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# Experimental investigation on the process parameter of rapid prototyping technique for the improvement of disposal glass material replace by PLA

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## ABSTRACT

***This work proposes to characterize the influence of the physical build parameters over the part quality. An L9 orthogonal array was designed with the minimum number of experimental runs with desired parameter settings and also by analysis tools such as ANOVA (analysis of variance). Establishment of experimentally verified correlations between the physical part characteristics and mechanical part characteristics to obtain an optimal process parameter level for the betterment of part quality is obtained. The process model obtained by the empirical relation can be used to determine the strength of the prototype for the given set of parameters that shows the dependency of strength, which is essential for designers and RP machine users. It was concluded that layer thickness has a significant influence on physical and mechanical properties of PLA. The results show that only layer thickness is the most significant factor.***

***Keyword:*** *Fused deposition modelling, PLA, Layer thickness, Raster angle, ANOVA and Taguchi method*

## 1. INTRODUCTION

Rapid prototyping (RP) is a non-exclusive term for various advances that empower manufacture of physical questions straightforwardly from CAD information sources. As opposed to traditional systems for manufacturing, for example, milling and forging which are of subtractive and formative principles separately, these techniques are taking into account additive principles. The greatest focal point of RP techniques is that a whole 3-D (three-dimensional) consolidated gathering can be created in a single setup with no tooling or human interference, further, the part creation strategy is autonomous of the unpredictability of the part geometry [3]. Because of a few focal points, RP has pulled in the significant consideration of assembling commercial enterprises to meet the client requests for consolidating nonstop and quick changes in assembling in most limited conceivable time and added an edge over contenders.

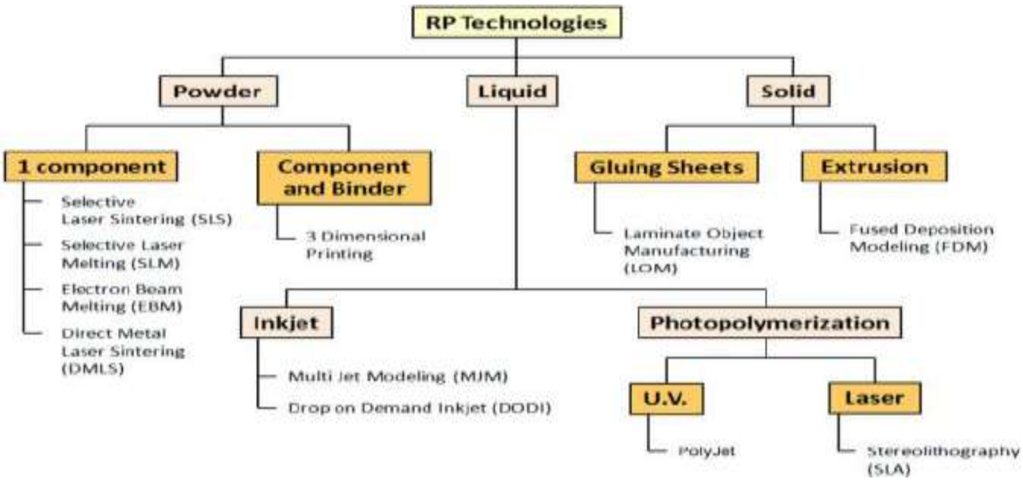


**Fig. 1: RP Techniques**

Out of all economically accessible RP courses of action, fused deposition molding (FDM) uses warmed thermoplastic fiber which is expelled from the tip of the spout in an endorsed way in a temperature controlled environment for building the part through a layer by layer deposition technique. The simplicity of operation together with the capacity to create parts with independently controlled properties brought about its far-reaching application for prototyping as well as for making practical parts. Nonetheless, FDM procedure has its own negative aspects related to precision, surface completion, quality and so forth. Thus, it is completely important to comprehend the deficiencies of the methodology and distinguish the controllable elements for the development of part quality. In this article, present study concentrates on the change of part fabrication technique by appropriately controlling the methodology parameters.

