INVESTIGATION OF MECHANICAL PROPERTIES OF POLY LACTIC ACID EMBEDDED NATURAL FIBRES STRUCTURES MADE USING FUSED DEPOSITION MODELLING

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Abstract - *Fused deposition modelling or FDM is most popular method of manufacturing and is widely accepted all around the world. Fused deposition modelling is a subpart of additive manufacturing or AM as is more popularly known which can be used to make intricate and complex structures very easily. In this research, laminates are made using Natural fibres which included the plant as well as animal fibres. The plant fibres used in the current study is cotton and the Animal fibre used is sheep wool. The fibres are embedded into the layers of Polylactic acid randomly. The samples are prepared using the Taguchi orthogonal arrays and Tensile and flexural strength of the samples is measured using Universal Tensile testing machine. The parameters taken into account were the infill density, the raster angle and the number of laminates. The achieved data is statistically studied using sum of squares. The effect of the parameters on the tensile and flexural strength is studied and the ANOVA analysis is also done which is used to study the contribution of the factors. Trends revealed that the maximum Tensile and flexural is obtained at the 4 number of laminates, 100 % of infill density and 90° of raster angle for both. The raster angle was in fact nearly an insignificant parameter in both cases. Trends of the both strength revealed that the maximum strength is at maximum number of laminates and maximum infill density which means it is directly proportional. The contribution of the parameters was found to be accurate at 95% confidence level and the raster angle came out to be nearly insignificant.*

Keywords— Natural fibres, Additive Manufacturing, Polylactic Acid, Fused deposition modelling, Tensile strength, Taguchi, laminates

1. INTRODUCTION

Major concern in today's manufacturing business is the reduction in the process cycle time and development of new product design, so as to survive and compete in this fast-growing market globally. So, to accomplish this, industries are focusing on new traditional methodologies that is faster and paced fabrication techniques. Additive manufacturing is considered as one of the latest development adopted by the industries specifically automobile industry as it reduces the lead time in developing the prototype [1]. This AM technology consist of various processes which includes fused deposition modelling (FDM), Laminated object manufacturing (LOM), selective laser sintering (SLS) etc. [2] that uses CAD model to fabricated 3D samples. The machine used in AM fabricate model automatically in simple two steps, first is 2D CAD model generally that represents cross section of model that in series of layer will form the part model and second is that the generation of the desired vectors for the axis of machine. The material is then deposited layer over the preceding layer for fabrication of the 3D model part [3][4].

Despite being advantageous in fabricating of complex models and reduction in lead time and product development time, there are some demerits of the process that need to be considered before its application the particular industry. RP technology has been found to be successful in improvement of model surface quality, strength of the model, fabrication time, wastage in the process, repeatability, accuracy and precision [6][7]. These days FDM process has found its application in various areas like household parts, medical area, computers, automobiles, construction and many more [8]. Now it is quite easy in fabrication of the complex structures due to the revolution that FDM has brought in the AM without the much assistance of any conventional tools. The most common applications of FDM is concept modelling, batch production and making of prototype [9]. It has been seen absolute reduction in the cycle time while developing the complex shapes but there are some process parameters like surface quality, strength of the part, dimensional accuracy of the fabricated part and build quality that need to be addressed [7] [10]. A large number of research has been carried to for improvement of dimensional accuracy, strength, surface roughness etc. by varying the process parameters in machine and by using various optimization tools. The effect of control factors like hatch spacing, over-cure, part location on the machine platform and layer thickness have been studied by Zhou et al. [11]. The results of this research concluded that for maximum accuracy in fabricated part geometrical feature has a great role. Venkata et al. [12] have studied the effect of orientation and found that it largely influences the dimensional accuracy, strength, build time and cost of fabrication. As per the literature survey various researchers have been using different combination for fabrication and finding out mechanical properties [13] [14] [15].

