is the term that will be used to describe extrusion technologies that diverge from FDM, which is trademarked by Stratasys. EF parts are built by depositing a small bead of softened polymer through an extrusion head onto a work platform. The nozzle (or platform) moves via computer control to put down a pattern on the platform. Complete parts are built by laying down successive patterns one layer at a time.

Since the release of the original patent for FDM, sales of low cost extrusion based machines has increased dramatically. This has also lead to a conforming growth in the number of vendors providing filament materials and a consequent drop in material prices. Due to the fact many different materials can be extruded through a nozzle, extrusion based Additive Manufacturing (AM) provides greater flexibility in producing multi-material parts and assemblies than powder based methods. Nevertheless, FDM has a number of short comings when compared with other AM technologies. In particular, the build speed, strength and surface quality of FDM parts is lesser to Laser Sintering parts (Tomaz *et al.* 2011), (Anita *et al.* 2001).

Additive Manufacturing is a form of manufacturing where the materials are added layer by layer to definite points in space to build up a solid part. In order to create parts layer by layer of material addition, Additive Manufacturing is applied as a new and developing manufacturing technology. This type of technology is often referred to as also layered manufacturing, rapid manufacturing or additive fabrication. During the beginning stages of use of this technology, it was mainly used to build smaller models or prototypes of new products or products being developed, but due to their much wider range of applications, they are now being used in different fields (Kamrani and Nasr 2006), (Pham and Dimov 2001).

Additive Manufacturing is the automatic construction of physical objects using additive manufacturing technology. The first techniques for Additive Manufacturing became available in the late 1980s and were used to produce models and prototype parts. Today, they are used for a much wider range of applications and are even used to manufacture production-quality parts in relatively small numbers. The use of additive manufacturing for Additive Manufacturing takes virtual designs from computer aided design (CAD), transforms them into thin, virtual, horizontal cross-sections and then creates successive layers until the model is complete. The primary advantage to additive fabrication is its ability to create almost any shape or geometric feature. In addition also, the RP technologies can convert a three dimensional CAD model into a physical model directly without any tool or die (Marcincinova and Kuric 2012), (Patel *et al.* 2014).

In the freeform filament extrusion process, softened polymer flows through a nozzle that is translated along a prescribed path over a build platform. The deposited material solidifies very quickly. Once the layer is formed, the build platform lowers by an amount equal to the layer thickness so that the next layer can be printed. With the help of numerically controlled stages, the movement of the nozzle (deposition head) and the building platform is controlled in the horizontal and vertical directions respectively. Furthermore, thermoplastics are low-cost and safe to use. The build volume of most freeform filament fabrication machines is comparatively small, hence they are most usually used as desktop prototyping machines (Wohlers, 2012).

METHODOLOGY

Experimental setup for jig testing

Extruder is a main component in this project. It has played an important role in the process to melt the thermoplastic filaments. There are several important components in the extruder namely brass nozzle, stepper motor and filament drive. Nozzle size used in this study is 0.4 mm and 0.6 mm. In this study, the extruder will be installed on the jig body for experiments conducted. Figure-1 below shows the complete set of the extruder.

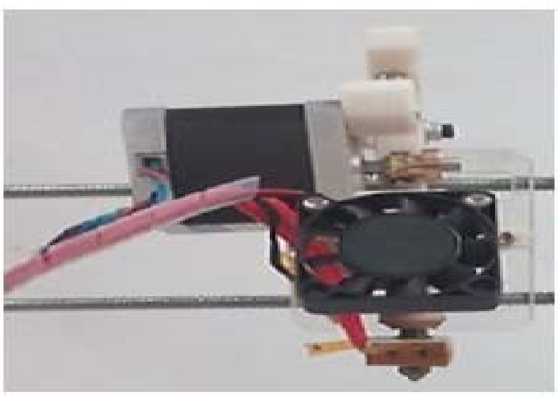

Figure-1. Complete set of the extruder.

In this study software also plays an important role because it is used to setup the desired parameters in the data collection process. While the Arduino Mega Pololu Servo Shield is a circuit board that will be used in this study. Before the experiments conducted, Arduino MEGA 2560 should be programmed in advance using computer software that will be discussed in more detail in this chapter. After that, the Arduino Mega Pololu Servo Shield (RAMPS) will be plugged into the Arduino and the wiring process for extruder components to be connected.
The Arduino board is the link between the power supply and stepper motors. Thus, it is important to understand the input/output pins of the microcontroller. As shown in Figure-2 below, the Arduino board contains a 2.1mm power jack for external 7-12V power source. There is also a USB interface that can power the board by connect it to the computer. It has a total of 54 input/output pins that can operate at 5V and they can provide or receive a maximum of 40mA. Moreover, a RepRap Arduino MEGA Pololu Shield, which is called RAMPS, is needed for the stepper motors and extruder connection. First step is to carefully plug the RAMPS into the Arduino without pinning any pins. Figure-3 is shown the Arduino as it connected to the RAMPS.

