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Parametric Optimization of Fused Deposition Modeling Process in Rapid Prototyping Technology

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Abstract —: *Fused Deposition Modelling (FDM) is a rapid prototyping system that produces physical models directly from the computer aided design (CAD) drawings. These models can be used to evaluate the assembly and the functionality of the design, also producing a manufacturing tools, and end-use parts. Parts built with production-grade thermoplastics that match the traditional machined parts, and according to the real-world conditions. FDM can produce instantly functional parts that used mainly in medical and automotive applications, with the use of reverse engineering techniques such as engineering scanning or digitizing systems. Knowledge of the quality characteristics of FDM fabricated parts is crucial. Quality significantly depends on process variable parameters. Optimizing the process parameters of FDM can make the system more precise and repeatable and such advancement can lead to use of FDM in rapid manufacturing applications rather than only producing prototypes. The part building is influenced by variant processing conditions.*

Thus, FDM process variable parameters are required to be collectively optimized rather than individually. In order to understand this issue, this study presents results of the experimental work on the effect of the main FDM process variable parameters of layer thickness (A), air gap (B), raster width (C), contour width (D), and raster orientation (E) on the mechanical properties viz. tensile, flexural, impact strength and hardness of part fabricated using fused deposition modelling (FDM) technology. Previous studies have investigated the quality characteristics but limited knowledge is available on FDM newly improved materials. Thus, the new ABS- M30 material was used in this experimental work to build parts. To conduct this study, a full factorial experiment was used to obtain the test runs. A number of analytical methods Analysis of Variance (ANOVA), used to determine the influence of the variable FDM process parameter settings. Results show that these process parameters have significant effect on the quality of finished products.

***Keywords** – Fused deposition modelling, CAD, Anova.*

I INTRODUCTION

The FDM process was originally developed by Advanced Ceramics Research (ACR) in Tucson, Arizona, but the process has been significantly advanced by Stratasys, Inc. FDM is a non-laser filament extrusion process that utilizes engineering thermoplastics, which are heated from filament form and extruded in very fine layers to build each model from the bottom up. The models can be made from acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyphenylsulfone (PPSF), and various versions of these materials.

Main process parameter are layer thickness, orientation, raster angle, raster width and air gap.

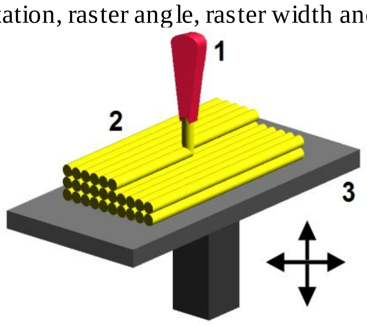

Figure. 1 Fused deposition modeling

II LITERATURE REVIEW

[1] S. Dineshkumar et al[1] (2014) In this paper, the main FDM process variable parameters namely, layer thickness, air gap, raster width, contour width, and raster orientation can be optimize by the using Taguchi's design of experiment. This research to conduct an experimentation plan to determine the optimum parameters settings that affect the output characteristic response i.e., surface roughness (Ra). In this paper, the result of the different parameter are compare to surface roughness

[2] Sandeep Raut et al[2] (2014) In the paper, the effect of built orientation on the mechanical properties and total cost of the FDM parts was investigated. The responses considered are mechanical property of FDM produced parts such as tensile and bending strength. Also the effect of main material required, support material required, number of layers **and** built time is considered in the evaluation of the total cost of FDM parts.

[3] Anoop Kumar Sood. et al[3] (2010) They have studied the influence of important process parameter viz. layer thickness, part orientation, raster angle, air gap and raster width along with their interaction on dimensional accuracy of fused deposition modeling (FDM) process ABS parts. He conclude that, Optimum parameter settings to minimize percentage change in length, width and thickness of standard test specimen have been found out using Taguchi's parameter design

[4] L.M. Galantucci et al[4] (2005) In this paper, the influence on compressive mechanical behavior, manufacturing time and costs of the internal angle of the cones, of the raster width and of the shell width has been studied, demonstrating that the raster width is relevant only for the manufacturing time, while it has no influence on the maximum compressive stress.

III METHODOLOGY

A. Selection of material: ABS-M30

- 25-70 percent stronger than standard ABS material,
- Greater tensile, impact, and flexural strength,
- Layer bonding is significantly stronger for a more durable part,
- Versatile Material: Good for form, fit and moderate functional applications.

