The Influence Of Process Parameters On The Surface Roughness Of The 3d Printed Part In FDM Process

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Abstract. 3D printing is a promising digital manufacturing technique that produces parts with layer by layer. The influence of process parameters is investigated for ABS material in fused deposition modelling (FDM). This work aimed to determine the surface roughness of 3d printed parts of the ABS material with varied parameters of infill height and infill density. The results of the test show that the, surface roughness is higher (11.6mm) at 20% infill density with 0.26mm infill layer height. Also, ABS material surface shows good finish (lower surface roughness) at 100% infill density with 0.06mm infill layer height. The infill layer height clearly visible under microscope at higher infill layer height with all the infill densities.

Keywords:3D printing, Fused Deposition Modelling, surface roughness, Micro structure analysis

1. Introduction

In recent years, the technology of 3D printing is being widely used in various industries from the manufacturing of prototypes to the functional applications. This 3D printing technology comes under the additive manufacturing process which is opposite to the conventional subtractive manufacturing process. The advantage of the subtractive manufacturing process is the material wastage and complex parts manufacturing. These disadvantages are successfully overcome by the additive manufacturing process, where the material is added layer by layer according to the cross-sectional geometry of the component [1].

In late 2016 ASTM International gave a framework for global 3D printing standards, called the “Additive Manufacturing Standards Structure” [2]. It is a very high-level set of categories that represent the 3D printing industry. ISO/ASTM52900-15 is the standard which represents basic nomenclature, important terminology, and commonly used acronyms in the industry. 3D printing industry is divided into three high-level divisions of feed stock materials, process/equipment and finished parts. Also, the above industry divisions produced parts which are related to quality control, testing and measurement.

Parts are printed using a material extrusion process which is also called a fused deposition modelling process that uses a continuous filament of a thermoplastic material (ABS). The basic setup of fused deposition modelling is shown in Figure 1. The filament is fed into the extrusion head where the
filament gets melted and is forced to pass through a nozzle. The material coming out from the nozzle is deposited on the bed according to the sliced CAD model. 3D model is made in CAD software, and then it is exported to the STL file. This file is imported into the pre-processing software of the FDM machine. The model is first oriented and then sliced into many horizontal layers. When path data is reviewed and tool paths are generated, the data is sent to the FDM machine [4].

![Fused deposition modeling process](image)

*Figure 1. Fused deposition modeling process*

The 3D printing process is acceptable advantages of dimensional accuracy and highly durability of the components. Also, 3D printer shows disadvantages of low mechanical strength and very difficult to produce thin walls [5]. The filament used in this work is ABS (Acrylonitrile-butadiene-styrene) which is the most widely used industrial thermoplastic. It is a low-cost engineering thermoplastic that can machined, fabricated and thermo-formed. The ABS material has excellent chemical, stress and creep resistance and also offers a good balance of impact, heat, abrasion resistance hardness, rigidity and electrical characteristics [6].

The quality of the part produced depends on various input parameters to be given to the machine. The parameters include layer height, infill density, Orientation. Various works have been carried out by using different values of input parameters and observing the change in output [7]. The effect of two controllable process parameters of layer thickness and infill density on fused deposition modelling and mathematical modelling of configuration, strength and surface roughness. Printing parameters of infill density and layer thickness have a considerable effect on the quality and surface finish [8]. Also studied the influence of layer height and infill on the mechanical properties of the part [9]. The ABS micro structure consists of diameter between 0.2 and 50-mm. Campbell et al., investigated surface roughness for different materials [10]. Also found that, in case of ABS material, the surface roughness of FDM process ranges between 9 µm and 40 µm using a layer thickness of 0.253mm. [11,12] Various author presented design and fabrication of knee implants using different 3D printing techniques. Various author performed testing and characterization of the fabricated components includes tensile strength, hardness, joint quality such as surface roughness [13-16].

Research on the effect of layer heights and infill densities on qualities of printed parts is still missing in the FDM process. Accordingly, this work is mainly focused on the influence of layer height and infill of ABS polymer on the print qualities using FDM process considering surface roughness and microstructure. The best heights and densities strategy will be able to be found based on the requirements of the final product.
2. Methodology

2.1. Parameters Selection

In order to comprehensively investigate the impact of infill density and layer height on the print qualities (surface roughness and changes in micro structure) of the final product. The following parameters are selected to improve the quality of surface as shown in Table 1.

| Parameters | Infill Density, % | 20 | 40 | 60 | 80 | 100 | - |
|------------|-------------------|----|----|----|----|-----|---|
| Infill Layer Height, mm | 0.06 | 0.1 | 0.14 | 0.18 | 0.22 | 0.26 |

2.2. Material Selection & Design in Creo

Dimensions of these samples are 20 X 20 mm. The design of the sample is done using Creo 5.0 software as shown in Figure 2.

