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Fabrication and Performance Analysis of Indirect Extruder based 3D Printer

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Abstract*— Fused Deposition Modeling based 3D printers have become very popular in Additive manufacturing because of its low cost and simplicity. But the FDM process is a slow process as compare to the other 3D printing technologies because surface roughness creates a limitation to increase the speed of the 3D printer. In this paper, a FDM 3D printer was modified with indirect extruder. Surface roughness has been evaluated as performance parameter. An effort has been made to compare the surface roughness of printed sample using direct and indirect extruders. Role of printing parameters such as printing speed, nozzle temperature and layer size have studied for achieving a better surface finish. Taguchi L9 array for 3 variables has been used to study these parameters. Results by Taguchi method were validated by experiments and found that better surface finish is possible with indirect extruder in comparison to direct extruder based 3D printer.

Index Terms*— Indirect Approach (IA), Bowden tube, Direct Approach (DA), Fused Filament Fabrication (FFF)

I. INTRODUCTION

Additive manufacturing (AM) is the layer by layer process to join materials for building 3D objects [8]. 3D printing is a type of Additive manufacturing process, which is used to make a 3D objects of any shape from a 3D model designed in CAD software [9-10]. Now a days, various types of 3D printer and printing technologies are available worldwide. First 3D printing technology was Stereolithography (SLA) which was invented by Chuck hull in the 1980s, but FDM based 3D printing technology is cheap one and most commonly used as compared to other 3D printing technologies. Fused filament fabrication (FFF) is a 3D printing process used in FDM that uses a continuous filament of a thermoplastic material which can be fed from a large coil, through a moving heated extruder head. The molten material is forced out of the nozzle and gets deposited on the heated bed layer by layer one over other thus forming the required 3D shape. As compared to other 3D printing methods FDM is a relatively slow process.

In FDM based 3D printer there are two types of approaches, first direct type and secondly is indirect type as:

In the case of *direct type approach* (Figure 1 (a)), the extruder is usually mounted directly on top of the nozzle's hot end, and the filament is holed tightly by a wheel and gear. The stepper motor precisely rotates the gear which drives the filament in a downward direction on a short journey to the hot end. For extraction of the filament the gear can rotate forward or backward direction from the hot end when changing the filament [2].

In the case of *indirect type approach* (Figure 1 b), the hot end is separated physically from the extruder. Usually, the extruder is mounted anywhere on the interior of the 3D printer. The bowden tube based extruder works basically as similar to direct extruder. But, the slight difference is that nozzle with heater and extruder with gear drive to push the filament is separated by a Bowden tube. The filament travels inside the Bowden tube [2]. The advantage of Bowden tube based extruder over direct extruder is reduced weight of moving parts with nozzle. 3D printers can be run on higher printing speeds because there of less momentum due to reduced weight and vibration during changing directions of printing.

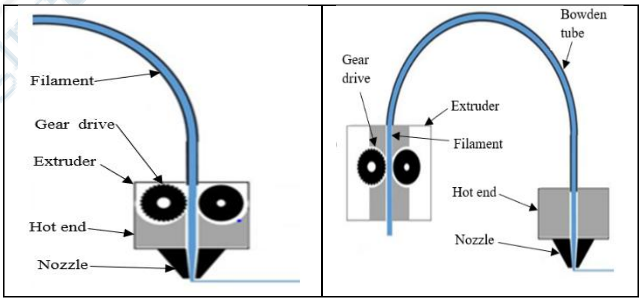

Fig 1. (a) Direct extruder mechanism (b) Bowden tube based extruder mechanism

In this paper existing FDM based 3D printer was modified with indirect type extruder and experimental study of printing parameters such as printing speed, layer size and nozzle temperature upon roughness have been performed as performance parameter in comparison to performance with direct extruder based 3D printer. For reducing the number of experiments Taguchi method with L9 array of three variables has been used.

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II. FABRICATION

The indirect extruder based FDM printer was fabricated by replacing direct extruder from existing FDM based 3D printer with indirect extruder assembly (Figure 2). Indirect extruder assembly of make 3D Innovations with details CHPSS531-2 V6 J Head Full set with Fan, 12 V heater, PTFE tubing for 0.4 mm to 1.75 Bowden tube was used for modification. Extruder with gear drive was fixed over frame of the printer and connected to the hot end with the help of a Bowden tube.

