# Pilot Testing of FDM Samples by Taguchi's $L_4$ Orthogonal Array and Multi Response Optimization using GRA and DEAR Approaches

**N.Mohammed Raffic[1] Dr.K.Ganesh Babu[2]Arjun.C[3] Ashiq Nowfel[4]**

*[1]Assistant Professor, Department of Mechanical Engineering, Nehru Institute of Technology, Coimbatore, India*
*[2]Principal, Chendhuran College of Engineering & Technology, Pudukottai, Tamil Nadu, India*
*[3, 4]UG Scholar, Department of Mechanical Engineering, Nehru Institute of Technology, Coimbatore, India*

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**Abstract :** *The concept of conducting pilot testing or study is like a rehearsal of the main experimental work which will be conducted in later stages. The aim of conducting such a study is to ensure the validity of the proposed experimental setup, research methodology and other related concepts in a research to endup in a successful manner. The conduction of pilot study many not ensure complete success but it increases the likelihood of success of the main research. The present work conducts pilot testing of four different FDM (Fused Deposition Modelling) samples printed using ABS (Acronitrile Butadiene Styrene) material by adopting Taguchi's $L_4$ Orthogonal Array experimental design matrix prepared by varying the inputs such as layer thickness, infill density and printing speed into two levels. The printing time taken, material consumed by the individual specimen and its compressive strength are evaluated for analysis. The results obtained from the pilot study as per experimental design is further subjected for Mono response optimization through Signal to Noise ratio method and Multi Response Optimization through Grey Relational Analysis (GRA) and Data Envelopment Analysis Based Ranking (DEAR) approaches for comparison. The research findings have shown that from both the Multi Response Optimization methods the optimized parameter setting is found to be A1B2C2* (0.1mm, 80%, 75 mm/s) *and Infill density is the most significant factor followed by layer thickness and printing speed affecting the output characteristics. From mono optimization done through signal to noise ratio method, for both model building time and material consumption the parameter setting A2B1C2 (0.3mm, 40%, 75 mm/s) is recommended and for compression strength A1B2C1*(0.1mm, 80%, 25 mm/s) *is to be followed for maximization. Printing speed is the factor with very low significance over all the output parameters considered in both mono and multi response optimization methods.*

**Keywords: Data Envelopment Analysis Based Ranking Method, Grey Relational Analysis, $L_4$ Orthogonal Array, Pilot Testing**

## 1. INTRODUCTION

Research is an interesting process which involves rigorous activities like data collection, conducting experiments, analysis of the experimental results, deriving conclusions ¸ providing suggestions for future scope of work and recommendations for improvement on the topic which has got analyzed. The researchers of any field have to adopt a suitable research methodology pertinent to their research area in order to end up the research process successfully. Pilot study or pilot run is an important step in a research process which acts like a rehearsal of the main study and also it helps in ensuring the capability and genuineness of the methodology proposed for conducting experiments , analyzing the experimental data and execution of the results. Polit study does not ensure the total success of the research work carried out but it gives a indication over the success of the research. The present work conducts pilot testing of ABS samples prepared using fused deposition modelling process to understand the effect of input variables such as layer thickness, infill density and printing speed over the economical factors such as model building time and material consumption. Compressive strength of the sample is the only technical parameter considered in the present study. For the past two decades numerous research work has been carried out in the field of fused deposition modelling to optimize input process parameters to reduce production time, part weight, surface roughness, dimensional error and to enhance the mechanical properties such as tensile strength, impact strength, compression strength, flexural and fatigue strength etc. Rupinder Singh et.al [1] conducted pilot study for the selection of process variables while making an attempt to reduce the surface roughness of hip implant processed by FDM process and identified that the minimum surface roughness was resulted with low infill density part with zero degree orientation. Kamaljit Singh Boparai et.al [2] adopted pilot study while making an attempt to model and optimize the extrusion process parameters such as composition , mean barrel temperature and die temperature in making of $Nylon_6$–Al–$Al_2O_3$ as an alternative FDM filament for ABS. The authors have identified that the barrel temperature for extrusion should be kept between 160 – 180°. Harish K. Garg and Rupinder Singh [3] reported that the mean barrel temperature has to be kept in the range of 180 – 195° for making a composite filament made with Nylon6 and Fe powder wire for FDM process through pilot study. Kehui Deng et.al [4] conducted pilot study for the evaluation of using polylactic acid as a material for making pattern of maxillary complete dentures through FDM process and made comparison with patterns made out of wax. The authors have found PLA as a suitable material for making dentures at low cost without compromising accuracy. Mohammad S. Alsoufi et.al [5] investigated the reduction of stair stepping effect in printed FDM parts in the shape of semi sphere profile using filament materials such as PLA, PLA+ and ABS+ . The authors have suggested that the chemical treatment using acetone vapour can improve the surface roughness of the finished parts and reduce stair stepping effect. Divyathej M V et.al [6] involved in a detailed study in comparing parts made of injection moulding and fused deposition modelling process to understand their performance in tests such as tensile , compressive and flexural . The authors have reported that the injection moulded parts are found to have superior strength than FDM made ABS parts and FDM parts have anisotropic properties. Satish Kumar Singh and Prof. R.K.Agrawal [7] conducted compression and flexural testing of FDM made ABS parts as per ASTM standards to understand the effect of parameters such as layer thickness, number of contours and part orientation. The authors have reported that maximum compression strength and flexural strength may be obtained from low layer thickness, higher number of contours for part making and part orientation at 0 °. Dr.Tahseen Fadhil et.al [8] studied the effect of FDM parameters such as layer thickness, shell thickness, infill density and print speed over the compression strength of the part printed using ABS filaments and reported that higher infill density increases the compressive strength and also increases the printing time. Elena Verdejo de Toro et.al [9] analysed the influence of the FDM variables such as layer height, infill pattern, nozzle diameter and infill density by using the Carbon X CRF-Nylon composite material with 20% fibre content with a filament diameter of 2.85mm. The authors have conducted mechanical tests such as bending and impact as per standard procedures and also thermal analysis of printed parts. The results have revealed that layer height plays a vital role in bending and impact strength, nozzle diameter is the parameter with least significance over the properties studied. . J.Lluch –Cerezo et.al [10] has studied the influence of input parameters such as wall thickness, orientation of building wall lines , infill pattern density using PLA samples made by FDM process . The authors have reported that annealing treatment has been done on the printed samples to avoid stress concentration and the treatment has decreased the tensile strength of the parts printed.