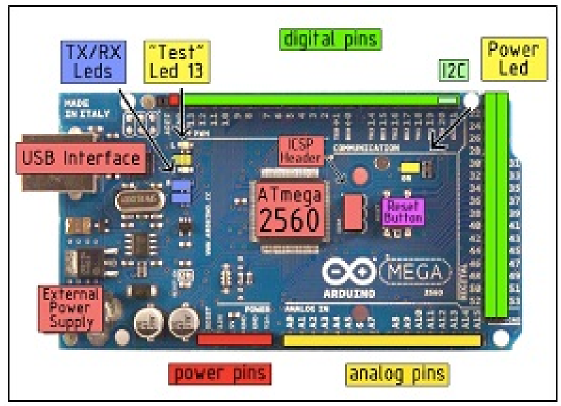

Figure-2. Arduino MEGA 2560 board.

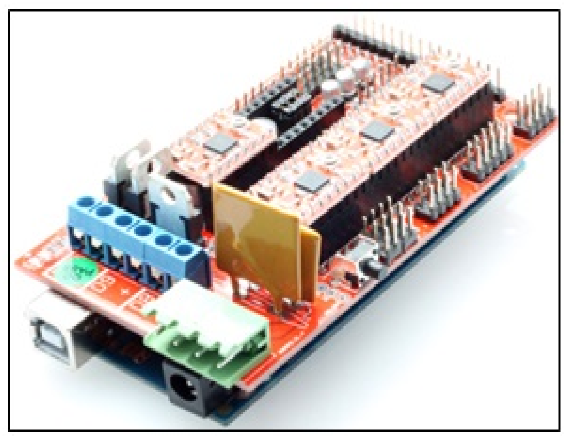

Figure-3. RAMPS plugged into the Arduino.

After the RAMPS and Arduino is plugged, power supply will be connected for the run the application and can used the computer software. To get the full potential of the RAMPS, it must be used a 12V power supply that can output 5A or greater (RepRap) as Figure-4 below. After all the apparatus is ready to assemble. Pronterface and Arduino software will be installed to the computer. Figure-5 shows the complete set of the extruder testing for filament extrusion in this study.

ARPN Journal of Engineering and Applied Sciences

Figure-4. Firmware and power supply connection.

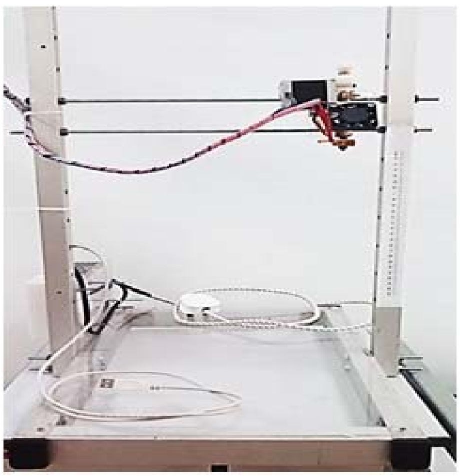

Figure-5. Jig testing.

Material preparation

Three filaments have selected to investigate some important parameters such as those in the freeform filament fabrication machine software are feed rate speed of the extruder motor, filament diameter after extrusion, and temperature effect on the hot-end. The filaments was used are Acrylonitrile Butadiene Styrene (ABS), High Impact Polystyrene (HIPS), and (ABS + Copper) by 3mm diameter size of the filament. Therefore, the filament size of 3mm was selected in this study should be consistent with the extruder head where the size of the hole to extrude the filament must also 3mm in size to facilitate entry and filament extrusion process. Figure-6 shows the filaments were used in this study.

Figure-6. (a) Acrylonitrile butadiene styrene (ABS); (b) High impact polystyrene (HIPS); (c) ABS + Copper.

However, in studies that have been conducted, two types of brass nozzle were used as shown in Figure-7. The size of the nozzle used is 0.4 mm and 0.6 mm. The purpose of these different nozzle size is used to determine the consistency of filament diameter after extrusion process carried out between three filaments of ABS, HIPS, and ABS + Copper.

