



# OPTIMISATION OF PROCESS PARAMETERS IN RAPID PROTOTYPING FOR ABS MATERIAL

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## ABSTRACT

Rapid Prototyping (RP) is finding applications in diverse fields in the industry today, with prototypes used for form, fit and function. Design Engineers around the world use Rapid Prototyping to pre-estimate product characteristics like shape, manufacturability and finish. Due to the excellent advantages of rp, it is fast catching the fancy of large number of people. One of the famous RP techniques is Fused Deposition Modeling. Quality characteristics of rapid prototyping (RP) parts largely depend on process parameters. A functional part must possess different quality characteristics. Therefore, process parameters need to be determined in such a way that they collectively optimize more than one response simultaneously. To address this issue, effect of important process parameters viz., layer thickness, air gap and raster angle have been studied. The quality characteristics are surface finish, dimensional accuracy, density and hardness. Thaguchi's designs of experiments were used and the results are statistically analyzed.

**Keywords :** Rapid Prototyping , FDM, ANOVA, etc

## INTRODUCTION

Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereo lithography, was developed by 3D Systems of Valencia, CA, USA. Rapid Prototyping improves product development by enabling better communication in a concurrent engineering environment. There are many commercial RP systems available in market today such as Stereo lithography (SLA), Selective Laser Sintering (SLS), Laser Engineering Net Shaping (LENS), 3D Printing, Fused Deposition Modeling (FDM). All RP systems have a limit on the type and properties of material that can be fabricated. Fused Deposition Modeling from Strategy's produces prototypes made out of ABS Plastics.



Wang Rong-Ji, Li Xin-hua, Wu Qing-ding, Wang Lingling has done the work on Optimizing process parameters for selective laser sintering based on neural network and genetic algorithm. AsifEqubal, Anoop Kumar Sood, S.S. Mahapatra made a work named Prediction of dimensional accuracy in fused deposition modeling: a fuzzy logic approach. S.S. Mahapatra, Anoop Kumar Sood<sup>1</sup>, S.K. Patel and S.Sahu conducted Optimization of Process Parameters in Fused deposition modeling using Weighted Principal Component Analysis. Therefore in this work, the FDM Process parameters like layer thickness, raster angle and air gap for their influence on physical properties like surface finish, dimensional accuracy, density, hardness are considered. These process parameters are optimized and the effects of each parameter on quality characteristic are investigated using statistical techniques. Thus the contribution to this extent will definitely help in improving the quality of prototypes in FDM process as well as simplifying the contribution to this extent will definitely help in improving the quality of prototypes in the contribution to this extent will definitely help in improving the quality of prototypes in the contribution to this extent will definitely help in improving the quality of prototypes in FDM process as well as simplifying the process parameters for desired quality standards.

### 1.1 Process Parameters in FDM process

When preparing to build FDM parts, many fabrication parameters are needed in the software. To achieve optimum quality, these parameters are set differently according to requirements of applications. Therefore, the first step in the experiment was to identify the process control parameters that are likely to affect the quality of FDM parts. The selected parameters are listed below.

#### **Layer thickness:**

Slice height is the thickness of each layer measured in the vertical or Z direction. Varying the slice height would most likely have the same effect as varying the bead width of the ABS plastic.

#### **Raster angle:**

It is the angle between the two consecutive layers.

#### **Air Gap:**

It is the space between the beads of FDM material.

### 1.2 Thaguchi Method:

Thaguchi design of experiments was used in this work in order to evaluate the relative contribution of process parameter on various characteristics like Dimensional accuracy, Surface quality, Density and Hardness.

