|| Volume 6 || Issue 11 || November 2021 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH AND ENGINEERING TRENDS

EXPERIMENTAL INVESTIGATION ON SPECIMENS MAKING AND ANALYSIS OF THE MECHANICAL PROPERTIES OF THE ANTIBACTERIAL PLA PREPARED BY USING THE FUSED DEPOSITION MODELING PROCESS

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Abstract: In this experimental investigation, the tensile, flexural and compression specimens of antibacterial PLA materials were printed by the help of the fused deposition modeling process. The different factors in the process were taken as print speed, in-fill density and layer height. The experiment was organized by selecting the said factors at the three levels using Taguchi L9 method for estimation of the ideal state for the successful printing of the desired number of specimens. The maximum tensile, compressive and flexural strength is obtained as 25.08MPa, 57.29MPa and 36MPa respectively. The useful factors for the printing of the said specimens are print speed, 80mm/sec then infill density, 80% and layer height, 120microns. The experimental outcomes are useful to decide the suitable factors and their working levels for the printing of the specimens and parts for the appropriate use and applications.

Keywords: Anti-bacterial PLA; Larger is better; Fused deposition modeling (FDM); Tensile strength; Compressive strength; Flexural strength.

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I INTRODUCTION

The development of the additive manufacturing technique solved the complexity in manufacturing of complex geometries and parts by its unique method of production which is layer over layer depositions over a dedicated substrate. The widely used thermoplastic material is Carbon fiber reinforced poly-lactic-acid (PLA) for its features like greater strength, lighter weight and produces exceptional dimensional accuracy, firmness and impact resistivity. A number of experiments were executed by other researchers in 3D printing of numerous thermoplastic polymers to make the process more robust and applicable for several industrial applications. The preparation was taken to print continuous fiber reinforced thermo plastic by the application of a high- pressure roller. The prepared specimen was checked for the properties with and without the use of the pressure. The development was found as 644MPa and 401MPa by the function of pressure and 110MPa and 163.13MPa by without application of pressure. But excess pressure was reported damaging the layer of surfaces and the desired quality of the prepared specimen [1]. The Acrylonitrile Butadiene Styrene (ABS) samples were 3D printed following the Taguchi L9 experimental approach. The chosen3D printing process parameters were infill density (40%, 60%, and 80%), print speed (60mm/min, 80mm/min, and 100 mm/min) and layer thickness (100µ, 200µ and 300µ). The tensile strength of ABS 3D printed samples was gained as 25 MPa when the factors are infill density, print speed and layer thickness is 80%, 100mm/min and 0.2mm respectively (2). Wood fiber of 15% and 25% were mixed into the poly-lactic acid and the filament was prepared and effect of wood fiber content on infill orientation was investigated. The larger percentage of wood fiber gave the better mechanical properties (3). Different geometrical forms such as cylindrical, pyramid, cone, cube and sphere were 3D printed by intensively taking the process parameters and their influences on quality of the prepared shapes were checked following the experiments [4]. For the improvement of mechanical properties of general continuous carbon fibers was mixed with PLA by the careful implementation of the double nozzle instrument in the 3D printing process. The strength (tensile) of fabricated thermoplastic was increased from 51MPa to 143MPa. The use and performance of 3D printing processes was investigated and outcomes reported from their research [5]. Another investigation reported that complex and strong structures were possible to give the shape by using the 3D printing technique. The printing technique was becoming more ideal for its ease in operation, quick and economic. The variable parameters were checked for desired properties and their influences were studied for applicable use [6, 7]. The composite specimens were made with the additions of carbon in fiber form by altering the thickness of layers and print direction [8]. Roughness of the surface was measured and the effect of layer thickness, print speed and nozzle temperature upon roughness of printed samples was examined by the operative use of Taguchi L9 methodology [9]. Material extrusion in additive manufacturing technique was utilized to make commercially available PLA specimens. The improvement in the specimen was highlighted [10 - 13]. There were various difficulties faced and tackled by the researchers in identification of the effective process, their factors and influences upon the properties were reported significantly to say the advantages of the chosen processes. The influences of the definite parameters in the chosen process on the strength of poly-lactide (PLA) and ABS samples were highlighted. It was stated as the in-fill density has high influence upon the properties of the fabricated specimens. And finally, it was suggested that the Carbon fiber PLA specimens gives the better results than ABS samples [14 - 16]. The objective is to make tensile, flexural and compression specimens and gets the optimum condition for experimentation and suitable application.

