OPTIMIZATION OF 3D PRINTING PARAMETERS ON SURFACE ROUGHNESS BY TAGUCHI METHOD

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ABSTRACT

Fused Deposition Modeling (FDM) is a type of rapid prototyping technique used in manufacturing prototypes among the additive manufacturing technologies. 3D printing is a type of FDM where the prototypes are made layer by layer addition of molten filament material. 3D printing directly converts the 3D-CAD data into prototypes(model). Our present involves studying the parameters which affect the surface roughness of 3D printed material are optimized. The material used for deposition is Polylactic Acid (PLA), a common thermoplastic polymer. The parameters like infill density, print speed, printing temperature and wall thickness are varied according to the design of experiments. Taguchi method was adopted to design the experiments and an orthogonal array of L9 (34) is designated and performed to find out the optimal values to minimize the surface roughness of 3D printed PLA material. The surface roughness test is conducted on each specimen as per standards.

KEYWORDS: *Fused Deposition Modeling (FDM), Additive Manufacturing, Poly Lactic Acid (PLA), Taguchi Method & Surface Roughness Test*

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1. INTRODUCTION

In the manufacturing zone, Additive manufacturing a new technology has been proven to be a promising method for adopting in rapid prototyping. This technology substantially has evolved and improved into a useful tool for many fields like in researcher, designing, manufacturing sector. Collaborating different fields in single package molded 3D printer which includes Design, manufacturing, electronics, materials, and business. The classic difference between traditional manufacturing method and 3D printing is, the 3D printer involves additive approach but mostly traditional manufacturing processes involve subtractive approach which includes a combination of cutting, bending, grinding, forging, molding, welding and assembling operations.

Additive Manufacturing (AM), usually known as 3D printing, is defined as the “joining of materials to make an object from 3D model data, generally by layer upon layer, as opposed to formative manufacturing methodologies” according to International Organization for Standardization (ISO)/American Society for Testing and Materials (ASTM) 52900:2015 standard [1]. Based on standards, AM processes is classified into seven classes: Binder-Jetting, Material’s Extrusion, Powder Bed Fusion, Directed Energy Deposition, Material-Jetting, Sheet Lamination and Vat Photo Polymerization.

2 FUSED DEPOSITION MODELING

Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) is a 3D printing material-extrusion process which employs, a continuous distributing of filament of a thermoplastic material which is encouraged from a large

and moving loop with an in situ -heater in printer extruder head. Molten material is pumped out of the print head's nozzle which gets deposited on the growing work piece. The head movement is under computer control, to define the printed shape. Usually the head moves in layers and in two dimensions to deposit one horizontal plane at a time, before moving marginally upwards to begin a new slice. The speed of the extruder head can be controlled, to start and stop the deposition and to form an interrupted plane short of stringing or dribbling among the sections[2].

Figure 1: Fused Deposition Modeling.

3D printing works on three main steps:

- **The first step** is designing an object, you design a 3D file of the object that need to be printed[3]. This 3D file are created using CAD software's, with a 3D scanner or designed in modeling software. Once you have checked that your 3D file to be printed is ready, we can proceed to the second step.
- **The second step** is the actual printing process. First, you need to choose which material with desirable properties for the object. Large variety of materials are used in 3D printing which includes plastics, ceramics, resins, metals, sand, textiles, biomaterials, glass, food and even lunar dust.
- **The third step** is the finishing process. This step necessitates specific skills for producing final object. When the object is first printed, regularly it cannot be directly delivered or used until it has to be sanded, lacquered or painted to complete it as intended.

Figure 2: 3D Printing Process.

Parameters of 3D Printing:

- **Infill density:** Infill is a value which is represented in percentages that shows how much a solid model should be filled-in with material, when printed. Normally, except if you need maximum strength/stiffness you would not have to go for extreme fill of a 3D model, particularly in the event if you want to save on material costs, model weight and want to get the print quicker.
- **Number of shells:** Number of Shells (Outline/Perimeter Shells) is a value that sets the number of outlines to be printed on each layer of the object more the shells the stronger the printed object is, hence setting high number of basic shells make the printed part with denser outside walls.
- **Layer Height:** Layer Height is the main parameter which reflects the print quality, it sets the thickness of each layer to be printed. Lower the number, the thinner each layer so best of quality 3D prints can be deposited. However decreasing the layer thickness means more layers are needed to be printed and the time required for the 3D printing will significantly increase[4].
- **Extruder Temperature:** Extruder Temperature is the temperature at which the extruder requires while performing printing. The extruder temperature depends on the material used, the value of 230°C is taken for printing using PLA/ABS filaments as per the standards and however flexible filaments typically require lower extruder temperature.
- **Printing Speed:** Printing Speed (Speed while extruding) is the speed at which the printing head moves while extruding the filament to make the physical representation of the 3D model[5]. Depending upon the model and the filament, we can optimize the printing speed to obtain excellent quality prints.
- **Movement Speed:** Movement Speed (Speed while Traveling) is the speed that the printing head moves when not extruding filament, the speed can normally be quicker than while extruding the filament and is generally twice the speed while printing the object.

Material used in FDM

Poly-Lactic-Acid (PLA), a thermoplastic polymer materials which is synthesized from corn, starch and sugarcane, possessing

a low melting point is selected, which is a suitable material for depositing complicate objects with an ease and resulting in smooth prints. Hence it's highly recommended for prototypes, probes and models [6].