B. Selection of machine tool

Stratasys FDM 360mc Machine

Fortus systems include Insight™ and Control Center™ job Processing and management software.

Parts are produced within an accuracy of +/- 0.127 mm or +/-0.0015 mm per mm whichever is greater.

It have two build and two support material canisters 1508 cc

C. Selection of preocess parameter

The five process cutting parameters in FDM operation are layer thickness, orientation, raster angle, raster width and air gap.

Table 1 Process Parameter

Factor	Symbol	Low level(-1)	High level(1)	Unit
Layer thickness	A	0.127	0.254	Mm
Orientation	B	0	45	°
Raster angle	C	0	60	°
Raster width	D	0.4564	0.5814	Mm
Air gap	E	-0.04	0.004	Mm

D. Design of experiment

A full factorial design, is used for simultaneous study of several factor effects on the process. By varying levels of factors simultaneously we can find optimal solution. Responses are measured at all combinations of the experimental factor levels.

E. Grey Relational Analysis

Through the grey relational analysis, a grey relational grade can be obtained to evaluate the multiple performance characteristic. As a result, optimization of the complicated multiple performance characteristic can be converted into the optimization of a single grey relation grade. For multiple performance characteristic optimizations using GRA, following steps are followed:

1. Normalization of experimental result for all performance characteristics.
2. Performance of grey relational generating and calculation of grey relational coefficient (GRC).
3. Calculation of grey relation grade (GRG) using, weighing factor for performance characteristics.
4. Analysis of experimental results using GRG and statistical analysis of variance (ANOVA).
5. Selection of optimal levels of process parameters

IV EXPERIMENTAL RESULT AND DISCUSSION

The experiment was conducted as CENTRAL INSTITUTE OF PLASTIC ENGINEERING AND TECHNOLOGY, G.I.D.C. Vatva, Ahmedabad and results are recorded in a table as shown below.

Table .2 SN Ratio calculations

Exp. Run.	Tensile Strength (Mpa)	Flexural Strength (Mpa)	Izod Impact Strength (KJ/m^2)	Hardness (R scale)	SNR Tensile strength	SNR Flexural strength	SNR Impact strength	SNR Hardness
1	33.6900	53.1272	12.7337	106	30.5500	34.5063	22.0991	40.5061
2	35.8050	58.1784	13.4899	106	31.0789	35.2952	22.6002	40.5061
3	27.9287	49.9641	13.3281	103	28.9210	33.9732	22.4954	40.2567
4	32.3006	55.2816	14.4081	105	30.1842	34.8516	23.1721	40.4238
5	29.8387	51.7159	14.1774	106	29.4956	34.2725	23.0319	40.5061
6	31.1206	53.5453	11.9081	107	29.8610	34.5744	21.5168	40.5877
7	27.6094	45.8166	12.8718	104	25.8211	33.2205	22.1928	40.3407
8	33.5756	53.2791	12.1843	102	30.5205	34.5311	21.7160	40.1720
9	28.8912	48.6459	10.6024	104	29.2153	33.7409	20.5081	40.3407
10	31.9537	56.7672	14.9337	106	30.0904	35.0819	23.4833	40.5061
11	36.1519	56.6928	13.9644	105	31.1626	35.0706	22.9004	40.4238
12	33.3433	54.6128	12.2594	106	30.4602	34.7459	21.7694	40.5061
13	33.9225	51.7934	11.6587	103	30.6098	34.2855	21.3330	40.2567
14	32.1148	54.7135	11.9537	105	30.1341	34.7619	21.5500	40.4238
15	33.2356	58.5966	12.6643	106	30.4321	35.3574	22.0516	40.5061
16	30.7737	55.0309	12.4337	107	29.7636	34.8121	21.8920	40.5877
17	33.5825	57.1109	12.1387	106	30.5223	35.1344	21.6834	40.5061
18	31.0062	53.6972	11.3587	104	29.8290	34.5990	21.1066	40.3407
19	31.4606	48.2278	11.4281	103	29.9553	33.6659	21.1595	40.2567
20	29.4919	53.2016	14.7031	107	29.3941	34.5185	23.3482	40.5877
21	28.2631	50.3220	15.3975	102	29.0244	34.0352	23.7490	40.1720
22	33.2938	50.4497	12.4537	102	30.4473	34.0572	21.9060	40.1720
23	31.7243	51.8678	14.6281	103	30.0278	34.2980	23.3038	40.2567
24	34.8700	54.8634	15.2337	105	30.8490	34.7857	23.6561	40.4238
25	29.8319	45.8841	14.2231	104	29.4936	33.2332	23.0599	40.3407
26	32.0612	52.7834	15.5287	106	30.1196	34.4499	23.8227	40.5061
27	30.0712	50.3822	13.1024	103	29.5630	34.0455	22.3470	40.2567
28	34.5231	54.3491	14.7594	104	30.7622	34.7038	23.3814	40.3407
29	31.3521	52.2116	10.8331	103	29.9253	34.3553	20..6951	40.2567
30	28.5444	50.1316	11.4481	105	29.1104	34.0022	21.1747	40.4238
31	30.1787	46.3984	13.6974	104	29.5940	33.3301	22.7328	40.3407
32	32.4081	51.2978	15.0031	105	30.2131	34.2020	23.5236	40.4238