II EXPERMENTAL INVESTIGATION

The FDM method was used in this experiment to prepare the tensile, flexural, and compression specimens of antibacterial PLA material followed by the ASTM standards. The chosen process parameters were for making of the specimens are in-fill density, print speed, and thickness of the layer. The working limits of selected process parameters are shown in the table 1. The experimental design and optimization technique was used as Taguchi L9 approach. As per the design nine numbers of experiments was performed and the testing results were obtained. The complete details are shown in the table 2. The FDM machine arrangement and the tensile, the flexural and compressive specimens are presented in fig.1.

Table 1. 3D printing process parameters & their feasible working limits

S. No.	Parameters	-1	0	1
1	Infill density (%)	40	60	80
2	Print speed (mm/sec)	40	60	80
3	Layer height (µ)	120	180	300

Figure 1. 3D printing machine set-up

Table 2. Taguchi L9 Design matrix and experimental results

Exp. No.	Infill density (%)	Print speed (mm/sec)	Layer height (microns)	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)
1	40	40	120	11.02	28.69	46.94
2	40	60	180	15.92	31.17	40.26
3	40	80	300	25.05	35.12	53.81
4	60	40	180	14.16	26.94	42.64
5	60	60	300	18.78	30.72	44.24
6	60	80	120	24.77	33.97	57.29
7	80	40	300	14.44	30.27	43.53
8	80	60	120	15.91	33.69	44.62
9	80	80	180	25.08	35.58	49.91

III RESULTS AND DISCUSSION

3.1 Taguchi Analysis: Tensile strength versus printing speed, in-fill density and layer height

The analysis of the obtained experimental results of the tensile, flexural and compressive strength of the fabricated antibacterial specimens was followed for the Taguchi and linear model analysis for the showing the most suitable and optimum condition to maximize the chosen mechanical properties. The said properties are fixed and estimated to be greater is better. The response model, tensile strength was estimated for the valuation of root square. It was obtained as 99.75% shows the prediction of the response values was desirable. The table 3 presents the estimated values of the signal - noise ratios (SN ratio) in terms of ANOVA analysis of P and F values of chosen factors for the response model, tensile strength. It represents the response value terminologies are significant because the estimated values are lower than desirable value i.e., 0.05.

Table 3. Analysis of variance for response model tensile strength – Signal to noise ratio

Model terms	Degrees of Freedom	Sum of Square	Adjusted sum of Squares	Adjusted Mean Square	F Ratio	P value	Whether significant or not
Infill density (%)	2	2.1380	2.1380	1.0690	16.28	0.05	Yes
Print speed (mm/sec)	2	47.7603	47.7603	23.8802	363.77	0.003	Yes
Layer height (microns)	2	2.5436	2.5436	1.2718	19.37	0.04	Yes
Error	2	0.1313	0.1313	0.0656			
Total	8	52.5732					

3.2 Linear model analysis: Means versus infill density, print speed and layer height

The table 4 shows the estimated values of mean values of tensile strength in terms of ANOVA analysis of P and F estimations of selected factors. It signifies the response model terms are substantial because the estimated values are less than required value i.e., 0.05. The table 5 shows the valuations of response model terms and it states that the most effective factor is print speed then layer height and finally infill density upon the tensile strength of the printed specimens of anti-bacterial PLA thermoplastic materials. The figure 2 represents the suitable factor is print speed, 60mm/sec, infill density, 80% and layer height 300microns.

Table 4. Analysis of variance for response model tensile strength – Signal to noise ratio

Source	Degrees of Freedom	Sum of Square	Adjusted sum of Squares	Adjusted Mean Square	F Ratio	P value	Whether significant or not
Infill density (%)	2	5.528	5.528	2.764	413.90	0.002	Yes
Print speed (mm/sec)	2	217.274	217.274	108.637	16268.41	0.000	Yes
Layer height (microns)	2	7.201	7.201	3.600	539.17	0.002	Yes
Residual Error	2	0.013	0.013	0.007			
Total	8	230.016					

|| Volume 6 || Issue 11 || November 2021 || ISSN (Online) 2456-0774
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Table 5. Response Table for Signal to Noise Ratios and mean values of the response model: tensile strength

