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Optimization of Infill patterns for shaft coupling in 3D printer using PLA and ABS

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Abstract — *In the recent trends of rapid prototyping all are going towards the additive layer manufacturing process. Most common technique of additive layer manufacturing is 3D printing. 3D printing is the process of making a physical component in the three dimensional aspects by generating many thin layers of material. In the 3D printer, any component is generated with different infill patterns. By changing the parameters, it results to change in the important parameters like strength and material cost. My project deals with manufacturing the coupler by using two different materials i.e Polylactic acid(PLA) and Acrylonitrile Butadiene Styrene(ABS). Printing process utilised is Fused Deposition Modelling(FDM). For each material different infill patterns would be utilised. At last comparative study of all the printed models would be done based on the surface roughness and torque at failure of the model*

Keywords- *Additive manufacturing, 3D printing, PLA, ABS, Rapid prototyping, Fused deposition modelling, torque at failure, Surface roughness , ANOVA*

1. INTRODUCTION

It is the 3D printer which makes possible to develop the prototype of any complex or simple object. 3D printing refers to the process in which material is joined or solidified under computer control to create a three dimensional object with material being added together. Unlike material removed from a stock in the conventional machining process, 3D printing builds a three dimensional object from computer aided design model usually by successively adding material layer by layer.The process used in my project is of Fused Deposition Modelling(FDM). I have tried to print the coupling which is used in printer with the Acrylonitrile Butadiene Styrene(ABS) and Polylactic acid(PLA). The methodology used is Taguchi's analysis based on S/N ratio and ANOVA. The input parameters taken are infill pattern, infill density and solid infill layer and the output consist of Surface roughness and Torque at failure. Surface roughness is measured by surface roughness tester and Torque at failure is measured by Torsion tester. Based on the output data S/N ratio was calculated and ANOVA was performed which shows that which process parameter is more influential and which has less influence. Surface roughness was calculated for ABS and PLA 3D printed coupling. Similarly Torque at failure was calculated for ABS and PLA 3D printed coupling.

2. LITERATURE SURVEY

This section briefly discuss about the previous work carried out by the researchers on 3D printing and its process parameter optimization. ***Siddharth Bhandari, B Regina*** has worked on 3D Printing and Its Applications. Research paper is based on 3D printing. The future potential of this technology is outlined in the research article [1]. ***Elizabeth Matias, Bharat Rao*** has worked on 3D Printing: On Its Historical Evolution and the Implications for Business. This was an exploratory research study, which utilized both a consumer survey and interviews in the business segment to gather quantitative and qualitative research [2]. ***Annamalai Pandian, Cameron Belavek*** has worked on A review of recent trends and challenges in 3D printing [3]. ***Ojas Dangaval , Pranita Bichkar*** has worked on rapid prototyping technology using fused deposition modelling process**.** This paper focus on Fused Deposition Modeling Technique [4]. ***Vinod G. Surange, Punit V. Gharat*** has worked on 3D Printing Process using fused deposition modelling .The main purpose of the research is to develop a low cost 3D Printer using easily available materials [5]. ***Fawaz Alabdullah*** has worked on Fused Deposition Modelling mechanism [6]. ***Ludmila Novakova-Marcincinova, Ivan Kuric*** has worked on Basic and Advanced Materials for Fused Deposition Modeling [7]. ***Raj Kalavadiya, Sahil kalal, Dilavar dodiya, Priyank Zaveri*** has worked on optimisation of infill pattern for designing the 3d printed gear by using the fdm process. Result and conclusion explains that hillburt curve pattern used for infill has more compressive strength than other pattern. Maximum material used is in the case of honeyfill pattern. For hillburt curve pattern if the density is reduced to 80% than there is no change in compressive strength but weight of gear is reduced [8]. ***M. A. Nazan, F. R. Ramli, M. R. Alkahari, M. N. Sudin and M. A. Abdulla*** has worked on process parameter optimization of 3d printer using response surface method. The experiment produced the minimum result of warping deformation value when the layer temperature, infill density, first layer height and other layer height is 192°C, 13%, 0.20mm and 0.30mmrespectively[9]. ***M.Naveen Kumar, Sriram Venkatesh and M.Manzoor Hussain*** has worked on Influence of 3D material properties on quality prototypes using SLS and FDM process of a 3D printer**.** They concluded that strength is more in selective layer sintering based prototype[10]. ***Quan Zhu, Yushan Liu, Yujun Cai and Meng Wu*** has worked on Research on the Shrinkage of Model with Hole in PLA Material Based on the FDM 3D Printing. In this paper, the orthogonal test of 4 factors 3 levels is designed, and the optimal combination of process parameters of reducing the shrinkage error of model with hole is obtained which is A3B1C1D2 that extruded head temperature is 210°c, hot bed temperature is 45 °c, layer thickness is 0.1 mm, printing speed is 45 mm/s[11]. ***Brent Stephens , Parham Azimi , Zeineb El Orch , Tiffanie Ramos*** has worked on Ultrafine particle emissions from desktop 3D printers[12].

