

Parametric Study of Fused Deposition Modelling Process During Fabrication of Acrylonitrile Butadiene Styrene (ABS) Based Injection Molding Die

Shivam Singh^{1*}, S.K.S. Yadav²

Abstract

The purpose of this study is to dictate an optimum process parameter during the fabrication of additively manufactured acrylonitrile butadiene styrene (ABS) based injection mold using fused deposition modelling methodology based additive manufacturing process and to assess the quality of the injection mold by analyzing the surface roughness of the injection mold, and the time taken in the manufacturing of the mold. The ABS PRO+ filament is used in manufacturing ABS-based injection mold which is manufactured by the WOL 3D. The printer used for manufacturing of ABS-based injection mold is manufactured by Creality Ender-3 3D printing machine working on the Fused Deposition Modelling or FDM principle. FDM is a filament-based process and uses polymer-based filament for printing. The filament used in developing the mold has a nozzle temperature of about 250°C and a bed temperature of about 90°C. The mold was manufactured by changing different process parameters such as speed of printing and layer height of printing and all the other parameters of the experiment were kept constant throughout the experiment. Three parameters of both layer height and printing speed are taken for this study. A total of nine molds were manufactured at different combinations of layer height and printing speed. The 3D printed mold was then analyzed for the processing effects on the surface roughness and time taken in 3D printing of the injection mold. The study concluded the optimum value of printing speed and layer height for better surface finish and less time consumption for 3D printing the injection mold.

Keywords: Additive manufacturing, ABS, FDM, mold

INTRODUCTION

Injection molding manufacture parts for industries that range from aerospace to consumer electronics. Having a short production cycle time and low manufacturing cost parts, it is one of the

best plastic manufacturing processes there in the industry for high-volume production. To achieve that injection molding uses complex tooling which can take months to make and cost a fortune. So, the flaws in the design must be corrected initially for making the mold. Conventionally, injection molding molds are metal-based such as steel and aluminum. Additive Manufacturing also called 3D printing can print ABS-based mold that can reduce the burden of prototyping and is feasible for low-volume production. 3D printing can overcome the drawback of the traditional mold manufacturing method. Mold printed using additive manufacturing consumes less time and costs much less compared to traditional mold [1, 2].

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Additive Manufacturing can produce complex mold designs in a brief period of time. Time consumed in the printing of the mold can be reduced by increasing printing speed and layer height. However, changing these parameters does have some drawbacks to the quality of the mold. Increasing the printing speed have an adverse effect on the surface finish of the mold. The surface roughness gradually increases with the increase of the printing speed. The same effect can be seen in increasing layer height. So, an optimum value of printing speed and layer height must be considered to get a better surface finish of the mold as well as not increase the manufacturing time [3, 4].

Selecting the material for printing the mold is a challenge in itself. As the process temperature of the injection mold ranges very high. So, the material to be selected must sustain high temperature and pressure without losing its structural integrity. Acrylonitrile Butadiene Styrene (ABS) solves these problems [5]. ABS has high-temperature resistance and a high level of toughness. ABS-based mold can be used for injection molding of polymer-based plastic [6, 7].

This study will examine the mold manufactured by considering different process parameters. Each mold will be then investigated for time consumption and surface finish as these are the parameters having an adverse effect on the quality of the mold. Evaluation of the best process parameters for mold making.

METHODS AND MATERIALS

Additive Manufacturing

Additive Manufacturing (AM) also known as 3D printing is a technology that can create a prototype or fully functional parts with the help of digital data (CAD) using additive manufacturing machines. As the name suggests material is added layer-by-layer to build the required part using slicer software. First, the part is designed on CAD software then it is converted in STL extinction and then the designed part is added to a slicer software which then segments the part layer-by-layer and gives a g-code of the part to the 3D printer for printing and then the file is imported to the 3D printer and the printing starts (Figure 1). The biggest advantage of 3D printing is that this process has negligible wastage or scrape as compared to the traditional subtractive machining processes. Complex designs that cannot be made by conventional machining processes can be manufactured with the help of additive manufacturing. Additive manufacturing finds its application in different industries. 3D printed parts are used in aerospace industries for making form and fit prototypes and functional parts for aircraft. In the medical field, 3D-printed parts are used as implants for surgical purposes and solve the problem of customization as per the patient. However, additive manufacturing also has some drawbacks. The printing speed is slow, and the surface finish is a big problem in additive manufacturing. So, its application in mass production in industries is quite questionable. Though there is much research on making the 3D printing process faster and with a better-finished product. Advancement in the material used in 3D printing is also needed for increasing the area of application of 3D printing in different industries.

