Analysis of Process Parameter Effect on Surface Roughness During Fused Deposition Modeling on PLA

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Abstract- FDM (Fused Deposition Modeling) is favored to be applied for manufacturing over other methods of 3d printing these days. The FDM approach may easily be fit perfectly if a preset process and model are directed to the machine utilizing a data transmission device. There are various possibilities for altering the input values as per the user demand. In this work, polylactic acid (PLA) is employed for specimen production. The tests in this research were done to investigate how four process parameters which are layer thickness, infill percentage, extrusion temperature, and print speed influenced surface roughness. Furthermore, the relative influences of these components on the response have been discovered and optimized using the Taguchi approach, and findings have been derived. Furthermore, findings and significant analysis were done utilizing the ANOVA approach. The Confirmation testing for SR was done to validate the findings.

Keywords– 3D Printing, FDM, Rapid Prototyping

1. INTRODUCTION

Rapid product development is highly critical for the organization to have a competitive edge over its rivals. [1] The history of additive manufacturing reveals a different type of advancement in 3D printing from the recent three decades. Around the 1980s inkjet printing was the most often utilized quick production. Later the true 3D printing technique i.e., Stereo Lithography was applied for production in 1984 by Charles Hulls [2]. Later in the 1990s, stereolithographic gear was created by Hull to augment SLA technology. Initially, the Hull device was relatively basic which operates on heating optically using a laser and discovered that production could be done considerably quicker than standard ways. Stereolithography (SLA) depends on a sort of acrylic-based material called photopolymer. When you discharge a UV laser beam into a pool of liquid photopolymer, the light-exposed section changes into a solid piece of plastic that can be molded into the shape of your 3D- printed model [3]. In 1992, DTM, a start-up, launched the world's first selective laser sintering (SLS) equipment which employs a laser to sinter powder rather than liquid. In the same year, 3D Systems (Charles Hull's business) built the world's first stereolithographic apparatus (SLA) machine, which permitted the layer-by-layer manufacture of complicated products in a fraction of the time [4]. Later, a 3D printer was employed to manufacture an organic body, which was generated for the first time in 1999 A.D. To adapt that component of the body, the part was covered by the patient's cells. This notion was created by the Wake Forest Institute for Regenerative Medicine. In 2002, for the 1st time, the same scientists constructed a successful artificial kidney printed using a 3D printing machine [5]. In 2005, Adrian Boywery of the University of Bath, England invented a 3D printer that can produce body components of a new 3D printer itself called a Rep-Rap. Finally, in 2008, the Rep-Rap project was released and dubbed Darwin. In 2008 the 3D printing industry and health industry worked simultaneously on the development of prosthetic limbs and even used for the successful implant in many patients. Similarly, Bespoke Innovations researched and invented prosthetic feet and developed the same application today [6]. The University of Southampton created 1st robotic-controlled aircraft using the 3D printer in 2011. Later, I. Materialise began working on printing jewelry pieces. MakerBot offers open-source DIY kits for creators to construct their 3D printers and goods. While the price of 3D printers has declined quickly and the precision of 3D printing has improved, Designers are no longer confined to printing with plastic and have begun employing metals to print. Engineers from the University of Southampton have flown the world's first 3D-printed unmanned aircraft, while KOR Ecologic has prototyped Urbee, a vehicle with a 3D-printed body expected to obtain 200 mpg on the highway [7]. Beyond ornaments and airliners, 3D printing is increasingly being utilized to create moderately priced residences for the developing world, and pioneers are utilizing the technology to print everything from clever robotic arms to bone replacements and even atom-thin particles (which could help in building even smaller electronics and batteries) (which could help in building even smaller electronics and batteries) [8].

From the above literature, it is understood that various development in 3D printing is needed for further development of this process and different characteristics need to be optimized. As structural characteristics are highly influenced by the process variables, Accurate control of process parameters is essential to gain better products with less material wastage, which reduces the machining and assembly time. The present work focused on determining the optimum levels of process parameters to gain a better surface finish of PLA plastic material fabricated by an FDM-type 3D printer.