## 2. MATERIALS AND METHODS

### 2.1 Acronitrile Butadiene Styrene

In the present work the samples for conducting pilot study were prepared using ABS material available in the form of a filament through fused deposition modelling. ABS is an opaque thermoplastic and amorphous polymer which is created by polymerization of styrene and acronitrile in the presence of butadiene. The composition of ABS consists of half amount of styrene and the balance composition is divide between acronitrile and butadiene. The three monomers involved in the formation of ABS plays a different role in the performance of material as acrylonitrile provides chemical and thermal stability to the polymer, butadiene enhances its toughness and strength and styrene gives it a final nice and glossy finish.The material has numerous attractive advantages for its usage in making products which include high impact resistance, good structural strength and stiffness, excellent high and low temperature performance , easy to apply paint and glue in the finished products. ABS has been used in making products such as tool boxes, camera bodies, packing crates, radio, automotive instrument panels, bumpers, food processing components and various furniture parts. The material has a profound application in the research area of additive manufacturing in particular with fused deposition modelling as the material can be formed into thin wires for getting extruded through the heated nozzle.

### 2.2 Fused Deposition Modeling

The preparation of specimens for the sample study to understand the effect of input variables over the output characteristics has been done by fused deposition modelling. The process has got invented and patented by Scott Crump in the late 1980's. FDM is a widely used low cost additive manufacturing process which can print parts from a 3D digital data of the object by adding one layer over the another. The cad data is further transferred to the appropriate slicing software as a .stl file for dividing the model in to convenient number of layers and the slicing software generates G code for the specimen printing. The machine consists a spool to carry the raw feedstock which is generally extruded through a heated nozzle and deposited over the bed of the FDM machine layer by layer to attain the final model. The models printed can be further subjected to post processing to improve their properties to desired level. The process is found to be capable of making prototypes in the early stages and now it has seen a development in producing functional parts. The materials that can be printed form FDM process are basically thermoplastics such as ABS (Acronitrile Butadiene Styrene), PLA (Poly Lactic Acid), PET-G (Poly Ethylene Terethalate – Glycol modified), HIPS (High Impact Polystyrene), PC (Poly Carbonate) and also composite filaments with glass or carbon fibre reinforced thermoplastics. The process involves numerous input parameters which can varied and fixed before the start of the process and factors such as layer thickness, infill density , raster orientation , air gap , raster angle are found to have influencing effect over the mechanical properties of the part printed . The material compatibility of the FDM machine varies between the desktop and industrial versions.