A. **Main Effects Plot of tensile strength**

Fig. 2 shows that high tensile strength will meet at layer thickness 0.254 mm, orientation 0, raster angle 60, raster width 0.5814 mm and air gap -0.040 mm.It has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high layer thickness [A2], orientation [B1], raster angle [C2], raster width [D2] and air gap [E1].

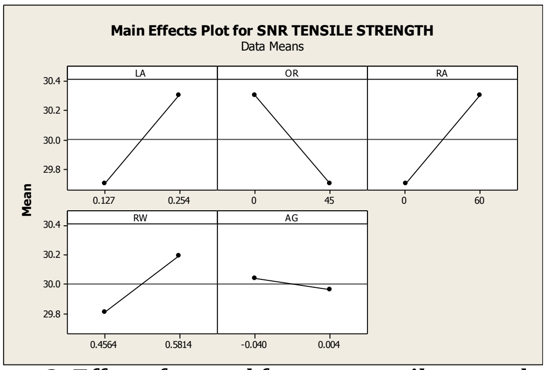

Figure 2. Effect of control factor on tensile strength

B. Main Effects Plot of flexural strength

Fig. 3 shows that high flexural strength will meet at layer thickness 0.127 mm, orientation 0, raster angle 60, raster width 0.5814 mm and air gap -0.040 mm. It has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high layer thickness [A1], orientation [B1], raster angle [C2], raster width [D2] and air gap [E1].

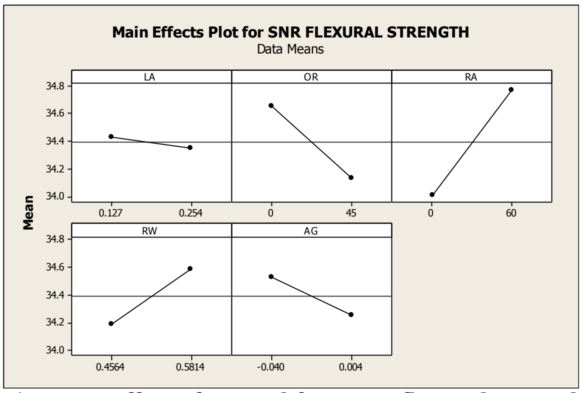

Figure 3. Effect of control factor on flexural strength

C. Main Effects Plot of impact strength

Fig.4 shows that high impact strength will meet at layer thickness 0.254 mm, orientation 0, raster angle 60, raster width 0.4564 mm and air gap -0.040 mm. It has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high layer thickness [A2], orientation [B1], raster angle [C2], raster width [D1] and air gap [E1].

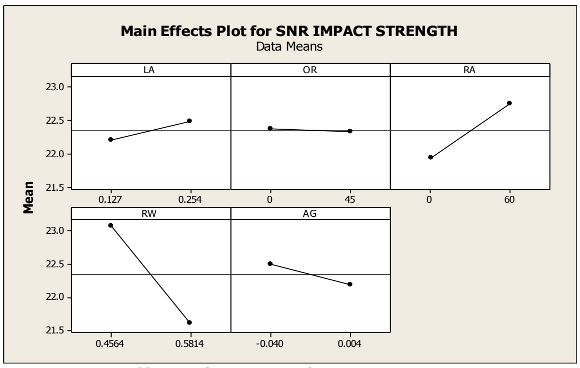

Figure 4. Effect of control factor on tensile strength

D. Main Effects Plot of hardness

Fig.5 shows that high hardness will meet at layer thickness 0.127 mm, orientation 45, raster angle 60, raster width 0.5814 mm and air gap -0.040 mm. It has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high layer thickness [A1], orientation [B2], raster angle [C2], raster width [D2] and air gap [E1].