2. EXPERIMENTAL SETUP

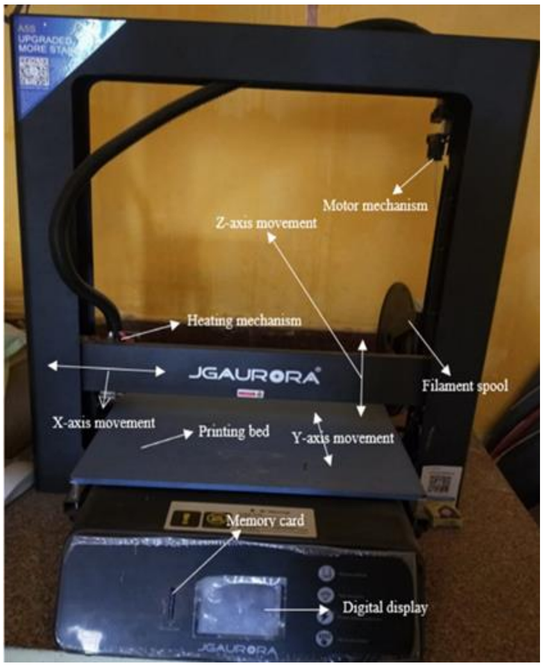

Figure 1: - JGAURORA A5S 3D Printer (Courtesy: Mystical Design tech., Jaipur)

Fused deposition modeling (FDM) is an important additive manufacturing process due to its easy operations, comparatively cheaper machinery of the specimen formed by the technique, durability of the products, and easy material swapping. In the FDM machine (Figure 1), there is a heated nozzle extruder head that is employed for depositing filament which is heated to a prefixed temperature by a heating block. Some FDM machines have an extra nozzle that feeds the support filament in case of a part printing requirement. Support filament is optional and is remover d later on after solidification of the specimen. The nozzle moves along a fixed path to fabricate a specimen. The path is determined by the STL file. The procedure for FDM printing comprises the feeding of filaments from filament rolls with the help of a roller feeding mechanism into the extruder nozzle head where it is heated by heating the block to a molten state or semi-liquid state and then deposited on the sliding platform. After finishing of deposition of a layer each time, the moveable nozzle holder will shift upward in Z – direction or vertical direction according to layer thickness to further add the next layer of material. This procedure continues till the component is entirely developed. Table 1 shows the technical specification of the 3D printer used for the research work.

Table 1: - Technical specification of JGAURORA A5S 3D Printer machine

S. No.	Name	Value
1.	Technology	Fused filament Fabrication
2.	Build volume (XYZ)	305×305×320 mm
3.	Printer dimensions (XYZ)	536×480×543 mm
4.	Printing Material	ABS, PLA, Nylon, Wood, etc.
5.	Nozzle bore	0.2-0.4 mm
6.	Extrusion temp. range	180~240 °C
7.	Platform for print	Heated type
9.	XY positioning system	Belt driven precision H-Bolt XY drive
10.	Z- positioning system	Lead screw
11.	Print speed range	10~150mm/s
12.	CAD input formats	STL, OBJ, G-Code
13.	Operating Platforms	Windows7/XP/Vista/Linux/Mac-Control
14.	Electrical Voltage AC	110~220V
15.	Power	300W

3. EXPERIMENTAL CONDITIONS AND MEASUREMENT PROCEDURE

3.1 Workpiece Selection

The specific density and tensile strength of PLA material used for the present work are 1.24 g/cm2 and 62 MPa, respectively. Due to the superior property of PLA than ABS or other filament material, it becomes 1st choice for 3D printers. Also compared to others, PLA has a lower melting point than others. The JGAURORA A5S 3D Printer was utilized for this research, and it employs CURA Ultimaker for configuring the operation settings (factors). The component design was originally developed in Rhinoceros 3D (Figure 2) and then converted to STL file format before getting loaded into the machinery for setup of processing parameters and conversion of the STL file to a print file that describes the path planning for fabrication of the parts.