## 3. EXPERIMENTAL WORK

In the present work three different output characteristics namely model building time, material consumption and compressive strength has been considered. The output parameters model building time and material consumption can be recorded once the specimen preparation got over and compressive strength of the specimen can be found only through experimentation. The compressive strength of the specimen has been calculated from equation 1.

$$Compressive\ Strength = \frac{Load\ Applied}{Area\ of\ the\ Specimen} \quad (1)$$

### 3.1 Experimental Design and Sample Preparation

The experimental plan for conducting pilot study of the FDM parts is prepared using the Taguchi's orthogonal array .The study considers three FDM factors namely layer thickness, infill density and printing speed varied in to three levels. As per the factors and their levels Taguchi's $L_4$ orthogonal array is the suitable experimental plan or matrix for conducting the study. The plan has been prepared using MINITAB 17.0 software by simple steps. The table 1 shows the input parameters considered and their levels. The full factorial experimental plan for the present condition consists 8 experiments in total but the adoption of Taguchi's OA reduces the experimental plan to 4 experiments which reduces time and money involved in the conduction of experimental work and specimen preparation.

**Table – 1 Input Variables and their Levels with S.I Unit**

| Input Variables | Symbol | S.I Unit | Level 1 | Level 2 |
|---|---|---|---|---|
| Layer Thickness | A | mm | 0.1 | 0.3 |
| Infill Density | B | % | 40 | 80 |
| Printing Speed | C | mm/s | 25 | 75 |

**Table – 2 $L_4$ Orthogonal Array Experimental Plan with Coded and Uncoded Values of Input Variables**

| Trial No | Coded Values | | | Actual Values | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| | (mm) | (%) | (mm/s) | (mm) | (%) | (mm/s) |
| 1 | 1 | 1 | 1 | 0.1 | 40 | 25 |
| 2 | 1 | 2 | 2 | 0.1 | 80 | 75 |
| 3 | 2 | 1 | 2 | 0.3 | 40 | 75 |
| 4 | 2 | 2 | 1 | 0.3 | 80 | 25 |

**Table – 3 Output Variables with S.I Unit**

| Output Variables | Symbol | S.I Unit |
|---|---|---|
| Model Building Time | R1 | Secs |
| Material Consumption | R2 | gms |
| Compressive Strength | R3 | MPa |

The Table 2 shows the experimental plan with factors in the form of coded and uncoded values. Table 3 shows the output parameters considered for evaluation.

The present work utilizes RAISE 3D PRO 2 dual extruder FDM printer for printing the samples using ABS filament with 1.75mm diameter. The printer used has a build volume of 305 x 305 x 300 mm. The solid model of the compression testing sample is prepared using CATIAV5R20 as shown in figure 1 and it is saved in .stl format. The figure shows the solid model of the specimen and specimen is in the form of a square prism with 40 x 40 x 25 mm dimensions. The saved solid model is exported to ideamaker software for slicing the model in to thin layers as per the experimental design. The software prepares the G-code for operating the machine to print the specimen by making the filament to get deposited in thin layers one over the another.

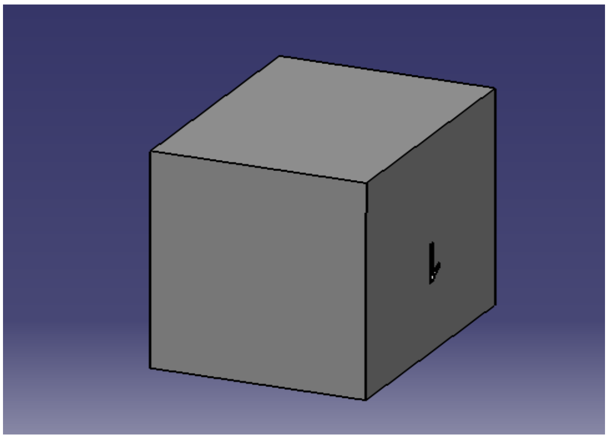
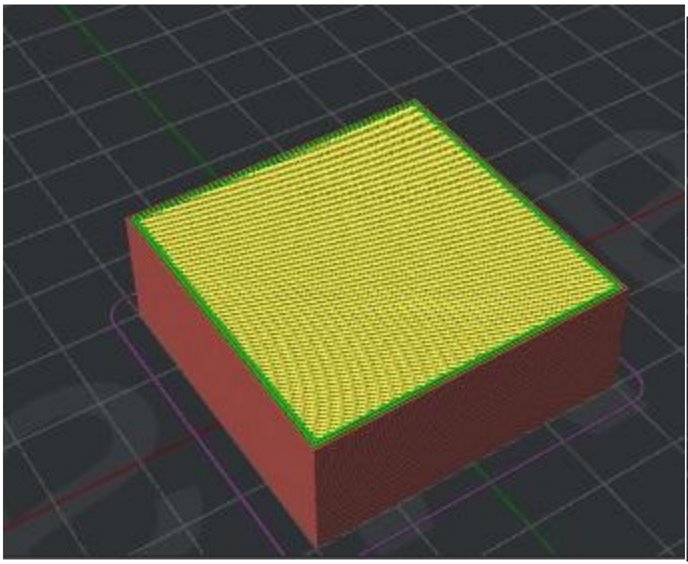