3. METHODOLOGY AND MEASUREMENTS

3.1 Designing CAD model for coupling

Coupling which is taken for 3D printing is of the same dimension which is utilised in our 3D printer. For fabricating any kind of part with the use of rapid prototyping or 3D printer technology first step is to make the 3D CAD model. Solidworks 2016(student version) ex64 edition is used for designing CAD model of Coupling. It is converted into STL file format for 3D printing as input file for slicing software Repetier-Host

Figure 1. CAD model of coupling

Dimension of coupling	
Length of coupling	25 mm
Outer diameter of coupling	17 mm
Lead screw hole diameter	10 mm
Stepper motor hole diameter	8 mm
Other hole diameter	2 mm

Table 1. Dimension for coupling

3.2 Slicing process of CAD file

Software used for slicing the CAD file is Repetier host with Version 2.0.1 Slicer is nothing but it is just one process which is making G code from given configuration. 3D printer read Gcode file. Repetier host is been used for slicing purpose. Repetier host can directly slice the STL file with different layer patterns in Slice3r slicer engine and save in Gcode file format. That file can directly input in the 3D printer with online as well as offline.

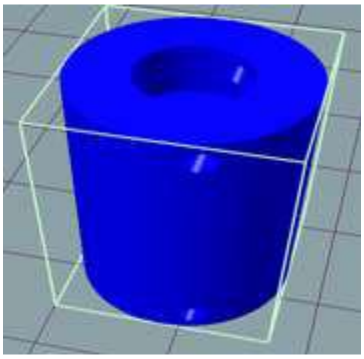

Figure 2. STL file of coupling

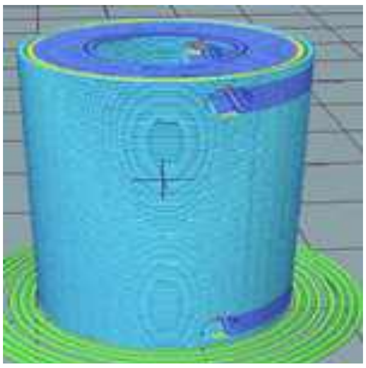

Figure 3. Sliced file of coupling

Constant parameter of Sliced model

1. First layer height: 0.35 mm

2. Other layer height: 0.25 mm

3. Fill angle: 900

4. Extruder temperature : 2000c

5. Bed temperature: 700c

6. Feed rate: 70mm/min

3.3 Taguchi method

Taguchi method has been used mostly in engineering fields for the analysis and consist of a plan of experiments. The main advantage of this method is the reduction in experimental time, cost and discovering significant factors quickly. Taguchi's robust design method is very effective tool for the design of a high quality system. In addition to the S/N ratio, a statistical ANOVA can be used to show the effects of factors of the process on surface roughness and torque at failure for ABS and PLA 3D printed part.