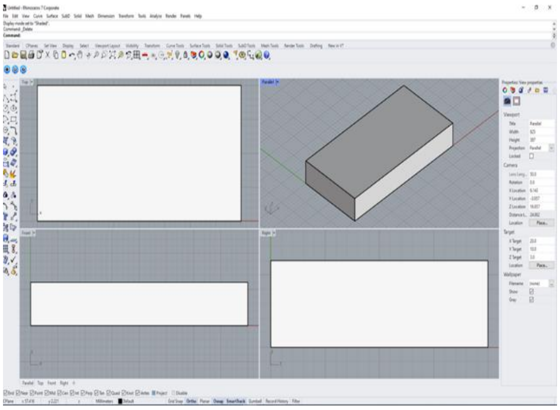

Figure 2: - Rhinoceros 3D used for designing of specimen

3.2 Experimental Parameters

As per the literature review, the following parameters are selected for this study:

1. General-
 (a). Nozzle Dia. & Contour width = 4 mm
 (b). Infill pattern & Raster angle = Linear & 45

2. Inputs-
 (a). Layer thickness (mm) = 0.1, 0.2, 0.3
 (b). Infill Percentage (%) = 90, 95, 100
 (c). Extrusion temperature (ºC) = 195, 205, 215
 (d). Print speed (mm/s.) = 40, 50, 60

3. Outputs- Surface roughness (SR)

3.3 Output Response Measurement

A portable surface roughness tester, the SURFTEST SJ-210 series, is being used to measure surface quality (Figure 4). It is a very lightweight roughness measuring tool that may show an SR waveform on an LCD color screen to the user (provided on the equipment) (given on the equipment). On the equipment, a 2.4-inch color graphic LCD with a backlight is offered for outstanding reading and easy presentation. According to the level of process parameters and for detail analysis, the L27 orthogonal array used for the specimen fabrication and experimentations, shown in Fig. 3.

Figure 3: - Fabricated specimens

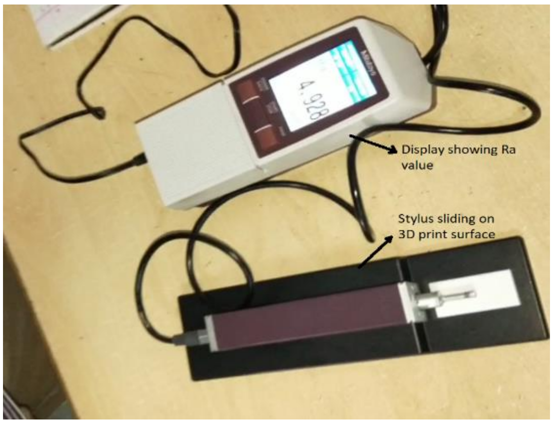

Figure 4: - Surface roughness measurement using SURFTEST SJ-210

A stylus is coupled with the equipment which features a sensitive 2 µm width diamond tip. Also, the measuring force and tip angle of the stylus is 0.75 mN and 60º. Figure 4 depicts the passage of the probe on the flat surface of the produced specimen. The apparatus has the adaptability that the user may use it via a long wire linked to the displaying machine and the stylus probe as per the comfortability. The least value of surface roughness of the equipment is 0.001 µm.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Result analysis on surface roughness

Signal to noise ratio analysis is done for Surface roughness utilizing the option "smaller is better" and the findings are given in Table 2 for the same. The S/N ratio is more relevant than the original data of Surface roughness and offers a better picture of varied changes due to adjustments in parameters. Here we can see that the SN ratio for experiment-1 is the lowest hence these values of parameters must be closer to ideal settings.