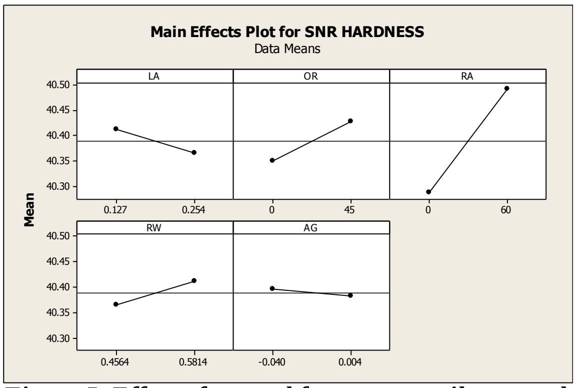

Figure 5. Effect of control factor on tensile strength

E. Analysis of Variance for tensile strength

Table 3 Analysis of Variance for tensile strength

source	DF	Seq SS	Adj SS	Adj MS	F	P
LA	1	2.8868	2.8868	2.8868	37.87	0.000
OR	1	2.9526	2.9526	2.9526	38373	0.000
RA	1	2.9686	2.9686	2.9686	38.94	0.000
RW	1	1.1743	1.1743	1.1743	15.41	0.001
AG	1	0.0484	0.0484	0.0484	0.64	0.433
Error	26	1.9819	1.9819	0.0762		
Total	31	12.0126				

S = 0.276092 R-Sq = 83.50% R-Sq(adj) = 80.33%

From ANOVA result it is observed that the layer thickness, orientation, raster angle and raster width are influencing parameter for tensile strength, while the value of p for air gap is 0.433 which is greater than 0.05 p values. So, it is not influencing parameter for tensile strength.

F. Analysis of variance for flexural strength

Table 4 Analysis of Variance for flexural strength

source	DF	Seq SS	Adj SS	Adj MS	F	P
LA	1	0.0530	0.0530	0.0530	1.36	0.255
OR	1	2.1809	2.1809	2.1809	55.80	0.000
RA	1	4.6723	4.6723	4.6723	119.55	0.000
RW	1	1.2719	1.2719	1.2719	32.54	0.000
AG	1	0.6240	0.6240	0.6240	15.97	0.000
Error	26	1.0161	1.0161	0.0391		
Total	31	9.8181				

S = 0.197690 R-Sq = 89.65% R-Sq(adj) = 87.66%

From ANOVA result it is observed that the orientation, raster angle, raster width and air gap are influencing parameter for flexural strength, while the value of p for layer thickness is 0.255 which is greater than 0.05 p values. So, it is not influencing parameter for flexural strength.

D. Analysis of variance for impact strength

Table 5 Analysis of Variance for impact strength

source	DF	Seq SS	Adj SS	Adj MS	F	P
LA	1	0.6185	0.6185	0.6185	3.58	0.070
OR	1	0.0154	0.0154	0.0154	0.09	0.768
RA	1	5.2027	5.2027	5.2027	30.13	0.000
RW	1	17.1845	17.1845	17.1845	99.51	0.000
AG	1	0.7404	0.7404	0.7404	4.29	0.048
Error	26	4.4902	4.4902	0.1727		

Total	31	28.2516				

S = 0.415570 R-Sq = 84.11% R-Sq(adj) = 81.05%

From ANOVA result it is observed that the raster angle, raster width and air gap are influencing parameter for impact strength, while the value of p for layer thickness is 0.070 and orientation is 0.768, which is greater than 0.05 p values. So, it is not influencing parameter for impact strength.

F. Analysis of Variance for Hardness

Table 6 Analysis of Variance for hardness

source	DF	Seq SS	Adj SS	Adj MS	F	P
LA	1	0.017272	0.017272	0.017272	5.44	0.028
OR	1	0.048468	0.048468	0.048468	15.27	0.001
RA	1	0.328130	0.328130	0.0328130	103.38	0.000
RW	1	0.017418	0.017418	0.017418	5.49	0.027
AG	1	0.001821	0.001821	0.001821	0.57	0.456
Error	26	0.082526	0.082526	0.082526	0.57	0.456
Total	31	0.495635				

S = 0.0563391 R-Sq = 83.35% R-Sq(adj) = 80.15%

From ANOVA result it is observed that the layer thickness, orientation, raster angle and raster width are influencing parameter for hardness, while the value of p for air gap is 0.456 which is greater than 0.05 p values. So, it is not influencing parameter for tensile strength.