## 2. REVIEW OF PAST RESEARCH

Afizah Ibrahim et al (2017) conducted on test sample of B9R-1-Red built using B9 Creators machine. All the samples are tested under specific ASTM test conditions. The finding results shows that layer thickness of 50 μm with exposure time of 9 sec have tensile and flexural strength of 8.98 N/mm2 and 18.39 N/mm2 respectively. As for dimensional accuracy, the percentage difference across dimension of B9R-1-Red is found to be 3.8%. It was found that for B9R-1-Red, the layer thickness of 50 μm with exposure time of 9 sec would provide the best mechanical properties along with minimum dimensional error. O.Y. Venkata Subba Reddy et al (2017) studied the effect of the process parameters layer thickness, raster width, raster angle and air gap that affects the surface roughness of the part produced by the manner of Fused Deposition Modelling. Hence, the Optimization of these process parameters of FDM is able to make the system more specific and repeatable and such progression can guide to use of FDM in rapid manufacturing solicitations rather than only producing prototypes. The novel ABS- M30 biomedical material was used in this research work to build parts. The experimentation has been completed with the help of Taguchi. Taguchi grey relational analysis is used to optimize the process parameters on multiple performance distinctiveness such as length, diameter, width and surface finish. The proposed method enables decision analysts to better recognise the complete evaluation process and provide good surface finish and dimensional accuracy. A. E. Tontowi et al (2017) used as a tensile strength and dimension error test to represent printed part quality. Three printing process parameters: layer thickness (0.05, 0.1 and 0.15 mm), temperatures (195, 200 and 205°C) and raster angles (-45°, 0° and 60°) have been optimized using Taguchi and Response Surface Methods. Test was carried out to find the highest tensile strength and the lowest dimension error based on the optimum parameter setting and validated them with experiment and default setting. Quality of printed part obtained by optimum parameter setting of RSM [0.05 mm, 199.8oC, 45.1°] showed better than that by Taguchi [0.15 mm, 195°C, 0°] and default setting [0.1 mm, 200°C, 0.0°]. In addition, tensile strength of printed part mostly was affected by layer thickness, while dimension error was caused by raster angle. Shishir Kumar Singh and Rajesh K Satankar (2017) studied different optimization techniques used for 3D printing or fused deposition modelling processes and after effects of various input parameters on some performance parameters of 3D printed component like surface finish have been reviewed. The aim of this work is to investigate the effect of input parameters like filament diameter, extruder temperature, feed rate, raster angle, characteristic of working material, nozzle angle, distance between parallel faces on output parameters like surface finishing, moving speed or movement of nozzle head, material volumetric concentration, cooling of print, strength, number of shells and deposition rate in 3D printing through different optimization techniques. Azhar Equbal et al (2017) studied the parametric optimization of FDM ABS part for improving its dimensional accuracy. Three important factors that are considered for optimization are raster angle, air gap and raster width.

## 3. PROBLEM IDENTIFICATION

The present company AM Enterprises, Bhopal produce plastic disposable cups and facing a problem for heat resistant material for plastic disposal cups made from polystyrene. According to company details provided the tensile strength of the material is 35 N/mm$^2$. The packaging industry is under pressure to offer more sustainable solutions and is, therefore, looking to plastics suppliers to provide an alternative to traditional fossil fuel based plastics. From soft-drink cups at fast food restaurants and festivals to fresh fruit and vegetable containers: the packaging industry is no stranger to bio-based polylactic acid (PLA) plastic. Made from natural, renewable resources such as sugar cane or corn, PLA provides packaging producers with a reliable, bio-based solution that can be recycled or composted after use. So far these bio-based plastics have largely been limited to cold food packaging and disposable applications. PLA is a bioplastic, meaning that it is derived from renewable plant products like corn and sugarcane. It is an environmentalist's dream plastic in that it biodegrades in a relatively short period of time when exposed to the elements. Hence our research work proves an innovative solution to replace polystyrene to PLA for disposal cups.

(a) (b)

**Fig. 2: Coffee at 100°C (a) polystyrene (b) PLA**

## 4. METHODOLOGY AND EXPERIMENTAL PLAN

The objectives of the present work have already been mentioned in the previous chapter. Accordingly, the present study has been done through the following plan of the experiment.

1. 3D solid model of test part is modeled in PROE software and exported as STL file.
2. STL file is imported to FDM software.
3. Experiments were carried in Zcorp Spectrum 510 3D printer.


4. The parameters and their levels that affect the performance of 3DP process are identified from the previous literature and manufacturer's manual.
5. The control factors and their levels considered in this study are shown in table 1.
6. The experiments were conducted according to the L9 orthogonal array as shown in table 2.

