Parametric Analysis and Optimization of FDM Parameters on Rapid Prototyping

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Abstract

- Fused Deposition Modeling(FDM) is gaining district advantages in manufacturing industries because of its ability to manufacturing part with complex shapes without any tooling requirement and human interface.

- FDM is one of the rapid prototype process that produce prototype from plastic materials such as ABS, PLA, PP, PC etc.

- It is the process that create parts in an additive layer by layer manner. In FDM process, the critical factors are selected for making component to measure different properties.

Cont…

- The properties of FDM built parts exhibit high dependence on process parameters and can be improved by setting parameters at suitable levels.
- Experimental design is done by TAGUCHI design of experiments L9 array is used.
- The input parameters are layer thickness, air gap, raster width, raster angle and output parameters are tensile strength, surface roughness, dimension accuracy.
- The multi-objective optimization is perform by GRA(Gray Relationship Analysis).

PROJECT BACKGROUND

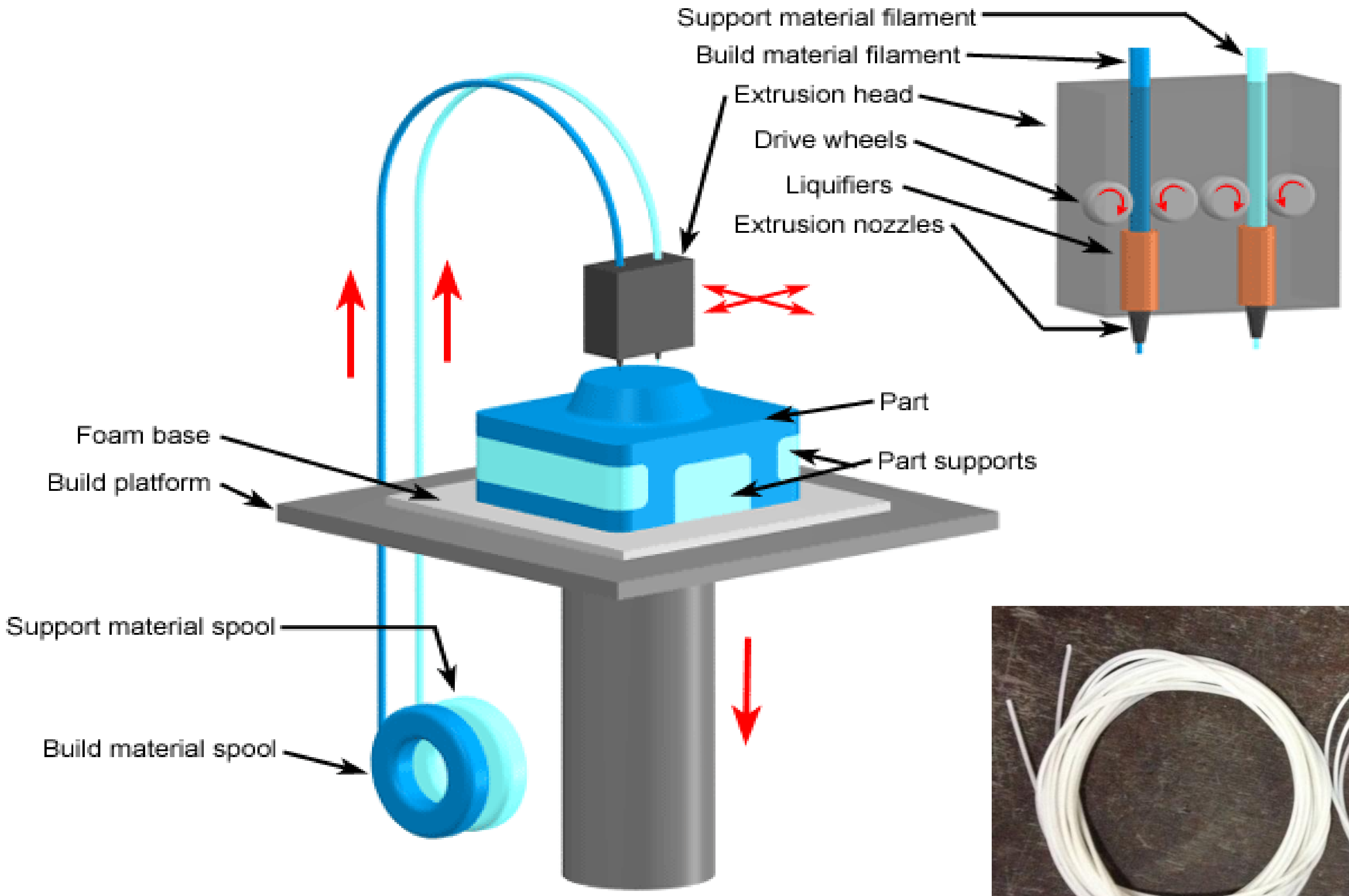
- In recent years, The manufactures should be capable in delivering products in fulfilling the total satisfaction of customers, product in high quality, short delivery time, at reasonable cost, environmental concern and fulfill all safety requirements.
- In many fields, there is great uncertainty as to whether a new design will actually do what is desired. New design often have unexpected problems. A prototype is often used as part of the product design process to allow engineers and designers the ability to explore design alternatives, test theory and confirm performance prior to starting production of new products.
- We propose a prototyping framework for such systems which allows designers to rapidly create a prototype and efficiently test against parameters.

What is FDM ?

- Fused deposition modeling is one of the RP process.
- These process is work on the additive principle.
- It produced prototype from plastic material by layering track of semi molten plastic filament on to a platform in a layer wise manner from bottom to top.

FDM MACHINE

How it work?


Support material filament
Build material filament
Extrusion head
Drive wheels
Liquifiers
Extrusion nozzles
Part
Part supports
Foam base
Build platform
Support material spool
Build material spool

Basic Process

- Create a CAD model of the Design.
- Convert the CAD model to STL format.
- Slice the STL file into thin cross section layers.
- Construct the model one layer atop another.
- Clean and finish the model.

FDM Parameters

Input *Parameters*

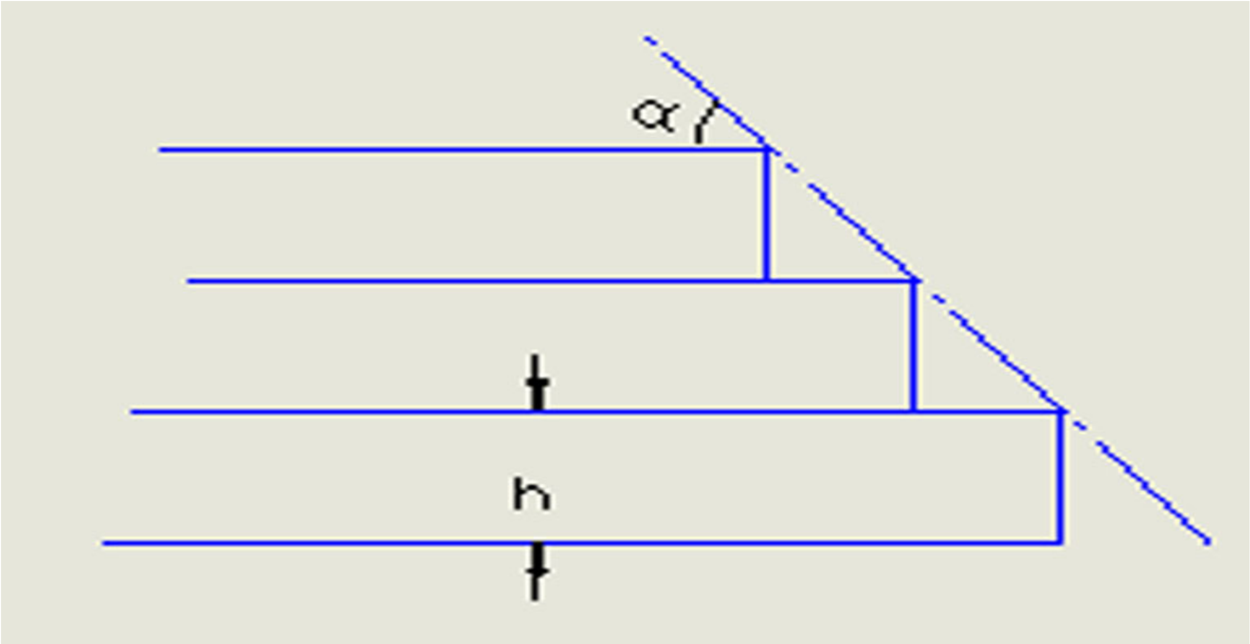
- **Air gap**
- **Raster width**
- **Raster angle**
- **Layer thickness**
- **Orientation**

Output Parameters

- **Tensile strength**
- **Surface roughness**
- **Built time**
- **Built material**
- **Support material**

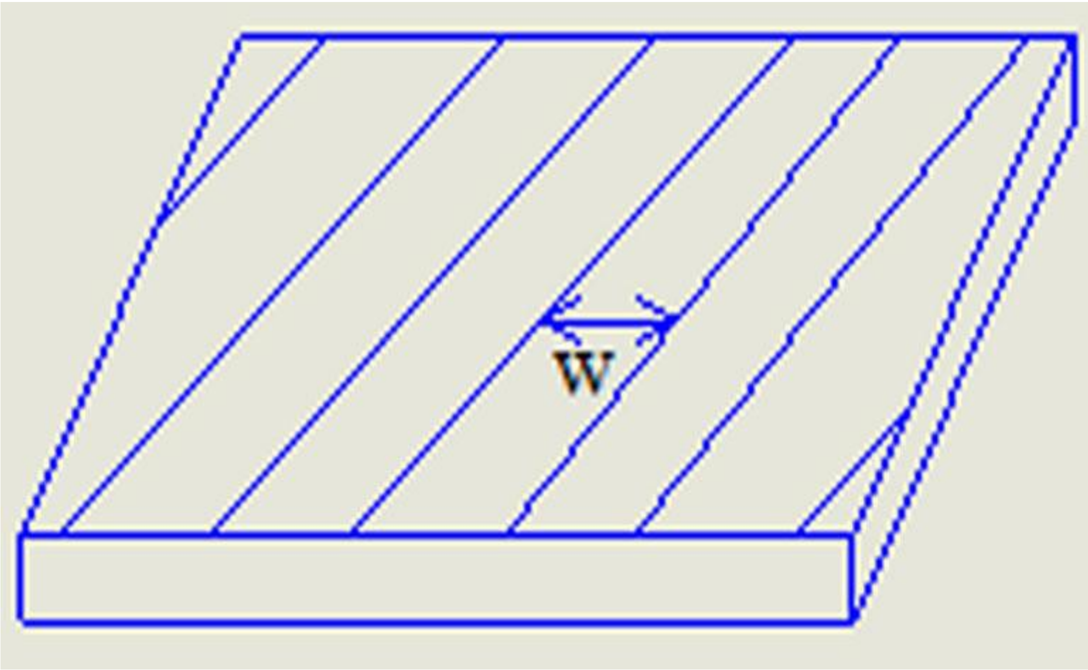
Layer thickness

- It is a thickness of layer deposited by nozzle and depends upon the type of nozzle used.