3.4 Selection of variables

The different parameters selected for experiments are infill pattern, infill density and solid infill layer.

Parameters	Level 1	Level 2	Level 3
Infill pattern	Concentric	Rectilinear	Hillburt curve
Infill density	90%	80%	70%
Solid infill layer	2	1	0

Table 2. Input process parameters and their levels

3.5 Experimental setup

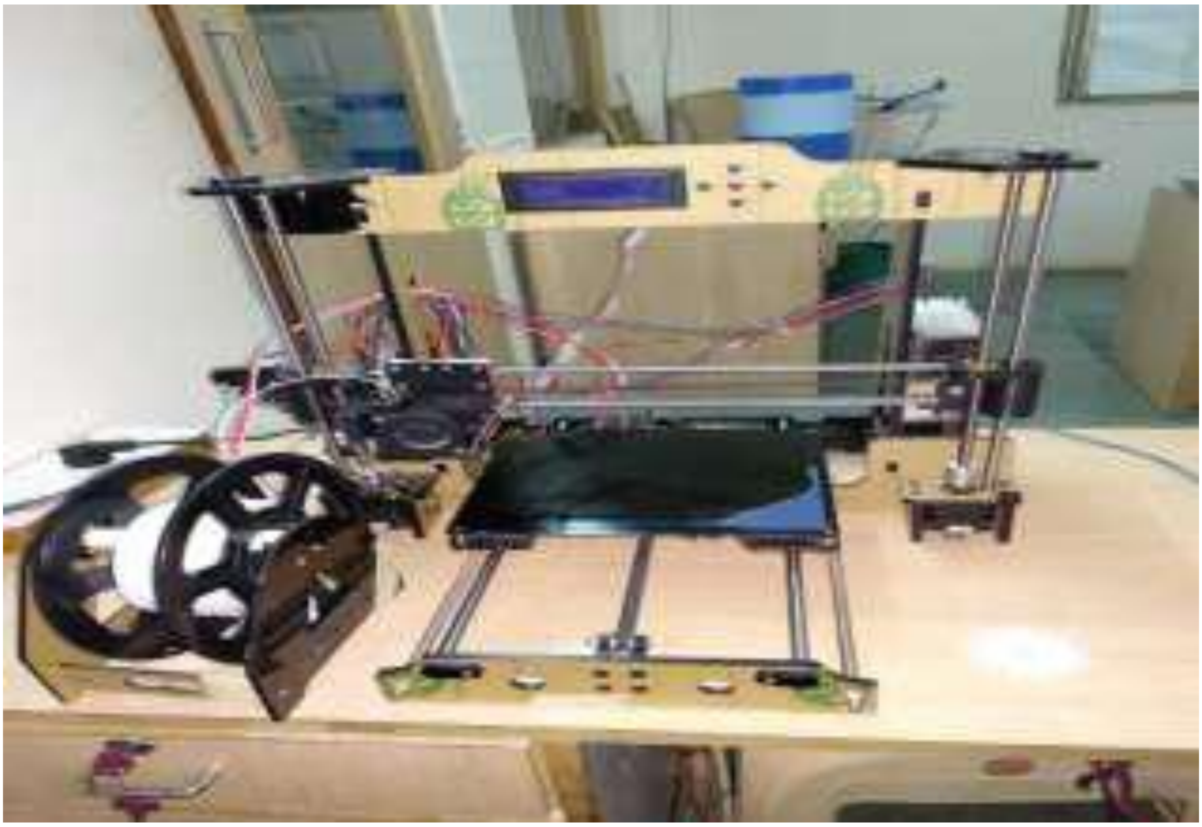

Figure 4. 3D printer

Dimension	33 x 42 x 36 cm
Weight	10kg
Build Volume	160 x 250 x 150 mm
Filament diameter	1.75 mm
Nozzle diameter	0.4 mm
Max. Temperature	250°c
Print Material	PLA, ABS
Slicing software	Repetier host
Print speed	50 – 150 mm/s
Travel speed	150 – 250 mm/s
OS supported	Windows, Mac OS, Linux

Table 3 Specifications of 3D printer

Above table shows the specification of 3D printer machine which is utilised for experiments

3.6 Measuring surface roughness

After all the parts are printed they will undergo the measurement of surface roughness. For that surface roughness tester was utilised which was utilised at Akshar analytical laboratory.

