Influence of Process Parameters on Tensile Strength of Additive Manufactured PLA Parts using Taguchi Method

Y. Venkata Narayana, N Pruthvi Reddy

Abstract: — Influence of layer thickness nozzle temperature and angle on tensile strength of PLA fabricated with FDM (FFF) was experimentally investigated. Polylactic Acid (PLA) is a semi-crystalline and bio-friendly thermoplastic polymer has identified as important material in different applications due to its mechanical characteristics. Fused Deposition Modeling (FDM) is a one of the proved technology in Fused Filament Fabrication (FFF) technique in additive manufacturing process. In present investigation different specimens were fabricated using FDM technique with different layer height and different layer angles for finding influence of these manufacturing parameters on tensile strength of the specimen. Specimens were fabricated and tested as per ASTM D638 standard. It is clearly observed that tensile strength is more for +45^0/-45^0 layer angle than the +0^0/-0^0 layer angle for a given layer height(h=0.10 mm, h=0.15mm and h=0.20mm).The TAGUCHI analysis is carried with nozzle temperature, layer thickness and angle finding optimal values. It has been observed that, the optimal parameter is angle, which is equal to 30^0.the ANOVA variation of angle layer with tensile strength has been observed that 18.10-31.90.

Keywords: specimen preparation, 3D-printing, testing machine, orthogonal array, TAGUCHI analysis, ANOVA.

I. INTRODUCTION

F or the last 3-decades additive manufacturing process has been increased more attention in manufacturing industry, specifically to create part models, prototypes of complex geometry with customized material properties from 3D CAD models. Additive manufacturing process a small quantity of novel components without special tooling and with less material wastage, less lead time and less manufacturing cost can be produced. Additive Manufacturing technology, initially applied to fabricate prototypes or inspection tools, and recently even in final production. In Additive manufacturing technologies, the functional end use products fabrication has become the new development and it has been bit by bit applied to deliver parts in little or medium amounts. Added substance assembling finds wide applications in manufacture of aviation, engine vehicle, restorative/dental, mechanical machine, and customer items etc. To determine suitable material deposition and part orientation in additive manufacturing, several attempts has been made by different researchers [1,2,3,4,5,6,7,8,11-15] for achieving accuracy, built up time, support structure. Due to rigorous efforts from the researchers more and more industries have inclined to use Additive manufacturing technologies to decrease lead time to manufacturing, improve product quality and performance and to decrease production cost. . Alexander et al. [1] studied a cost model in Fused Deposition Modeling [FDM] and identified that the finished cost and support removal cost contributes the more total post-processing cost of the Additive Manufacturing process. A similar examination among unidirectional and bidirectional layer point has been completed at a mix of various layer structure and raster width by Shilpesh R et al.[17]. Taguchi has envisioned another method for coordinating the arrangement of examinations which reply upon especially described guidelines. This methodology uses an uncommon course of action of displays called even bunches. These standard shows stipulate the technique for coordinating the important number of tests which could give the full information of the significant number of factors that impact the introduction parameter. The center of the even bunches procedure lies in picking the level blends of the information structure factors for every investigation. The methodology is unmistakably known as the factorial structure of assessments. A full factorial arrangement will recognize each possible blend for a given plan of components. Since the most part incorporate a basic number of components, a full factorial arrangement realizes a colossal number of preliminaries. To reduce the amount of tests to a business like level, only somewhat set from all of the possible results is picked. The procedure for picking a foreordained number of examinations which conveys the most information is known as a midway part attempt. Taguchi built up an exceptional course of action of general structure decides for factorial examinations that spread various applications.

II. PROCEDURE FOR DESIGN OF EXPERIMENT

A productive technique for trial arranging is structure of examinations (DoE), which joins the symmetrical exhibit created by taguchi to gather measurably noteworthy information with the base conceivable number of redundancies. Here L9 array was chosen, and the degrees of the parameter. Before deciding on the orthogonal array, the minimum variety of experiments to be conducted shall be fixed based on the total wide variety of stages of freedom. The minimum variety of experiments that must be run to learn about the factors shall be more than the total degrees of freedom available.