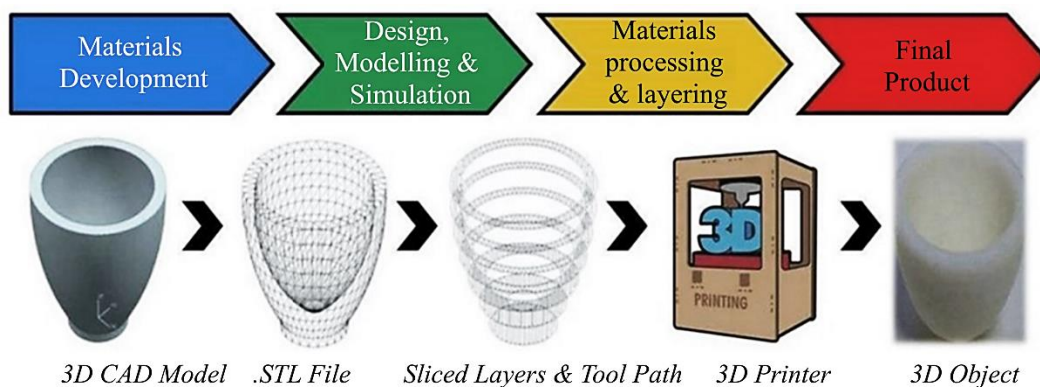


Figure 1. Steps of additive manufacturing [8].

Fused Deposition Modelling

Fused deposition modelling (FDM) is the most recurrently used type of additive manufacturing process. In this method, the material filament is used which is fed with a feeding system to a heated nozzle that melts the filament material. The melted material is then extruded to a hotbed in a controlled manner forming a layer on the material. Layer-by-layer deposition of material gives the final part. The main advantage of this method is it gives a variety of material scope. Many materials can be printed using this method the only condition is that the material must come at the service temperature of the 3D printer. ABS material can be easily printed with this methodology. ABS requires an enclosed system for FDM printing otherwise there are high chances of warping the part. In this study, the mold is printed with Creality Ender 3 printing machine using FDM as its working principle (Figure 2) [9].

Acrylonitrile Butadiene Styrene

Acrylonitrile butadiene styrene is the most recurrently used thermoplastic polymer for additive manufacturing or 3d printing applications in the industry. This thermoplastic polymer is in demand in the market due to its availability in abundance, ease of production, and cost-effectiveness. This material is affordable and machinable. The ABS materials have high impact resistance, structural strength and stiffness, chemical resistance, excellent high and low-temperature performance, and great electrical insulation properties [10, 11]. Though printing ABS is a challenge in itself. Because of its warping properties. This problem is solved by using ABS PRO+ filament by the WOL 3D. this additive-reinforced ABS filament has superior properties as compared to the generic ABS filament. ABS PRO+ provides resistance to elevated temperature and has a high impact strength with a superior finish as compared to the generic ABS [11]. heat resistant property helps the mold in the molding of high-temperature plastics with ease. This study is the printing of ABS-based mold using ABS PRO+ filament [12].

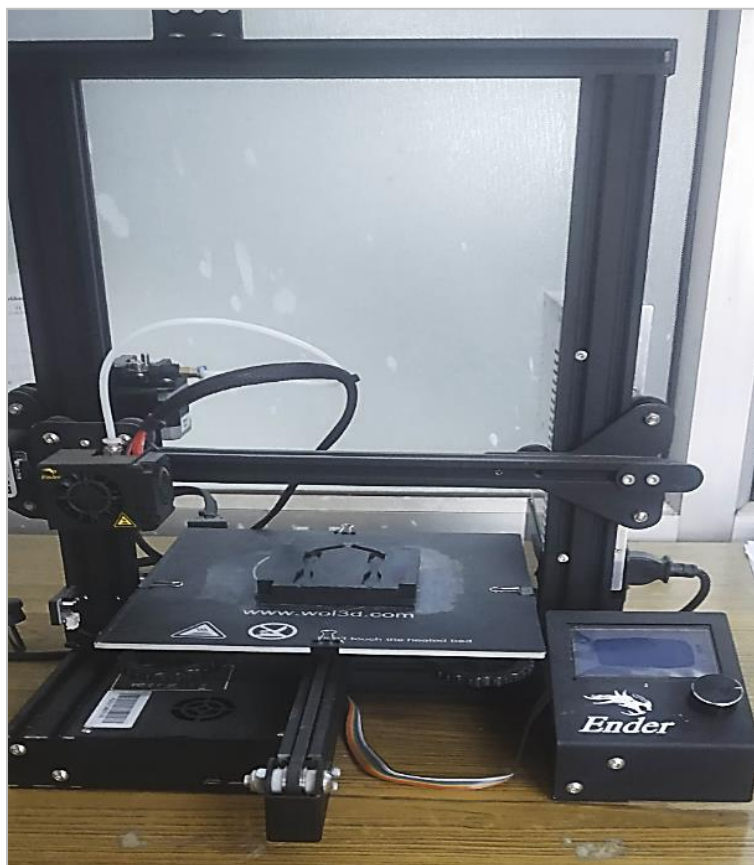


Figure 2. 3D printing of ABS-based mold.