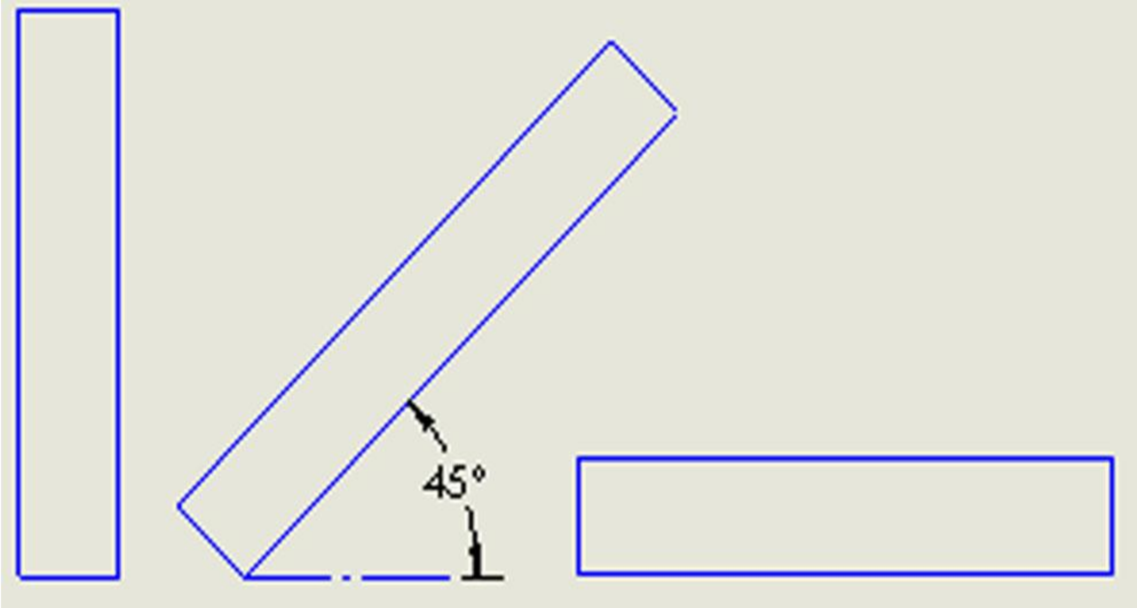
Raster width

- Width of raster pattern used to fill interior regions of part curves



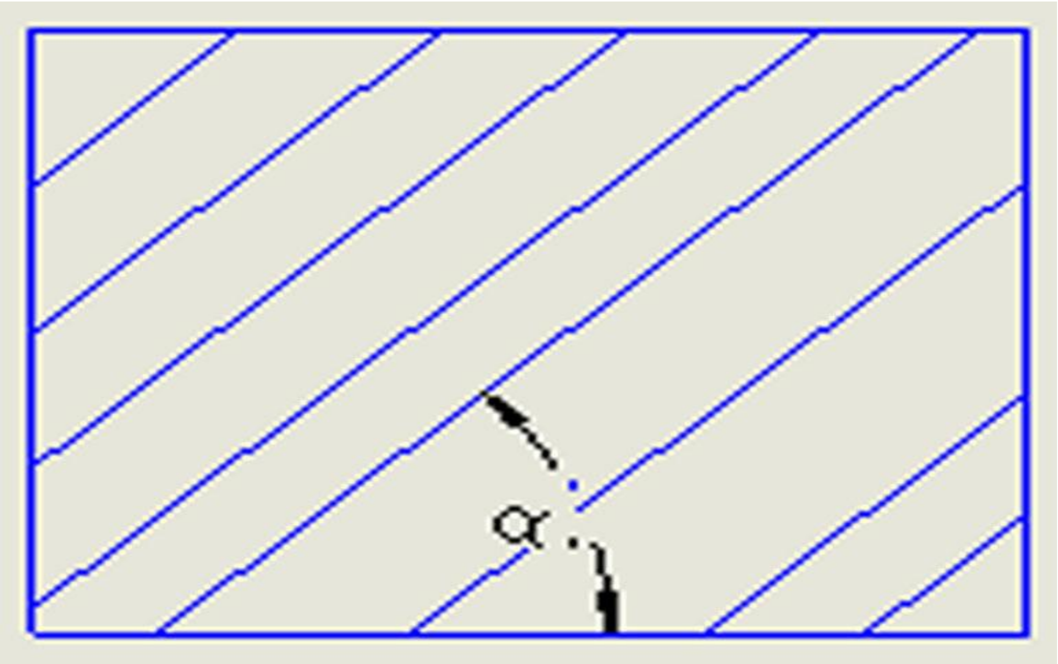
Orientation

- Part build orientation or orientation referrers to the inclination of part in a build platform with respect to X, Y, Z axis, where X and Y-axis are considered parallel to build platform and Z-axis is along the direction of part build.



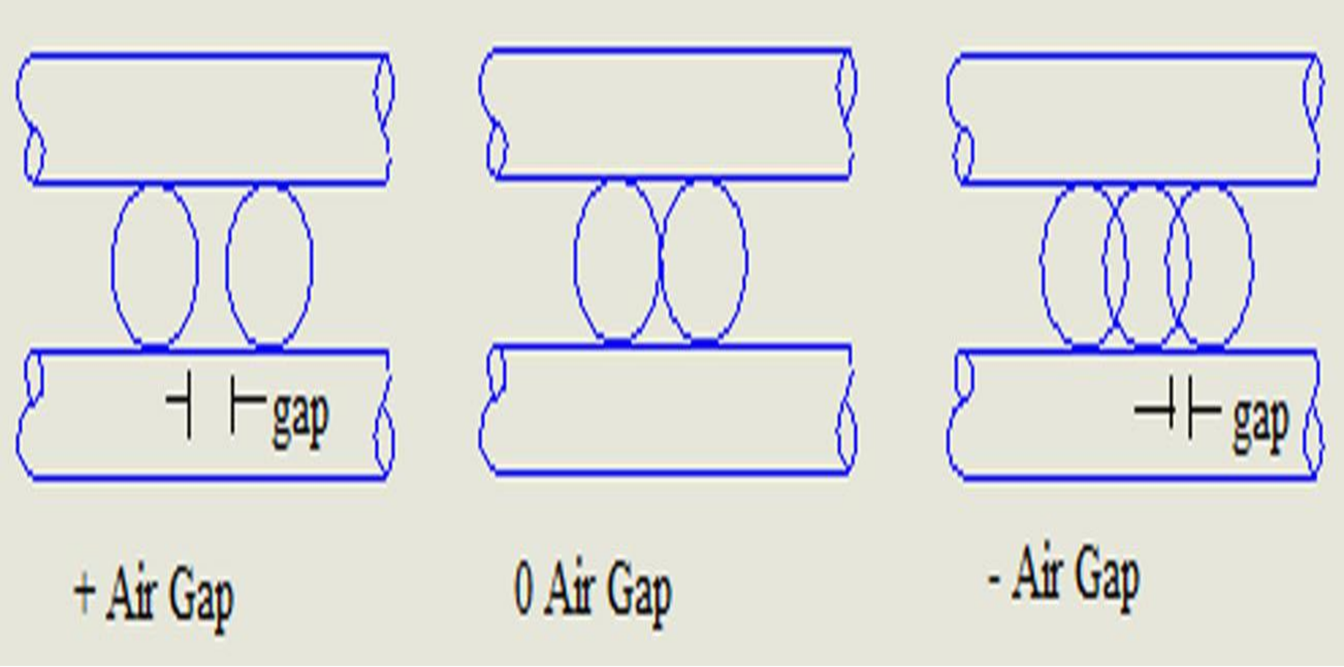
Raster angle

- It is a direction of raster relative to the axis of build table.



Raster to raster gap (air gap)

- It is the gap between two adjacent raster on same layer.



FDM Specification

System size/weight	• 1281 x 896 x 1962 mm (50.5 x 35.5 x 77.3 in.)/with crate: 786 kg , without crate: 593 kg
Materials	• ABS-M307 • FDM Nylon 12 • PC • PC-ABS
Build envelope options	• 355 x 254 x 254 mm (14 x 10 x 10 in.)
Layer thicknesses	• 0.254 mm (0.010 in.) • 0.178 mm (0.007 in.) • 0.127 mm (0.005 in.)
Support structure	• Soluble for most materials; break-away for PC-ISO • ULTEM and PPSF; soluble or break-away for PC
Achievable accuracy	• Parts are produced within an accuracy of ± .127 mm (± .005 in.) or ± .0015 mm/mm (± .0015 in/in), whichever is greater. (Accuracy is geometry dependent. Achievable accuracy specification derived from statistical data at 95% dimensional yield.)
Power requirements	• 230V AC, 50/60 Hz, 3 phase, 16A/phase
Material Bay	1 material bay 1 support bay

LITERATURE REVIEW

- Rayegani et al.has been found that negative air gap and smaller raster widths parameters affect tensile strength on ABS material. Negative air gap and smaller raster widths improve tensile strength. The zero part orientation maximum tensile strength is obtained. Increased raster angle also improves tensile strength.

- Sood et al. has been found that the maximum compressive stress of 17.4751 MPa achive the optimum value of layer thickness 0.254 mm , orientation 0.036 degree, raster angle 59.44 degree, raster width 0.422 mm and air gap 0.00026 mm on ABS material.

- Rishi kumar et al has been Found that The optimum conditions for obtaining higher grey relational grade such as C1S2F3D2, (Coolant emp. on, speed 765Rpm, feed 50mm/min, Depth of cut 0.8mm) were obtained. After conducting the confirmation test with the optimal level of end milling process parameters, it has been found that GRA based Taguchi method coupled with PCA is best suitable for solving the quality problem of machining in the end milling of Al-6061 alloy.

LITERATURE REVIEW

- S. Dinesh Kumar et al. has been Found that negative air gap at (-0.01 mm) and layer thickness at (0.254 mm) or raster width at (0.508 mm) can be used to reduce surface roughness. Using small layer thickness to increase Surface Quality. Using the optimal part orientation is vital to reduce support material, which will lead to reduce building time and improve the surface finish. ABS-M30i use in experiment.

- Sandeep Raut et al.has been found that about y-axis at 0 angle built up orientation FDM parts has good tensile strength and minimum cost. And about x-axis 0 angle built up orientation FDM parts has good flexural strength and medium cost.

- Nancharaiah et al. has been found that the layer thickness and road width affect the surface quality and part accuracy greatly. Raster angle has little effect. But air gap has more effect on dimensional accuracy and little effect on surface quality.

LITERATURE REVIEW

- L.M. Galantucci et al. has been Found that the effect of three important FDM parameters like Tip size, Raster width and Slice height to improve surface finish and roughness of parts use ABS material. The slice height and the raster width are important parameters while the tip diameter has little importance for surfaces running either parallel or perpendicular to the build direction.

- Jaimin Patel at al. has been Found that the effect of three important FDM parameters like layer thickness, orientation angle and raster width on tensile strength and flexural strength of FDM fabricate test specimens. Taguchi method was employed for design of experiments. Analysis of variance and signal to noise ratio were used to find out which parameter is significant over output response. After the experimental work and ANOVA analysis they have conclude that the layer thickness and orientation angle is highly significant to response characteristics whereas raster width have a little effect.