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In counting the complete degree of freedom the one degree of freedom to the normal suggest of the response below study. The number of levels of freedom related with every element below learns about equals one less than the quantity of levels available for that factor. Hence the whole ranges of freedom barring interaction impact are 1 + as already.in case of eleven independent variables, every two levels, the whole ranges of freedom is 12.

An L9 orthogonal satisfies this requirement. Once the minimum range of experiments is decided, in additional determining of orthogonal array is based on the quantity of unbiased variables and wide variety of component ranges for each independent variable. Layer thickness, angle, nozzle temperature.

A. SPECIMEN PREPARATION

Polyamide powder (PA12) pliable example, 115 × 6 × 4 mm3, as recommended by ASTM standard of D638 was utilized for the trials. This material was chosen for the trials as it very well may be utilized for medical applications. Increased stiffness and heat resistance are some advantages. Polylactic Acid (PLA), is a semi-crystalline and bio-degradable thermoplastic polymer and has become very popular among the additive manufacturing material due to its mechanical characteristics and wide variety of applications. In present study PLA samples were prepared with Fused Filament Fabrication(FFF) technique using JULIA 3D printing machine for finding the tensile strength of the material with different parameters like layer thickness or height and layer angle(raster angle) with reference to the machine reference angle. To fabricate the specimen 1.75 mm diameter single extruder printer with Factorial work software was used. The PLA filament material was extruded and deposited at 2100 C from the extruded nozzle with 100% infill density and rectilinear pattern. 600 C bed temperatures was settled and upon completion, thin metal blade has been used to remove the spacemen from the build plate.

B. TESTING PROCEDURE

ASTM D638 standard tensile test specimen was used for preparing with FDM (FFF) technique, because the PLA sample behaves like a an isotropic material. The dimensions and geometry of the specimen as per above standard for conducting tensile test the PLA test specimens before testing and after testing. The tensile test was carried out using TNE-2.5, MCS-25T Universal Testing Machine (UTM). The Universal Testing Machine consists of displacement controlled ram speed of 1.5mm per minute and load cell of 25KN with data logging system to record the data for measurement and analysis of purpose. Specially jigged fixtures are used for fixing the specimens in the UTM machine very accurately without losing its accuracy. The load-displacement, stress-strain data were recorded and plotted with software which was interfaced with the machine. set up with the specimen before testing and specimen after testing respectively.*A number of tests have been carried out for finding the influence of layer/play height and layer angle (Raster angle) on the tensile strength of Polylactic Acid (PLA) samples fabricated with FDM (FFF) technique. Six samples were taken with different layer angles (+0^0/-0^0) and (+45^0/ (-45^0) and with different layer heights (h=0.1mm, h=0.15mm and h=0.20mm) for investigating tensile strength using Universal Testing Machine (UTM). The Fig.III shows the effect of the layer height with different layer angles*

It is also observed that the as the thickness/ height of the layer increases for a given specimen the tensile strength of the specimen decreasing.Fig.I (a), (b) and (c) also shows that for a given layer thickness/height (h=0.1mm, h=0.15mm and h=0.20mm) as the layer angle increases from (+0^0/-0^0) to (+45^0/ (-45^0) the tensile strength of the specimen increasing.

C. TAGUCHI ANALYSIS

A TOA (Taguchi orthogonal array) design was used to recognized the optimal conditions and to select the parameters which has most principal influence on particle size of BSA nano particles. the structure of TOA design and the results is measured by PCS. The variance of the particle size was calculated. The purpose of the analysis of variance is identify factors which significantly affects quality characteristic.. In the analysis of taguchi method we are going to take mainly three parameters they are layer thickness, angle, and nozzle temperature.