Response table for signal to noise ratio				Response table for means			
Level	Infill density (%)	Print speed (mm/sec)	Layer height (microns)	Level	Infill density (%)	Print speed (mm/sec)	Layer height (microns)
1	24.29	22.35	24.25	1	17.33	13.21	17.23
2	25.46	24.52	25.02	2	19.24	16.87	18.39
3	25.07	27.95	25.55	3	18.48	24.97	19.42
Delta	1.17	5.59	1.30	Delta	1.91	11.76	2.19
Rank	3	1	2	Rank	3	1	2

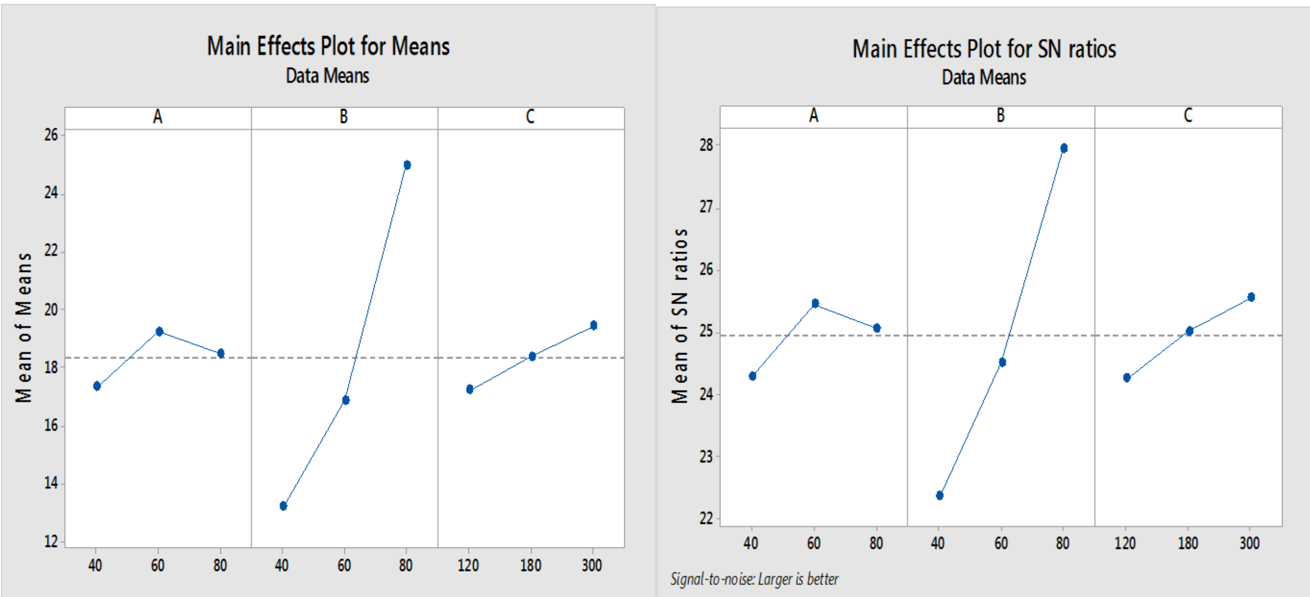

Figure 2 Main effect plot to show the effective factors for SN and mean value of tensile strength; A- print speed, B- infill density, C- layer height

3.3 Taguchi Analysis: Compressive strength versus Infill density (%), Print speed (mm/sec) and Layer height (microns)

The model root square is value is obtained as 99.88% for signal to noise ratios and mean value of the response model compressive strength of antibacterial PLA. The table 6 shows the variance analysis which states that the estimated P- values are less than the desirable value 0.05. It satisfies the response model terms are valid and significant. The obtained tested values are well predicted. The table 7 represents estimations of mean values of response model compressive strength of antibacterial PLA. In the table the layer heights is not a significant factor and have no effect upon the compressive strength. The table 8 shows that the most useful factor is print speed then infill density and lastly layer height. The Figure 3 shows that the effective factors are print speed 80mm/sec, infill density 80% and layer height 120microns produces higher compressive strength.