- Panda et al. has been find out that the layer thickness and orientation angle is highly significant parameters for FDM fabricated parts whereas remaining parameter have little effect.

LITERATURE REVIEW

- Mayank Zelawat at al. has been Found that five FDM parameters layer thickness, air gap, raster width, contour width and raster orientation. Building parts with thinner layers or narrower roads may reduce the surface roughness. it has been concluded that negative air gap was sufficient to increase the tensile strength of the building parts where by filling the porosity or voids the beads has increased significantly the bonding between the deposited.

- Tejendrasinh S. Raol at al. has been Found that the effect of three important FDM parameters like layer thickness, part built orientation and raster angle. In this paper the authors study the influence of FDM machining parameters on polycarbonate (PC) prototypes surface roughness. They have methodology Response surface methodology (RSM) was used to find out which parameter is significant over output response. The response plots are analyzed to assess influence of each factor and their interaction on surface roughness. Experimental result analysis and surface plots concluded that part build orientation has the most significant effect on surface roughness followed by layer thickness. However raster angle has least significant influence on surface roughness.

LITERATURE REVIEW

- Raghuraman S et al has been Found that Optimization is one of the techniques used in manufacturing sectors to arrive for the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. The obtained results show that the Taguchi Grey relational Analysis is being effective technique to optimize the machining parameters for EDM process.

- Vikas Sukhdeve1 et al has been Found that Taguchi based Grey Relational Analysis is implemented to optimize a set of operational parameters of any process to achieve best result of any performance parameter, of that process. After discussion on different aspects of Taguchi design different aspects of Grey Relational Numerical Method like ‘Processing of Primitive Data’, ‘Grey Relational Coefficient’ ‘Grey Relational Grade’, ‘Grey Relational Ordering’ and ‘Grey relational Matrix’ have been done

Literature Review Conclusion

- Negative air gap and smaller raster widths improve tensile strength.
- Using the optimal part orientation is vital to reduce support material, which will lead to reduce building time and improve the surface finish.
- Using small layer thickness to increase Surface Quality.
- Taguchi method give lowest cost, minimum number of experiments and Industrial Engineers can use this method compare with other.

RESEARCH GAP

- In Fused Deposition Modeling machine most of Design Of Experiment is done by RSM but very few DOE using TAGUCHI method.
- Very few Researchers have used Raster width and raster angle in Parametric analysis of FDM parameter.
- Multi-objective optimization using GRA in Parametric analysis of FDM parameter has not been used.

OBJECTIVE

- To analyze parameter effect such as, orientation, layer thickness, and air gap.
- Make a Design Of Experiment.
- Multi Objective optimization.
- Improve tensile strength, surface roughness, and dimension accuracy.
- Analysis of experimental results using statistical methods and developing mathematical models

SCOPE OF PROJECT

- Use in industry for making prototype of new product .
- Produce product with high strength ,dimension accuracy and batter surface finish.

Design Of Experiment

- Design of experiments (DOE), is a scientific method to identify how the input parameters (factors) affects the output or quality characteristic system.
- It is important to obtain maximum realistic information with the minimum number of well designed experiments.

- Design of experiments can be used to:

- To Study the effect of different factors on the product or process behavior on the component.
- To know and identification of the relationship between the input variables and the output variables which affects on the quality characteristic.
- To minimize the product or process development time.
- To decrease manufacturing cost of any product or process.

Methods of DOE

There are three methods for Design of Experiment

- ❖ Full Factorial Design
- ❖ Taguchi Method
- ❖ Response Surface Design

Taguchi Method

- Taguchi's philosophy, developed by Dr. Genichi Taguchi, is an efficient tool for the design of high quality manufacturing system which gives minimum no. Of experiments to be performed.

- In Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases.

- In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a design of orthogonal arrays to study the entire parameter space with small number of experiments only.

Cont…

- The Taguchi Method is applied in four steps.

1. Brainstorm the quality characteristics and design parameters important to the product/process.
2. Design and conduct the experiments.
3. Analyse the results to determine the optimum conditions.
4. Run a confirmatory test using the optimum conditions.

Advantages

1. The main advantage of using Taguchi method is that it gives more importance to the mean performance characteristic value which is very close to the target value than the value within a definite specification limits, thus improves the quality of the product.
2. Taguchi's method is a powerful simple tool and easy to apply to many engineering processes for experimental design.
3. The Taguchi method is used to narrow down the scope of a research project or to know the problems in a manufacturing process from existence data.

Factors & Levels

Parameters	Unit	Level
Layer thickness	mm	0.127

Parameters	Unit	Low Level	Center Level	High Level
Raster Width	mm	0.2032	0.4032	0.5782
Raster Angle	Degree	0	15	45
Air gap	mm	0	0.004	0.008
Orientation Angle	Degree	0	15	30

Taguchi Design

Taguchi Orthogonal Array Design

L9(3**4)

Factors: 4

Runs: 9

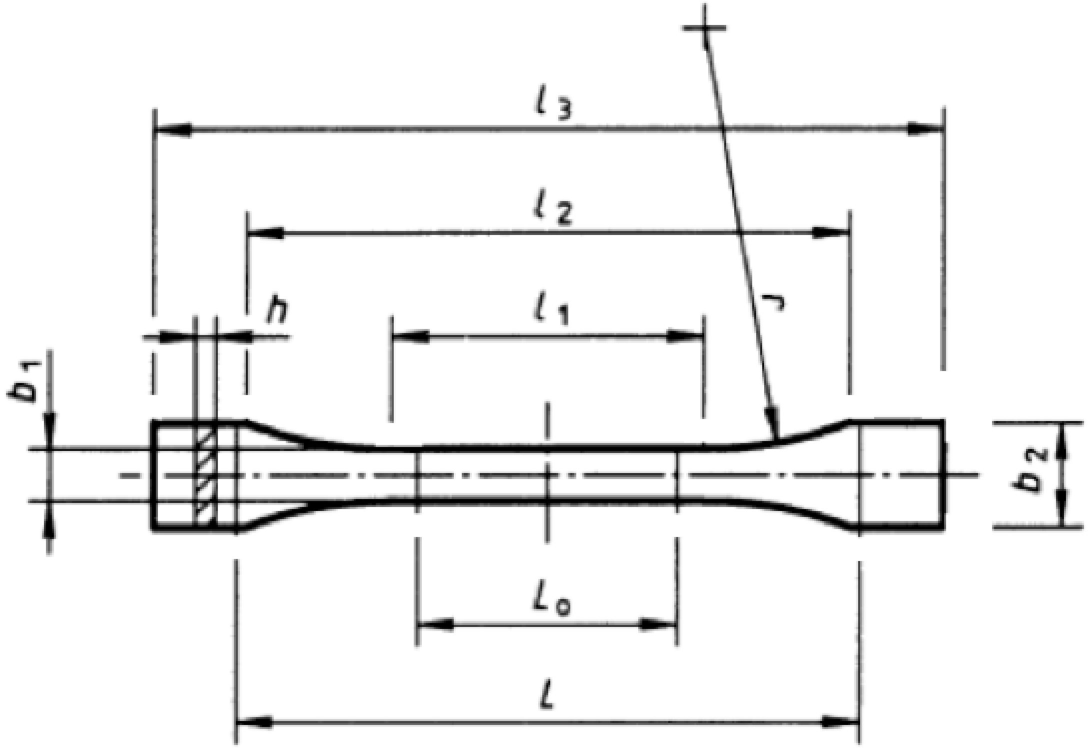
Columns of L9(3**4) Array

1 2 3 4

Design Of Experiment

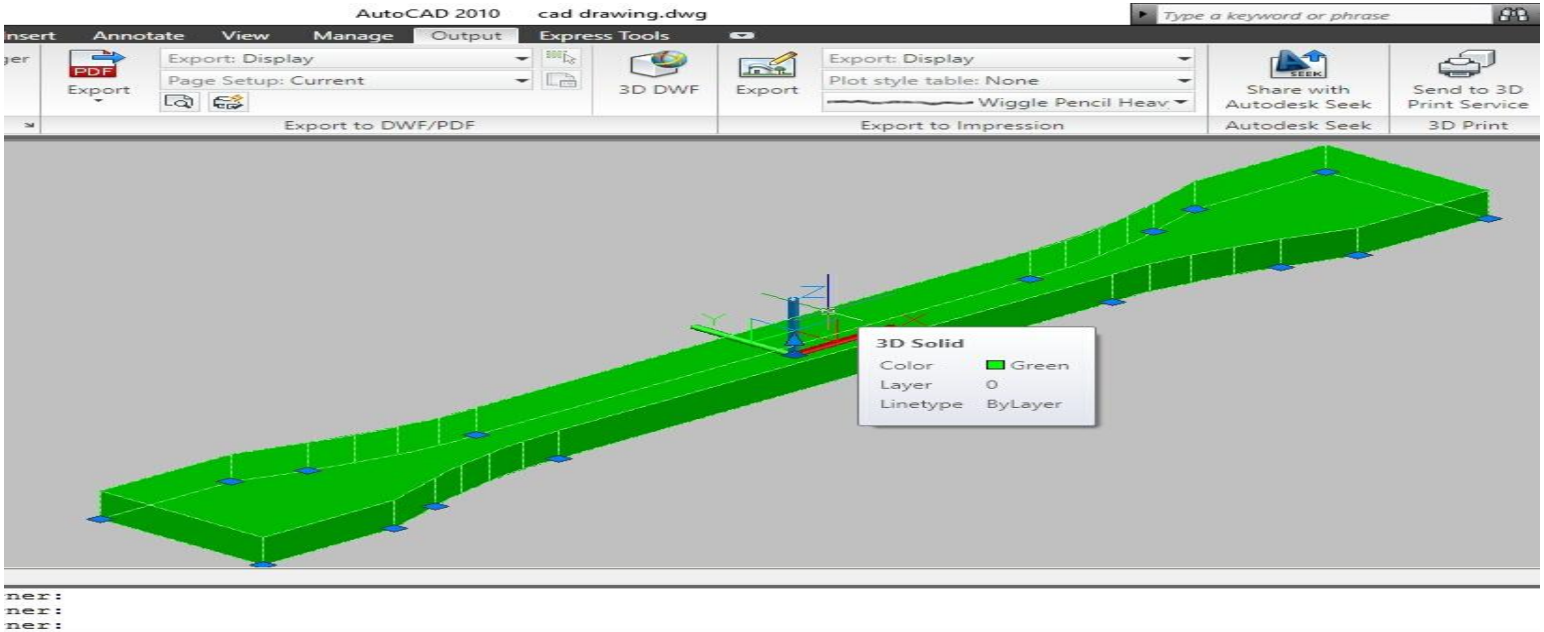
S.NO	Raster Width (mm)	Air gap (mm)	Raster Angle(deg)	Orientation Angle(deg)
1	0.2032	0	0	0
2	0.2032	0.004	15	15
3	0.2032	0.008	45	30
4	0.4032	0	15	30
5	0.4032	0.004	45	0
6	0.4032	0.008	0	15
7	0.5782	0	45	15
8	0.5782	0.004	0	30
9	0.5782	0.008	15	0