Figure 5. Surface roughness tester

Measuring length (horizontal)	60 mm
Stylus force	0.7 Mn
Rotating angle	360°
Tracing speed	0.5 mm/sec
Measuring range	Ra – 0.005 to 20 micrometer
Dimension	144 x 55 x 40

Table 4. Specifications of surface roughness tester

Above table shows the specification of surface roughness tester

3.7 Measuring Torque at failure

Figure 6. ADMET 9614 for PLA

Figure 7. ADMET 9613 for ABS

Above image shows the torque measurement machine which were utilised for the measurement of torque at failure. Different machines were used, for example ADMET 9614 was used for PLA and ADMET 9613 was used for ABS. Testing facility was available at Akshar analytical laboratory.

Specifications	ADMET 9614	ADMET 9613
Torque capacity	100 Nm	50 Nm
Angle resolution	0.0008°	0.0008°
Max Power	1100 VA	880 VA
Minimum speed	0.005 rpm	0.0035 rpm

Table 5 Specifications of Torsion testing machine

4. EXPERIMENTAL DESIGN

According to taguchi method based on 3 input process parameters and 3 levels of design L9 orthogonal array was selected which is shown below for ABS and PLA.

Component	Infill pattern	Infill density	Solid infill pattern	Surface roughness (µm)	Torque at failure (Nm)
1	Concentric	30	2	15.2883	23.2
2	Concentric	40	1	15.0698	22.8
3	Concentric	50	0	14.0912	23.5
4	Rectilinear	30	1	15.3820	22.4
5	Rectilinear	40	0	14.6310	22.6
6	Rectilinear	50	2	15.7710	23.6
7	Hillburt curve	30	0	14.3618	22.4
8	Hillburt curve	40	2	15.9713	23.3
9	Hillburt curve	50	1	15.6712	23.5

Table 6 L9 orthogonal array for ABS

Similarly L9 orthogonal array was devised for PLA

Component	Infill pattern	Infill density	Solid infill pattern	Surface roughness (μm)	Torque at failure (Nm)
1	Concentric	30	2	16.9312	79.3
2	Concentric	40	1	15.8710	78.7
3	Concentric	50	0	15.3316	79.9
4	Rectilinear	30	1	15.3810	78.6
5	Rectilinear	40	0	15.3310	78.8
6	Rectilinear	50	2	16.8510	79.9
7	Hillburt curve	30	0	15.5618	78.6
8	Hillburt curve	40	2	15.9710	79.5
9	Hillburt curve	50	1	15.3215	79.7

Table 7 L9 orthogonal array for PLA

5. OPTIMIZATION OF MACHINING PARAMETERS USING TAGUCHI'S S/N RATIO ANALYSIS

The outcome of Experimental work of Surface Finish (Ra) and Torque at failure is analyzed using Taguchi Design in Minitab software and S/N ratio values are determined. The Optimum levels of influential parameters are determined based on the obtained S/N ratios.