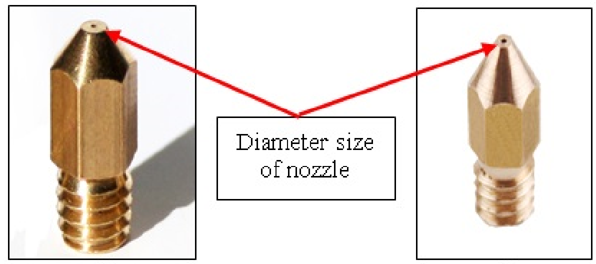

Figure-7. (a) Nozzle size 0.4 mm; (b) 0.6 mm

Filament extrusion process

Pronterface software was used for filament extrusion process. Firstly, to start this process the parameters must be set first in Pronterface software. The parameters were selected in this study has found in Pronterface software such as temperature effects and feed rate of the extruder motor. After the setting of the parameter was completed, make sure the temperature range applied to the hot-end is really hot before extrude the filament wire. In this process the extruder motor plays an important role to the extrusion of filament into the extruder head that the extrusion process applies to the size of the nozzle diameter required. In this study the temperature parameter imposed is based on the melt temperature of each filament such as ABS, HIPS, and ABS + Copper. Therefore, the temperature range of ABS and HIPS was tested at 230 °C until 250 °C and for ABS + Copper at 180 °C to 270 °C with override 5 °C respectively (Sa'ude *et al.* 2013). Furthermore, for the extruder motor speed the parameters were changed in the filament extrusion process are 5 mm/s, 10 mm/s, 15 mm/s, 20 mm/s, and 25 mm/s respectively.

When the process of extrusion filament was done, at the same time, data readings were taken as an initial observation. The data were obtained in this process was the time taken by the motor speed extruder and a length of filament after leaving the extrusion nozzle. In addition, to measure the length of the filament, the measurements were taken using a ruler paper that has been pasted on the pillar jig testing. After that, the readings were taken during filament out of the extruder nozzle until the motor stopped as it has been set to Pronterface software for parameter extruder motor speed. A measurement already taken in millimeters (mm).

After that, the filament was extruded through different nozzle sizes were measured to determine the consistency of diameter size using the Vernier Caliper. In this experimental process, the methods that have been

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

conducted to determine the diameter of the filament is taking measures 10 mm on each filament's length. This is so that the size of the filament diameter can be measured more accurately according to the length of the filament that has been extruded.

RESULTS AND DISCUSSION

Filament feed rate effect

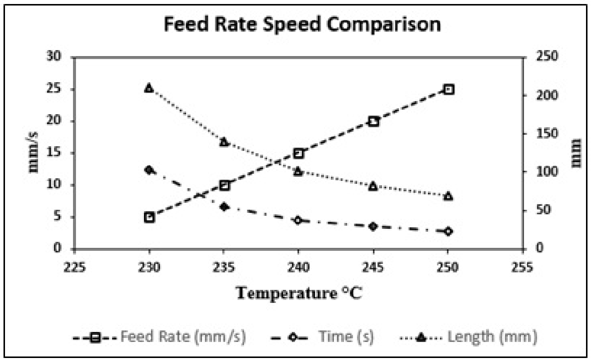

Figure-8. Feed rate versus time and length

Figure-8 shows the comparison of feed rate between time and length through the temperature obtained after the filament extrusion process. The result shows, when the temperature and the feed rate is higher, the time and length decreased. For confirmation, it can be compare between the filament feed rate by calculation.

In order to find the filament linear speed, simple geometrical calculations are performed. With the simple right angle triangle geometry, the length of filament feed (L_f) in one revolution of feed-in screw can then be calculated. The following calculations show the mathematical relationships as well as calculated filament linear speed (L_{ABS}) using measured values from the extruder head.

$\theta = 15°$ (measured on extruder head)

$N_t = 1$ thread/mm

$p = \frac{1}{Nt} = 1$ mm / sec

For right angle triangle,

$$\cos\theta = \frac{p}{fl} \quad (1)$$

$$L_f = \frac{p}{\cos\theta} = \frac{1}{\cos(15°)} = 1.0353 \text{ mm/s}$$

To calculate the linear feed rate of filament (f_f), the feed screw revolution speed (N_f) should be multiplied by the length of passed over filament (L_f). Following sample calculations are for feed in screw speed of 5 mm/sec.

$$f_f = N_f \times L_f \quad (2)$$

$$f_f = 5 \text{ mm/s} \times 1.0353 \text{ mm/s} = 5.1765 \text{ mm/s}$$

Table-1. Feed screw speed versus calculated and actual filament feed rates for ABS.