DESIGN OF EXPERIMENT

In this experiment first, we design a mold for the injection molding process in SOLIDWORKS software. A core and a cavity of the mold are designed, and a draft analysis has been done on the mold designed within the CAD software giving a 2-degree angle draft on both core and cavity as recommended for the ABS mold. Then the compatibility of the mold is checked in the assembly of the parts in the SOLIDWORKS software. The mold is then saved in the STL extinction for the slicer software.

The designed mold STL file is then imported to Ultimaker Cura slicer software which segments the mold layer-by-layer. The data has been fed to the 3D printer. The same mold is manufactured by only changing the printing speed from 50 mm/s to 70 mm/s and the printing layer height from 0.12 mm to 0.2 mm. All the other parameters like filament diameter, nozzle diameter, bed temperature, nozzle temperature, infill, and infill pattern are kept constant. A total of nine experiment cycles will be completed [13].

The time taken in the printing of each mold is recorded and matched by the slicer software for double verification. The surface roughness was tested with the help of a surface roughness tester with an accuracy of about 0.001 μm . Then choosing the combination of the best value of the layer height and printing speed gives the optimum result (Figure 3).

RESULTS AND DISCUSSIONS

A total of nine experiments have been made during the study by only changing the value of layer height and printing speed and keeping other parameters such as filament diameter, nozzle diameter, bed temperature, nozzle temperature, infill, and infill pattern at constant (Table 1).

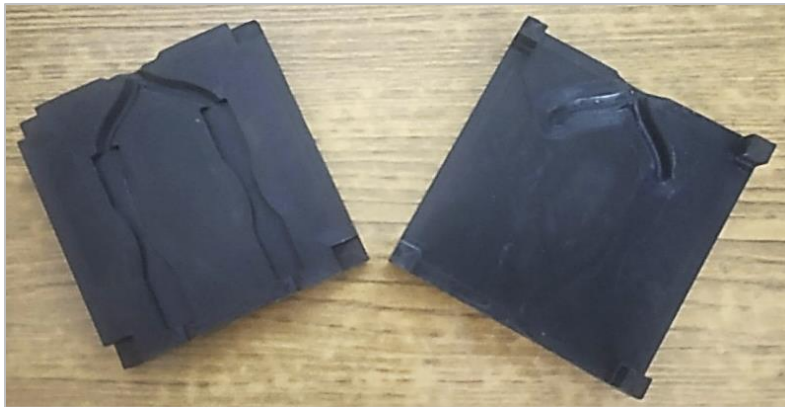


Figure 3. ABS mold manufactured by additive manufacturing.

Table 1. Variable and fixed printing parameters for the experiment.

Variable parameters	Low	High	Fixed parameters	
Layer height (mm)	.12	.2	Filament diameter (mm)	1.75
Printing speed (mm/s)	50	70	Nozzle diameter (mm)	.4
			Bed temperature ($^{\circ}\text{C}$)	90
			Nozzle temperature ($^{\circ}\text{C}$)	250
			Infill (%)	20
			Infill pattern	Cubic

The mold produced has then been tested on the time consumption of the manufacturing and the surface finish of the mold manufactured. The time consumption has been recorded and rematched by the Ultimaker Cura software for double confirmation of the data. The surface roughness of each mold is tested with the help of a surface roughness tester machine (Figure 4).

Data from each mold is collected and analyzed. The data shows that when the printing speed is increased keeping layer height constant the value of the surface roughness increase gradually. Though printing time decrease with the increase of the printing speed keeping layer height constant (Table 2). So, there must be an optimum point at which a faster-printed mold can be created with a smooth surface finish.

Paying attention to Figures 5 and 6 show the variation in surface roughness and printing time with respect to the printing speed at different layer heights. Looking at the chart in Figure 6 confirms that the surface finishes at a printing speed of 60 mm/s and a layer height of 0.16 mm is quite considerable. The same can be observed in Figure 6 which confirms that the time consumed in printing at a layer height of 0.16 mm and a printing speed of 60 mm/s gives a faster and good quality mold.