#### **Experimental Procedure:**

A trial run was performed in which a series of samples were built on FDM Prodigy plus machine. The dimensions of the samples were as shown. A total of 8 samples were made using FDM according to L8 orthogonal array

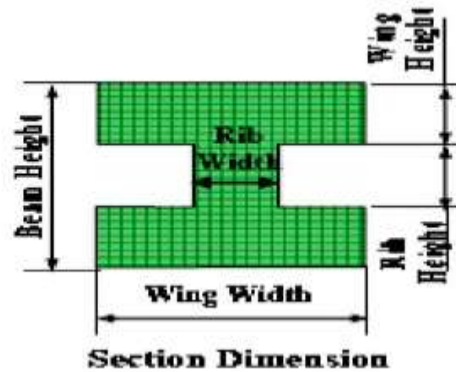


Fig 1: Test Specimen

Thaguchi method uses a special set of arrays called orthogonal arrays.

These standard arrays stipulate the way of conducting the minimum number of experiments, which would give the full information of all factors that affect the performance parameters. The selected process parameters affecting the quality of FDM parts and their levels are mentioned in the table 1:L8 Orthogonal array was used and it is shown in table 2.

Table 1: List of process parameters considered and their Levels

FACTOR	LEVEL1	LEVEL2
LayerThickness,mm(A)	0.1778	0.254
Air Gap,mm (B)	0.1	0.2
Raster Angle ,° (C)	0	30

Table 2:L8 Orthogonal Array

Trial no	Dummy level	A	B	C	AxB	AxC	BxC
1	0	1	1	1	1	1	1
2	0	1	1	2	1	2	2
3	0	1	2	1	2	1	2
4	0	1	2	2	2	2	1
5	0	2	1	1	2	2	1
6	0	2	1	2	2	1	2
7	0	2	2	1	1	2	2
8	0	2	2	2	1	1	1

Dimensions are as follows. (mm)

Beam Height 25, Wing Width 15, Wing Height 5,

Rib Width 5, Rib Height 15, Thickness 5

**A. FDM Prodigy Plus:**

Prodigy Plus builds parts, including internal features, directly from CAD.stl files. The system builds three dimensional parts by extruding a bead of ABS plastic through a computer-controlled extrusion head, producing high quality parts that are ready to use immediately after completion. With three layer resolution settings, it can be choose to build a part quickly for design verification, or finer settings for higher quality surface detail also can be choose. The Prodigy Plus system consists of two main components - the machine itself and insight, the preprocessing software that runs on a Windows NT, Windows 2000, or Windows XP platform. Prodigy Plus's build envelope measures  $203 \times 203 \times 305\text{mm}$  ( $8 \times 8 \times 12$  in). Each material cartridge contains 922 cc (56.3cu.in.) of usable material - enough to build continuously for about four days without reloading. Fig. 4 (a) shows the Prodigy Plus machine.



**Fig 2: FDM Prodigy plus Machine**

**B. Part accuracy:**

Minimum deviation between fabricated part dimension and CAD model dimension was selected as one of the part accuracy criteria. To measure the deviation each dimension is studied separately. For finding the deviation each and every dimension of the fabricated part is measured using micrometer. The least count of micrometer is 0.01 and 0.001mm respectively.

**C. Surface Quality:**

Roughness values on the surface of the samples were obtained using surf test, a contact type of measuring instrument and the Ra values are noted. Each measurement is taken a length of over 4 mm.

**D. Density:**

Density of every model is calculated using weight and volume measurement.

**E. Hardness:**

Hardness of each and every model is calculated using Rockwell hardness tester for hardness.



**II RESULTS AND DISCUSSION**

The study involved 8 samples produced by FDM prodigy plus machine.

**2.1 Signal to Noise Ratio:**

The signal to noise ratio measures the sensitivity of the quality characteristic being investigated to those uncontrollable external factors. To minimize the problem, the governing.

Relationships for the S/N ratio in terms of the experimentally measured values of Ra, i.e.,  $y_i$  calculated as follows:

$$S/N \text{ ratio} = -10 \log_{10} MSD$$

Where  $MSD = \frac{1}{n} \sum (y_i - \hat{y})^2$ ,  $\hat{y}$  the target value that is to be achieved, the number of samples. The S/N ratio values obtained for the trials are listed in following table.