2. EXPERIMENTATION

In this research work PLA filament of 1.75mm in diameter was utilized which is bio-compatible. System used for printing of samples was Acuu-FDM 250 Di system and it was carried out at 220°C of Melting temperature, 30mm/s of Nozzle Speed and 0.4mm of layer thickness. Animal fiber (wool) and plant fiber (cotton) were obtained from local industries and stores and then treated chemically as per the standard. Fabrication of tensile and flexural sample were as per standard ASTM-D638 and ASTM-D790 respectively which is shown in Figure 1. Figure 2 shows preparation of the specimen layer over the layer and layer of both natural fiber in 50:50 proportion is manually placed between the layers of PLA matrix.

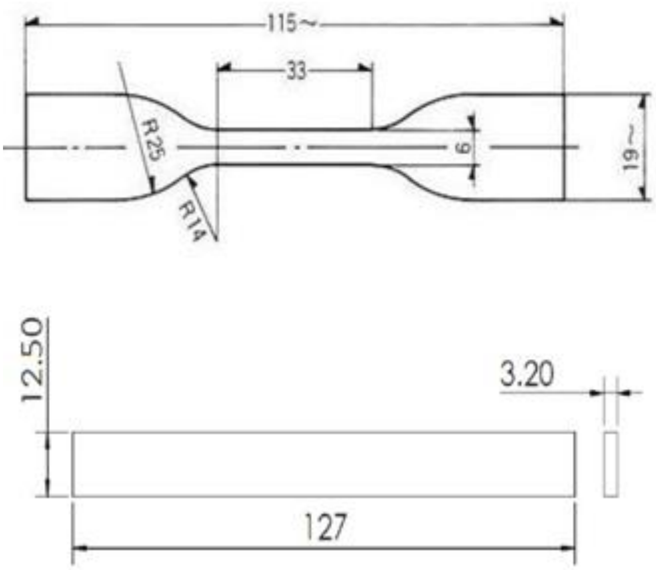

Figure 1. ASTM standard sample for Tensile and flexural testing (dimensions in mm)

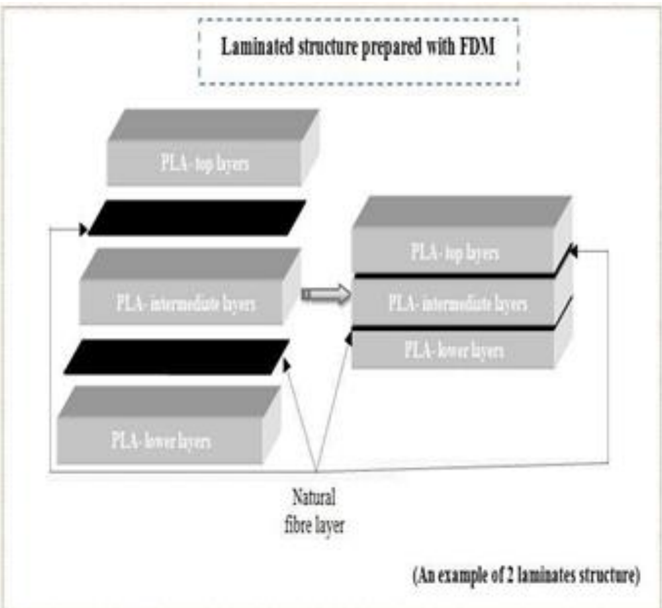

Figure 2. Layering and embedding process to develop samples

Process parameters and generation of the G-codes file are done by a software and timely controlling of the variables are done. Solid Works is used for preparation of geometry of samples and then STL or Stereolithographic file is used for generation of G-codes. The process parameters which were used in this research were infill density, raster angle and number of laminates. The levels of Parameters were decided on the basis of a pilot study and three levels of each of the parameter were taken. Taguchi L9 orthogonal array was used as we had 3 factors and three levels i.e. 3^3. The Parameters and their taken values are shown in the Table. 1 and also the control log is made using these parameters to determine the Tensile and flexural strength of the developed samples.