Tensile Test Specimen



Tensile test specimen design according to ISO 527

Type of specimen	**Dimensions in mm**
l3 overall length	≥75
*l*1 Length of narrow parallel-sided portion	30 ± 0,5
r Radius	≥30
*l*2 Distance between broad parallel-sided portions	58 ± 2
b2 Width at ends	10 ± 0,5
b1 Width of narrow portion	5 ± 0,5
h Thickness	≥2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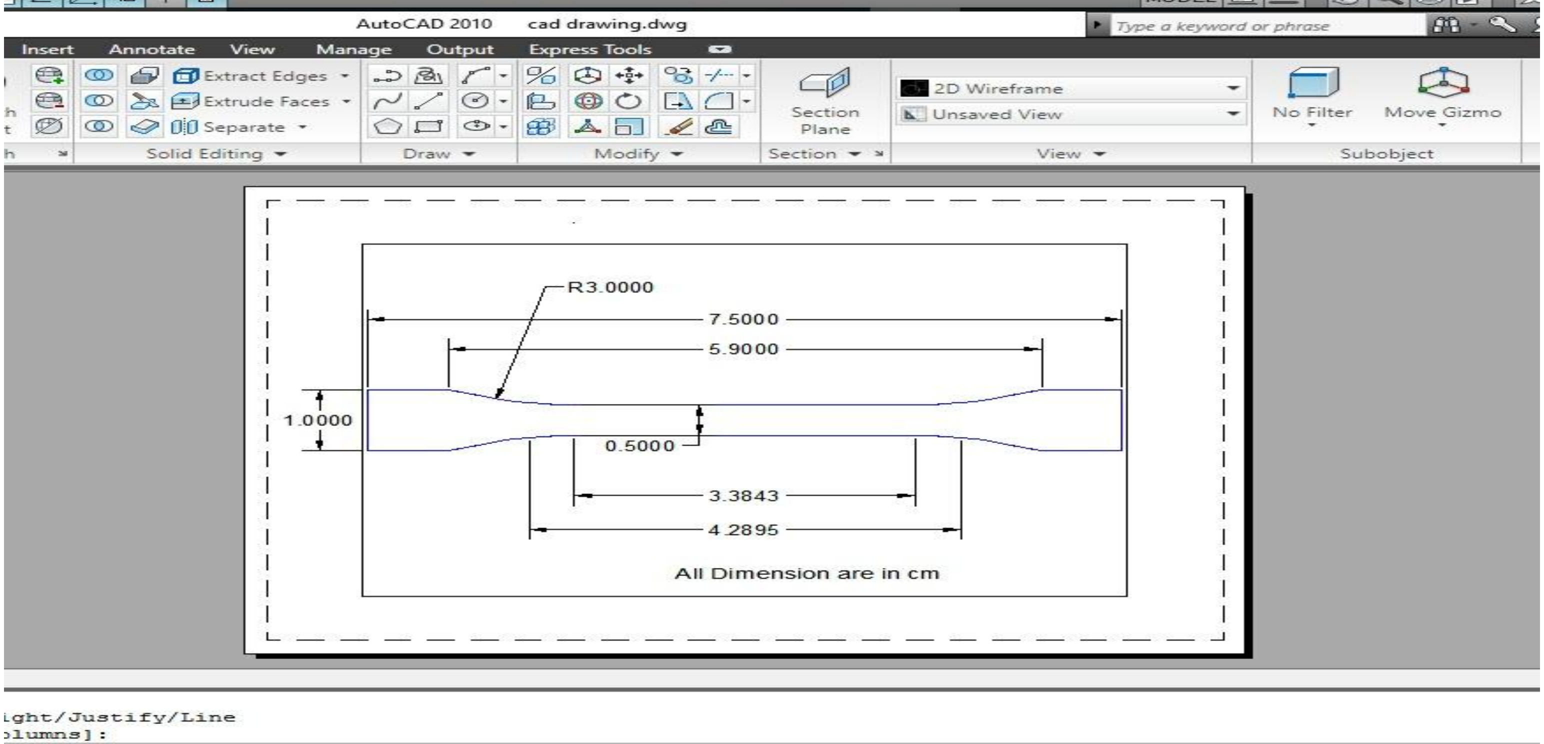
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Extract Edges
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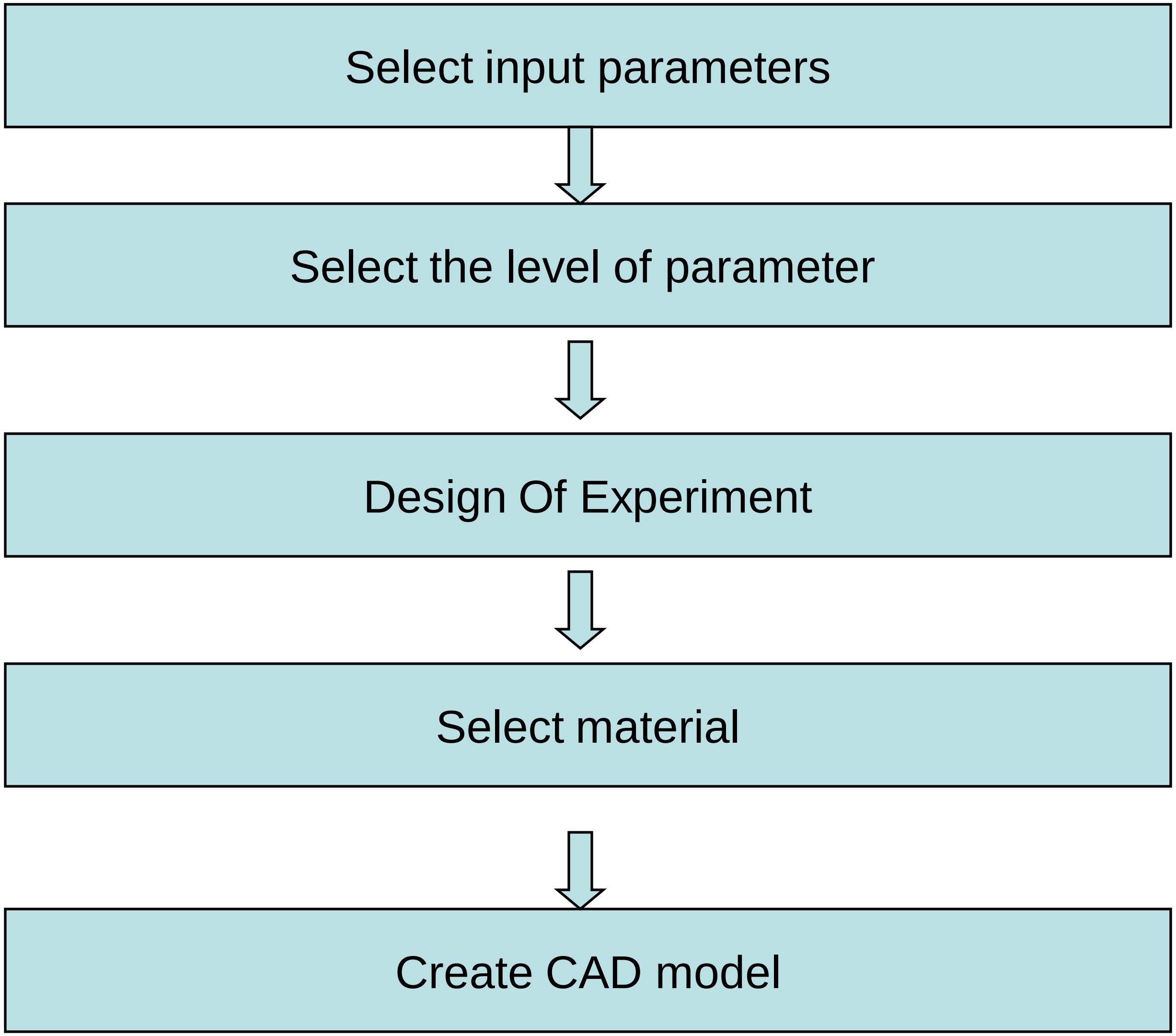
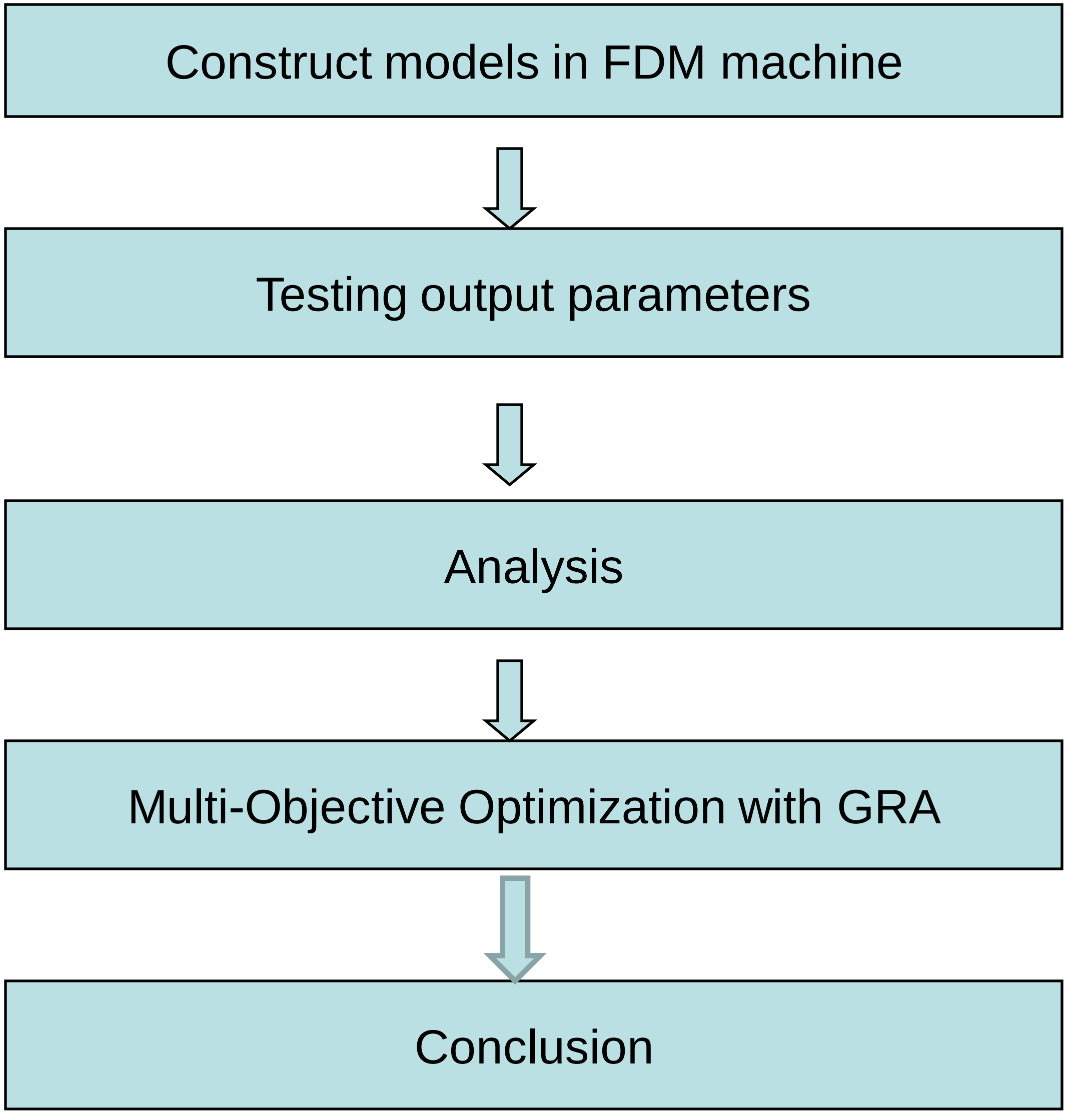
No Filter
Move Gizmo
Subobject
R3.0000
7.5000
5.9000
1.0000
0.5000
3.3843
4.2895
All Dimension are in cm

