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Parametric Investigations of 3D-Printing of Fused Deposition Manufactured (FDM) Structures of Polylactic Acid (PLA)

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Abstract: 3D printing is technique of fabricating three dimensional objects from a digital design. In order to produce the well quality 3D printed parts for that proper selection of printing parameters are challenging. This research investigates how speed, temperature and layer thickness influence on the flexural (bending) strength of the ASTM D- 790 specimens. A 3D printer with polylactic acid (PLA) filament material has been applied in this investigation. A specimen standard of ASTM D790 has been use as flexural strength test to represents printed part quality. The parametric dependence is investigated through a design of experiments (DOE) as per Taguchi's L9 Array with speed, nozzle temperature and layer thickness. Analysis of variance (ANOVA) is performed to identify significant 3D printing process parameter it is observed that temperature and layer thickness are most significant factor for flexural(bending) strength.
Keywords: 3D printer, FDM, Taguchi method, PLA (polylactic acid) MTS 3-point bend fixture, Flexural strength.

I. INTRODUCTION

Additives manufacturing (AM) is focused on and popular because of tremendous advantages it offers. 3D-Printing, a type of additive manufacturing is a rapidly advancing digital manufacturing technique that produces parts in a layered fashion. The technology has benefits over traditional manufacturing techniques such as being able to produced very complex geometries without any tooling as well as consolidated functional parts and multi-material component with high dimensional accuracy. Among the various type of additive manufacturing(AM) processes fused deposition modeling(FDM) is a technique in which thermoplastic filaments are melted, extruded and deposited.

There are several processing parameters influencing the mechanical properties of parts manufactured with FDM process, recent work focused on studying these process parameters [1]. The term rapid prototyping(RP) refers to a class of technology that can automatically construct physical models from CAD data. In addition, prototypes can be used for design testing. An attempt is made to select optimized process parameters to enhance the part quality, dimensional accuracy micro-hardness and other mechanical properties by using Taguchi method [8].

3D-Printers often to generate parts that are modeled as solid objects in CAD software but when fabricated, the shape includes user specific infill geometries which replace the solid internal volume with more material efficient, structural lattice known as infill [9]. The main advantage of using this technique is that it can produced almost near-net shape produced without building a physical mould to the desired shape of the product.

The desired object can be drawn as a 3D object using computer software packages. AutoCAD and solid work are some of the most industrially popular software platforms for designing complicated prototypes for 3D printing applications [2]. Recently, numerous studies are underway to check the possibility of using composite materials in 3D printing due to the limitation of the exiting materials.

At present, the main types of material for FDM are thermoplastic polymeric materials with low melting point. However, the strength of these materials may not adequate for some high-performance applications [7].

Learning form the exiting publications above Taguchi Method tool of optimization that can be adopted for this current research. several common printing parameters have also been concerned such as layer thickness, density, temperature, infill rate(speed) and orientation angle. The difference between the exiting research and present work were layer thickness, speed and temperature are selected in the range of (0.1,0.2,0.3mm), (20,40,60 mm/sec), (210,220,230^{o}C) respectively as input parameters and flexural strength as response factor and PLA filaments of diameter 1.75mm.

II. METHODOLOGY

A. *Material*

Material used for fabrication of specimen was yellow polylactic acid (PLA) filament with diameter 1.75 mm. This material has operation temperature of 190 ^{0}C to 230 ^{0}C.

B. *Equipments*

1) 3D printer of global 3D type.
2) software Minitab 16 for optimization process.
3) software solid works premium 2014 for drawing specimens having standard ASTM D790.
4) MTS 3-Point flexural (bend) test fixture.