Table 2 S-N Ratio analysis for Surface roughness

Exp. No.	Layer thickness (mm)	Infill per. (%)	Extrusion Temp. (°C)	Print speed (mm/s.)	SR R_a(μm)	SN Ratio
1.	0.1	90	195	40	4.70	-13.44
2.	0.1	90	205	50	4.96	-13.92
3.	0.1	90	215	60	5.33	-14.54
4.	0.1	95	195	50	5.34	-14.56
5.	0.1	95	205	60	5.72	-15.15
6.	0.1	95	215	40	4.94	-13.87
7.	0.1	100	195	60	6.13	-15.76
8.	0.1	100	205	40	5.34	-14.55
9.	0.1	100	215	50	5.73	-15.16
10.	0.2	90	195	50	5.32	-14.52
11.	0.2	90	205	60	5.81	-15.29
12.	0.2	90	215	40	4.92	-13.85
13.	0.2	95	195	60	6.13	-15.75
14.	0.2	95	205	40	5.35	-14.57
15.	0.2	95	215	50	5.75	-15.20
16.	0.2	100	195	40	5.73	-15.16
17.	0.2	100	205	50	6.05	-15.64
18.	0.2	100	215	60	6.12	-15.74
19.	0.3	90	195	60	5.72	-15.15
20.	0.3	90	205	40	4.91	-13.83
21.	0.3	90	215	50	5.42	-14.68
22.	0.3	95	195	40	5.48	-14.78
23.	0.3	95	205	50	5.85	-15.35
24.	0.3	95	215	60	6.24	-15.91
25.	0.3	100	195	50	6.19	-15.84
26.	0.3	100	205	60	6.58	-16.37
27.	0.3	100	215	40	5.83	-15.31

4.2 Effect of Process Parameters on SR During FDM on PLA Material

The major impacts of each process parameter's S/N ratio on surface roughness at all levels were investigated. When it comes to surface roughness, smaller is preferable to achieving the required surface finish or enhancing the surface of specimens. In Figure 5, 0.1 mm layer thickness,90 percent of infill percentage, 215 °C extrusion temperature, and 40 mm/s print speed of print speed demonstrate the maximum value may be regarded as the best point for surface roughness which also correlates with the data obtained from Table 3. The average influence of process factors on surface roughness variation is given in Figure 6. From the graphic, we can observe that the infill % and print speed exhibit larger proportional fluctuation to surface roughness than the remaining four parameters. Also, surface roughness increases with an increase in layer thickness, but the rise is not steep as it is lower from between 0.1-0.2 to 0.2-0.3.

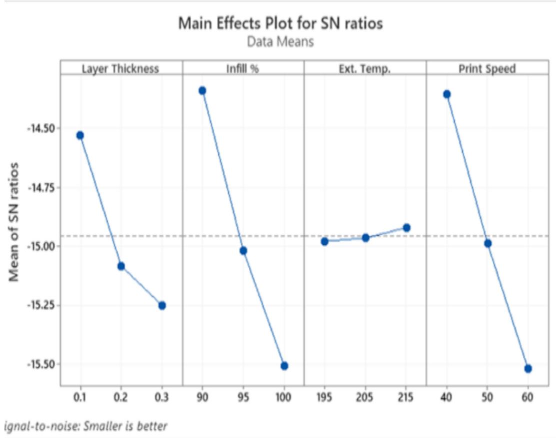

Figure 5: - S/N ratio graph for SR

Table 3: - Rank identification for surface roughness

	S/N ratio			
Level	**Layer Thickness**	**Infill %**	**Ext. Temp.**	**Print speed**
1	-14.55	-14.36	-15.00	-14.38
2	-15.08	-15.02	-14.97	-14.99
3	-15.25	-15.51	-14.92	-15.52
Delta	0.70	1.15	0.08	1.14
Rank	3	1	4	2