Table. 1 Input Variables

S. No.	No. of laminates	Infill Density (%)	Raster Angle (Degree)
1.	2	30	0/90
2.	3	65	45/135
3.	4	100	30/120

Table. 2 Control LOG of Experiment

S. No.	No. of laminates	Infill percentage (%)	Raster Angle (degree)
1	2	30	0/90
2	2	65	45/135
3	2	100	30/120
4	3	30	45/135
5	3	65	30/120
6	3	100	0/90
7	4	30	30/120
8	4	65	0/90
9	4	100	45/135

3. RESULTS AND DISCUSSION

3.1. TENSILE TESTING

Universal Tensile Testing machine was used to test the samples. The samples were made as per the ASTM standard and therefore we were able to lock the flat pieces in the Jig or the clamps. The process of testing is shown in Fig 3. Nine samples were tested as per the orthogonal array which would be used to calculate the SN Ratio and plot the trend of parameters on the Output response which is the tensile strength.

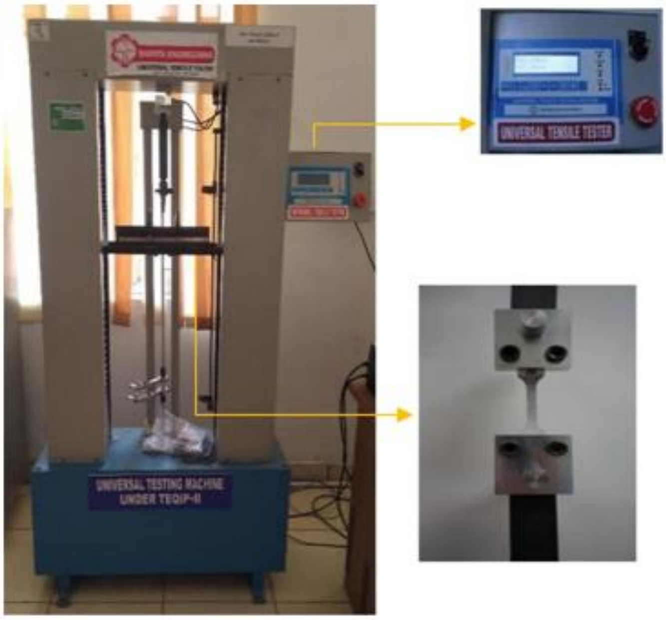

Fig. 3 Tensile testing in Universal Tensile Testing Machine

The effects of different parameters i.e. the raster angle, nozzle speed and number of laminates on the Tensile strength is studied. The SN Ratio of the Tensile Strength was calculated at different combination of the parameters as given by the Taguchi design array and the same is tabulated in Table. 2 and the effect of parameters or the trends are revealed in Fig. 4. The output response in our case i.e. Tensile strength is which is required the maximum would be Larger-is-Better.

Table No. 3 S/N ratio for tensile strength

S. No.	No. of laminates	Infill percentage (%)	Raster Angle (degree)	Strength at peak (MPa)	S/N Ratio
1	2	30	90	44.76	33.01
2	2	65	135	46.08	33.27
3	2	100	120	51.22	34.18
4	3	30	135	47.98	33.62
5	3	65	120	53.61	34.58
6	3	100	90	60.30	35.60
7	4	30	120	49.31	33.85
8	4	65	90	52.40	34.38
9	4	100	135	62.66	35.93

The control log of Experiment using Taguchi L9 design for 3^3 array and the SN Ratio is shown in Table. 3.