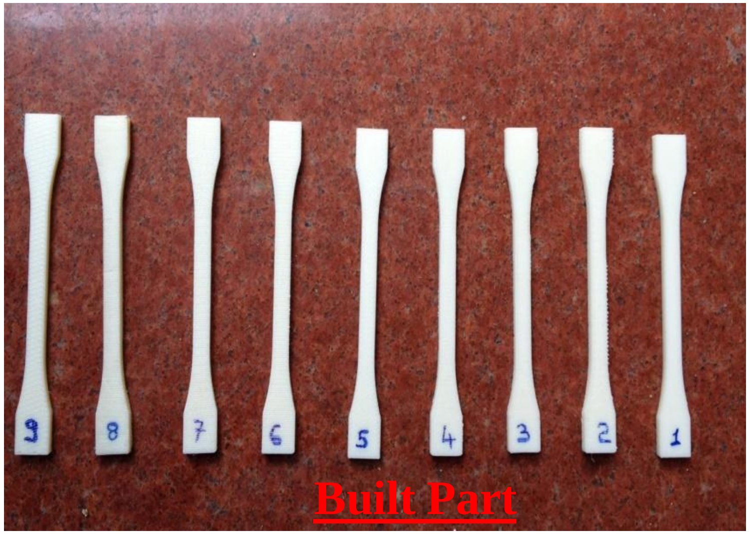
METHODOLOGY




Construct models in FDM machine
Testing output parameters
Analysis
Multi-Objective Optimization with GRA
Conclusion

Experimentation

FDM Machine

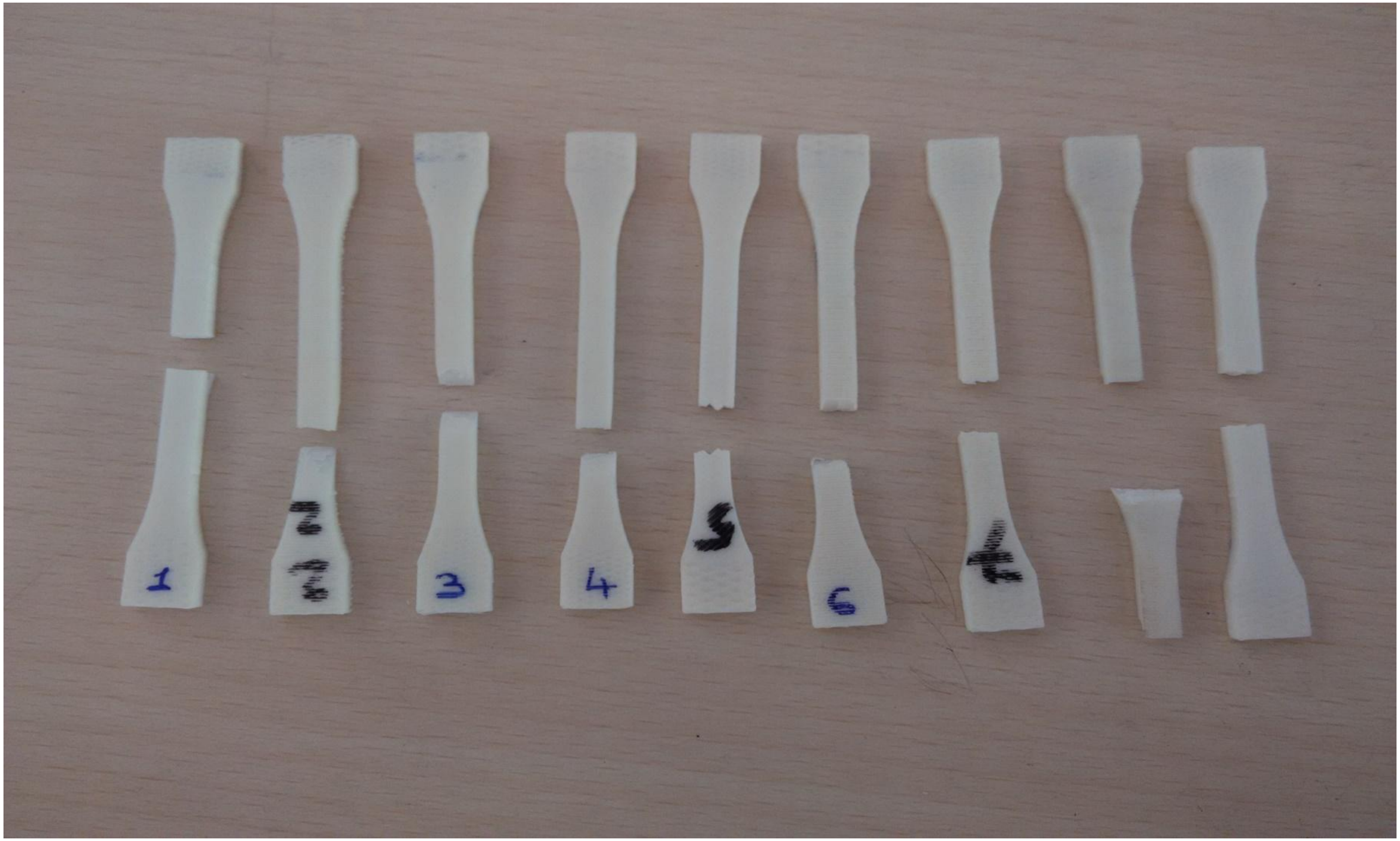


Built Part

Ra Tester

Tensile Strength Tester

After experiment



Experimental result

S.NO	Raster Width (mm)	Air gap (mm)	Raster Angle (deg)	Orientation Angle (deg)	Tensile Strength (N/mm2)	Ra (µm)	Built time (min)	Builtmaterial (cm3)	Support material (cm3)
1	0.2032	0	0	0	377	9.4	27	2.048	0.251
2	0.2032	0.004	15	15	198	27.5	176	2.048	2.832
3	0.2032	0.008	45	30	130	20.2	298	1.965	4.392
4	0.4032	0	15	30	157	19	298	2.007	4.479
5	0.4032	0.004	45	0	335	9.3	19	2.091	0.254
6	0.4032	0.008	0	15	224	34.9	168	2.035	2.817
7	0.5782	0	45	15	281	34.2	166	2.125	2.761
8	0.5782	0.004	0	30	120	17.4	293	1.96	4.446
9	0.5782	0.008	15	0	290	15.4	16	2.073	0.254