**Table 1: Process variables and their limits**

| Parameters/Factors | | level | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| A | Layer thickness (mm) | 0.3 | 0.4 | 0.5 |
| B | Pitch (mm) | 3 | 4 | 5 |
| C | Raster Angle (°) | 0 | 45 | 90 |

**Table 2: Parameters and levels for experiments**

| Experiment no. | Layer thickness (mm) | Pitch (mm) | Raster Angle (°) |
|---|---|---|---|
| 1 | 0.3 | 3 | 0 |
| 2 | 0.3 | 4 | 45 |
| 3 | 0.3 | 5 | 90 |
| 4 | 0.4 | 3 | 45 |
| 5 | 0.4 | 4 | 90 |
| 6 | 0.4 | 5 | 0 |
| 7 | 0.5 | 3 | 90 |
| 8 | 0.5 | 4 | 0 |
| 9 | 0.5 | 5 | 45 |

7. Nine models were built with different parameter settings in the 3DP machine as per the experimental layout is shown in table 2.
8. The response i.e. tensile strength and hardness value are measured using UTM and shore's hardness test.

## 5. MACHINE AND MATERIAL

A trial run was performed in which a series of samples were built on the FDM machine using PLA material. The machine is equipped with Insight software that assists the user to adjust the variable parameters in building part specification. Principally, the FDM variables are considered as four groups of operating parameters, as follows; FDM builds specification, FDM environment/machine, and material specification. The full factor experiment was obtained to develop the experimentation plan for three parameters and three levels, considering the highest number of experimentation runs for the specified number of runs and levels in order to optimize the maximum parameters combinations. In this study, Full factor experiment, L9 has been selected initially according to the number of FDM variable parameters and number of settings or levels. Nine parts of the experiment are fabricated by the use of FDM Vantage SE machine.

**Table 3: Properties of PLA**

| Property | Value |
|---|---|
| Technical Name | Polylactic Acid (PLA) |
| Chemical Formula | $(C_3H_4O_2)_n$ |
| Melt Temperature | PLLA: 157 - 170 °C (315 - 338 °F) |
| Tensile Strength | 61- 66 MPa |
| Flexural Strength | 48-110 MPa |

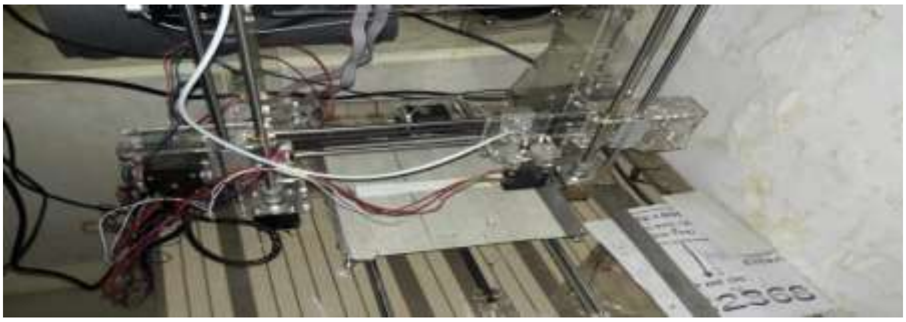

**Fig. 3: Parts fabrication using FDM machine**

 

## 6. TESTING PROCEDURE

### 6.1 Tensile test

After fabrication, the tensile test is performed on the universal testing machine. If A is the cross-sectional area and F is the maximum force and tensile strength calculated by:
Tensile strength=F/A

**Fig. 4: Process setup for the tensile test**

**Fig. 5: Specimen failure after the test**

### 6.2 Shore hardness test

These Shore electronic hardness testers are used for determining the hardness of plastics and rubber to ISO 7619-1, ASTM D2240, ISO 868, NFT 51109 and BS 903 Part A26. For on-site testing on the product, analog versions with and without drag-pointer are available. The instruments with drag-pointers simplify testing, particularly in difficult-to-access locations, as the pointer still indicates the measured value after the test. Hardness value determination after dwell times of 3 seconds (ISO 7619-1) and 1 second (ISO 868) can be accommodated with digital hardness testing instruments.

**Fig. 6: Durometer**

## 7. DATA COLLECTION

We have successfully fabricated our nine parts according to process parameter on FDM machine and then perform tensile strength test and shore hardness test to predict the quality of the part. Results were tabulated in table 4 and 5.