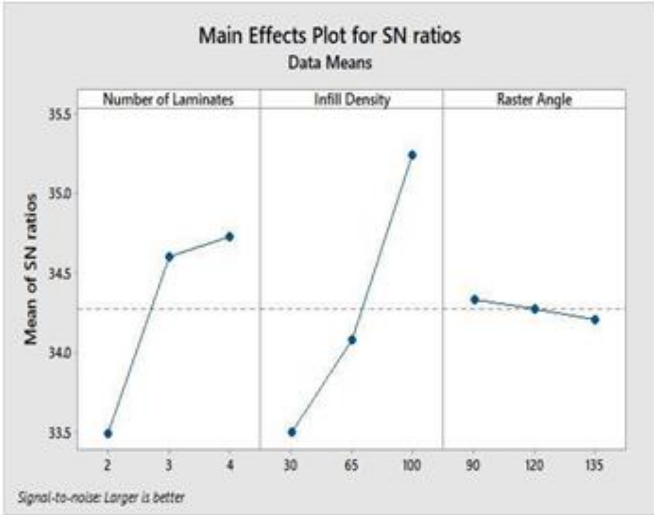

Fig. 4 Trends for the Tensile Strength

The trends for the Tensile strength are analyzed and shown in Fig. 4 and it is revealed that as we increase the number of laminates, the tensile strength is increased simultaneously. This trend is obvious that if we will have more number of laminates, the strength will be increased as it will be harder to break a specimen with more number of laminates. Same is the trend with the infill density which is the space between two adjacent paths of the nozzle in this case which is joint. With the increase in infill density the tensile strength is increased. This may be due to the fact that the material is packed more densely and the bonding is therefore stronger which helps increase the tensile strength. The Tensile strength is more at a raster angle of 90° but as it is visible from the trend, the raster angle does not have much effect on the Tensile Strength and thus its effect is taken as negligible which means that the raster angle is a nearly insignificant parameter. In addition, ANOVA or Analysis of Variance is also performed on the process to know the contribution of each parameter. The contribution is checked at a confidence level of 95% using Fisher tables and the results were found to be in the range. The ANOVA analysis is shown in Table 4.

TABLE 4 ANOVA Analysis for Tensile Strength

Factor	DOF	Sum of Squares	VarX	Fisher value	P value	% Contri
Number of Laminate	2	2.5796	0.309	29.09	0.017	32.85
Infill Density	2	4.1265	0.128	31.74	0.031	52.56
Raster Angle	2	0.0233	0.011	2.88	0.258	0.68

Residual Error	2	0.8388	0.004			3.89
Total	8	7.8508				100

The ANOVA analysis reveals that the Infill density has the maximum contribution on the tensile strength and is 32.85%. The number of laminates also has a significant effect on the output response and its effect is calculated to be 32.85%. The raster angle is a nearly insignificant parameter. The error came about to be about 3.89%.

3.2. FLEXURAL TESTING

It was performed on same testing machine where tensile was performed as per the ASTM standard. For testing these flexural samples, jigs and fixtures are changed and then clamped to carry out the test. The process of testing is shown in Fig 5. Rest of the test and analysis are same as tensile test like number of samples, calculation of SN Ratio and plotting of trends of output response.

Fig. 5 Flexural testing in Universal Tensile Testing Machine

The effects of different parameters i.e. the raster angle, nozzle speed and number of laminates on the Flexural strength is studied. The SN Ratio of the Flexural Strength was calculated at different combination of the parameters as given by the Taguchi design array and the same is tabulated in Table. 5 and the effect of parameters or the trends are revealed in Fig. 6. The output response in our case i.e. Flexural strength is which is required the maximum would be Larger-is-Better.

Table No. 5 S/N ratio for Flexural strength

S. No.	No. of laminates	Infill percentage (%)	Raster Angle (degree)	Strength at peak (MPa)	S/N Ratio
1	2	30	90	16.02	24.0933
2	2	65	135	18.44	25.3152
3	2	100	120	19.49	25.7962
4	3	30	135	17.81	25.0133
5	3	65	120	20.15	26.0855
6	3	100	90	23.65	27.4766
7	4	30	120	19.30	25.7111
8	4	65	90	21.65	26.7092
9	4	100	135	24.60	27.8187

The control log of Experiment using Taguchi L9 design for 3^3 array and the SN Ratio is shown in Table. 3