Sr. No	S/N ratio for ABS		S/N ratio for PLA	
	S/N ratio for Surface roughness	S/N ratio for torque at failure	S/N ratio for Surface roughness	S/N ratio for torque at failure
1	-23.6872	27.3098	-24.5738	37.9855
2	-23.5621	27.1587	-24.0121	37.9195
3	-22.979	27.4214	-23.7117	38.0509
4	-23.7403	27.005	-23.7397	37.9085
5	-23.3055	27.0822	-23.7114	37.9305
6	-23.9572	27.4582	-24.5325	38.0509
7	-23.144	27.005	-23.8412	37.9085
8	-24.0668	27.3471	-24.0666	38.0073
9	-23.902	27.4214	-23.706	38.0292

Table 8 S/N ratio calculation for ABS and PLA

6. RESULTS AND DISCUSSIONS

6.1 Process parameter's influence based on S/N ratio

Levels	Factors		
	Infill pattern	Infill density	Solid infill layer
1	-23.41	-23.52	-23.14
2	-23.67	-23.64	-23.73
3	-23.70	-23.61	-23.90
Delta	**0.29**	**0.12**	**0.76**
Rank	**2**	**3**	**1**

TABLE 9 RESPONSE TABLE FOR SURFACE ROUGHNESS IN ABS

Table 9 shows that solid infill layer is most predominant factor followed by infill pattern and infill density for surface roughness in ABS

Levels	Factors		
	Infill pattern	**Infill density**	**Solid infill layer**
1	27.30	27.11	27.17
2	27.18	27.20	27.20
3	27.26	27.43	27.37
Delta	**0.11**	**0.33**	**0.20**
Rank	**3**	**1**	**2**

Table 10 Response table for torque at failure in ABS

Table 10 shows that Infill density is the most predominant factor followed by solid infill layer and infill pattern

Levels	Factors		
	Infill pattern	**Infill density**	**Solid infill layer**
1	-24.10	-24.05	-23.75
2	-23.99	-23.93	-23.82
3	-23.87	-23.98	-24.39
Delta	**0.23**	**0.12**	**0.64**
Rank	**2**	**3**	**1**

Table 11 Response table for surface roughness in PLA

Table 11 shows that solid infill layer is the most predominant factor followed by infill pattern and infill density for Surface roughness in PLA

Levels	Factors		
	Infill pattern	**Infill density**	**Solid infill layer**
1	37.99	37.93	37.96
2	37.96	37.95	37.95
3	37.98	38.04	38.01
Delta	**0.02**	**0.11**	**0.06**
Rank	**3**	**1**	**2**

Table 12 Response table for Torque at failure in PLA

Table 12 shows that infill density is the most predominant parameter followed by solid infill layer and infill pattern

6.2 Process parameters effect on output parameters based on response table

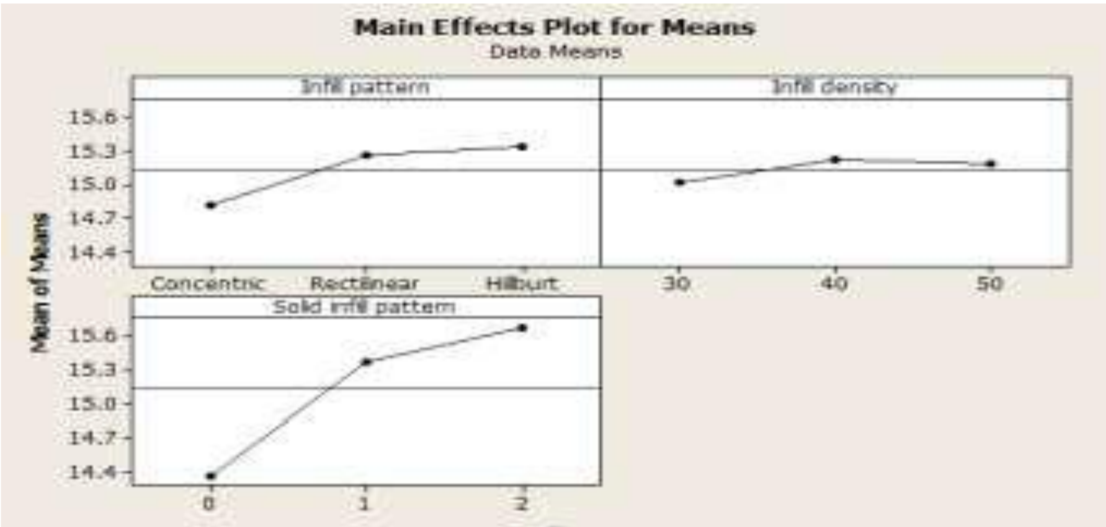

Figure 8 Data means for surface roughness in ABS

Above figure shows that for better value of surface roughness i.e for less value of surface roughness in ABS the parameter selected should be Infill pattern as Concentric, Infill density as 30% and solid infill pattern as 0.