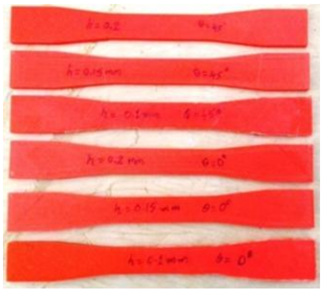

Fig I Specimen before testing Fig II after load applied

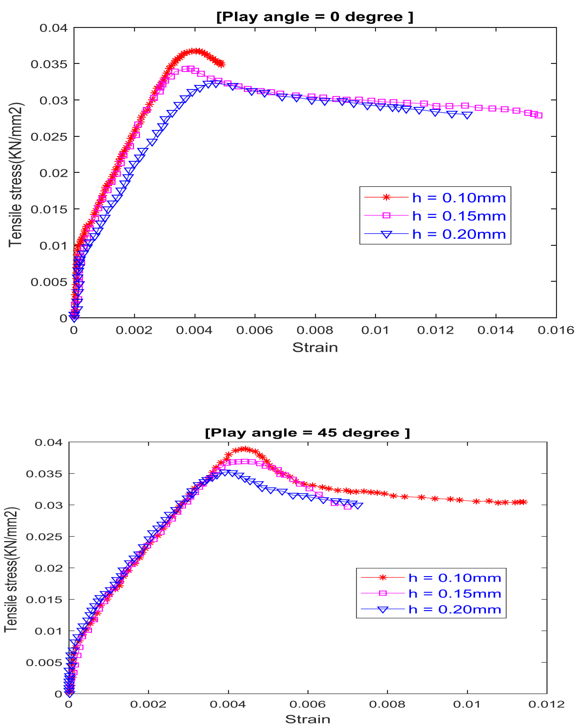

Fig.III Influence of Layer angle on Layer height

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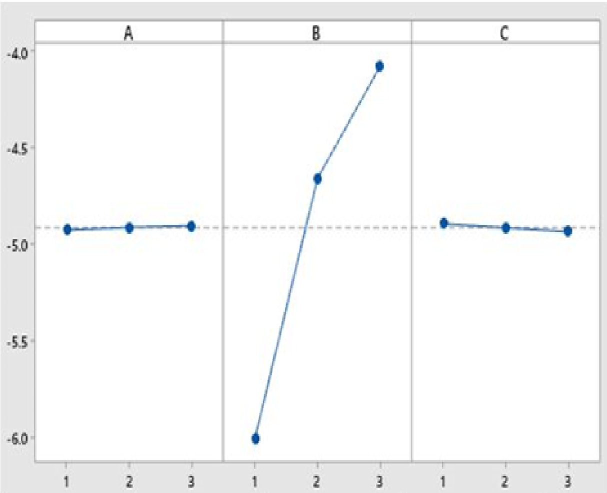
Theses parameter is taken to get the design error and which parameter is affected more due to the response factor tensile strength. In the orthogonal array, we consider L9 because due to the more expensive we have 9 level of tensile strength.. In Taguchi's method, layer thickness, angle, nozzle temperature are used as primary parameter, and tensile strength is used as a response factor.

Table I primary parameters
In Taguchi's analysis, after the value inserted

Layer thickness	Layer orientation	Nozzle temperature
0.10 mm	0^0	230^0 C
0.15 mm	30^0	235^0C
0.20 mm	45^0	240^0C

LAYER	ANGLE	NOZZLE TEMPERATURE	TENSILE STRENGTH
0.10	0	230	0.09583
0.10	30	235	0.09852
0.10	45	240	0.10430
0.15	0	235	0.03227
0.15	30	240	0.03321
0.15	45	230	0.03523
0.20	0	240	0.03479
0.20	30	230	0.03526
0.20	45	235	0.03686

Fig IV Tensile strength value after experiment



Level		A	B	C
1		65.05	58.80	63.80
2		65.05	66.30	65.05
3		65.06	70.05	66.30
Rank		3	1	2