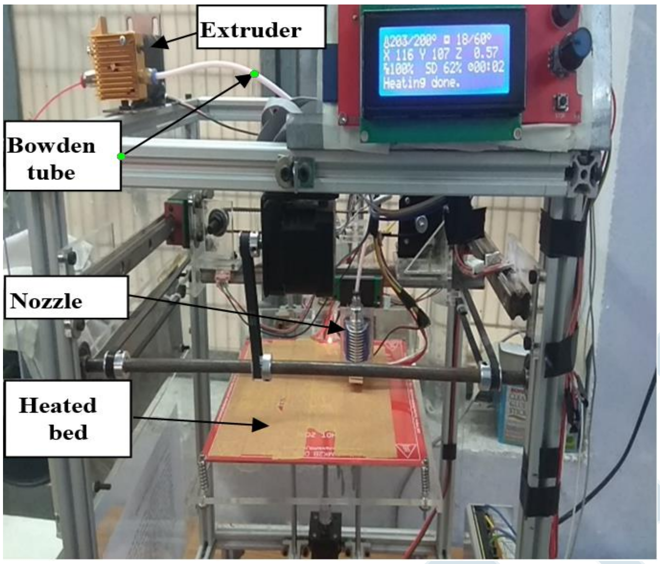

Fig 2. Indirect Extruder based 3D Printer

III. SAMPLE PREPARATION

A sample of rectangular cuboid 25 x 25 x 0.4 mm^3 is designed by CAD software CREO 2.0 and converted into a standard triangular language (STL) format (.stl format). Then the .stl file imported into Repetier-Host for G-codes conversion using the appropriate settings and sample is printed at different parameters such as speed, nozzle temperature and layer size.

Fig 3. Printed Sample

IV. EXPERIMENT

A modified indirect extruder based 3D printer was used for experimentation for comparison between direct and indirect extruder using different parameters.

Specification of the 3D printer are as following:

Extruder Type: Indirect with MK8 gearing; Type: Cartesian

Parameters	**Description**
Nozzle diameter	0.4 mm
Shell thickness	1.0 mm
Bed temperature	45^0C
% Infill	20%
Raster angle	45^0C
Material PLA	1.75mm (Gray Color)

Safe level of design taken from Pilot Experiments are

Layer Size: 0.1mm, 0.2mm, 0.3mm
Print Speed: 40mm/s, 50mm/s, 60mm-/s
Nozzle Temp: 215^0C, 220^0C, 225^0C

The above parameters are adopted from a research paper based on the indirect approach to compare the surface roughness between the Indirect and direct approach for the same sets of parameters [1].

V. DESIGN OF EXPERIMENT

For DOE, Taguchi L9 array is chosen from the past research works and papers [1] for comparing the surface roughness between the previous setup (direct approach based 3D printer) and the modified setup (indirect approach based 3D printer) for the same configuration. To plot the surface roughness vs print speed and nozzle temp at various layer size from the model obtained after analyzing in Mini-Tab software.

Table I. Design of Experiment (L9)

Printing Speed (mm/s)	Nozzle Temp (deg C)	Layer Size (mm)	Roughness through DA (micron)[1]	Roughness through IA (micron)	% difference
40	215	0.1	7.5	6.16	17.86
40	220	0.2	9.5	7.12	25.05
40	225	0.3	11.4	8.50	25.43
50	215	0.2	10.9	7.40	32.11
50	220	0.3	11.7	10.11	13.59
50	225	0.1	7.9	6.58	16.7
60	215	0.3	15.9	11.33	28.74
60	220	0.1	9.9	6.80	31.32
60	225	0.2	10.8	7.6	29.62

VI. RESULT AND DISCUSSIONS

So from Table 1, we can see that the roughness through IA at different printing speed, nozzle temperature and layer size decreases as compared to roughness through DA for same parameters. Thus it is evident that for the same surface configuration and similar parameters IA provides a better finish than DA.

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Other computed results for IA are given below which can again be compared to the computed results of DA. These results also show that the surface finish is better for IA as compared to DA.

6.1 Analysis of Variance

Response: Roughness ANOVA for Response Surface 2FI Model

Analysis of variance for surface roughness response through 2FI model is found significant.