**Table 4: Tensile test result**

| Experiment no. | Layer thickness (mm) | Pitch (mm) | Raster Angle (°) | Load (N) | Tensile strength (MPa) |
|---|---|---|---|---|---|
| 1 | 0.3 | 3 | 0 | 1579.83 | 37.1 |
| 2 | 0.3 | 4 | 45 | 1613.01 | 40.7 |
| 3 | 0.3 | 5 | 90 | 1234.79 | 30.6 |
| 4 | 0.4 | 3 | 45 | 1738.42 | 41.9 |
| 5 | 0.4 | 4 | 90 | 1294.19 | 30.7 |
| 6 | 0.4 | 5 | 0 | 429.08 | 11.5 |
| 7 | 0.5 | 3 | 90 | 1868.17 | 47.6 |
| 8 | 0.5 | 4 | 0 | 2025.39 | 52.6 |
| 9 | 0.5 | 5 | 45 | 2293.93 | 48.4 |

**Table 5: Shore Hardness results**

| Experiment no. | Layer thickness (mm) | Pitch (mm) | Raster Angle (°) | Hardness value |
|---|---|---|---|---|
| 1 | 0.3 | 3 | 0 | 65 |
| 2 | 0.3 | 4 | 45 | 77 |
| 3 | 0.3 | 5 | 90 | 73 |
| 4 | 0.4 | 3 | 45 | 79 |
| 5 | 0.4 | 4 | 90 | 75 |
| 6 | 0.4 | 5 | 0 | 82 |
| 7 | 0.5 | 3 | 90 | 76 |
| 8 | 0.5 | 4 | 0 | 68 |
| 9 | 0.5 | 5 | 45 | 78 |

## 8. RESULTS AND DISCUSSIONS

### 8.1. Anova analysis

The results for tensile strength were obtained from the 9 experiments performed of Taguchi. The experimental results analyzed with ANOVA are shown in Table 6. The F value calculated through MINITAB 15 software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%). The results show that only layer thickness is the most significant factor.

**Table 6: Analysis of Variance for S/N ratio for tensile strength**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Layer thickness | 2 | 707.4 | 353.71 | 6.44 | 0.134 |
| Pitch | 2 | 270.2 | 135.12 | 2.46 | 0.289 |
| Raster Angle | 2 | 159.5 | 79.76 | 1.45 | 0.408 |
| Error | 2 | 109.8 | 54.90 | | |
| Total | 8 | 1247.0 | | | |

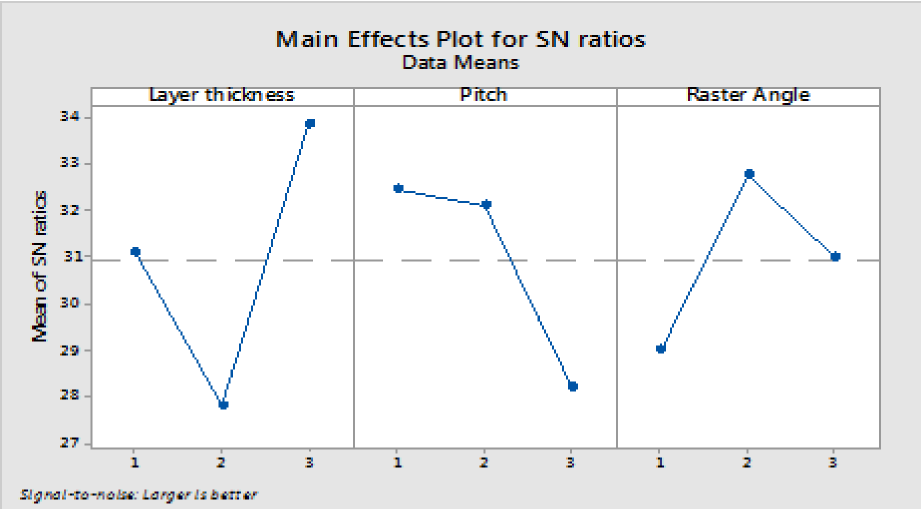


**Fig 7: Main effects plot for tensile strength**

The signal to noise ratios tells us about the deviations present in the process. The values of all the results conferring to Taguchi array parameter design layout are accessible in this section. The S/N ratios have been considered to identify the foremost contributing factors for variation of values. In this design situation, bigger-the-better is used.

Table 7 shows the ANOVA calculations for the S/N ratio. The analysis was carried out at a significance of α=0.05. Ranks have been given to the various factors. Higher is the rank higher is the significance so Layer thickness is the most significant factor. It was found that only Layer thickness is a significant factor with F value of 1.32.