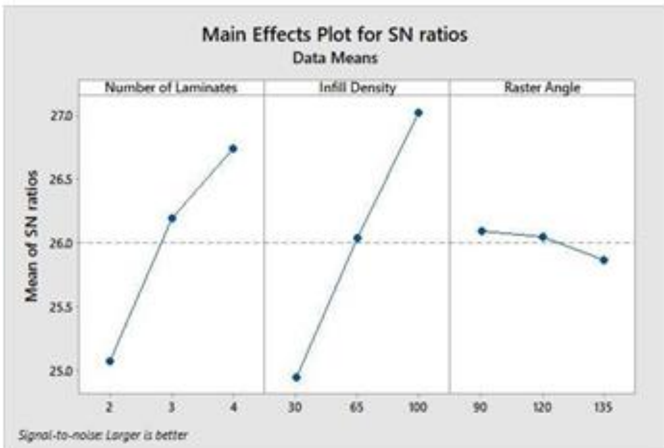

Fig. 6 Trends for the flexural Strength

The trends for the Flexural strength are analyzed and shown in Fig. 4 and it is revealed that as we increase the number of laminates, the bending strength is increased simultaneously. This trend is obvious that if we will have more number of laminates, the strength will be increased as it will be harder to break a specimen with more number of laminates. Same is the trend with the infill density which is the space between two adjacent paths of the nozzle in this case which is joint. With the increase in infill density the tensile strength is increased. This may be due to the fact that the material is packed more densely and the bonding is therefore stronger which helps increase the tensile strength. The flexural strength is more at a raster angle of 90° but as it is visible from the trend, the raster angle does not have much effect on the Tensile Strength and thus its effect is taken as negligible which means that the raster angle is a nearly insignificant parameter. In addition, ANOVA or Analysis of Variance is also performed on the process to know the contribution of each parameter. The contribution is checked at a confidence level of 95% using Fisher tables and the results were found to be in the range. The ANOVA analysis is shown in Table 4.

TABLE 6 ANOVA Analysis for Tensile Strength

Factor	DOF	Sum of Squares	VarX	Fisher value	P value	% Contri
Number of Laminate	2	4.3859	2.1929	27.1	0.036	39.15
Infill Density	2	6.5656	3.2828	40.6	0.024	58.61
Raster Angle	2	0.0884	0.0441	0.55	0.646	0.79
Residual Error	2	0.1615	0.08076			1.44
Total	8	11.2015				100

The ANOVA analysis reveals that the Infill density has the maximum contribution on the tensile strength and is 32.85%. The number of laminates also has a significant effect on the output response and its effect is calculated to be 32.85%. The raster angle is a nearly insignificant parameter. The error came about to be about 3.89%.

4. CONCLUSION

In the current research work the Poly Lactic acid or more commonly known as PLA embedded plant (cotton) and Animal Fibres (wool) in the form of sheets or laminates. The samples were prepared successfully using a 3D printer and design of experiment was applied to reveal the effects of parameters on the output response in our case which was Tensile strength and the Flexural strength. ANOVA analysis is also used study the contribution of Parameters on the Tensile strength and the Flexural Strength. Maximum tensile strength was achieved at 4 number of laminates, 100% of infill density and 90° of raster angle. The infill density had the maximum contribution of 52% in determining the tensile strength which is followed by number of laminates whose contribution is just over 32%. However, in the case of Flexural strength, the maximum strength was achieved at maximum number of laminates i.e. 4, 100% of infill density and 90° of Raster angle which is same as in the case of Tensile strength but the ANOVA analysis revealed that the contribution of the infill density is maximum in determining the Flexural strength and it has a contribution of just over 58%. The number of laminates also had a 39% effect while the raster angle in this case was also insignificant. The residual error in this case came out to be 1.44%. All the values were checked at a confidence level of 95% using the Fisher tables. The research will be further extended to thorough analysis of the samples using finite element analysis and other rigorous analysis and statistical techniques.

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