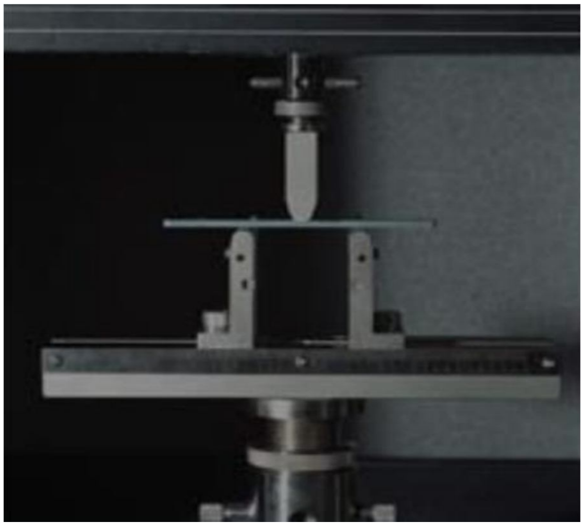

Fig 1: ASTM D790 Flexural properties

C. *Specimen And Preparation*

Specimen for flexural strength test was built by 3D printing machine (Global 3D printer) following a standard of ASTM D790. Process fabrication was carried out as, first drawing a specimen with geometry and shape as described in ASTM D790 for that used solid work software after that save the file in format of. STL. next the file was ready to be inserted in 3D printer. The printing parameter on optimum setting was obtained by using Taguchi's method. There were several combinations setting of printing process parameters have been arrange by DOE.

D. *Parameters, Level And Response*

This research investigates the highest bending strength of printed specimen as response to varying settings of printing process parameter of 3D printer. Thus flexural (bending) strength was selected as response. There were three printing process parameters like speed (mm/s), temperature (^{o}C) layer thickness (mm) was taken as input parameters as shown in table 01.

Table 1. 3D Printing Process Parameters and Levels of Parameters

Sr No	Variable Factor	Symbol	Level 1	Level 2	Level 3
1	Speed (mm/sec)	A	20	40	60
2	Temperature (^{o}C)	B	210	220	230
3	Layer Thickness (mm)	C	0.1	0.2	0.3

Each experiment was repeated twice and flexural strength value was taken for analysis. The specimens are experimentally tested on a universal testing machine with a three-point bend fixture. The flexural strength represents the highest stress experienced within the material at its moment of yield. The flexural strength is denoted by sigma σ.

for a ASTM D790 specimen under a load in a three point in bending set up, flexural strength calculated by using formula

$$\sigma = 3FL/2bd^2$$

where, F = load or force at the fracture point (N)
L = length of supports span
b = width
d = thickness

Table 02: Response Table for Means (Flexural strength)

Experiment no.	Speed (mm/sec)	Temperature (^oC)	Layer Thickness (mm)	Flexural Strength (Mpa)	Mean
1	20	210	0.1	24.9903	24.9903
2	20	220	0.2	30.8832	30.8832
3	20	230	0.3	38.1003	38.1003
4	40	210	0.2	26.9211	26.9211
5	40	220	0.3	33.9574	33.9574
6	40	230	0.1	36.3646	36.3646
7	60	210	0.3	31.0464	31.0464
8	60	220	0.1	35.1149	35.1149
9	60	230	0.2	37.8213	37.8213

III. RESULTS AND ANALYSIS

Flexural (bending) strength is measured for all the samples and it is represented in table 3. in order to investigate the effect of each process parameter on the performance characteristic i.e. flexural (bending) strength "σ", ANOVA analysis is carried out for each set of process parameters. table 3 represents the analysis of variance results for flexural strength.

Table.3 ANOVA calculations for Means (flexural strength).

Sr no	Source	D.O.F.	Adj. S.S.	Adj. M.S.	F	P	Percentage of Contribution
1	Speed (mm/sec)	2	17.365	8.6825	9.16	0.038	9.92
2	Temperature (^oC)	2	144.569	72.2846	76.28	0.013	82.60
3	Layer Thickness (mm)	2	11.184	5.5919	5.90	0.045	6.39
4	Error	2	1.895	0.9477	-	-	1.08
5	Total	8	175.013	-	-	-	100

P-value indicates that temperature and speed are the most important parameters influencing on the flexural strength. The percentage contribution of layer thickness, speed and temperature are 6.39%, 9.92%, 82.60% respectively.
Optimization is carried out by consider "Larger the better" criteria.
fig. 2a and 2b presents the mean of mean and signal to noise (S/N) ratio respectively.
Thus, level 3 of speed, level 3 of temperature and level 3 of layer thickness are the optimum values for maximum flexural strength for the present experimental conditions.

The effect of different process parameters on the flexural strength is explained as follows.

1) *Effect of Speed:* The AVOVA analysis shows that, printing speed has only 9.92% percentage contribution indicating it as less significant parameter. Level 3 of speed (60 mm/s) shows the optimum results of the give experimental conditions.