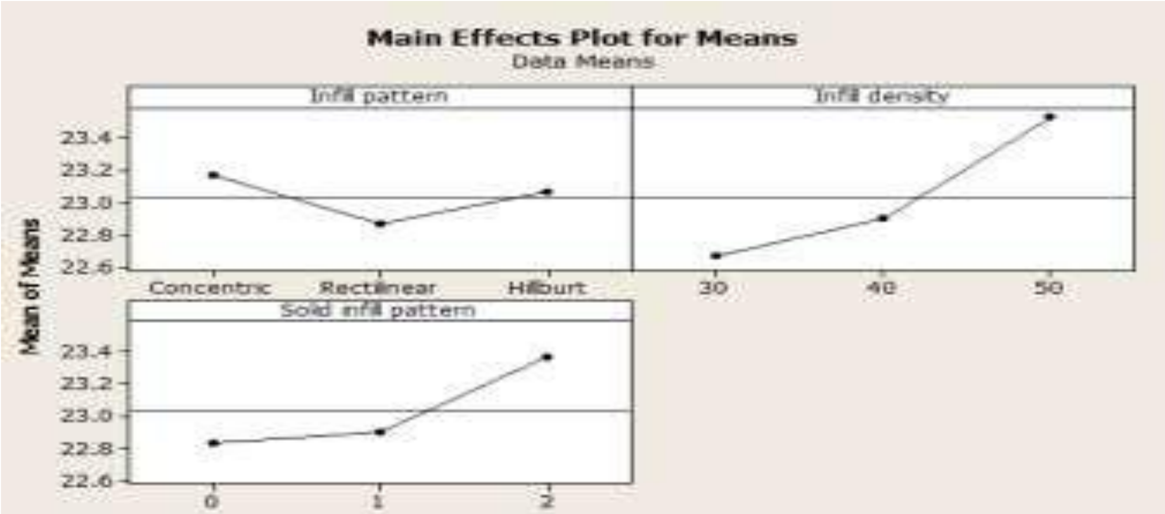

Figure 9 Data means for Torque at failure in ABS

Above figure shows that for higher value of torque at failure in ABS the parameter selected should be Infill pattern as Concentric, Infill density as 50% and solid infill pattern as 2.