S/N Ratio

Smaller the better

$$n_{ij} = -10 \log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right)$$

Larger the better

$$n_{ij} = -10 \log\left(\frac{1}{n}\sum_{j=1}^{n} 1/y_{ij}^2\right)$$

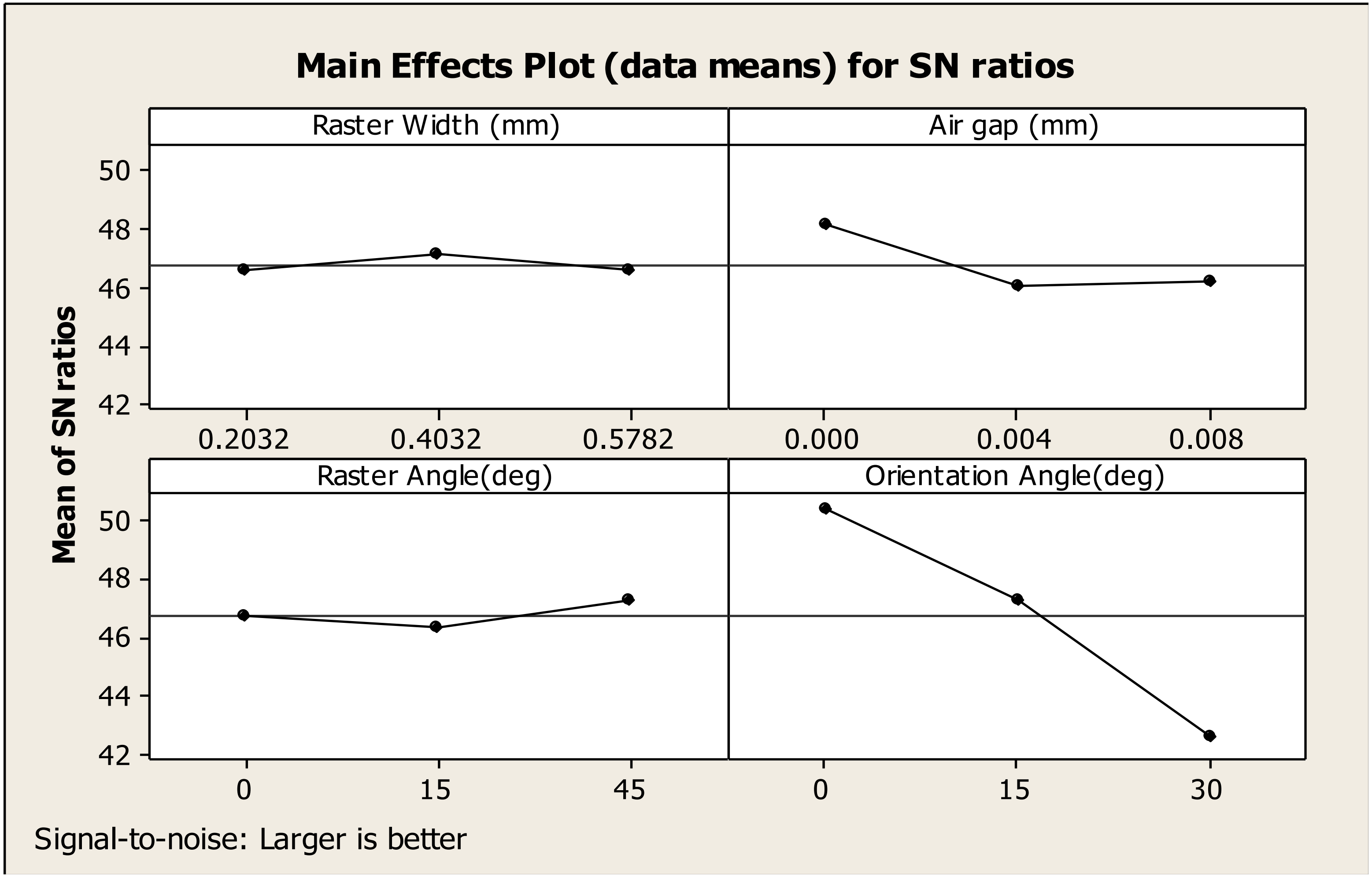
Nominal-the-better

$$n_{ij} = -10 \log\left(\frac{1}{ns}\sum_{j=1}^{n} y_{ij}^2\right)$$

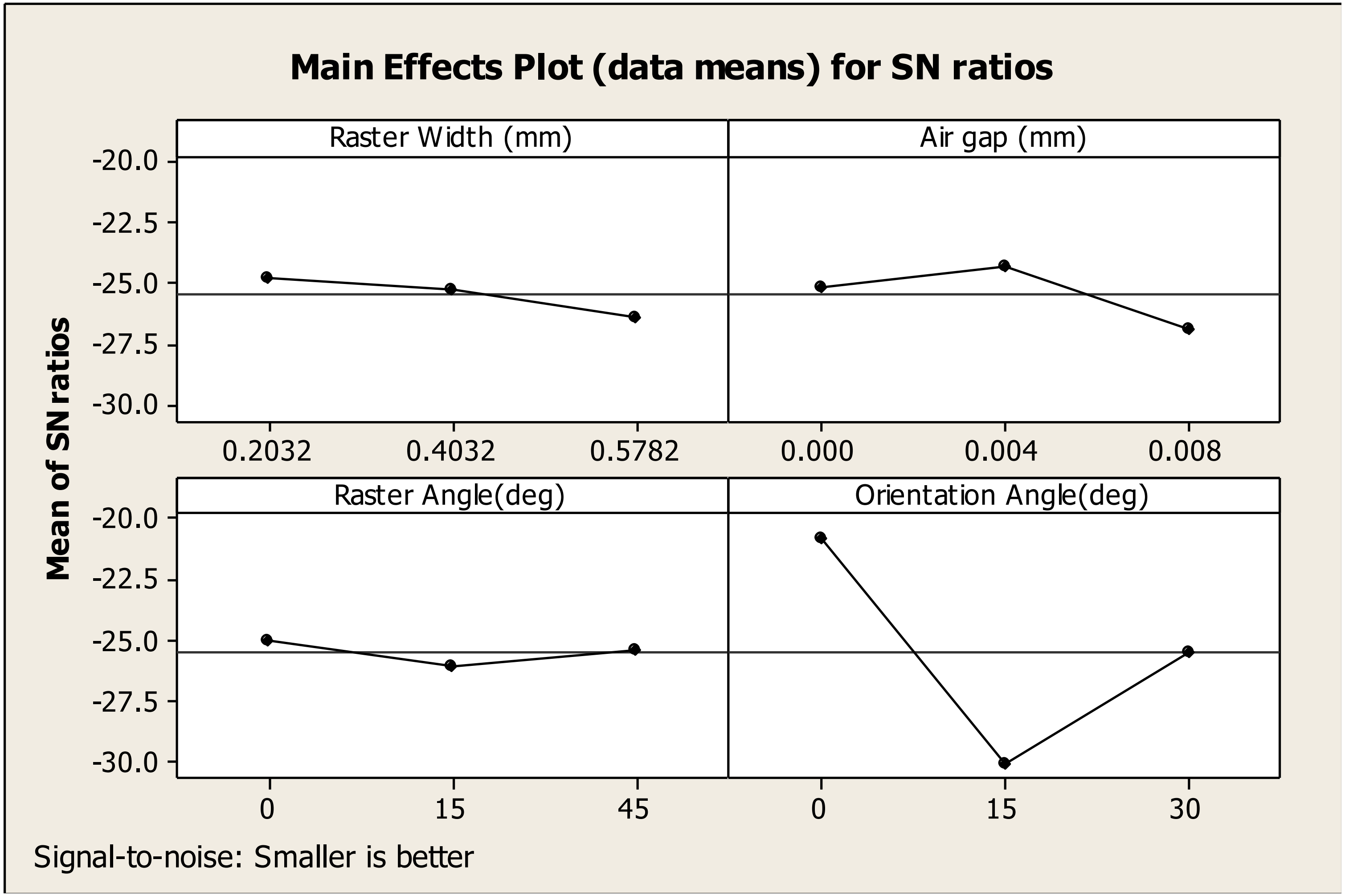
S/N Ratio

S.NO	SNR T.S	SNR Ra	SNR B.T	SNR B.M	SNR S.M
1	51.5268	-19.4626	-28.6273	-6.2266	12.0065
2	45.9333	-28.7867	-44.9103	-6.2266	-9.0419
3	42.2789	-26.107	-49.4843	-5.86725	-12.8532
4	43.918	-25.5751	-49.4843	-6.05095	-13.0236
5	50.5009	-19.3697	-25.5751	-6.40708	11.9033
6	47.005	-30.8565	-44.5062	-6.17129	-8.9957
7	48.9741	-30.6805	-44.4022	-6.54718	-8.8213
8	41.5836	-24.811	-49.3374	-5.84512	-12.9594
9	49.248	-23.7504	-24.0824	-6.33199	11.9033

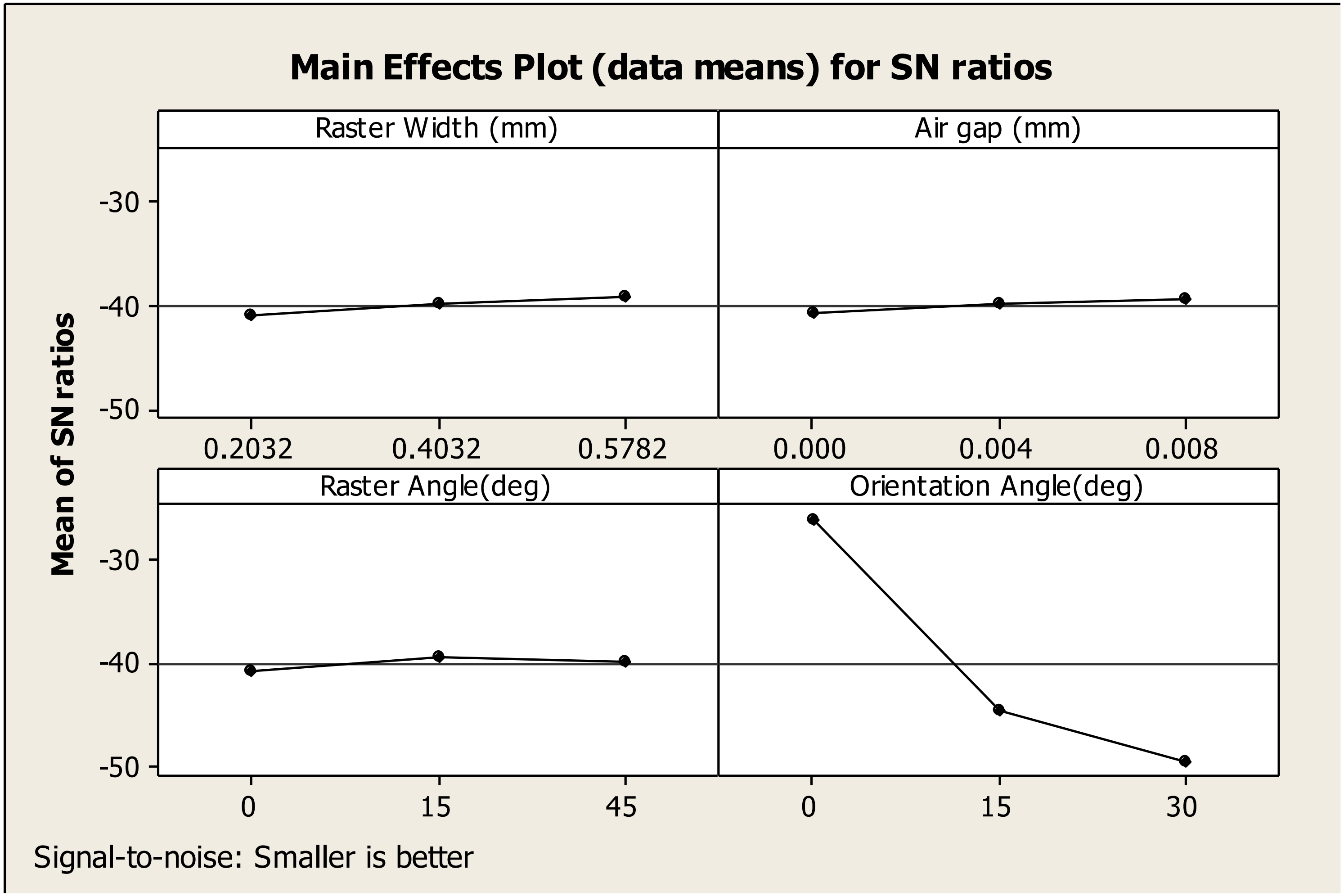
Main Effect Plot for S/N Ratio of Tensile Strength