The material used in this research is one kg ABS (Acrylonitrile-butadiene-styrene) polymer filament with a 1.75mm diameter. The color of the ABS polymer was yellow. Then the 3D objects need to be sliced into layers and sent to a printer in a G-code format to print the product. Slicer software Ultimaker is used for slicing digital models as shown in Figure 3.
2.3. Material Selection & Design in Creo
PRAMAAN 500 is an industrial-grade large format 3D Printer used for Manufacturing Enterprises and professionals for sample printing. It consists of 2.8inch Touch Screen Display that supports standalone printing. The body of the printer Aluminum Extrusion Chassis covered with Steel. Following are the specifications of the PRAMAAN 500 printer as shown in Figure 4:
- Maximum Build Volume: 500mm X 500mm X 500mm
- Filament Diameter: 1.75
- Nozzle Type: Brass
- Nozzle Diameter: 0.4mm
- Printable materials: PLA, ABS, Nylon, TPU
- Maximum Printing Temperature: 265oC
- Maximum Bed Temperature: 150oC
- No. Of Extruders: 1

2.4. Surface Roughness (Taly Surf)
The standard surface roughness tester of Mitutoyo 178-561-02A Surftest SJ-210 is used to record the surface roughness (Ra). At three different spots on the sample are recorded and consider the average of three values. Figure 5 shows the measurement of surface roughness using Taly Surf on ABS material. Inverted Metallurgical Microscope is used to study the surface characteristics of the printed material as shown in Figure 6.
3. Results and discussions

The surface roughness of the ABS material printed using 3D printing varied due to variation of the infill density and layer height as shown in Table 2. The analysis done specifically to study the influence of infill density and layer height. Surface roughness of ABS material increases with increasing infill height. At 20% infill density, maximum surface roughness of 11.6µm occurred at 0.26mm infill height and minimum surface roughness 2.16µm at 0.06mm of infill height. This clearly shows higher infill height results higher surface roughness due to more visibility and height of layer.

Table 2. Measured Surface roughness

| Infill Height, mm | D20 Avg. | D40 Avg. | D60 Avg. | D80 Avg. | D100 Avg. |
|-------------------|----------|----------|----------|----------|-----------|
| 0.06              | 2.9      | 2.5      | 2.18     | 2.15     | 2.16      |
| 0.1               | 4.6      | 3.94     | 4.57     | 3.7      | 3.84      |
| 0.14              | 5.62     | 5.29     | 5.14     | 5.12     | 4.56      |
| 0.18              | 8.52     | 7.05     | 7.02     | 7.01     | 5.35      |
| 0.22              | 9.93     | 9.62     | 8.09     | 7.58     | 7.49      |
| 0.26              | 11.6     | 10.98    | 10.39    | 10.21    | 8.54      |

3.1. Microstructures

The following figures below are the microstructures observed under the Trinocular microscope.
Table 3. Microstructure variation with Infill density and Infill height

| DENSITY LAYER HEIGHT | 20% | 40% | 60% | 80% | 100% |
|----------------------|-----|-----|-----|-----|------|
| 0.06                 | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) | ![Image](image4.png) | ![Image](image5.png) |
| 0.10                 | ![Image](image6.png) | ![Image](image7.png) | ![Image](image8.png) | ![Image](image9.png) | ![Image](image10.png) |
| 0.14                 | ![Image](image11.png) | ![Image](image12.png) | ![Image](image13.png) | ![Image](image14.png) | ![Image](image15.png) |
| 0.18                 | ![Image](image16.png) | ![Image](image17.png) | ![Image](image18.png) | ![Image](image19.png) | ![Image](image20.png) |
| 0.22                 | ![Image](image21.png) | ![Image](image22.png) | ![Image](image23.png) | ![Image](image24.png) | ![Image](image25.png) |
| 0.26                 | ![Image](image26.png) | ![Image](image27.png) | ![Image](image28.png) | ![Image](image29.png) | ![Image](image30.png) |

Images of the hundred fabricated samples after testing are provided in Table.2. The Trinocular microscope in Figure.6 the results are surprising, as we increase the layer height of various Infill densities like 20%, 40%, 60%, 80%, and 100%. The accuracy of the specimen and strength of the specimen increases and the weight of the specimen is also increased and as increasing of the height of the layer, the time decreases.

The observed preferable layer height for the ABS polymer is 0.06mm, 0.1mm and 0.26mm. accordingly; the layer heights are categorized in to three types, as follows:
- 0.06mm: This layer height is a high resolution at which the layers are visible directly/barely.
- 0.1mm: This is preferred for most prints. The golden mean between fast and good quality print.
- 0.26mm these layer heights are used for fast print. In this speed, the layer still creates an overall usable part while reducing the print time.
The results of the test show that the surface roughness is higher (11.6mm) at 20% infill density with 0.26mm infill layer height. Also, ABS material surface shows good finish (lower surface roughness) at 100% infill density with 0.06mm infill layer height. The infill layer height clearly visible under microscope at higher infill layer height with all the infill densities.

4. Results and discussions
Fused Deposition Modelling (FDM) technology is used to analyze the ABS material with variation in parameters of infill layer height and infill density. The following conclusions are extracted in the present work are:
- The higher infill density and lower infill layer height suggested the optimum output of the surface roughness.
- It has been seen that increasing the overlap distance between two layers and part orientation, results in decreasing surface roughness.
- It is noted that by increasing layer height then the surface roughness increases.
- Surface roughness is higher (11.6mm) at 20% infill density with 0.26mm infill layer height.
- The ABS material surface shows good finish (lower surface roughness) at 100% infill density with 0.06mm infill layer height.
- The infill layer height clearly visible under microscope at higher infill layer height with all the infill densities.

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