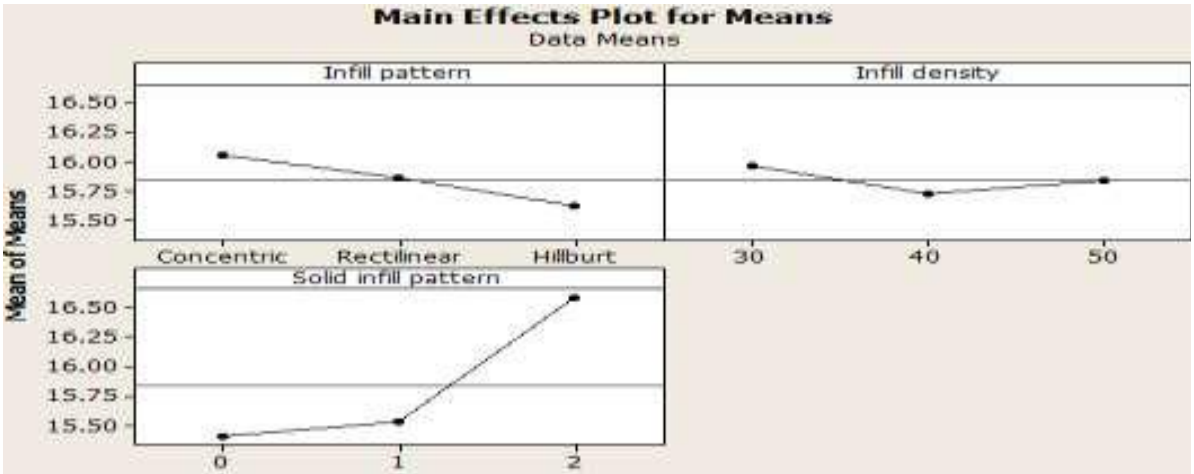

Figure 10 Data means for Surface roughness in PLA

Above figure shows that for lower value of surface roughness in PLA the parameter selected should be Infill pattern as Hillburt curve, Infill density as 40% and solid infill pattern as 0.

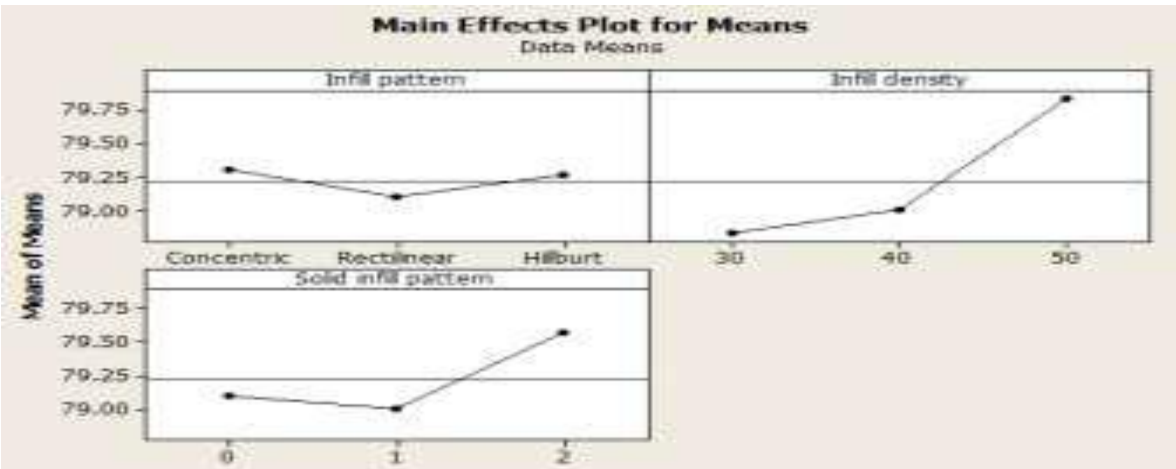

Figure 11 Data means for Torque at failure in PLA

Above figure shows that for higher value of torque at failure in PLA the parameter selected should be Infill pattern as concentric, Infill density as 50% and solid infill pattern as 2.

6.3 ANOVA (ANALYSIS OF VARIANCE)

6.3.1 ANOVA for Surface roughness in ABS

Source	DF	Seq.SS	Contribution	Adj.SS	Adj.MS	F-value	P-value
Infill pattern	2	0.47188	13.79%	0.47188	0.23594	18.41	0.052
Infill density	2	0.07565	2.21%	0.07565	0.03782	2.95	0.253
Solid infill layer	2	2.84879	83.25%	2.84879	1.42439	111.15	0.009
Error	2	0.02563	0.75%	0.02563	0.01282		
Total	8	3.42195	100%				
Model Summary							
S	**R-sq**	**R-sq (adj.)**		**PRESS**	**R-sq (pred)**		
0.113205	99.25%	97.00%		0.519021	84.83%		

Table 13 ANOVA for surface roughness in ABS

The above table shows that solid infill layer has most statistical and physical contribution i.e. 83.25% followed by infill pattern and infill density. The total error related to anova is 0.75%