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Table 6. Analysis of variance for response model Compressive strength – Signal to noise ratio

Source	Degrees of Freedom	Sum of Square	Adjusted sum of Squares	Adjusted Mean Square	F- Ratio	P- value	Significant or not
Infill density (%)	2	0.82325	0.82325	0.41162	126.81	0.008	Yes
Print speed (mm/sec)	2	4.47142	4.47142	2.23571	688.76	0.001	Yes
Layer height (microns)	2	0.14129	0.14129	0.07065	21.76	0.044	Yes
Error	2	0.00649	0.00649	0.00325			
Total	8	5.44245					

3.4 Linear model analysis: Mean value of Compressive strength versus infill density, print speed and layer height

Table 7. Analysis of variance for response model Compressive strength – Mean value

Source	Degrees of Freedom	Sum of Square	Adjusted sum of Squares	Adjusted Mean Square	F - Ratio	P -value	Significant or not
Infill density (%)	2	10.5094	10.5094	5.2547	108.77	0.009	Yes
Print speed (mm/sec)	2	58.7382	58.7382	29.3691	607.92	0.002	Yes
Layer height (microns)	2	1.4433	1.4433	0.7216	14.94	0.063	No
Error	2	0.0966	0.0966	0.0483			
Total	8	70.7874					

Table 8. Response Table for Signal to Noise Ratios and mean values of the response model: Compressive strength

Response table for signal to noise ratio				Response table for means			
Level	Infill density (%)	Print speed (mm/sec)	Layer height (microns)	Level	Infill density (%)	Print speed (mm/sec)	Layer height (microns)
1	29.98	29.13	30.11	1	31.66	28.63	32.12
2	29.66	30.06	29.84	2	30.54	31.86	31.23
3	30.40	30.85	30.09	3	33.18	34.89	32.04
Delta	0.74	1.72	0.27	Delta	2.64	6.26	0.89
Rank	2	1	3	Rank	2	1	3

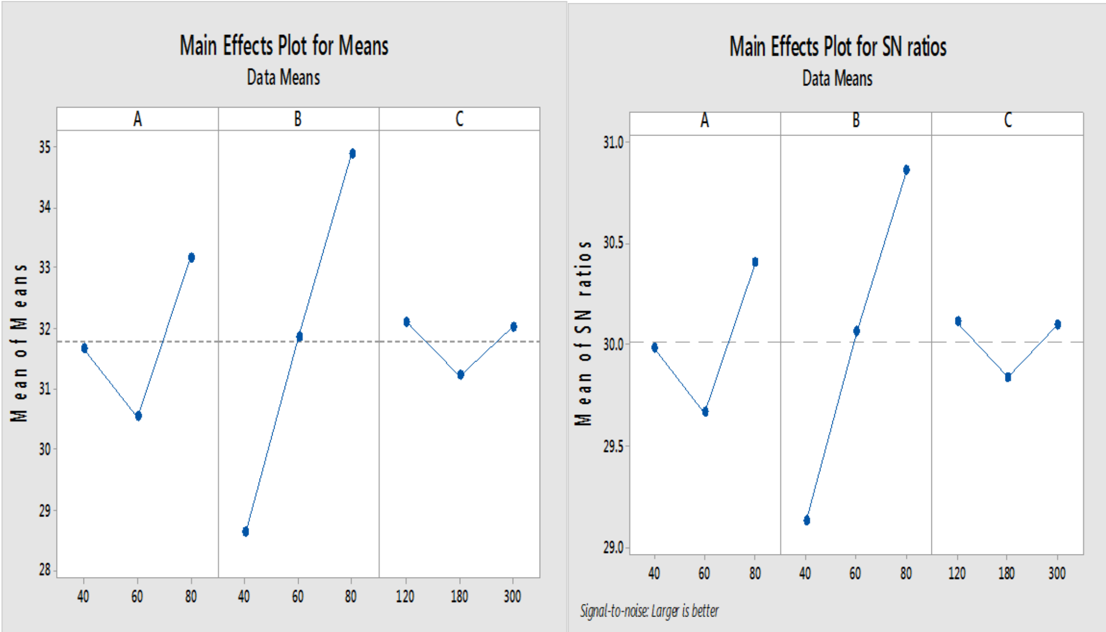

Figure 3 Main effect plot to show the effective factors for SN and mean value of compressive strength; A- print speed, B- infill density, C- layer height

3.5 Taguchi Analysis: Flexural strength versus Infill density, Print speed and Layer height

The model root square value is 99.84% for signal to noise ratios and mean value of the response model compressive strength of antibacterial PLA. It shows that the experimental model is well predicted. The table 9 demonstrates the analysis of variance which states that the assessed P- values are less than the desirable value 0.05. It satisfies the response model relations are effective. The table 10 represents the valuations of mean values of response model flexural strength of antibacterial PLA which shows that the chosen factors and its working limits are significant. The table 11 shows that the most effective factors and that is print speed then layer height and finally infill density. The Figure 4 illustrates that the operative factors are print speed 60mm/sec, infill density 80% and layer height 120microns gives greater flexural strength.