Figure 4. Surface roughness testing of mold.

Table 2. Experimental plan and results.

Test	Speed (mm/s)	Layer height (t)	Surface roughness (μm)	Time (hr.)
1	50	.12	2.881	9.316
2	50	.16	6.122	6.766
3	50	.2	9.911	5.566
4	60	.12	3.619	8.100
5	60	.16	7.737	5.500
6	60	.2	11.855	4.900
7	70	.12	6.832	7.250
8	70	.16	11.986	5.300
9	70	.2	19.177	4.400

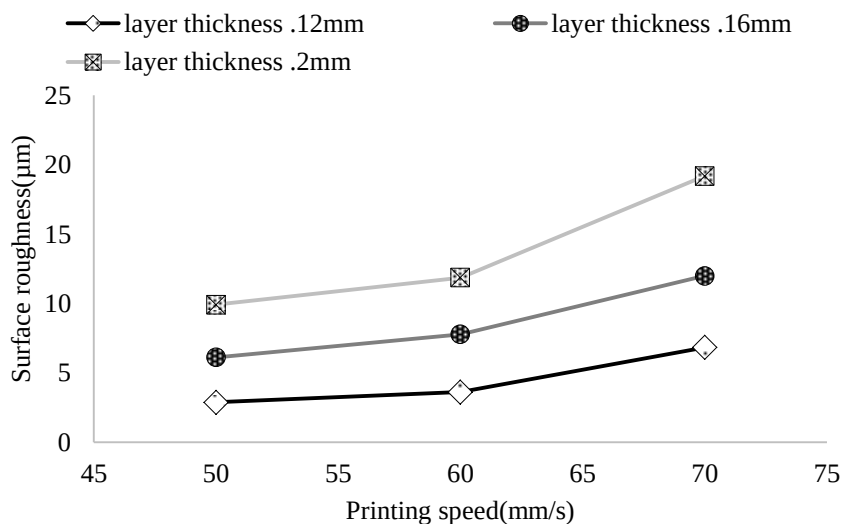


Figure 5. Variation of surface roughness with respect to printing speed.

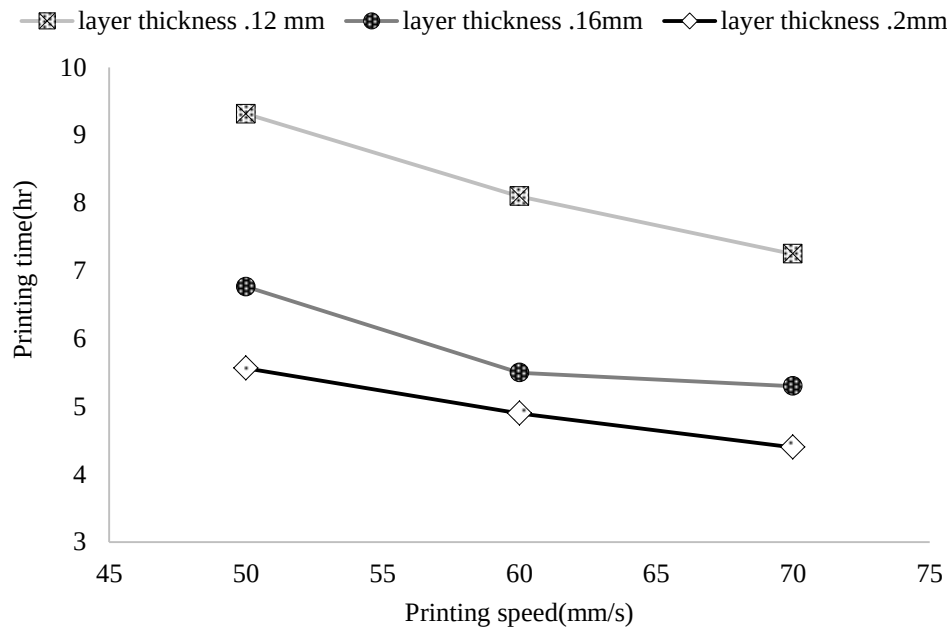


Figure 6. Variation of printing time with respect to printing speed.

CONCLUSIONS

This study concludes printing time and better quality of a mold depend upon both heights of the layer and the printing speed of the mold. When the height of the layer is increased results in a decrease in the printing time, but this results in the poor surface finishing of the mold. Further, it has also been observed when the printing speed is increased the surface roughness of the mold increase, and the printing time of the mold decrease. This study also suggests a speed of printing at 60 mm/sec and a layer height of 0.16 mm for effectively printing ABS-based mold with a smoother surface finish and less time consumption in printing.

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