6.3.2 ANOVA for Torque at failure in ABS

Source	DF	Seq.SS	Contribution	Adj.SS	Adj.MS	F-value	P-value
Infill pattern	2	0.14000	7.37%	0.14000	0.07000	3.00	0.250
Infill density	2	1.20667	63.51%	1.20667	0.60333	25.86	0.037
Solid infill layer	2	0.50667	26.67%	0.50667	0.25333	10.86	0.084
Error	2	0.04667	2.46%	0.04667	0.02333		
Total	8	1.90000	100.00%				
Model Summary							
S	**R-sq**	**R-sq (adj.)**		**PRESS**	**R-sq (pred)**		
0.152753	97.54%	90.18%		0.945	50.26%		

Table 14 ANOVA for torque at failure in ABS

The above table shows that infill density has most statistical and physical contribution i.e. 63.51% followed by solid infill layer and infill pattern. The total error related to anova is 2.46%

6.3.3 ANOVA for Surface roughness in PLA

Source	DF	Seq.SS	Contribution	Adj.SS	Adj.MS	F-value	P-value
Infill pattern	2	0.27391	8.29%	0.27391	0.13695	0.64	0.610
Infill density	2	0.08189	2.48%	0.08198	0.04099	0.19	0.840
Solid infill layer	2	2.52053	76.25%	2.52053	1.26027	5.88	0.145
Error	2	0.42900	12.98%	0.42900	0.21450		
Total	8	3.30542	100.00%				
Model Summary							
S	**R-sq**	**R-sq (adj.)**		**PRESS**	**R-sq (pred)**		
0.463139	87.02%	48.09%		8.68716	0.00%		

Table 15 ANOVA for surface roughness in PLA

The above table shows that solid infill layer has most statistical and physical contribution i.e. 76.25% followed by infill pattern and infill density. The total error related to anova is 12.98%

6.3.4 ANOVA for Torque at failure in PLA

Source	DF	Seq.SS	Contribution	Adj.SS	Adj.MS	F-value	P-value
Infill pattern	2	0.06889	2.81%	0.06889	0.03444	0.60	0.627
Infill density	2	1.72222	70.14%	1.72222	0.86111	14.90	0.063
Solid infill layer	2	0.54889	22.35%	0.54889	0.27444	4.75	0.174
Error	2	0.11556	4.71%	0.11556	0.05778		
Total	8	2.45556	100.00%				
Model Summary							
S	**R-sq**	**R-sq (adj.)**		**PRESS**	**R-sq (pred)**		
0.240370	95.29%	81.18%		2.34	4.71%		

Table 16 ANOVA for torque at failure in PLA

The above table shows that infill density has most statistical and physical contribution i.e. 70.14% followed by solid infill layer and infill pattern. The total error related to anova is 4.71%

7. Conclusions

1) For better value of surface roughness in ABS the parameter selected should be Infill pattern as Concentric, Infill density as 30% and solid infill pattern as 0. Similarly for better value of surface roughness in PLA the parameter selected should be Infill pattern as Hillburt curve, Infill density as 40% and solid infill pattern as 0

2) For better value of Torque at failure in ABS the parameter selected should be Infill pattern as Concentric, Infill density as 50% and solid infill pattern as 2. Similarly for better value of torque at failure in PLA the parameter selected should be Infill pattern as concentric, Infill density as 50% and solid infill pattern as 2.

3) ANOVA for Surface roughness in ABS shows that solid infill layer has most statistical and physical contribution i.e. 83.25% and infill density has least contribution i.e. 2.21%. Similarly ANOVA for Surface roughness in PLA shows that solid infill layer has most statistical and physical contribution i.e. 76.25% and infill density has least contribution i.e. 2.48%

4) ANOVA for Torque at failure in ABS shows that infill density has most statistical and physical contribution i.e. 63.51% and infill pattern has least contribution i.e. 7.37%. Similarly ANOVA for torque at failure in PLA shows that infill density has most statistical and physical contribution i.e. 70.14% and infill pattern has least contribution i.e. 2.81%

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