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OPTIMIZATION OF ABS P430 MATERIAL MADE OF FUSED DEPOSITION MODELING (FDM) USING TAGUCHI METHOD

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Abstract- *The present study illustrates the performance of ABS P430 Material Made of Fused Deposition Modeling (FDM). The effect of FDM parameter of Surface Roughness, Tensile Strength and Percentage of Elongation is investigated. The experiments were conducted with two different parameters such as Layer thickness and air gap. The process parameters are optimized by using Taguchi method and the effect of these process parameters on Surface Roughness, Tensile Strength and Percentage of Elongation was evaluated by the analysis of variance. The analysis shows that the parameter that have the biggest effect on Surface Roughness, Tensile Strength and Percentage of Elongation is Layer Thickness.*

Keywords: *FDM, surface roughness, Tensile Strength, Percentage of Elongation, Taguchi method, ANOVA.*

I. INTRODUCTION

Rapid Prototyping (RP) can be defined as a group of techniques which is used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. Since the introduction of the first commercial rapid prototyping (RP) machine widely known as Stereo lithography in 1986, a wide range of RP machines has been commercialized and many newer systems continue to be developed in various parts of the world. In addition to prototypes, RP techniques can also be used to make tooling (referred to as rapid tooling) and even production-quality parts (rapid manufacturing). For small production runs and complicated objects, rapid prototyping is often the best manufacturing process available. RP techniques that are currently commercially available, including Stereo lithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), and Ink Jet printing techniques. In general, rapid prototyping (RP) machines utilize five common steps such as: (a) Create a CAD model of the design. (b) Convert the CAD model to STL format. (c) Slice the STL file into thin cross-sectional layers. (d) Construct the model one layer atop another. (e) Clean and finish the mode.

II. LITERATURE REVIEW

Sandeep Raut et al. [1] have studied the critical factor affects the different areas of the FDM model like main material, support material, built up time, total cost per part and most important the mechanical properties of the part. Investigated the effect of built orientation on the mechanical properties and total cost of the FDM parts. The responses are considered the mechanical property of FDM produced parts such as tensile and bending strength should be studied. The test specimens were prepared for the STRATASYS FDM type rapid prototyping machine coupled with CATALYST software and used the ABS material.
Farzad Rayegani et al. [2] Presented the functional relationship between process parameters and tensile strength of the FDM process has been developed using the group method for data modeling for prediction purposes. An initial test was carried out to determine whether part orientation and raster angle variations affect the tensile strength. It was found that both process parameters affect tensile strength. The negative air gap significantly improves the tensile strength. Smaller raster widths also improve tensile strength. At zero part orientation maximum tensile strength is obtained. Increased raster angle also improves tensile strength. The maximum tensile strength is obtained at part orientation is zero, raster angle 50°, raster width 0.2034mm and negative air gap-0.0025mm.
A. Bagsik et al. [3,4] Have worked on the mechanical properties of FDM samples built up with the FDM process were analyzed depending on the build direction. The influence orientation and the tool path generation of manufactured parts based on the mechanical data is analyzed. The tensile tests show different strength and strain characteristics that depend on the given structure and as a result of the build direction. The best results were achieved for all directions by using a negative raster air gap. The thick specimen has better mechanical properties in X and Z directions 81Mpa and 43Mpa. But the thin specimen improves the tensile strength 67Mpa in Y-direction. The results show that the geometry of the sample parts, independent of their build direction, does not conform to the nominal geometry. The test specimens built in X-direction, obtain the maximum strengths is 63Mpa as compared to Y and Z-direction. But the compressive strength of

specimens built up in XY-direction is lower than that of specimens built up in Z-direction. The compressive strength is 97Mpa. The tip is changed regularly for good result.

L.M. Galantucci et al. [5] Have analyzed and compared the mechanical properties and the surface quality of treated and untreated FDM parts with a solution of 90% dimethylketone and 10% water. Tensile and bending properties have been investigated by designing and performing four Central Composite Designs (CCDs) of experiments. The treatment can be used to dramatically improve the surface finish of ABS prototypes. A general tendency was observed where greater immersion times and lower raster widths resulted in lower tensile strength. The specimen should dissolve in chemical so it reduces the roughness and increasing the compactness of the structure in a tensile test. In bending tests the general improvement is of the flexural strength.

Anoop Kumar Sood et al. [6,7] Have studied the influence of important process parameters viz., layer thickness, part orientation, raster angle, air gap and raster width along with their interactions on the dimensional accuracy of Fused Deposition Modeling (FDM) processed ABSP400 part. It was observed that shrinkage is dominant along the length and width direction of built part. But the positive deviation from the required value is observed in the thickness direction. Optimum parameters setting to minimize percentage change in length, width and thickness of the standard test specimen have been found out using Taguchi's parameter design. They were used artificial neural network for prediction purpose. The result shows that for minimizing percentage change in length higher layer thickness 0.254 mm, 0 orientations, maximum raster angle 60°, the medium raster width and 0.004 air gap will give desired results. On the other hand lower value of layer thickness 0.127mm, orientation 0, raster angle 0° and higher value of raster width and minimum value of air gap 0.004 will minimize percentage change in thickness of the test specimen. The grey Taguchi method was used to fabricate the part in such a manner that all the 3 dimensions, i.e. length, width and thickness show minimum deviation from actual values. The maximization of gray relational grade shows that the layer thickness of 0.178 mm, part orientation of 0 degrees, raster angle of 0 degrees, road width of 0.4564 mm and air gap of 0.008 mm produce improved part dimensions. Impact strength is improving at higher values of the raster, strength increases with the increase in orientation. The Zero air gap will improve the diffusion between the adjacent raster but may also decrease the heat dissipation as well as total bonding area.