**Table 3: S/N Ratio for Dimensional Accuracy**

FACTOR	LEVEL 1	LEVEL 2	$L_2 - L_1$
Layer thickness	56.4005	53.9113	-2.4891
Air gap	55.7567	56.5678	0.8111
Raster angle	61.0585	49.2873	-11.7712

**Table 4: S/N Ratio for Surface Finish**

FACTOR	LEVEL 1	LEVEL 2	$L_2 - L_1$
Layer thickness	-24.3330	-28.0664	-3.7334
Air gap	-27.2887	-25.7548	1.53386
Raster angle	-27.7203	-25.3128	2.4075

**Table 5: S/N Ratio for Density**

FACTOR	LEVEL 1	LEVEL 2	$L_2 - L_1$
Layer thickness	-44.9295	-44.2732	0.6562
Air gap	-44.1390	-45.0766	-0.9376
Raster angle	-44.6660	-44.5248	0.141143



**Table 6: S/N Ratio for Hardness**

FACTOR	LEVEL 1	LEVEL 2	$L_2 - L_1$
Layer thickness	44.5624	44.9576	0.3952
Air gap	46.0908	42.8456	-3.2451
Raster angle	45.0177	44.5957	-0.5219

## 2.2 ANOVA

ANOVA analysis provides significance rating of the various factors analyzed in this study. Based on the above rating, factors, which influence the objective function significantly, could be identified and proper control measures adopted. In a similar way, those factors with minimum influence could be suitably modified to suit economic considerations. A variable possessing the maximum value of variance is said to have the most significant effect on the process under consideration.

**Table 7: ANOVA for Dimensional Accuracy**

Factor	D.O.F	Sum of squares	variance	%contribution
A	1	0.0120125	0.0120125	50
B	1	$1.125 \times 10^{-4}$	$1.125 \times 10^{-4}$	0.46
C	1	$3.125 \times 10^{-4}$	$3.125 \times 10^{-4}$	1.3
AxB	1	$2.8125 \times 10^{-3}$	$2.8125 \times 10^{-3}$	11
AxC	1	$7.8125 \times 10^{-3}$	$7.8125 \times 10^{-3}$	32
Error	2	$3.05 \times 10^{-4}$	$1.525 \times 10^{-4}$	0.63
Total	7	0.02398		

**Table 8: ANOVA for Surface finish**

Factor	D.O.F	Sum of squares	variance	%contribution
A	1	280.726	280.726	33
B	1	12.375	12.375	4.1
C	1	129.52	129.52	15
AxB	1	134.72	134.72	16
AxC	1	265.53	265.53	31
Error	2	1.4202	0.7101	0.0836
Total	7	838.469		



**Table 9: ANOVA for Density**

Factor	D.O.F	Sum of squares	variance	%contribution
A	1	6.188x10 <sup>-9</sup>	6.188x10 <sup>-9</sup>	30
B	1	1.26x10 <sup>-8</sup>	1.26x10 <sup>-10</sup>	62
C	1	2.86x10 <sup>-10</sup>	2.86x10 <sup>-10</sup>	1.42
AxB	1	5.13x10 <sup>-10</sup>	5.13x10 <sup>-10</sup>	2.5
AxC	1	4.31x10 <sup>-10</sup>	4.31x10 <sup>-10</sup>	2.14
Error	2	1.8x10 <sup>-10</sup>	0.9x10 <sup>-10</sup>	1.6
Total	7	2.007x10 <sup>-8</sup>		

**Table 10: ANOVA for Hardness**

Factor	D.O.F	Sum of squares	variance	%contribution
A	1	6.125	6.125	
B	1	496.125	496.125	81
C	1	21.125	21.125	3.4
AxB	1	1.125	1.125	0.18
AxC	1	6.125	6.125	1
Error	2	81.125	40.625	6.6
Total	7	611.125		

**2.3 F Statistic:** This is calculated as the ratio of observed sample variances. It is particularly helpful in comparison of variances.