V GREY RELATIONAL ANALYSIS

Table 7. Normalization, GRC and GRG of experimental data

	Normalization of the data				Grey relational coefficient				
Exp. No.	Tensile strength	Flexural strength	Impact strength	Hardness	Tensile strength	Flexural strength	Impact strength	Hardness	Grey relational grade (GRG)
1	0.7384	0.6017	0.4800	0.8037	0.6565	0.5566	0.4902	0.7181	0.6053
2	0.9643	0.9709	0.6312	0.8037	0.9333	0.9450	0.5755	0.7181	0.7930
3	0.0427	0.3522	0.5996	0.2038	0.3431	0.4356	0.5553	0.3857	0.4299
4	0.5821	0.7633	0.8037	0.6057	0.5448	0.6787	0.7151	0.5591	0.6252
5	0.2881	0.4923	0.7614	0.8037	0.4126	0.4962	0.6770	0.7181	0.5760
6	0.4441	0.6336	0.3043	1.0000	0.4735	0.5771	0.4182	1.0000	0.6172
7	0.0000	0.0000	0.5083	0.4058	0.3333	0.3333	0.5042	0.4570	0.4069
8	0.7258	0.6133	0.3644	0.0000	0.6458	0.5639	0.4403	0.3333	0.4958
9	0.1684	0.2435	0.0000	0.4058	0.3755	0.3979	0.3333	0.4570	0.3909
10	0.5421	0.8711	0.8976	0.8037	0.5220	0.7950	0.8300	0.7181	0.7163
11	1.0000	0.8658	0.7217	0.6057	1.0000	0.7884	0.6425	0.5591	0.7475
12	0.7000	0.7138	0.3805	0.8037	0.6250	0.6360	0.4466	0.7181	0.6064
13	0.7639	0.4984	0.2489	0.2038	0.6793	0.4992	0.3996	0.3857	0.4910
14	0.5608	0.7213	0.3143	0.6057	0.5323	0.6421	0.4217	0.5591	0.5388
15	0.6880	1.0000	0.4657	0.8037	0.6158	1.0000	0.4834	0.7181	0.7043
16	0.4025	0.7448	0.4175	1.0000	0.4556	0.6621	0.4619	.1.0000	0.6449
17	0.7265	0.8956	0.3546	0.8037	0.6464	0.8273	0.4365	0.7181	0.6571
18	0.4305	0.6451	0.1806	0.4058	0.4675	0.5849	0.3790	0.4570	0.4721
19	0.4844	0.2084	0.1965	0.2038	0.4923	0.3871	0.3836	0.3857	0.4122
20	0.2447	0.6074	0.8568	1.0000	0.3983	0.5602	0.7774	1.0000	0.6840
21	0.0868	0.3813	0.9778	0.0000	0.3538	0.4469	0.9574	0.3333	0.5229
22	0.6945	0.3915	0.4217	0.0000	0.6207	0.4511	0.4637	0.3333	0.4672

23	0.5154	0.5042	0.8435	0.2038	0.5078	0.5021	0.7616	0.3857	0.5393
24	0.8661	0.7325	0.9497	0.6057	0.7887	0.6514	0.9087	0.5591	0.7270
25	0.2872	0.0059	0.7699	0.4058	0.4123	0.3347	0.6848	0.4570	0.4722
26	0.5546	0.5753	1.0000	0.8037	0.5289	0.5407	1.0000	0.7181	0.6969
27	0.3168	0.3861	0.5548	0.2038	0.4226	0.4489	0.5290	0.3857	0.4465
28	0.8290	0.6941	0.8669	0.4058	0.7452	0.6205	0.7897	0.4570	0.6531
29	0.4716	0.5310	0.0564	0.2038	0.4862	0.5160	0.3464	0.3857	0.4336
30	0.1236	0.3658	0.2011	0.6057	0.3633	0.4408	0.3849	0.5591	0.4370
31	0.3301	0.0513	0.6712	0.4058	0.4274	0.3451	0.6033	0.4570	0.4582
32	0.5945	0.4593	0.9098	0.6057	0.5522	0.4805	0.5471	0.5591	0.6097