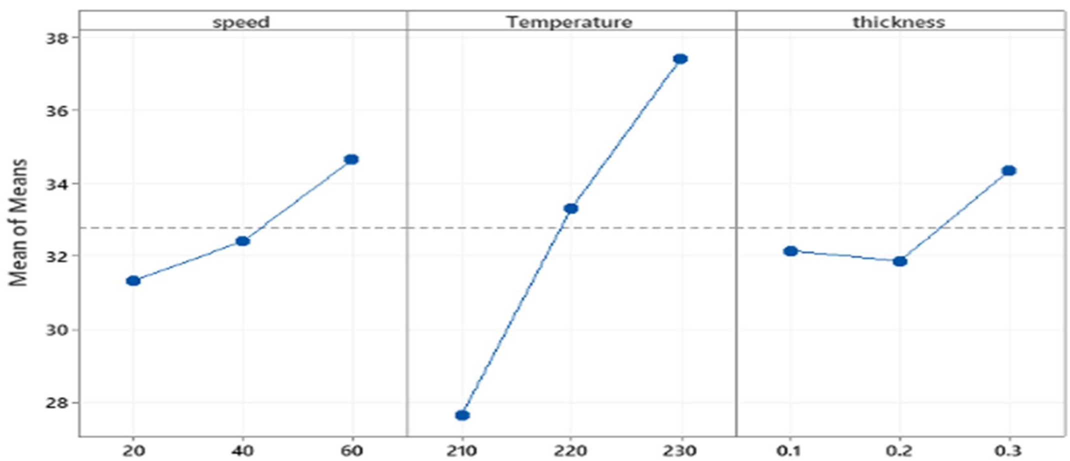

Fig.2a main effect plot for mean

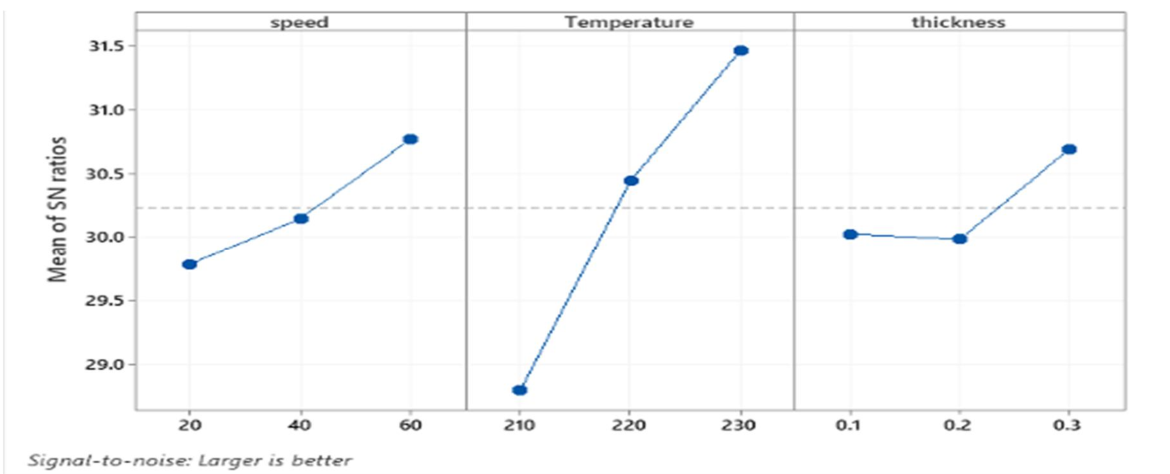

Fig. 2b main effect plot for S/N ratio

2) *Effect of Layer Thickness:* Layer thickness is directly effects to the number of layers needed to print a part hence to printing time [σ]. The thicker layer is the stronger layer in bond in holding the load bending [1]. The effect of layer thickness on the flexural properties was different for each sample. In this study, higher layer thickness (0.3mm) tended to promote higher flexural strength. Hence level 3 of layer thickness indicate as maximum value.
3) *Effect of Temperature:* The analysis shows that temperature has 82.60% percentage contribution indicating it as a most significant parameter. Effect of temperature on response factor i.e. Flexural strength was maximum up to certain limits as shown in fig 2a and fig 2b.

IV. CONCLUSION

A comprehensive study was carried out to investigate the effect of speed, temperature and layer thickness on the flexural strength of the 3D printed specimens. ANOVA analysis shows that the temperature is the most significant parameter followed by speed and layer thickness. Highest flexural strength is achieved at the optimum process parameter of 60mm/s speed, 230 ^{o}C temperature (nozzle) and 0.3 mm layer thickness. This procedure is applied in order to optimize the other additives manufacturing process with various material.

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