Mathematically,

$$F_{\text{calculated}} = \text{Mean SS}_{\text{treatment}} / \text{Mean SS}_{\text{error}}$$

If  $F_{\text{calculated}} \geq F(\alpha, k-1, N-k)$  then accept the hypothesis that treatment effects are significant, i.e., some of the treatments may be different from rest. On the other hand, if

$$F_{\text{calculated}} \leq F(\alpha, k-1, N-k)$$

Then there is not enough evidence in the observed data to reject the hypothesis that all treatments are equal.



**Table 11: F static for dimensional accuracy**

Factor	F statistic	F (0.05,1,7)	F(0.01,1,7)
A	78.7	5.59	12.25
B	0.737	5.59	12.25
C	2.049	5.59	12.25
AxB	1.8442	5.59	12.25
AxC	5.1229	5.59	12.25

**Table 12: F static for surface finish:**

Factor	F statistic	F (0.05,1,7)	F(0.01,1,7)
A	395.33	5.59	12.25
B	17.427	5.59	12.25
C	182.39	5.59	12.25
AxB	189.7	5.59	12.25
AxC	373.60	5.59	12.25

**Table 13: F static for density**

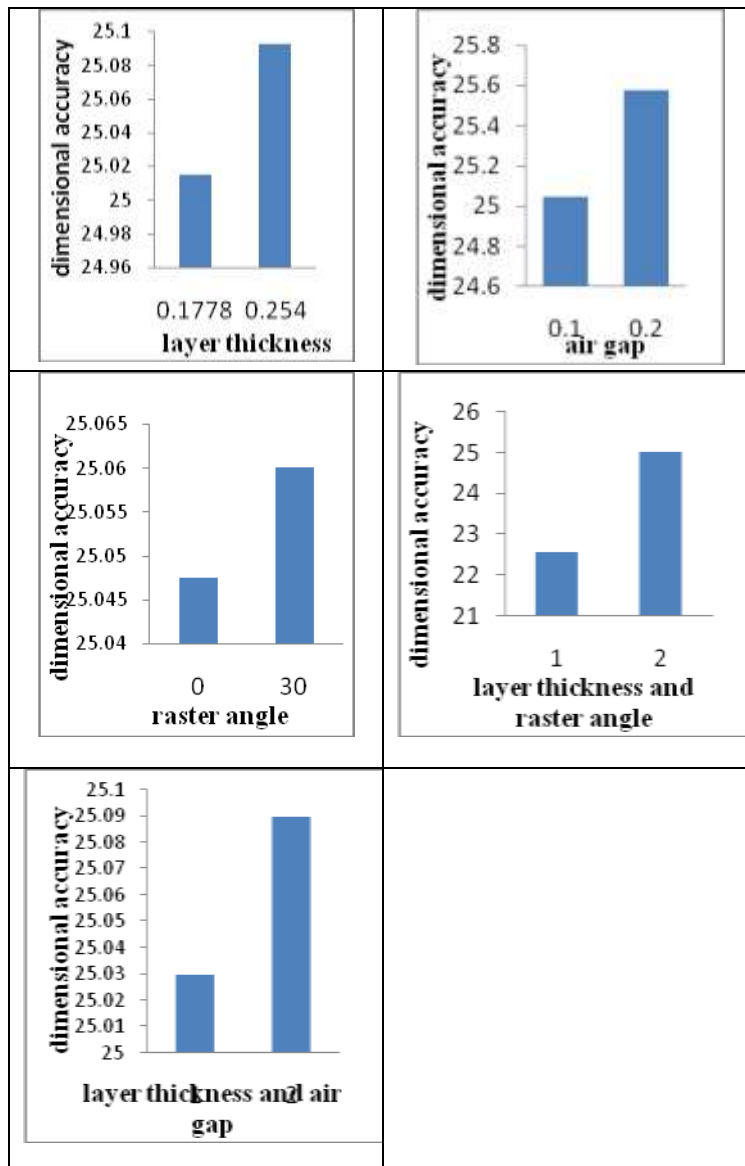
Factor	F statistic	F (0.05,1,7)	F(0.01,1,7)
A	34.377	5.59	12.25
B	70	5.59	12.25
C	0.158	5.59	12.25
AxB	0.285	5.59	12.25
AxC	0.239	5.59	12.25