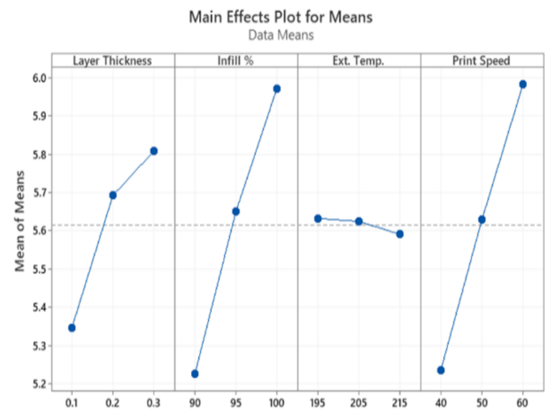

Figure 6: - Mean graph for SR

4.3 ANOVA Analysis on SR During FDM on PLA Material

The ANOVA findings for surface roughness in the S/N ratio form are provided in Table 4. the table show infill %, print speed, and layer thickness are the major factor for surface roughness fluctuation, while extrusion temperature is inconsequential for surface roughness. Infill percentage contributes the highest (~ 40.67 percent) followed by print speed (~ 40.18 percent), layer thickness (~ 16.34 percent), and extrusion temperature (~ 0.19 percent).

Table 4: - ANOVA (S/N ratio) for surface roughness

Source	DF	Seq SS	Adj MS	F	P	Contri. (%)
Layer Thickness	2	2.3921	1.19605	56.22	0.000	16.34
Infill %	2	5.9530	2.97648	139.92	0.000	40.67
Ext. Temp.	2	0.0281	0.01405	0.66	0.529	0.19
Print speed	2	5.8821	2.94104	138.25	0.000	40.18
Residual Error	18	0.3829	0.02127			
Total	26	14.6381				

4.4 Taguchi confirmation test for SR

Table 5 provides the best machining setting for surface roughness during specimen production. A confirmation test is performed to validate the Taguchi optimization findings. It was revealed that no specimen had ever been manufactured at the ideal machining setting. To forecast surface roughness, an experiment was done using 0.1 mm layer thickness,90 percent of infill percentage, 215 ºC, and 40 mm/s. of print speed. An experiment was done, and a fresh specimen was manufactured at the optimal machining setting. Finally, the experimental value recorded at the optimal setting was 4.554 µm. The actual value of surface roughness of the specimen created at optimal setting was assessed by the SURFTEST SJ-210.

Table 5: - Optimum machining setting for surface roughness

Layer Thickness (mm)	Infill percentage (%)	Ext. temp. (ºC)	Print speed (mm/s.)	Surface roughness Ra (µm)
0.1	90	215	40	4.554

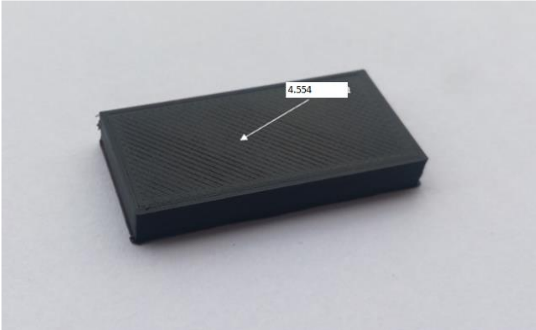

Figure 8: - Measurement of confirmation print for surface roughness

5. CONCLUSIONS

Fabrication and experimental research of specimens manufactured under 3D printing on surface roughness were effectively done. After the result observation, effect analysis and confirmation experiment were also completed successfully. These are the findings stated following the end of the study:

- For surface roughness, layer thickness, infill percentage, and print speed were significant factors.
- The optimal point for surface roughness was founded at 0.1 mm layer thickness,90% of infill percentage, 215 ºC extrusion temperature, and 40 mm/s print speed. The experimental optimum value observed at the optimum setting was 4.554 µm.
- A confirmation experiment for obtaining lower surface roughness shows that low layer thickness, low infill percentage, high extrusion temperature, and low print speed can be used for obtaining optimum results.

Furthermore, work can be performed in the same field which can be considered the future scope of this study, like- other printing techniques (SLA, SLS) can be also used with the same machining condition for comparison with the FDM. Different filament and their composite with supporting material (glass fibers) can also be used for the experiments for the enhancement of the machining characteristics.

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