Table 9. Analysis of variance for response model Flexural strength – Signal to noise ratio

Source	Degrees of Freedom	Sum of Square	Adjusted sum of Squares	Adjusted Mean Square	F- Ratio	P -value	Significant or not
Infill density (%)	2	0.14927	0.14927	0.07463	11.55	0.05	Yes
Print speed (mm/sec)	2	6.44052	6.44052	3.22026	498.40	0.002	Yes
Layer height (microns)	2	1.43433	1.43433	0.71716	111.00	0.009	Yes
Error	2	0.01292	0.01292	0.00646			
Total	8	8.03703					

3.6 Linear model analysis: Mean value of Flexural strength versus infill density, print speed and layer height

Table 10. Analysis of variance for response model Flexural strength – mean value

Source	Degrees of Freedom	Sum of Square	Adjusted sum of Squares	Adjusted Mean Square	F- Ratio	P - value	Significant or not
Infill density (%)	2	6.224	6.224	3.112	93367.00	0.000	Yes
Print speed (mm/sec)	2	201.256	201.256	100.628	3018837.00	0.000	Yes
Layer height (microns)	2	43.005	43.005	21.503	645079.00	0.000	Yes
Error	2	0.000	0.000	0.000			
Total	8	250.486					

Table 11. Response Table for Signal to Noise Ratios and mean values of the response model: Flexural strength

Response table for signal to noise ratio				Response table for means			
Level	Infill density (%)	Print speed (mm/sec)	Layer height (microns)	Level	Infill density (%)	Print speed (mm/sec)	Layer height (microns)
1	33.38	32.93	33.86	1	47.00	44.37	49.62
2	33.56	32.67	32.89	2	48.06	43.04	44.27
3	33.24	34.58	33.44	3	46.02	53.67	47.19
Delta	0.31	1.91	0.98	Delta	2.04	10.63	5.35
Rank	3	1	2	Rank	3	1	2

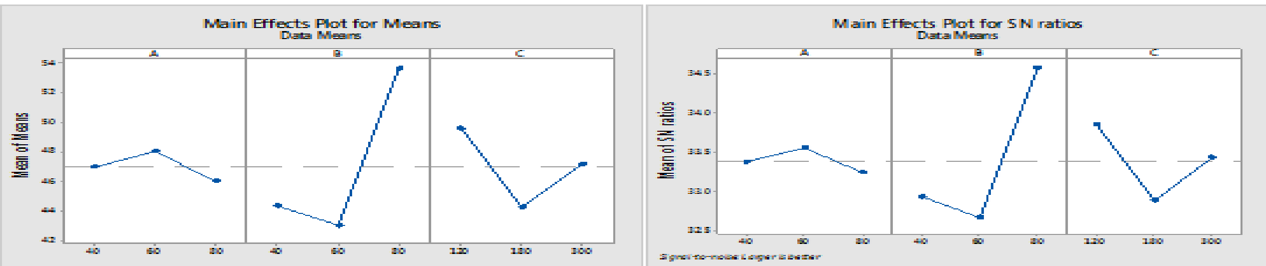

Figure 4 Main effect plot for estimated values of mean and SN ratios of the response model: flexural strength; A- print speed, B- infill density, C- layer height

CONCLUSION

The antibacterial PLA thermoplastic material was selected for the production of tensile, flexural and compressive specimens by using the FDM process. The most effective factor for the printing of the tensile specimen is print speed 60mm/sec then layer height 300microns and finally infill density 80. The maximum tensile strength is gained as 25.08MPa.The useful factors for the printing of compressive specimens are print speed 80mm/sec then infill density 80% and lastly layer height 120microns. The higher compression strength of the antibacterial PLA is obtained as 57.29MPa. The most useful factor is print speed 80mm/sec then layer height80% and finally infill density120microns. The maximum flexural strength is attained as 36MPa.

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