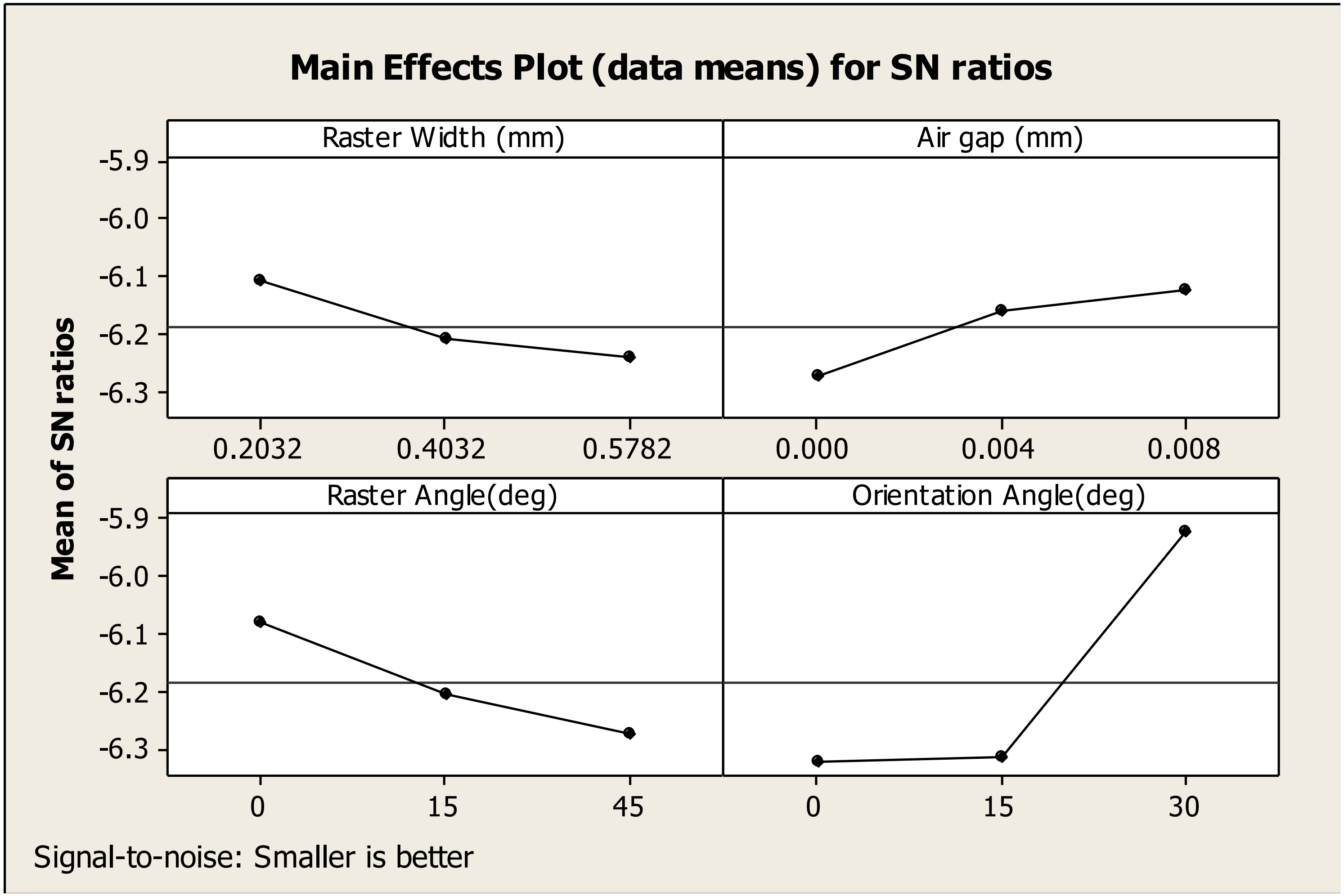
Main Effect Plot for S/N Ratio of Ra



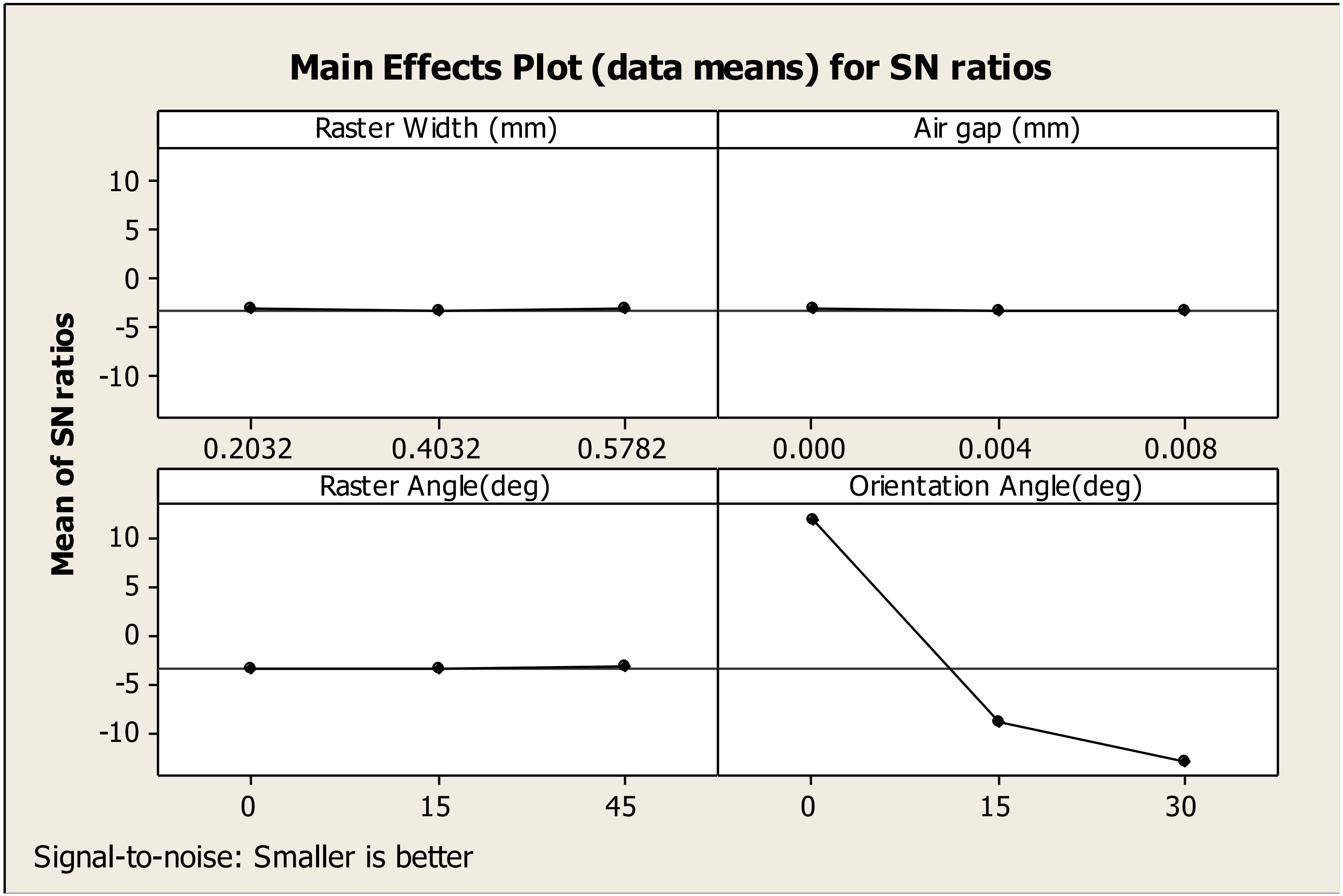
Main Effect Plot for S/N Ratio of Built Time



Main Effect Plot for S/N Ratio of Built Material



Main Effect Plot for S/N Ratio of Support Material



Gray Relational Analysis

- Grey relational analysis is used to solve interrelationships among the multiple responses. It was introduced by Deng [5]. In this approach a grey relational grade is obtained for analyzing the relational degree of the multiple responses. Lin et al. (2002) have attempt grey relational based approach to solve multi-response problems in the Taguchi method. The first step in the grey relational analysis is to pre process data in order to normalize the raw data for the analysis. This process is knows is grey relational generation. In the present study a linear normalization of the experimental result for the Tensile Strength, Ra, Built Time, Built Material, Support material were performed in range between 0 to 1.

- This the equestion used for S/N ration with larger the better case and smaller the better case respectively.

Cont…

- The following steps are followed in GRA:
- Experimental data are normalised in the range between zero and one.

(larger the better)

$$Z_{ij} = \frac{y_{ij} - min.(y_{ij}, i=1,2,....n)}{\max\left(y_{ij}, i=1,2,....n\right) - \min(y_{ij,}\ i=1,2....)},$$

(smaller the better)

$$Z_{ij} = \frac{max.\left(y_{ij}, i=1,2,....n\right) - y_{ij}}{\max\left(y_{ij}, i=1,2,....n\right) - \min(y_{ij,}\ i=1,2....)},$$

- Next, the grey relational coefficient is calculated from the normalised experimental data to express the relationship between the ideal (best) and the actual experimental data.

$$Gc_{ij} = \frac{\Delta_{min.} + \gamma\ \Delta_{max.}}{\Delta_{ij.} + \gamma\ \Delta_{max.}} \begin{pmatrix} i = i, 2 \ldots .n\ experments \\ j = 1,2 \ldots .m\ responses \end{pmatrix}$$

Cont…

- Grey relational grade is then computed by averaging the weighted grey relational coefficients corresponding to each performance characteristic.

$$GRG = \frac{1}{n}\sum_{k=1}^{n} Gc_i\ (k)$$

- Statistical analysis of variance is performed for the input parameters with the GRG and the parameters significantly affecting the process are found out.

- Optimal levels of process parameters are then chosen.

Normalized value

Normalizing :-

* larger is better (Tensile)

Normalizing =

$$Z_{ij} = \frac{y_{ij} - \min.(y_{ij};\ i = 1, 2, \dots n)}{\max.(y_{ij},\ i = 1, 2 \dots n) - \min(y_{ij}\ i = 1, 2 \dots)}$$

$$= \frac{36.9711 - 11.7680}{36.9711 - 11.7680} = 1$$

Smaller is better (Ra)

$$Z_{ij} = \frac{\max - y_{ij}}{\max - \min}$$

$$= \frac{34.9 - 9.4}{34.9 - 9.3} = 0.9960$$

$$\Delta = 1 - \text{Normalizing Value}$$

Normalized value

S.NO	Tensile Strength (N/mm2)	Ra	Built time (min)	Built material (cm3)	Support material (cm3)	**Normalized T.S**	**Normalized Ra**	**Normalized B.T**	**Normalized B.M**	**Normalized S.M**
1	36.9711	9.4	27	2.048	0.251	1	0.9960	0.9609	0.4666	1.00
2	19.4172	27.5	176	2.048	2.832	0.3035	0.2890	0.4326	0.2484	0.3895
3	12.7486	20.2	298	1.965	4.392	0.03990	0.5742	0.00	0.9696	0.0205
4	15.3964	19.0	298	2.007	4.479	0.1439	0.6210	0.00	0.7151	0.00
5	32.8523	9.3	19	2.091	0.254	0.8365	1.00	0.9893	0.2060	0.9992
6	21.9669	34.9	168	2.035	2.817	0.4046	0.00	0.4609	0.5454	0.3930
7	27.5567	34.2	166	2.125	2.761	0.6264	0.0273	0.4680	0.00	0.4063
8	11.7680	17.4	293	1.960	4.446	0.00	0.6835	0.0177	1.00	0.0078
9	28.4393	15.4	16	2.073	0.254	0.6614	0.7617	1.00	0.3151	0.9992

Deviation sequence

S.NO	Normalized T.S	Normalized Ra	Normalized B.T	Normalized B.M	Normalized S.M	Δ-T.S	Δ-Ra	Δ-B.T	Δ-B.M	Δ-S.M
1	1	0.9960	0.9609	0.4666	1.00	0	0.004	0.0391	0.5334	0.00
2	0.3035	0.2890	0.4326	0.2484	0.3895	0.6965	0.711	0.5674	0.7516	0.6105
3	0.03990	0.5742	0.00	0.9696	0.0205	0.9601	0.4258	1.00	0.0304	0.9795
4	0.1439	0.6210	0.00	0.7151	0.00	0.8561	0.379	1.00	0.2849	1.00
5	0.8365	1.00	0.9893	0.2060	0.9992	0.1635	0.00	0.0107	0.794	0.0008
6	0.4046	0.00	0.4609	0.5454	0.3930	0.5954	1.00	0.5391	0.4546	0.607
7	0.6264	0.0273	0.4680	0.00	0.4063	0.3736	0.9727	0.532	1.00	0.5937
8	0.00	0.6835	0.0177	1.00	0.0078	1.00	0.3165	0.9823	0.00	0.9922
9	0.6614	0.7617	1.00	0.3151	0.9992	0.3386	0.2383	0.00	0.6849	0.0008

GRC and GRA

γ = distinguishing co-efficient.