**Figure – 1 Compression Test Specimen Solid Model**



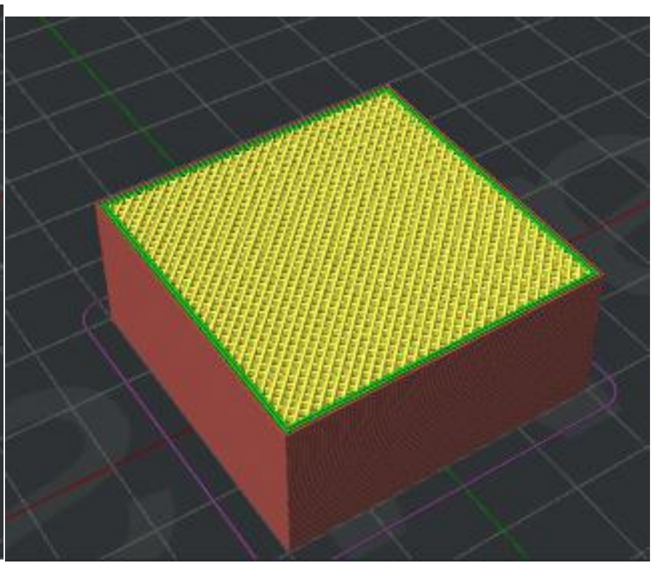


**Figure – 2 Specimen with 0.1mm Layer thickness and Figure – 3 Specimen with 0.3 mm Layer thickness and 80% Infill Density 40% Infill Density**

The figures 2 and 3 shows the sliced samples with 0.1mm layer thickness with 80% infill density and another one with 0.3mm layer thickness with 40% infill density. The prepared specimens are similar in their dimensions but vary in their printing parameter combination. The figure 4 shows the printed ABS samples and the samples have been numbered at their top using punch for easy identification.

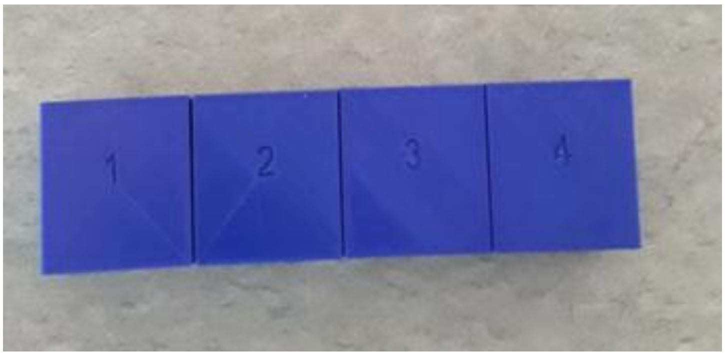



**Figure - 4 FDM Printed ABS Specimens**

The two output parameters model building time and material consumption has been recorded and tabulated in table 4

**Table – 4 Output Values of Model Building Time and Material Consumption**

| Trial No | A (mm) | B (%) | C (mm/s) | R1 (secs) | R2 (gms) |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 337 | 28 |
| 2 | 1 | 2 | 2 | 581 | 48 |
| 3 | 2 | 1 | 2 | 115 | 27 |
| 4 | 2 | 2 | 1 | 203 | 47 |

### 3.2 Experimental Setup

Compression testing is a very common method to evaluate the crush resistance or compressive strength of a material when a load is applied for a definite period of time. The present study considers a compressive testing machine which has two separate units i.e control panel and loading unit for the successful conduction of specimen testing. The control panel of the setup consists a power pack with drive motor and an oil tank, control valves and an electronic display unit for controlling and measuring the load that is being applied over the specien during testing. The loading consists a frame for the adjustment and movement of flat platforms and the setup has a moving platform above which the specimen is placed and an adjusting platform which can be moved up and down by rotating the wheel provided. The distance between the upper and lower platform may be varied according to the sie of the specimen that is being tested. The load to the specimen is applied through hydraulic transmission unit that is presnet below the lower platform. In the preset work the FDM sample is placed between the fixed and moving platen. The force over the specimen is applied through the hydualic load transmission and thereby making the unstable platen to move against the fixed one. The specimen placed in between those plates gets crushed due to the applied load and the load gets reversed to zero once it reaches the maximum value that the specimen can withstand. The maximum withstanding load value has been tabulated for the evaluation of compressive strength of the samples tested. The figure shows the experimental setup used in current study.