**Table 7: Analysis of Variance for S/N ratio for shore hardness**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Layer thickness | 2 | 76.22 | 38.11 | 1.32 | 0.430 |
| Pitch | 2 | 37.56 | 18.78 | 0.65 | 0.605 |
| Raster Angle | 2 | 60.22 | 30.11 | 1.05 | 0.489 |
| Error | 2 | 57.56 | 28.78 | | |
| Total | 8 | 231.56 | | | |

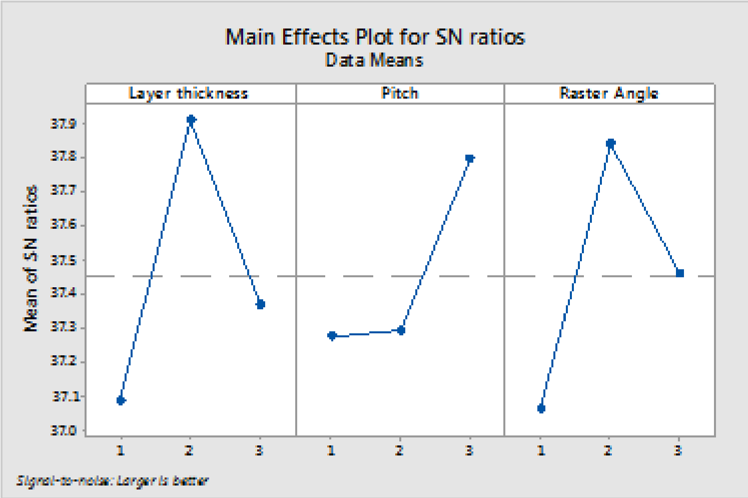


**Fig 8: Main effects plot for shore hardness**

## 9. DETERMINATION OF OPTIMUM SOLUTION

Optimum parameter setting for higher tensile strength and higher hardness value has been identified through Fig. 7 & 8. The best configurations are determined individually through Taguchi's approach. Table 8 & 9 indicates these individual maximum values and its related settings of the method parameters for the described performance characteristics.

**Table 8: Parameters and their selected levels for maximum tensile strength**

| Parameter designation | Process parameters | Optimal levels |
|---|---|---|
| A | Layer thickness (mm) | 3 ( 0.5 mm) |
| B | Pitch (mm) | 1 (3 mm) |
| C | Raster Angle (°) | 2 (45°) |

**Table 9: Parameters and their selected levels for maximum hardness value**

| Parameter designation | Process parameters | Optimal levels |
|---|---|---|
| A | Layer thickness (mm) | 2 (0.4 mm) |
| B | Pitch (mm) | 3 (5 mm) |
| C | Raster Angle (°) | 2 (45°) |

## 10. CONFIRMATION TEST

The level of a factor with the highest S/N ratio was the optimum level for responses measured. In order to test the predicted result, confirmation experiment has been conducted by running three trials at the optimal setting of the process parameters determined from the analysis i.e. A3, B1, C2 for tensile strength and A2, B3, C2 for hardness value.

**Table 10: Confirmation test for maximum tensile strength**

| S.no | Trials | | | Avg. Tensile strength (MPa) |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| 1 | 53.35 | 52.45 | 55.16 | 53.65 |

**Table 11: Confirmation test for maximum hardness value**

| S.no | Trials | | | Avg. Hardness value |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| 1 | 84 | 86 | 87 | 85.66 |

## 11. VALIDATION OF RESULT

We will validate our result with C K Basavaraj, M Vishwas (2016). They discussed the process parameters for fused deposition modeling (FDM). Layer thickness, Orientation angle and shell thickness are the process variables considered for studies. Ultimate tensile strength, dimensional accuracy and manufacturing time are the response parameters.

 

**Table 12: Validation of result**

| Experiment no. | Tensile strength (MPa) | C K Basavaraj, M Vishwas (2016) |
|---|---|---|
| 1 | 37.1 | 19.05 |
| 2 | 40.7 | 19.18 |
| 3 | 30.6 | 25.48 |
| 4 | 41.9 | 9.51 |
| 5 | 30.7 | 15.68 |
| 6 | 11.5 | 7.71 |
| 7 | 47.6 | 8.35 |
| 8 | 52.6 | 8.83 |
| 9 | 48.4 | 11.82 |