Feed Rate Speed (mm/s)	Calculated Filament Feed Rate (mm/s)	Actual Filament Feed Rate(mm/s)	Filament Feed Rate Error
5	5.1765	6.94	1.76
10	10.353	11.02	0.67
15	15.53	11.19	4.34
20	20.71	11.75	8.96
25	25.88	12.07	13.81

From Table-1, the results showed the feed rate speed at 5 mm/s, 10 mm/s and 15 mm/s, the value was obtained almost the same between the actual filament feed rate and calculated filament feed rate . While the feed rate speed at 20 mm/s and 25 mm/s shows the value between actual filaments feed rate and by calculation is very different. Therefore, the results were obtained the lower feed rate speed plays an important role in pushing the filament into the extruder head. Nevertheless, from the results achieved higher feed rate speed is not suitable in this process because it can cause the damaged of filament during the extrusion filament occurs.

Feed rate speed versus nozzle diameter

In the filament extrusion process, diameter of nozzle was used for comparison the consistency diameter filament extrusion. There are two types of nozzle diameter size used in this study which is 0.4 mm and 0.6 mm. In experimental process was conducted, it was found that the temperature affected to the filament extrusion depend on the types of filament used.

Table-2. Comparison of nozzle diameter for ABS filament.

Feed Rate (mm/s)	Temperature Extrusion	Diameter (0.4 mm)	Diameter (0.6mm)
5	230	0.5	0.7
10	235	0.5	0.7
15	240	0.5	0.7
20	245	0.5	0.7
25	250	0.5	0.7

Table-3. Comparison of nozzle diameter for HIPS filament.

Feed Rate (mm/s)	Temperature Extrusion	Diameter (0.4 mm)	Diameter (0.6mm)
5	230	0.5	0.7
10	235	0.5	0.7
15	240	0.5	0.7
20	245	0.6	0.8
25	250	0.6	0.8

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Based on the information from Table-2 and Table-3, it can be seen that the nozzle was used not same with filament extrusion flow compare by 0.4 mm and 0.6 mm where the filament extrusion out is 0.5 mm and 0.7. From the observation, it can be said that, the filament extrusion flow are not same with the diameter of nozzle used. It is because ABS and HIPS filament are based on the plastic material that can cause rapid expands. From Table-3 it shows that, at the temperature 245°C and 260°C the filament extrusion flow is much effect between 0.4 mm and 0.6 mm where it achieved 0.6 mm and 0.8 mm diameter size. Therefore, it shows that the high temperature effect the filament extrusion flow.

Different with ABS + Copper filament, the result shows the filament extrusion flow with diameter nozzle used is same after the extrusion process as shown in Table-4. Therefore, it can be conclude that the material properties affected of the diameter filament changes after the filament extrusion process.

Table-4. Comparison of nozzle diameter for ABS + copper filament.

Feed Rate (mm/s)	Temperature Extrusion	Diameter (0.4 mm)	Diameter (0.6mm)
5	240	0.4	0.6
10	245	0.4	0.6
15	250	0.4	0.6
20	255	0.4	0.6
25	260	0.4	0.6

In addition, the feed rate also affects the filament extrusion at temperature inappropriate imposed during the extrusion process. Figure-9 and Figure-10 shows the feed rate effects on the filament extrusion.

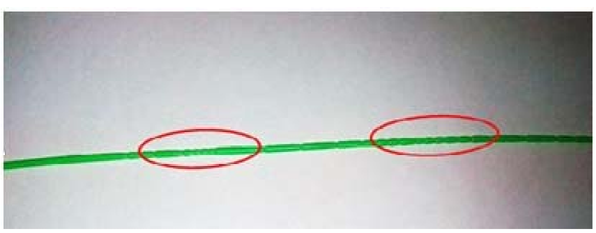

Figure-9. Feed rate effect on HIPS filament after extrusion process at temperature 240 °C by 0.6 mm nozzle diameter.