Table II. Analysis of variance table

	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	23.51	6	3.92	19.77	0.049
A-Print Speed	0.23	1	0.23	1.44	0.398
B-Nozzle Temp	0.10	1	0.10	0.51	0.550
C-Layer Size	0.13	1	0.13	0.65	0.506
AB	0.94	1	0.94	4.75	0.161
AC	0.29	1	0.29	1.48	0.348
BC	0.14	1	0.14	0.71	0.489
Residual	0.40	2	0.20		
Cor Total	23.91	8			

The Model F-value of 19.77 implies the model is significant. There is only a 4.89% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant.

Table III. Analysis of individual factor

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High
Intercept	-274.91	1	418.72	-2076.52	1526.71
A	-39.55	1	37.09	-199.15	120.04
B	119.21	1	167.50	-601.48	839.90
C	-198.78	1	247.19	-1262.37	864.81
AB	39.06	1	17.91	-38.02	116.14
AC	32.12	1	26.44	-81.66	145.90
BC	83.12	1	98.93	-342.53	508.78

Final Equation in Terms of Actual Factors:

Roughness = 318.04689 - 4.15831 * PrintSpeed-1.35237 * Nozzle Temp-316.24790 * Layer Size + 0.017553* Print Speed * Nozzle Temp + 0.93105 * Print Speed * Layer Size + 1.28874 * Nozzle Temp * Layer Size

Table IV. Diagnostics Case Statistics

Actual Value	Predicted Value	Residual	Leverage
11.33	11.33	0.000	1.000
8.50	8.69	-0.19	0.904
6.58	6.50	0.079	0.928
10.11	9.84	0.27	0.772
7.60	7.37	0.23	0.569
6.80	7.07	-0.27	0.772
7.40	7.56	-0.16	0.713
7.12	7.35	-0.23	0.569
6.16	5.89	0.27	0.772

6.2 Study of Model Equation

The surface graphs were plotted in MATLAB at the constant layer size of 0.1 mm, 0.2 mm and 0.3 mm from the above model:

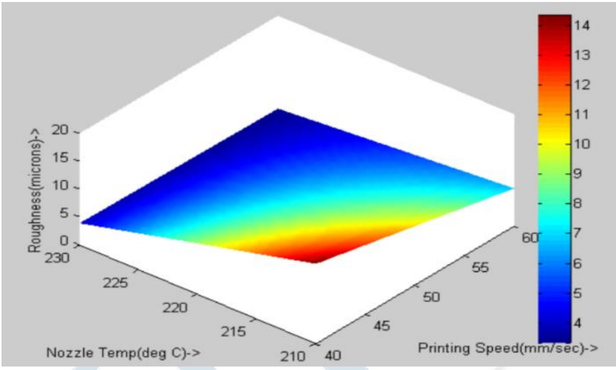

Fig 4.(a) Surface plot at layer size 0.1 mm

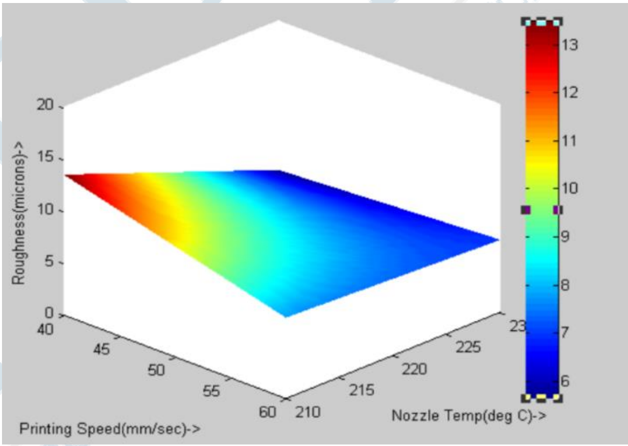

Fig 4.(b) Surface plot at layer size 0.2 mm

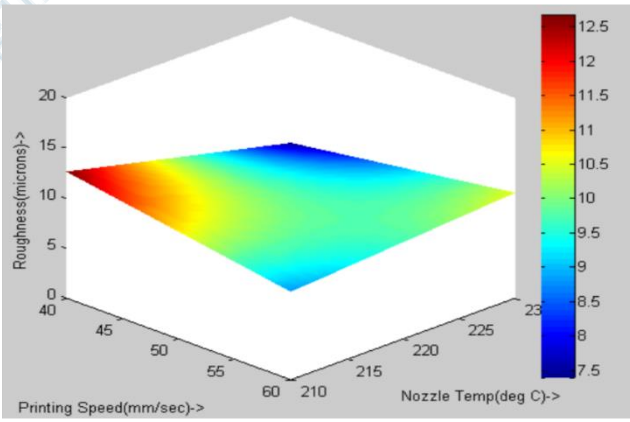

Fig 4.(c) Surface plot at layer size 0.3 mm

Figure 4a, 4b, 4c is showing the surface graph between surface roughness with respect to nozzle temperature and printing speed. Here at higher nozzle temperature of 230 ^{o}C and a lower printing speed of 40 mm/sec, found lower average surface roughness and at lower nozzle temperature of 210 ^{0}C and a higher printing speed of 60 mm/sec, found higher average surface roughness. The average lower surface

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roughness is 4 to 6 micron for 0.1 mm layer size, 6 to 8 micron for 0.2 mm layer size and 8.5 to 9.5 micron for 0.3 layer size.

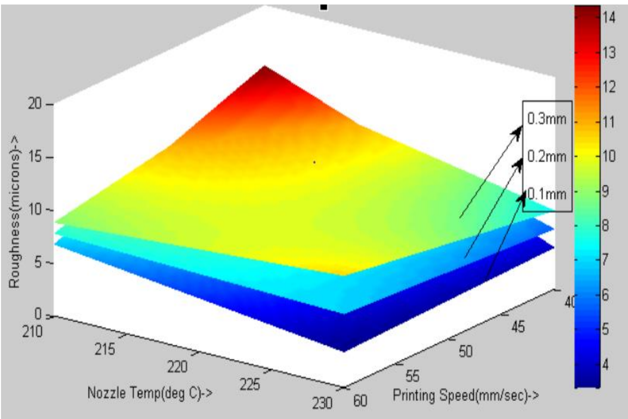

Fig 4.(d) Combined surface plot at all three layer size

Figure 4(d) showing the combined surface plot at all three different layer size as 0.1 mm, 0.2 mm, 0.3 mm to compare the effects. Here at increasing the layer size the slope of the curve increases while increasing the print speed as well the nozzle temperature. Figure showing the higher roughness at 0.3 mm layer size, 60 mm/sec print speed and 210 ^{0}C nozzle temperature.

6.3 Effect of Single Variable

Following observation have been made

- With the increase in printing speed, average surface roughness increases nonlinearly.
- With the increase in nozzle temperature, average surface roughness decreases nonlinearly.
- With the increase in layer size, average surface roughness increases nonlinearly.

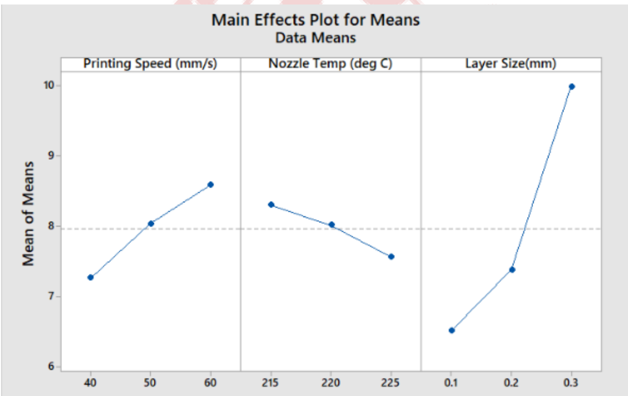

Fig 5. Single variable main effects plot for means

The results presented above are comparable to the results from the previous research paper [1] and presents a more acceptable Mean of Means as compared to the direct approach.

VII. CONCLUSIONS

Following conclusions have been made based on the current study are given below:

- On the bases of experimental study between direct and indirect type extruder, indirect type (Bowden tube based) extruder gives more accurate surface finish for same printing parameters such as printing speed, nozzle temperature and layer size.
- Surface roughness depends on the printing speed as well as layer size but printing speed effects higher when layer size tends to increases otherwise its effect is not much significant.

Nozzle temperature has a significant effect on surface roughness. When printing temperature is in the range of 180^{0}C to 215^{0}C. After that, it tends to stable and does not have a significant effect on surface roughness.

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