**Figure Compression Testing Machine Experimental Setup**


**Figure Deformed Specimens after Compression Testing**

The crushed specimens have been removed from the machine after subjected to the maximum compression load and the compressive strength of the specimen have been evaluated from equation 1. The load value is divided by the area of the specimen which is subjected to compression. The figure shows the deformed specimens after compression test. The table shows the maximum withstanding load value of individual specimen and their corresponding compressive strength.

**Table Experimental Values of Maximum Load and Compressive Strength of Specimens**

| Trial No | Maximum Load | R3 |
|---|---|---|
| | (KN) | (MPa) |
| 1 | 18 | 11.25 |
| 2 | 65 | 40.63 |
| 3 | 14 | 8.75 |
| 4 | 59 | 36.88 |

### 4. MONO RESPONSE OPTIMIZATION

The experimental values obtained for the output parameters are converted in to a suitable signal to noise ratio (S/N ratio) based upon their characteristic. Compression strength of the specimen obtained is considered to be larger the better in case of signal to noise ratio and other two parameters model building time and material consumption are considered to be with smaller the better characteristic.

The Signal to Noise ratio for Larger the better characteristic is given by

$$\eta = -10 \log\left(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{Yi^2}\right) \quad (2)$$

The Signal to Noise ratio for Smaller the better characteristic is given by

$$\eta = -10 \log\left(\frac{1}{n}\sum_{i=0}^{n} Yi^2\right) \quad (3)$$

**Table – 4 Signal to Noise Ratio Values of Output Parameters**

| Trial No | R1 (secs) | R2 (gms) | R3 (MPa) |
|---|---|---|---|
| 1 | -50.55 | -28.94 | 21.02 |
| 2 | -55.28 | -33.62 | 32.18 |
| 3 | -41.21 | -28.63 | 18.84 |
| 4 | -46.15 | -33.44 | 31.33 |

### 4.1 Compression Strength

**Table–5 Response Table for S/N ratio of Compression Strength**

| Level | A | B | C |
|---|---|---|---|
| 1 | 26.60 | 19.93 | 26.18 |
| 2 | 25.09 | 31.76 | 25.51 |
| Delta | 1.51 | 11.82 | 0.67 |
| Rank | 2 | 1 | 3 |

The optimized parameter setting to achieve a lower model building time is found to be A1B2C1 (0.1mm Layer Thickness, 80% Infill Density and 25 mm/s Printing Speed) and infill density is found to be the most significant factor than layer thickness and speed. An increase in infill density may increase the compression strength of the specimen tested and on the other hand it increases the material consumption of the specimen with no doubt and also increases the cost of making the specimen. The Fig shows the main effect plot for S/N ratio of compression strength.