Fig. V Main effect of S/N ratio based on normal is best

In taguchi analysis, the main effect of layer thickness, angle, nozzle temperature effect with tensile strength will differ with some apeak changes. Delta B(angle) differs more with tensile strength so the main effect of specimen is with angle with tensile strength as shown in Fig.V This is based on NORMIAL IS BEST analysis which can give an S/N ratio with perfect analsis. Normial to best analysis gives the value analysis of the parameter which can be high s/n ratio values. The value can differ with the s/n ratio parameter can change the design. Delta is used to differ the value of levels which can arrange the s/n ratio in varaiable throught of arranging level. . In taguchi analysis, the main effect of the parameter effected by the response factor tensile strength small changes to the larger value are shown in this main effect this can be high value. The differece between the normal to smaller the variation of the min value to high can be differed to the extreme value. Change in signal value to noise this s/n values differce throught response factor which be high effect value.

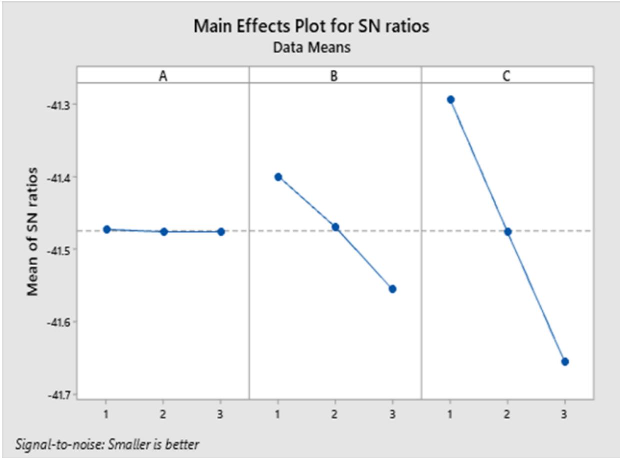
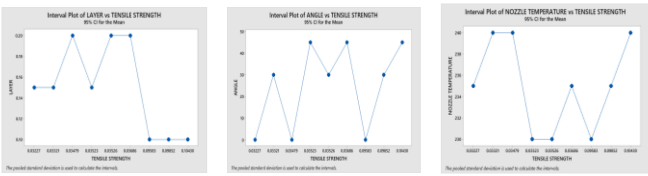


Fig. VI main effect of s/n smaller is best

D. ANOVA ANALYSIS

We present the output from the one-way ANOVA, the box plots is used to check significant outliers. The output Minitab produces Shapiro-Wilk test to determine normality and output Minitab produces Levine's test for homogeneity of variances.



a) b) c)

Fig. VII anone way anova layer vs tensile strength a)Layer, b) Angle c) Nozzle Temperature

In one-way ANOVA where the layer vs tensile strength difference between them with a 95% accurary of mean with the standard derivation. This is derived to find the fluctuation betwwen the layer and tensile strength in ANOVA. Angle vs tensile strength difference are used to check the mean plot value btween them. Angle-tensile strength the effect are more so the standard deviation are made to find the intervels with pin point locationas shown in Fig.VII. In ANOVA, nozzle temperature vs tensile strength differnce are used to check the mean plot value between them as shown in Fig.VIII. A Pareto chart gives plotted data which are arranged in largest to smallest. It identify the frequently occurring defects, the most common defects are detected through this pareto chart as shown in Fig.XI.

The optimum point between the layer vs Tensie strength with 95% CI is observed -6.7451, 7.0451, the same values with angle vs Tensile strength and nozzle temperature vs Tensile strength are (18.10, 31.90) and (228.10, 241.90) respectively. From the ANOVA analysis it has been found that the most influenced parameter on tensile strength is found to be angle as shown in Table II.