**Table 14: F static for hardness**

Factor	F statistic	F (0.05,1,7)	F(0.01,1,7)
A	0.15	5.59	12.25
B	12.26	5.59	12.25
C	0.52	5.59	12.25
AxB	0.02	5.59	12.25
AxC	0.15	5.59	12.25



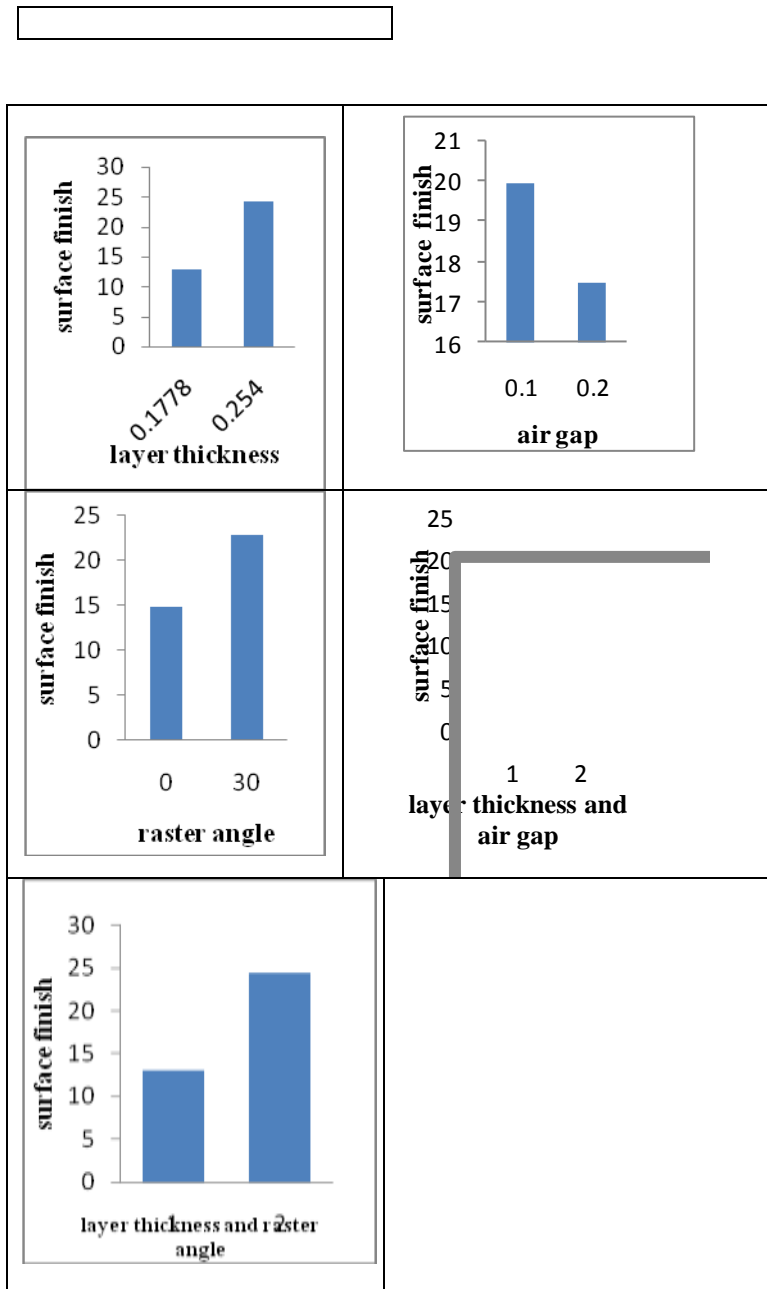


Fig 2 Surface finish Vs parameters

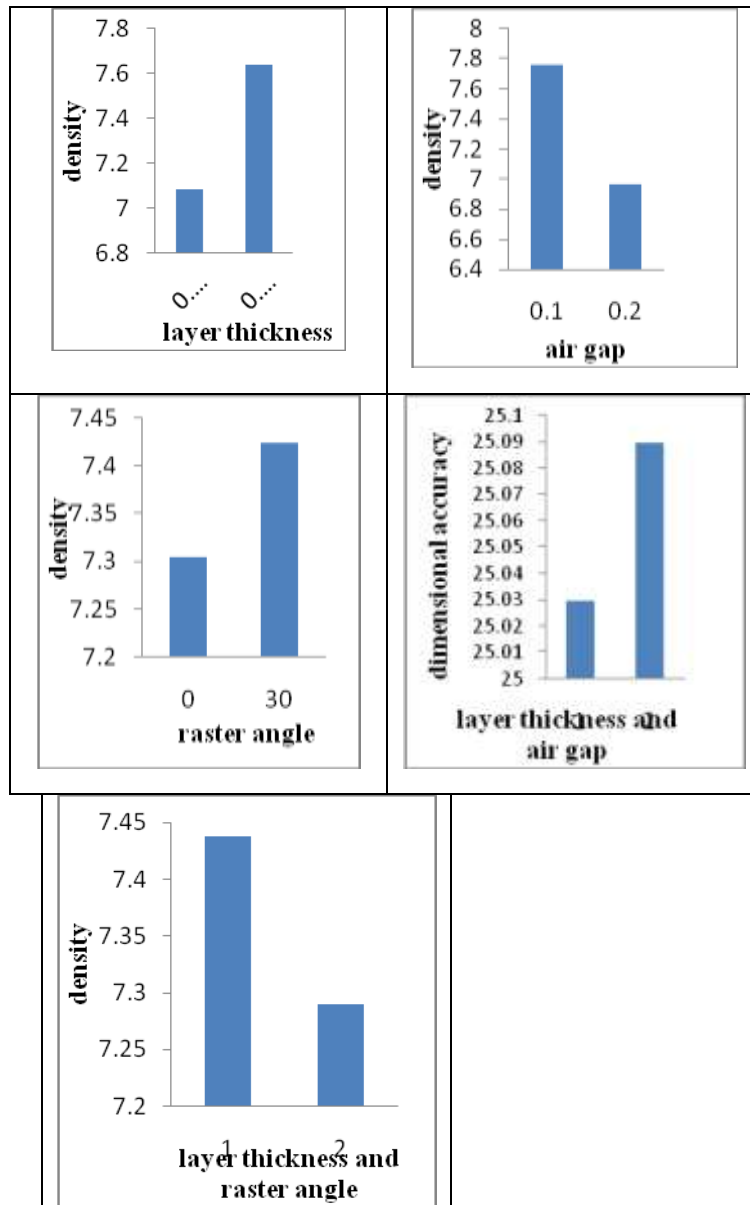


Fig 3 Density Vs parameters

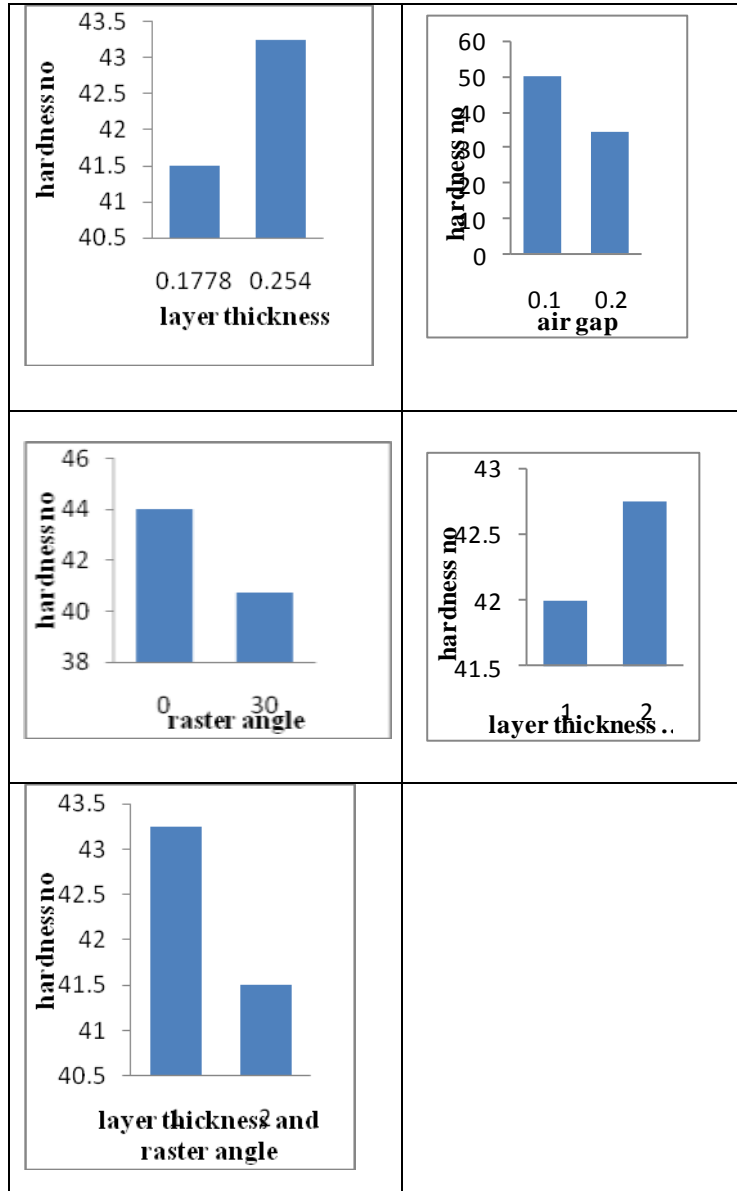


**III CONCLUSIONS**

**3.1. Dimensional accuracy**

**ANOVA:**

Layer thickness effects dimensional accuracy greatly.. Air gap has little effect Raster angle also has little effect coming to interactions layer thickness and raster angle effects dimensional accuracy greatly than that of layer thickness and air gap



**Fig 4.Hardness Vs parameters**

**S/N Ratio:**

Use small layer thickness to get more accuracy in dimensions. Use positive air gap to get more accuracy. Less raster angle gives more accuracy.