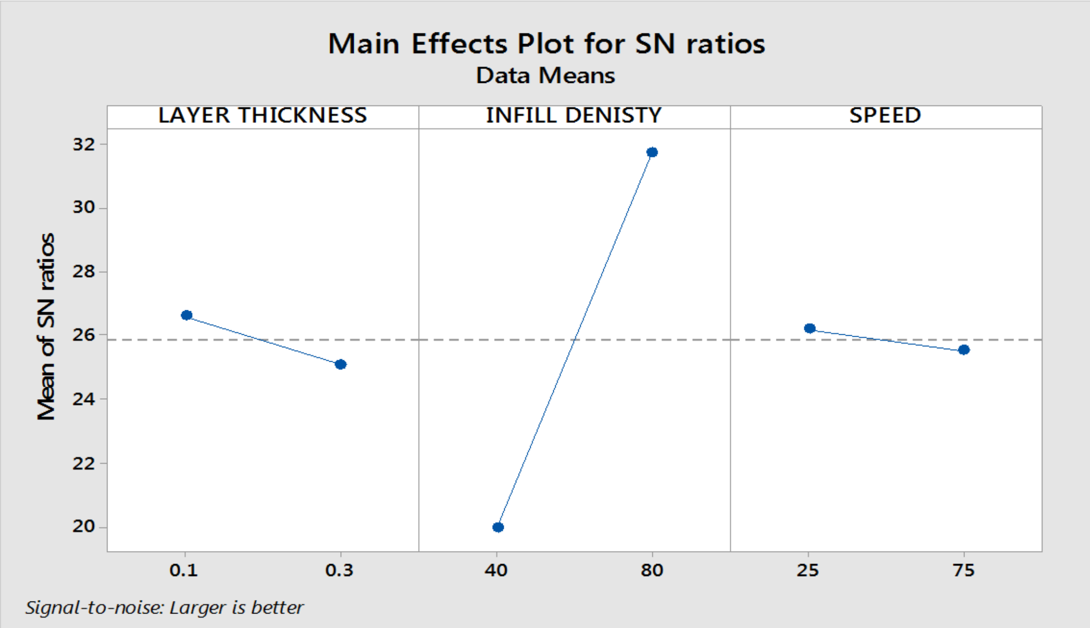



**Fig – Main Effect Plot for S/N Ratio of Compression Strength**

## 4.2 Model Building Time

**Table–6 Response Table for S/N ratio of Model Building Time**

| Level | A | B | C |
|---|---|---|---|
| 1 | -52.92 | -45.88 | -48.35 |
| 2 | -43.68 | -50.72 | -48.25 |
| Delta | 9.24 | 4.83 | 0.1 |
| Rank | 1 | 2 | 3 |

The optimized parameter setting to achieve a lower model building time is found to be A2B1C2 (0.3mm Layer Thickness, 40% Infill Density and 75 mm/s Printing Speed) and layer thickness is found to be the most significant factor than infill density and speed. The low value of layer thickness when it is preferred leads to more no of layers get printed to meet the solid model of the specimen in reality. As per 0.1mm layer thickness the specimen gets divided in to 400 layers and in case of 0.3mm layer thickness the specimens gets completed in 133 layers and reduces the printing time of the specimen. The Fig shows the main effect plot for S/N ratio of model building time.

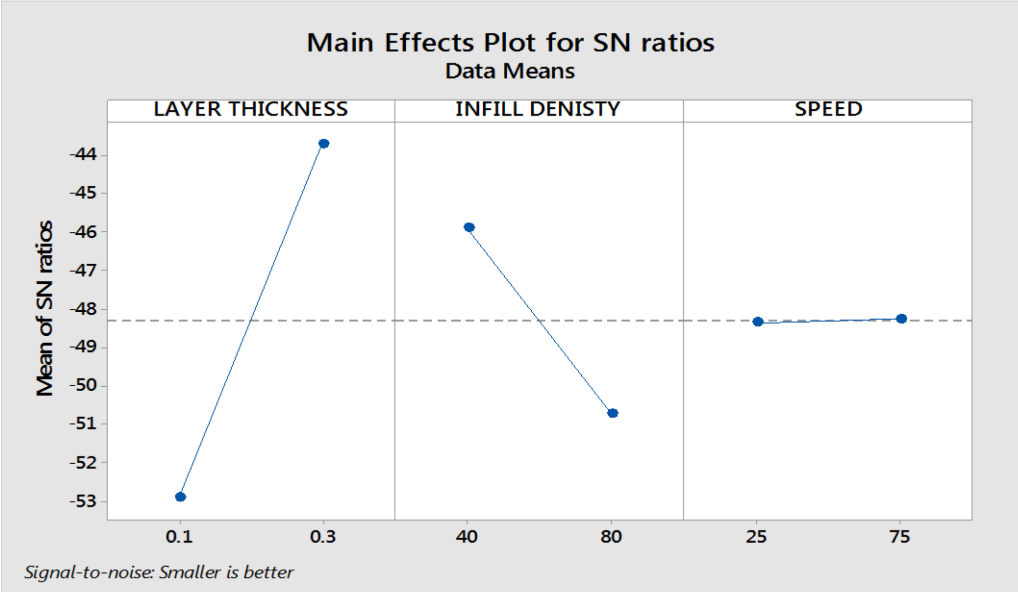



**Fig – Main Effect Plot for S/N Ratio of Model Building Time**

### 4.3 Material Consumption

**Table–7 Response Table for S/N ratio of Material Consumption**

| Level | A | B | C |
|---|---|---|---|
| 1 | -31.28 | -28.79 | -31.19 |
| 2 | -31.03 | -33.53 | -31.13 |
| Delta | 0.25 | 4.75 | 0.07 |
| Rank | 2 | 1 | 3 |

The optimized parameter setting to achieve a low material consumption is found as A2B1C2 (0.3mm Layer Thickness, 40% Infill Density and 75 mm/s Printing Speed) and infill density is found to be the most significant factor than layer thickness and speed. The infill density with 40% generally consumes less material when comparing the specimen made out of 80% infill density which takes more material and on the other hand when a lesser infill density is preferred it affects the compression strength of the material considerably as less material is getting filled inside of the part printed. The Fig shows the main effect plot for S/N ratio of material consumption of the specimen.