Table .II ANOVA analysis, Pooled St.Dev = 10.1551

Factor	N	Mean	StDev	95% CI
Layer	9	0.1500	0.0433	(-6.7451,7.0451)
Angle	9	25.00	19.84	(18.10, 31.90)
Nozzle Temperature	9	235.00	4.33	(228.10, 241.90)
Tensile Strength	9	0.0563	0.0326	(-6.8388,6.9513)

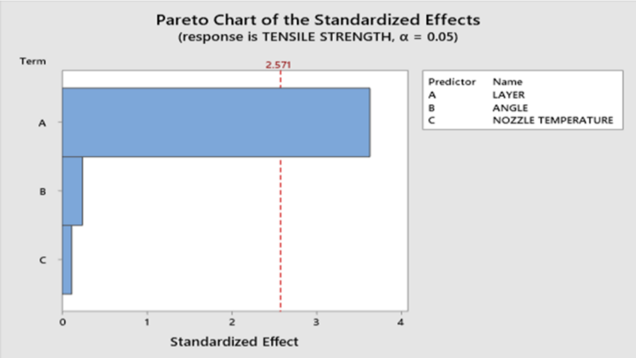


Fig. viiI pereto chart of standardized effect

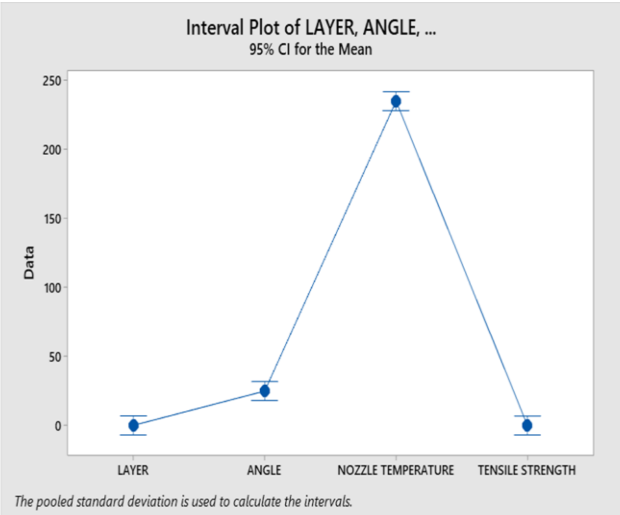


Fig. iX anova for all parameters

III. RESULT AND DISCUSSION

A number of tests have been carried out for finding the influence of layer/play thickness and layer angle (Raster angle) on the tensile strength of Polylactic Acid (PLA) samples fabricated with FDM (FFF) technique. Six samples were taken with different layer angles ($+0^0$ /-0^0) ,(30^0/-30^0) and ($+45^0$/-45^0) and with different layer thickness (h=0.1mm, h=0.15mm and h=0.20mm) for investigating tensile strength using Universal Testing Machine (UTM). The Fig.IV shows the effect of the layer height with different layer angles.it is evident that for a given thickness as you change the angle from 0^0 to 45^0 with reference to the horizontal axis of the machine tensile strength of the specimen increasing.

Layer Thickness = 0.15 mm Orientation =300 Nozzle Temperature = 2400 C Tensile Strength = 0.03321 Snra1 = -41.2765, Mean1 = 67.5458

IV. CONCLUSION

a) Taguchi Analysis with Orthogonal Array has been carried out for finding optimal value in 3D printing PLA with FDM
b) Nozzle temperature, angle, layer thickness are chosen in taguchi analysis as independent variable.
c) Experiment has been carried out as ASTMD638 for finding tensile stress with specimen with different combinations of variable.
d) After performing taguchi analysis optimal process parameter is found out of Nozzle temperature, angle, and layer thickness. It is observed that 30^0 layer angle is optimal angle.
e) ANOVA also performed for finding variance of optimal independent variables and it is evidence that the range of angle is 18.10-31.90 from the optimal value

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He is expert in Parametric modeling software Creo. 2.0., and he carried out several projects based on the finite element software and post processing software's. He published 2 national conference based on finite element analysis of bus body chassis and power transmission. He also a member in Society of Automobile Engineering and ISTE