Mostafa Nikzad et al. [8] Have introduced a new composite material for the FDM process. The new composite materials involving ABS and metals. The experiments have been conducted to characterize the thermal, mechanical, and rheological properties. The analyses have been carried out to investigate main flow parameters such as temperature, pressure drop and velocity using two CFD software, two-dimensional and three-dimensional analysis. The entrance velocity of filament at a rate of 0.001 m/s is maintained along the tube until it gets to the nozzle tip. The melt flow speed in the center is the highest while lowest at the wall due to no-slip condition. The results obtained from both of the analyses have been compared and show a very good correlation in predicting the flow behavior.

B.H. Lee et al. [9] Have perform the experiments for finding out the optimal process parameters of Fused deposition modeling, rapid prototyping machine to achieve maximum flexibility of ABS prototype. For design of the experiments Taguchi method was used. The process parameters such as air gap, raster angle, raster width and layer thickness each of at three levels is selected for the study. L9 orthogonal array was selected for design of experiments. The analysis of variance used to investigate the process parameters to achieve the optimum elastic performance of ABS prototype. It was found that for 10°angle of displacement, air gap produces a maximum contribution on throwing distance, for 15° angle of displacement, raster angle and layer thickness demonstrate almost equal maximum contribution on throwing distance. For 20° angle of displacement, layer thickness gives the highest contribution on throwing distance. From the results it was found that layer thickness, raster angle, raster width and air gap significantly affect the elastic performance of the compliant ABS prototype.

R. Anitha et al. [10] Have studied the effect of various process parameters, i.e. layer thickness, road width and speed deposition of fused deposition modeling part. These process parameters influence the quality characteristics of the FDM parts. Taguchi method was used for design of experiments. L18 orthogonal array was selected for experiments. The result shows that the layer thickness is effective to 43.37% at 95% without pooling. On the other hand the layer thickness is effective to 51.57% at 99% with pooling. The layer thickness is most effective at 0.3556mm, the road width at 0.537mm and the speed of deposition at200mm.

P. M. PANDEY et al. [11] have studied the orientation for part deposition as it affects part surface quality, production time and the requirement for support structure and cost in the RP processes. They used Multicriteria Genetic Algorithm to determine optimal solutions for part deposition orientation for the two contradicting objectives i.e. surface roughness and built time. The minimum average part surface roughness can be obtained at the maximum production time. On the other hand the minimum production time with maximum average part surface roughness. The best surface roughness were obtained at 240.001 angles about the axis 0.034, 0.369, and 0.289and the minimum production time at 89.97 about axis 0.749, 0.011, and 0.009.

III. MATERIAL AND METHOD

The experiments were carried out by using an FDM Fortus360 Machine. For tensile test specimen is designed on Pro-Engineering software as per ASTM D638 standards (165mm length X 19mm height x 4mm thickness). The Workpiece are modeled as per ASTM D638 standards. Parts are fabricated by the use of FDM 360 machine for the experiment. ABS

P430 is the material which is used for fabricating the designed part.The surface roughness was measured using a Mitutoyo SJ-301P portable device. Statistical software Minitab 16 is used to obtain results for the Analysis of Mean (ANOM) and Analysis Of Variance (ANOVA).

Table 1. Mechanical Properties Of ABS P430

Young's modulus (E)	Tensile Strength (σt)	Flexural Strength	Elongation (ε) @ Break	Rockwell Hardness	Izod Impact Strength
2.3 GPa	36 MPa	52 MPa	6 %	103 - 112	96 J/m

Table 2. Experimental design and optimization process parameters with their values at 3 levels

Process Parameters	**Level 1**	**Level 2**	**Level 3**
Layer Thickness (A)	1	2	3
Air Gap (B)	1	2	3

The experimental layout was developed based on Taguchi's Orthogonal Array Experimentation Technique. An L9 Orthogonal Array was selected to satisfy the minimum number of experimental conditions for the factors and levels presented in Table 3.

Table 3. L9 orthogonal array

Sr No.	**Layer Thickness**	**Air Gap**
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

The optimization of the measured control factors was provided by signal-to-noise (S/N) ratios. The lowest values of surface roughness are very important for quality improvement of the product. For this reason, the ''lower-the-better'' equation was used for the calculation of the S/N ratio. Table 4 shows the values of the S/N ratios for observations of the surface roughness. The higher value of Tensile Strength is very important for parts made of FDM. For this reason, the ''larger-the-better'' equation was used for the calculation of the S/N ratio. Design of Experiment [DOE] using Taguchi's Analysis & ANOVA for Main effects plot has been done using Minitab 16 application software. The results of the same with their respective graphs & interpretations are mentioned below in the sequential order.