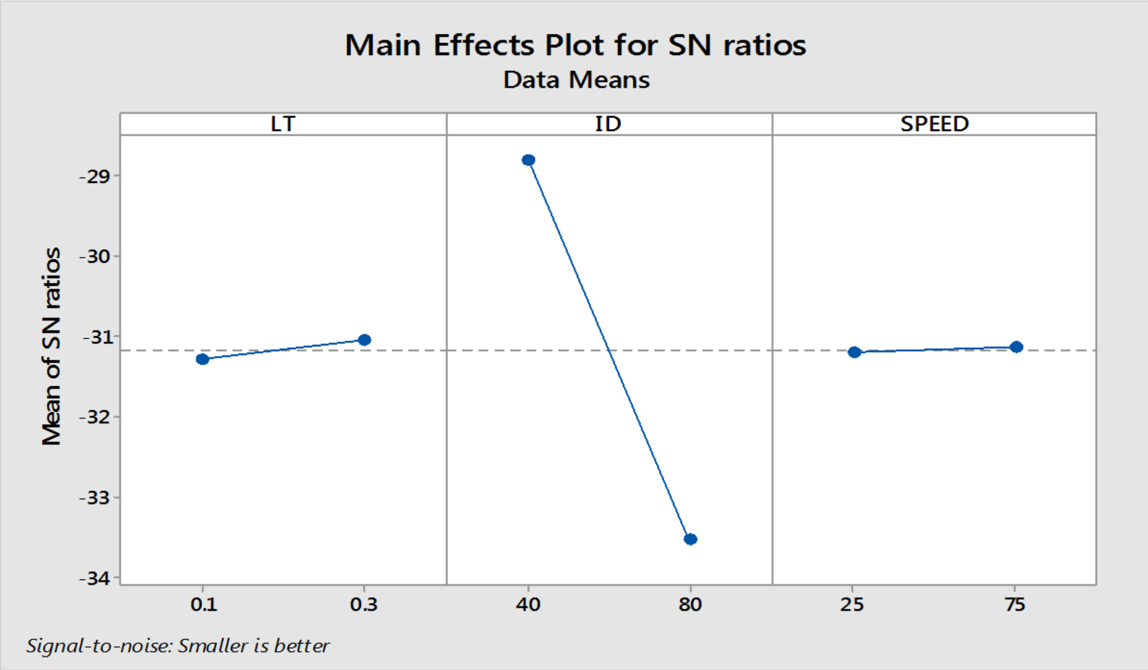



**Fig – Main Effect Plot for S/N Ratio of Material Consumption**

## 5. MULTI RESPONSE OPTIMIZATION

The optimized parameter setting obtained for one output characteristic may not be in good agreement for the other output parameters associated with a process. Inorder to obtain a parameter setting which can provide good results in case of all the output parameters, the problem has to be dealt with multi response optimization techniques. Multi response optimization techniques generally converts a multi response problem into a single response problem by considering all the parameters together and their associated attributes. The optimized parameter setting obtained is considered to be best combination to attain results with superior performance than the other combination of parameters provided in the experimental design. The present work considers two different approaches such as Grey Relational Analysis (GRA) and Data Envelopment Analysis Based Ranking (DEAR) for the multi response optimization of output characteristics considered in the present study.

### 5.1 Grey Relational Analysis (GRA)

**Table – 8 Normalized Signal to Noise Ratio Values of Different Responses**

| Trial No | R1 (Mpa) | R2 (secs) | R3 (gms) |
|---|---|---|---|
| 1 | 0.1637 | 0.6637 | 0.0632 |
| 2 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 0.0000 | 0.0000 | 0.0000 |
| 4 | 0.9369 | 0.3508 | 0.963 |

**Table – 9 Deviation Sequence of Different Responses**

| Trial No | R1 (Mpa) | R2 (secs) | R3 (gms) |
|---|---|---|---|
| 1 | 0.8363 | 0.3363 | 0.9368 |

| | | | |
|---|---|---|---|
| 2 | 0.0000 | 0.0000 | 0.0000 |
| 3 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 0.0631 | 0.6492 | 0.0366 |

**Table –10 Grey Relational Coefficient of Different Responses**

| Trial No | R1 (Mpa) | R2 (secs) | R3 (gms) |
|---|---|---|---|
| 1 | 0.5446 | 0.7484 | 0.5163 |
| 2 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 0.5000 | 0.5000 | 0.5000 |
| 4 | 0.9407 | 0.6064 | 0.9647 |

**Table –11 Grey Relational Grade or MRPI Values for GRA**

| Trial No | GRG | Rank |
|---|---|---|
| 1 | 0.6031 | 3 |
| 2 | 1.0000 | 1 |
| 3 | 0.5000 | 4 |
| 4 | 0.8372 | 2 |