The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. Experiment 28 has the best multiple performance characteristic among 32 experiments, because it has the highest grey relational grade shown in table 6. The higher the value of the grey relational grade, the closer the corresponding factor combination is, to optimal. A higher grey relational grade implies better product quality, therefore, on the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

A. Main Effect of Factors on Grey Relational Grade (GRG)

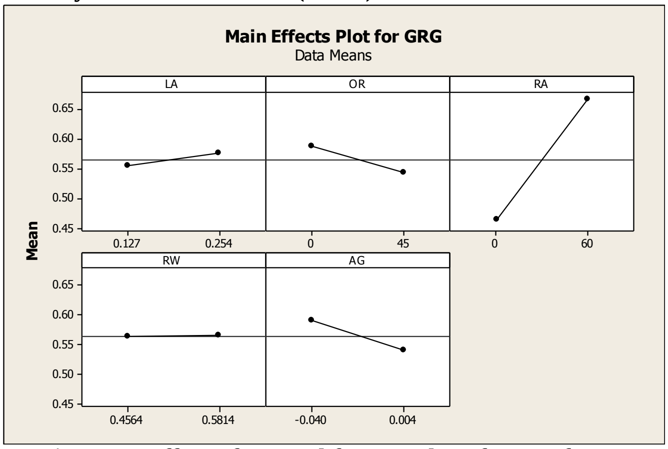

Figure 6. Effect of control factors plot of SNR of GRG

For the combined response maximization or minimization, fig.5.5 gives optimum value of each control factor. It interprets that level A2, B1, C2, D2 and E1 gives optimum result. The mean of grey relational grade for each level of the other machining parameters can be computed in similar manner. The mean of grey relational grade for each level of the machining parameters is summarized and shown in following table.

Table 8. Main effect of factors on Grey Relational Grade

Symbol	*Control Factor*	*Level-1*	*Level-2*
A	*Layer thickness*	*0.554638*	***0.575263***
B	*Orientation*	***0.587432***	*0.542469*
C	*Raster angle*	*0.463407*	***0.666494***
D	*Raster width*	***0.564457***	*0.564438*
E	*Air gap*	***0.600113***	*0.539638*

As we know that higher grey relational grade value will give optimum value of tensile strength, flexural strength, impact strength and hardness. So from above table, it is concluded that level-1 is higher for orientation, raster width, air gap and level-2 is higher than for layer thickness, raster angle.

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VI CONFIRMATION TEST

Confirmation Test Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the estimated result against experimental value. It may be noted that if the optimal combination of

parameters and their levels coincidently match with one of the experiments in the OA, then no confirmation test is required.
In our research study, Tensile strength, Flexural Strength, Impact strength, Hardness has optimal combination are A2 B1 C2 D2 E1, A1 B1 C2 D2 E1, A2 B1 C2 D1 E1 And A1 B2 C2 D2 E1 respectively. This optimal combination are match in orthogonal array. So there are not required to confirmation for Tensile strength, Flexural Strength, Impact strength, Hardness.

VII CONCLUSION

Experimental investigation on fused deposition modeling process has been done using ABS-M30. The following conclusions are made.
[1] From the S/N ratio plot the optimum parameter settings for tensile strength at, ie. Layer thickness= 0.254 mm, orientation= 0 degree, raster angle= 60 degree, raster width= 0.5814 and air gap= -0.040.
[2] From the S/N ratio plot the optimum parameter settings for flexural strength at, ie. Layer thickness= 0.127 mm, orientation= 0 degree, raster angle= 60 degree, raster width= 0.5814 and air gap= -0.040.

[3] From the S/N ratio plot the optimum parameter settings for impact strength at, ie. Layer thickness= 0.254 mm, orientation= 0 degree, raster angle= 60 degree, raster width= 0.4564 and air gap= -0.040.
[5] From the S/N ratio plot the optimum parameter settings for tensile strength at, ie. Layer thickness= 0.127 mm, orientation= 45 degree, raster angle= 60 degree, raster width= 0.5814 and air gap= -0.040.
[6] As we know that higher grey relational grade value will give optimum value of tensile strength, flexural strength, impact strength and hardness. So from above table, it is concluded that level-1 is higher for orientation, raster width, air gap and level-2 is higher than for layer thickness, raster angle.

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