Characteristics of PLA are:

- High tensile strength
- Good surface quality
- Ease to work at high print speeds
- Permits the creation of high-resolution parts and intricate objects
- Perfect for models and prototypes that require aesthetics
- Good for lost casting methods to produce metal parts

Table 1: Specifications of PLA $-(C_3H_4O_2)_n$

Specifications	PLA
Printing temperature(°C)	190-230
Bed temperature(°C)	70
Tensile yield strength (MPa)	60
Density (g/cm ³)	1.24
Tensile Modulus (GPa)	3.5
Tensile Elongation (%)	6
Biodegradable	Yes
Glass transition temperature (°C)	60

3 SPECIFICATIONS OF 3D PRINTER

Figure 3: 3D Printer (G3d Mini Instrument).

- **Technology:** Fused Deposition Modeling (FDM)
- **Instrument:** G3d Mini
- **Print Head:** Removable, Exchangeable
- **Build Volume:** 100 x 100 x 100

- **Filament Diameter:** 1.75mm
- **Layer Resolution:** 0.4mm Nozzle 300 to 50 microns
- **XYZ Accuracy :** 8, 8, 8 microns
- **Movement Speed:** Up to 150mm/s
- **Extrusion Speed:** 3mm³/s
- **Build Plate:** 4mm Acrylic
- **Material:** PLA, ABS
- **Nozzle Diameter:** 0.2, 0.3, 0.4 mm
- **Nozzle Temperature:** 170-240(°C)
- **Nozzle heat up time:** 50s

4 TAGUCHI METHOD

The Taguchi method was developed by Genichi Taguchi, encompasses reduction of variation in a process through a robust design of experimentation and produce high quality product at low cost to the manufacturer. The experimental design proposed by Taguchi involves using an orthogonal array to organize the parameters which affect the process and the dimensions at which they are varied [7]. Instead of testing all possible combinations like the factorial design, the Taguchi method tests pairs the combinations. This allows the collection of the essential data to determine what factors affects the product quality with a minimum amount of experimentation which helps to save time and resources.

4.1 Taguchi Orthogonal Array Design - L₉ (3*4):

Taguchi Orthogonal Array (OA) design is general fractional-factorial type model. The arrays are adjusted to ensure that all levels and all factors are considered equally. For this reason, the factors can be evaluated independently despite the fractionality of the design. Table.2 shows the Taguchi orthogonal array selector which shows the orthogonal array for the parameters and levels. For three parameters and three levels L₉ orthogonal arrays was selected from the array selector [8].

Table 2: Considered Parameters and Levels for Experimentation

Parameters	Level 1	Level 2	Level 3
Wall Thickness (mm)	0.8	1.2	1.6
Infill Density (%)	0	50	100
Print Speed (%)	20	60	100
Temperature (°C)	190	210	230

Table 3: S/N Ratio Values for Surface Roughness

Exp. No	Wall Thickness (mm)	Infill Density (%)	Print Speed (%)	Nozzle Temperature (°C)	Surface Roughness (μm)	S/N Ratio
1	0.8	0	20	190	4.12	-12.368
2	0.8	50	60	210	5.42	-14.66
3	0.8	100	100	230	6.23	-15.888
4	1.2	0	60	230	2.24	-7.004
5	1.2	50	100	190	1.66	-4.402
6	1.2	100	20	210	7.16	-17.336
7	1.6	0	100	210	5.46	-14.74
8	1.6	50	20	230	1.54	-3.75
9	1.6	100	60	190	3.72	-11.41

Figure 4: 3D Printed Samples Figure 5: Surface Roughness Tester.

Table 4: ANOVA Result

Factors	DOF	Sum of Squares	Mean Squares	F value	Contribution percentage
Wall thickness	2	41.2681	20.935	6.2057	20.1507
Infill density	2	69.400	34.7	10.4360	33.8872
Print speed	2	0.717	0.35	0.1052	0.3507
Nozzle temperature	2	73.4466	36.72	11.0436	35.8632
Error	6	19.95	3.325		9.7488
Total	8	204.7966			100

5 RESULTS AND DISCUSSIONS

Figure 6: Main Effects Plot for Signal to Noise ratio.

This figure will evaluate the main effects of each factor for various conditions. According to this figure surface roughness will decrease with major parameters wall thickness, infill density, print speed, nozzle temperature. The surface roughness will be minimum in case of wall thickness (1.2mm), infill density (50%), print speed (50%), nozzle temperature

(230°C), sooptimal parameter setting for surface roughness is shown below

Table 5: Optimal Values if Parameters

Parameters	Level	Actual value
Wall thickness	2	1.2mm
Infill Density	2	50%
Print speed	2	60%
Nozzle temperature	3	230°C

5.1 ANOVA Results for Taguchi

From the ANOVA test its observed that the experimental error is 9.7488, which is well below the 5%. f calculated values revealed that nozzle temperature, infill density and wall thickness played a significant role on surface roughness. Nozzle temperature 35.8632% and infill density 33.82% and wall thickness 20.152% affects the surface roughness.

6. CONCLUSIONS

In the experimentation with PLA, the taguchi optimization approach was successfully tested to determine the optimal level of printing parameters on surface roughness. The parameters of the 3D printing process were analyzed to obtain optimum results. Based on our analysis, nozzle temperature and infill density and wall thickness are exerting a strong influence on the final surface roughness of the prints. The other parameter which is print speed did not significantly affect the surface roughness. Finally, by tuning the parameters appropriately we obtain smooth surface finish products.

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