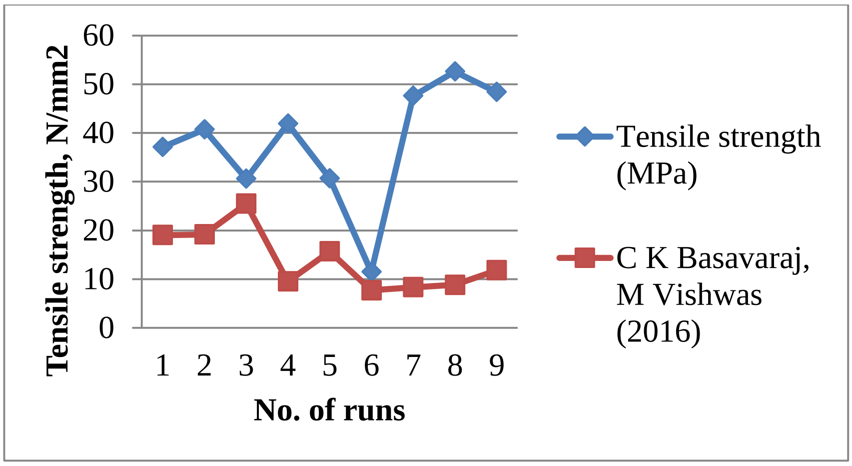


**Fig. 9: Validation of result**

## 12. FINDINGS

When we compare our experimental data with the tensile strength of polystyrene with our tensile strength of PLA it shows good results.

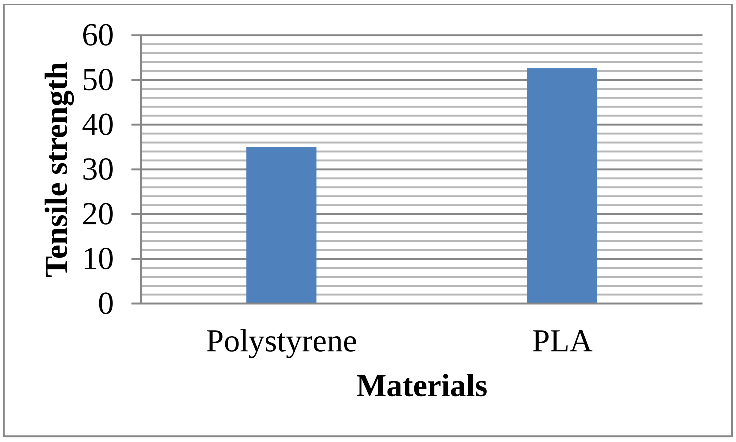


**Fig. 10: Comparison of tensile strength**

## 13. COST ANALYSIS

| | Polystyrene | PLA |
|---|---|---|
| Raw materials cost | Rs. 40000/- | 60000/- |
| Plastic Disposable Cups | 6000000 | 6000000 |
| Unit Sales Price (Rs) | Rs. 0.5 /- | Rs. 2.5 /- |

## 14. CONCLUSIONS

### 14.1. Conclusions for tensile strength and hardness value

The following conclusions have been noted by applying Taguchi methodology in the experimental investigations of the printed part by FDM

### 14.1.2 Conclusions for tensile strength

The subsequent conclusions are finished via the analysis

1. It was successfully proved that layer thickness has a significant influence on physical and mechanical properties of PLA.

2. The tensile strength first decreases and then increases with increase in the layer thickness. The optimum value of process parameters such as layer thickness, pitch, and raster angle is found to be 0.5 mm (level 3), 3 mm (level 1) and 45° (level 2) respectively.
3. The maximum tensile strength achieved was 52.6 MPa at layer thickness (0.5 mm), pitch (4 mm) and raster angle (0°).
4. The F value calculated through MINITAB 15 software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%). The results show that only layer thickness is the most significant factor.

### 14.1.3 Conclusions for shore hardness

The subsequent conclusions are finished via the analysis

1. It was successfully proved that layer thickness has a significant influence on physical and mechanical properties of PLA.
2. The hardness first increases and then decreases with increase in the layer thickness. The optimum value of process parameters such as layer thickness, pitch, and raster angle is found to be 0.4 mm (level 2), 5 mm (level 3) and 45° (level 2) respectively.
3. The maximum hardness achieved was 82 HV at layer thickness (0.4 mm), pitch (5 mm) and raster angle (0°).
4. The analysis was carried out at a significance of $\alpha$=0.05. Table 7 shows the response table for S/N for shore hardness. Ranks have been given to the various factors. Higher is the rank higher is the significance so Layer thickness is the most significant factor. It was found that only Layer thickness is a significant factor with F value of 1.32.

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