GRC - grey relation co-efficient.

$$GRC = \frac{\Delta_{min} + \gamma \Delta_{max}}{\Delta_{ij} + \gamma \Delta_{max}} \qquad \gamma = 0.5 \qquad 0 < \gamma < 1$$

Built material

$$GRC = \frac{0 + (0.5 \times 1)}{0.5334 + (0.5 \times 1)} = \frac{0.5}{1.0334} = 0.4838$$

GRG is the Average Value of GRC

GRC,GRG and Rank

S.NO	GRC TS	GRC Ra	GRC BT	GRC BM	GRC SM	GRG	RANK
1	1.00	0.9920	0.9274	0.4838	1.00	0.8806	1
2	0.4178	0.4128	0.4684	0.3994	0.4502	0.4297	9
3	0.3424	0.5401	0.3333	0.9426	0.3379	0.4995	5
4	0.3687	0.5688	0.3333	0.6370	0.3333	0.4482	7
5	0.7535	1.00	0.9790	0.3863	0.9984	0.8234	2
6	0.4564	0.3333	0.4812	0.5237	0.4516	0.4492	6
7	0.5723	0.3395	0.4844	0.3333	0.4571	0.4373	8
8	0.3333	0.6123	0.3373	1.00	0.3350	0.5236	4
9	0.5962	0.6772	1.00	0.4219	0.9984	0.7387	3

GRC,GRG and Rank For Mechanical Property

S.NO	GRC TS	GRC Ra	GRG	RANK
1	1.00	0.9920	0.996	1
2	0.4178	0.4128	0.8306	3
3	0.3424	0.5401	0.4413	8
4	0.3687	0.5688	0.4688	6
5	0.7535	1.00	0.8768	2
6	0.4564	0.3333	0.3949	9
7	0.5723	0.3395	0.4559	7
8	0.3333	0.6123	0.4728	5
9	0.5962	0.6772	0.6367	4

GRC,GRG and Rank For Cost

S.NO	GRC BT	GRC BM	GRC SM	GRG	RANK
1	0.9274	0.4838	1.00	0.8037	2
2	0.4684	0.3994	0.4502	0.4393	7
3	0.3333	0.9426	0.3379	0.5379	5
4	0.3333	0.6370	0.3333	0.4345	8
5	0.9790	0.3863	0.9984	0.7879	3
6	0.4812	0.5237	0.4516	0.4855	6
7	0.4844	0.3333	0.4571	0.4249	9
8	0.3373	1.00	0.3350	0.5574	4
9	1.00	0.4219	0.9984	0.8067	1

Optimal level factor for responses

- The optimal factor levels obtain from main effects plot of S/N Ratio of T.S

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	2	0.4032
2	Air Gap	1	0.00
3	Raster Angle	3	45
4	Orientation	1	0

- The optimal factor levels obtain from main effects plot of S/N Ratio of Ra

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	1	0.2032
2	Air Gap	2	0.004
3	Raster Angle	1	0
4	Orientation	1	0

Optimal level factor for responses

- The optimal factor levels obtain from main effects plot of S/N Ratio of B.T

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	3	0.5782
2	Air Gap	3	0.008
3	Raster Angle	2	15
4	Orientation	1	0

- The optimal factor levels obtain from main effects plot of S/N Ratio of B.M

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	1	0.2032
2	Air Gap	3	0.008
3	Raster Angle	1	0
4	Orientation	3	45

Optimal level factor for responses

- The optimal factor levels obtain from main effects plot of S/N Ratio of S.M

S.NO	Factor	Optimum level	Optimum value
1	Orientation	1	0

Support Material is only affected by Orientation

- The optimal factor levels obtain from main effects plot of S/N Ratio of GRG

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	1	0.2032
2	Air Gap	2	0.004
3	Raster Angle	1	0
4	Orientation	1	0

Optimal level factor for responses

- The optimal factor levels obtain from main effects plot of S/N Ratio of GRG M.P

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	1	0.2032
2	Air Gap	2	0.004
3	Raster Angle	3	15
4	Orientation	1	0

- The optimal factor levels obtain from main effects plot of S/N Ratio of GRG Cost

S.NO	Factor	Optimum level	Optimum value
1	Raster Width	3	0.5782
2	Air Gap	3	0.008
3	Raster Angle	1	0
4	Orientation	1	0

Conclusion

- In case of Tensile Strength, it was found that the Raster Width 0.4032mm, Air Gap 0.00mm, Raster Angle 45˚, and Orientation Angle 0 ˚ can reach the maximum value of Tensile Strength. Air Gap and Orientation Angle are main affecting parameters of Tensile Strength.
- In case of Ra, it was found that the Raster Width 0.2032mm, Air Gap 0.004mm, Raster Angle 0˚, and Orientation Angle 0 ˚ can reach the minium value of Ra. Raster Angle and Orientation Angle are main affecting parameters of Ra.
- In case of Built Time, it was found that the Raster Width 0.5782mm, Air Gap 0.008mm, Raster Angle 15˚, and Orientation Angle 0 ˚ can reach the minimum value of Built time . Raster Width and Orientation Angle are main affecting parameters of Built time.
- In case of Built material, it was found that the Raster Width 0.2032mm, Air Gap 0.008mm, Raster Angle 0˚, and Orientation Angle 45 ˚ can reach the minimum value of Built material .
- In case of Support material, it was found that Orientation Angle 0 ˚ can reach the minimum value of Support material. Here the support material is not affected by Raster width, Air Gap, Raster Angle.

Conclusion

- Multi response optimization problem has been solved very effectively by using GRA based Taguchi method and higher Grey Relational Grade has been obtained when the Raster Width 0.2032mm, Air Gap 0.004mm, Raster Angle 0˚, and Orientation Angle 0 ˚.
- Using GRA it was found that batter mechanical property obtain at the Raster Width 0.2032mm, Air Gap 0.004mm, Raster Angle 15˚, and Orientation Angle 0˚.
- Using GRA it was found that lower cost of built part obtain at the Raster Width 0.5782mm, Air Gap 0.008mm, Raster Angle 0˚, and Orientation Angle 0˚.

REFRENCES

1. **Ahn**, D., Kweon, J, Kwon, S., Song, J., and Lee, S. 2009. Representation of surface roughness in fused deposition modeling. *Journal of Materials Processing Technology*. 209 (2009). PP. 5593-5600.
2. **Bak**, D. 2003. Rapid prototyping or rapid production?. *Assembly Automation*. 23(4) PP. 340-345.
3. **British standard BS EN ISO 527-1**: 1996. Plastics- determination of tensile properties-Part 1: General principles.
4. **Hopkinson**, N and Dickens, P. (2001) Rapid prototyping for direct manufacture. *Rapid Prototyping Journal*. 7(4), *pp. 197-202*
5. **Kruth**, J. 1991. Materials increase manufacturing by rapid prototyping techniques. Annals of the CIRP. 40(2), pp. 603-614.
6. Rayegani F, Godfrey C. “Fused deposition modeling (FDM) process parameter prediction and optimization using group method for data handling (GMDH) and differential evolution (DE)”, Journal of Engineering Manufacture.
7. Sood A, Phdar RK, Mahapatra SS. “Experimental investigation and empirical modelling of FDM process for compressive strength improvement”, Journal of Advance Research.

REFRENCES

8. Nancharaiah T, Raju DR and Raju VR. “An experimental investigation on surface quality and dimensional accuracy of FDM components”, International Journal on Emerging Technologies.
9. Panda SK, Padhee S, Sood A, Mahapatra SS, 2009. ”Optimization of fused deposition modeling (FDM) process parameters using bacterial foraging technique”, Intelligent Information Management.
10. S. Dinesh Kumar, V. Nirmal Kannan and G. Sankaranarayanan, ―Parameter Optimization of ABS-M30i Parts Produced by Fused Deposition Modeling for Minimum Surface Roughness‖, International Journal of Current Engineering and Technology (April 2014)
11. Sandeep Raut,VijayKumar S. Jatti, Nitin K. Khedkar, T.P.Singh, ―Investigation of the effect of built orientation on mechanical properties and total cost of FDM parts‖, 3rd International Conference on Materials Processing and Characterization (ICMPC).
12. L.M. Galantucci , F. Lavecchia and G. Percoco “Experimental study aiming to enhance the surface finish of fused deposition modeled parts” (ABS material use) CIRP Annals - Manufacturing Technology 58 (2009) 189–192 Elsevier Science Ltd.
13. Mr. Jaimin P. Patel Prof. C. P. Patel and Mr. U. J. Patel “A review on various approach for process parameter optimization of fused deposition modeling (FDM) process and taguchi approach for optimization” International Journal of Engineering Research and Applications (IJERA)-2012 ISSN: 2248-9622.

REFRENCES

14. Mayank Zelawat, Hemendra Pratap Singh, , Mitali Sharma, Anamika Chouhan and Imtiyaz khan "A Review Paper on New Metal for Rapid Tooling using Fused Deposition Modeling" International Journal of Emerging Technology & Research (2014) ISSN (E): 2347-5900 ISSN (P): 2347-6079 .
15. Tejendrasinh S. Raol, Dr. K. G. Dave, Dharmesh B. Patel and Viral N. Talati "An Experimental Investigation of Effect of Process Parameters on Surface Roughness of Fused Deposition Modeling Built Parts" International
16. **Es-said**, S., Foyos, J., Noorani, R., Mendelson, M., Marloth, R., and Pregger, A. 2000. Effect of layer orientation on mechanical properties of rapid prototyping samples. Material and manufacturing processes, Vol 15, pp 107-122.
17. **Folkestad**, J. and Johnson, R. 2002 .Integrated rapid prototyping and rapid tooling (IRPRT). *Integrated manufacturing systems*. 13(2), pp. 97-103.
18. **Kruth**, J. 1991. Materials increase manufacturing by rapid prototyping techniques. Annals of the CIRP. 40(2), pp. 603-614.
19. **Pandey**, P., Thrimurthulu, K., and Reddy, N. 2004. Optimum part orientation in FDM using multi-criteria generic algorithm.

REFRENCES

20. **Perez**, L., 2002. Analysis of the surface roughness and dimensional accuracy capability of fused deposition modeling processes.
21. **Thrimurthulu**, K., Pulak, M., Pandey, N., Reddy, V. 2003. Optimum part deposition orientation in fused deposition modeling.
22. Kao, P.S., Hocheng, H., (2003), Optimization of electrochemical polishing of stainless steel by grey relational analysis, *J. Mat. Process. Technol*. 140, 255–259.
23. Lohithaksha M Maiyar, Dr.R.Ramanujam K.Venkatesan , Dr.J.Jerald (2013), Optimization of Machining Parameters for End Milling of Inconel 718 Super Alloy Using Taguchi Based Grey Relational Analysis, *Procedia Engingg* 64 (2013) 1276 – 1282.
24. M. K. Pradhan (2012), Estimating the effect of process parameters on MRR, TWR and radial overcut of EDMed AISI D2 tool steel by RSM and GRA coupled with PCA *Int J Adv Manuf Technol* (2013) 68:591–605
25. Montgomery,D.C., (2005), Design and analysis of experiments, *John Wiley and Sons*, New York

THANK YOU