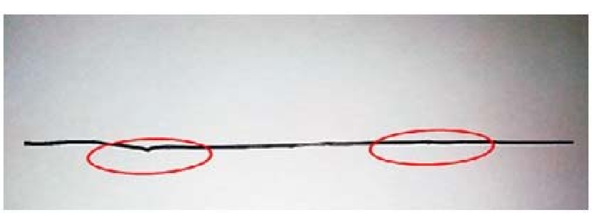

Figure-10. Feed rate effect on ABS filament after extrusion process at temperature 230 °C by 0.4 mm nozzle diameter.

In this process, if the feed rate speed is applied very high, the filament extrusion becomes non smooth and built the deform although the temperature imposed is suitable. So, temperature and feed rate effect is very important on the filament extrusion in order to achieve a good extrusion flow (Nancharaiah *et al.* 2010)

Validation

A validation experiment was conducted to verify the suitable feed rate and temperature for each materials to be used for the 3D printer machine. Table-5 and Table-6 show the validation obtained from three materials was conducted in the experiment by 0.4 mm and 0.6 mm nozzle diameter.

Results proved that the selected feed rate and temperature is in accordance with the extruded materials requirement.

Table-5. Result of the validation experiment for 0.4 mm nozzle diameter.

Material	Temperature Test (°C)	Extrusion Temperature (°C)	Filament Feed rate(mm/s)
HIPS	230-250	240	5
ABS	230-250	235	10
ABS + Copper	240-270	260	5

Table-6. Result of the validation experiment for 0.6 mm nozzle diameter.

Material	Temperatu re Test (°C)	Extrusion temperatur e (°C)	Filament Feed rate(mm/s)
HIPS	230-250	230	10
ABS	230-250	240	10
ABS + Copper	240-270	260	15

CONCLUSIONS

From this experiment, testing jig was built to ease the extrusion process is carried out. Testing jig was designed using the FDM extruder which are the major component in this study. From the results of the filament extrusion was conducted, feed rate plays an important role in smoothing the extrusion process. Based on the results obtained, the feed rate applied to drive the filament into the extruder head should be between 5 mm/s till 15 mm/s only. As it is known that different filament feed rates produce dramatically different extruded filament diameters, this fact can potentially be used to improve part quality especially in 3D printing machine.

In addition, the size of the nozzle also affects the filament diameter based on the material used. For ABS and HIPS filament, the diameter of filament has changed by not following the size of the nozzle used, while the

ABS + Copper filament still maintain by the diameter of nozzle and maintain good consistency of diameter. Finally, the validation has been carried to all the filaments being studied by determining the suitable temperature and feed rate speed for extrusion processes especially for the use in 3D printer machine.

REFERENCES

[1] Anitha. R, Arunachalam. S, and Radhakrishnan. P. (2001). Critical Parameters Influencing the Quality of Prototype in Fused Deposition Modeling, Journal of Processing Technology 118, pp.385-388.

[2] Evan, M. and Hod, L. (2007). Fab@Home: The Personal Desktop Fabricator Kit. Rapid Prototyping Journal 13(April): 245–55.

[3] Guohua, W., Noshir A.L., Rajendra, S., and Stephen, D. (2002). Solid Freeform Fabrication of Metal Components Using Fused Deposition of Metals. Materials and Design 23, pp. 97-105.

[4] Kamrani, A. and Nasr, E.A. (2006). Rapid Prototyping: Theory and Practice, Springer, New York, USA.

[5] Marcincinova, N. L. and Kuric. I. (2012). Basic and Advanced Materials for Fused Deposition Modeling Rapid Prototyping Technology, Manufacturing and Industrial Engineering, 11(1), ISSN 1338-6549.

[6] Nancharaiah. T., Raju. D. R., and Raju. V. R. (2010). An Experimental Investigation on Surface Quality and Dimensional Accuracy of FDM Components. ISSN: 0975-8364.

[7] Patel. R., Patel. S., and Pate. J. (2014). A Review on Optimization of Process Peramater of Fused Deposition Modeling For Better Dimensional Accuracy. International Journal of Engineering Development and Research, Volume 2, Issue 2, ISSN 2321-9939.

[8] Pham, D.T. Dimov, S.S. (2001). Rapid Manufacturing, Springer, Verlag London Limited.

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

[10] Tomaz, B., Bogdan V., Joze B., and Igor D. (2011). Speed and Accuracy Evaluation of and Accuracy Evaluation of Additive Manufacturing Machines. Rapid Prototyping Journal, Vol. 17 Issue: 1, pp.64 – 75.

[11] Wohlers, T. (2012). Wohlers report 2012. Additive Manufacturing and 3D Printing State of the Industry ISBN 0-9754429-8-8.