### **3.2. Surface Quality**

ANOVA:

Layer thickness effects greatly. Air gap has little effect. Raster angle's effect should be considered. Coming to interactions, layer thickness and raster angle combination effects greatly compared to that of layer thickness and air gap.

#### **S/N Ratio**

. Lesser the thickness of layer more will be the surface quality.. More air gap leads to good surface finish. More raster angle leads to good surface finish.

### **3.3. Density**

ANOVA:

Layer thickness has little effect. Air gap effect is more. Raster angle's effect is very less. Coming to interactions, layer thickness and raster angle, layer thickness and air gap is negligible.

#### **S/N Ratio**

More the thickness of layer more will be the density. Less air gap leads to more density more raster angle leads to more density.

### **3.4. Hardness**

ANOVA:

Layer thickness has least effect. Air gap effect is more Raster angle's effect is less. Coming to interactions, layer thickness and raster angle, layer thickness and air gap effects are negligible.

#### **S/N Ratio**

More the thickness of layer more will be the hardness Less Air gap leads to more hardness less raster angle leads to more hardness.

Finally,

A1B1C2 has more dimensional accuracy.

A1B1C1 has good surface quality.

A2B1C2 has more density.

A2B1C2 has more hardness

## **IV FUTURE SCOPE OF WORK**

Further work can be extended to check mechanical properties like flexural strength, compressive, etc. Thermal properties. Quality characteristics like production time cost etc other type of cross sections, other type of process parameters and various types of materials.



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