**Table – 12 Level Totals of MRPI Values as per GRA**

| Factors | Levels | | |
|---|---|---|---|
| | 1 | 2 | Max Min |
| Layer Thickness (A) | **1.6031** | 1.3372 | 0.2659 |
| Infill Density (B) | 1.1031 | **1.8372** | **0.7341** |
| Printing Speed (C) | 1.4403 | **1.5000** | 0.0597 |

### 5.2 Data Envelopment Analysis Based Ranking (DEAR)

Hung- Chang and Yan – Kwang (2002) proposed Data Envelopment Analysis Based Ranking (DEAR) approach for optimizing multi-response Taguchi experiments. The method converts a set of original responses in to a ratio i.e weighted sum of responses with larger the better is divided by weighted sum of responses with smaller the better or nominal the best. The optimal levels of the input variables can be found from this ratio and the ratio obtained can be treated as equivalent to Multi Response Performance Index.

**Steps in DEAR Approach**

1. Determine the weights associated with each response for all experiments.
2. Transform the observed data of each response into weighted data by multiplying the observed data with its own weight.
3. Divide the weighted data of larger the better type with weighted data of smaller the better type or nominal the best type.
4. Treat the ratio value obtained as the MRPI value for obtaining the solution

**Table – 13 Weights of Individual Responses**

| Trial No | $W_{R1}$ | $W_{R2}$ | $W_{R3}$ |
|---|---|---|---|
| 1 | 0.1154 | 3.709199 | 5.3305 |
| 2 | 0.4167 | 2.151463 | 3.1095 |
| 3 | 0.0897 | 10.86957 | 5.5279 |
| 4 | 0.3782 | 6.157635 | 3.1756 |

**Table – 14 MRPI Value and its Ranking**

| Trial No | R1* $W_{R1}$ (P) | R2* $W_{R2}$ (Q) | R3* $W_{R3}$ (R) | MRPI = $\frac{R}{(P+Q)}$ | Rank |
|---|---|---|---|---|---|
| 1 | 1.2981 | 1250 | 149.2537 | 0.0009 | 3 |
| 2 | 16.9271 | 1249 | 103.2702 | 0.0125 | 1 |
| 3 | 0.7853 | 1250 | 149.2537 | 0.0006 | 4 |
| 4 | 13.9463 | 1250 | 149.2537 | 0.0100 | 2 |

**Table – 15 Level Totals of MRPI Values as per DEAR**

| Factors | Levels | | |
|---|---|---|---|
| | 1 | 2 | Max Min |
| Layer Thickness (A) | **0.0134** | 0.0105 | 0.0029 |
| Infill Density (B) | 0.0015 | **0.0225** | **0.0210** |
| Speed (C) | 0.0109 | **0.0131** | 0.0022 |

**Conclusion**

The pilot study and multi response optimization conducted has led to the arrival of concluding remarks in this section

- The pilot testing of samples printed by using ABS material from fused deposition modeling is done by adopting Taguchi's $L_4$ Orthogonal Array for understanding the effect of input variables over the output parameters considered for study.
- Through Mono Response Optimization the optimized parameter setting for both model building time (R1) and material consumption (R2) are found to be similar and it has been identified that the setting A2B1C2 (high layer thickness , low infill density and high printing speed) is recommended.
- For both the output characteristics such as model building time and material consumption the influencing parameter varies. In case of model building time (R1) layer thickness (A) is found to be significant and for material consumption (R2) infill density (B) is found to be significant.
- In case of compression strength of the sample , infill density is highly significant.
- For all the three output parameters considered, the input variable printing speed ranks in the last position and shows low significance over the output parameters than other input variables.
- The optimized parameter setting obtained from both the Analysis methods (GRA and DEAR) are found to be A1B2C2 (0.1mm , 80% , 75 mm/s) which insists for Low value of layer thickness and higher values in terms of both infill density and printing speed to be selected.

- From both the multi response optimization methods adopted , Infill Density is found to be the most significant parameter affecting the responses with top ranking and it is followed by layer thickness and printing speed .
- The MRPI ranking obtained for the experimental trails from both the methods are found to be sameand it has good correlation with the optimized parameter setting from GRA and DEAR approaches.
- Similar to the evaluation of compression strength, other mechanical properties such as tensile strength, fatigue strength, impact and flexural strength may be computed with other FDM materials such as PLA, HIPS, PET-G and Glass filled composite filaments.
- Confirmation runs may be conducted to evaluate the correctness of optimized combination of parameter settings obtained.

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