Surface Roughness

Table 4. Experimental data of surface roughness

Sr No.	Layer Thickness (mm)	Air Gap (mm)	Surface Roughness	SN Ratio
1	0.127	-0.002	4.183	-12.4298
2	0.127	0	4.594	-13.2438
3	0.127	0.002	4.762	-13.5558
4	0.177	-0.002	5.729	-15.1616
5	0.177	0	7.701	-17.7309
6	0.177	0.002	7.246	-17.202
7	0.227	-0.002	8.194	-18.2699
8	0.227	0	8.747	-18.8372
9	0.227	0.002	10.47	-20.3989

Table 5. Response Table for Signal to Noise Ratios of surface roughness Smaller is better

Level	Layer Thickness (mm)	Air Gap (mm)
1	-13.08	-15.29
2	-16.70	-16.60
3	-19.17	-17.05
Delta	6.09	1.77
Rank	1	2

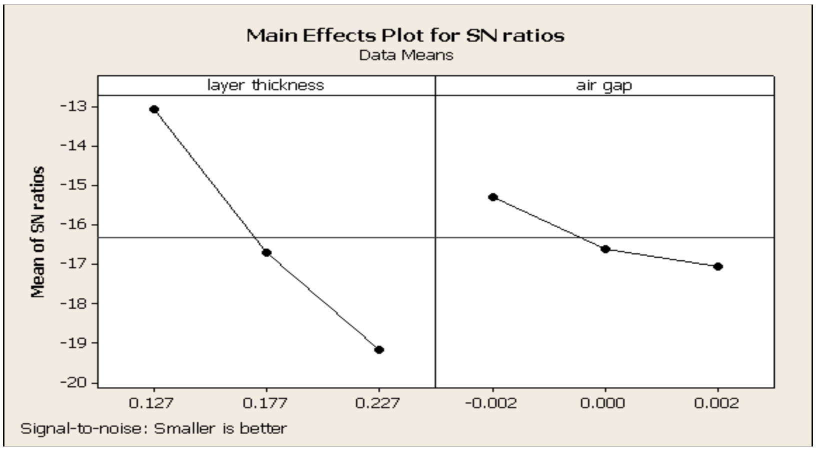

Fig.1. Main Effect plot for SN Ratios surface roughnes

Table 6. Response Table for Means of surface roughness Smaller is better

Level	Layer Thickness (mm)	Air Gap (mm)
1	4.513	6.035
2	6.892	7.014
3	9.137	7.493
Delta	4.624	1.457
Rank	1	2

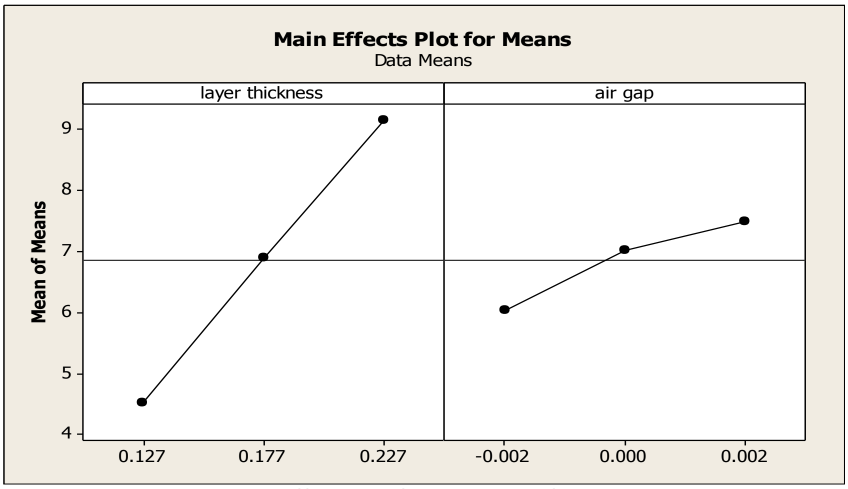

Fig.2. Main Effect plot for means surface roughness

Tensile Strength

Table 7. Experimental data of Tensile Strength.

Sr No.	Layer Thickness (mm)	Air Gap (mm)	Tensile Strength (Mpa)	SN Ratio
1	0.127	-0.002	37.64	31.51299
2	0.127	0	31.806	30.05018
3	0.127	0.002	34.839	30.84131
4	0.177	-0.002	35.989	31.1234
5	0.177	0	35.139	30.91579
6	0.177	0.002	29.438	29.37817
7	0.227	-0.002	36.478	31.24062
8	0.227	0	33.208	30.42485
9	0.227	0.002	31.557	29.98191

Table 8. Response Table for Signal to Noise Ratios of Tensile Strength larger is better

Level	Layer Thickness (mm)	Air Gap (mm)
1	30.80	31.29
2	30.47	30.46
3	30.55	30.07
Delta	0.33	1.23
Rank	2	1

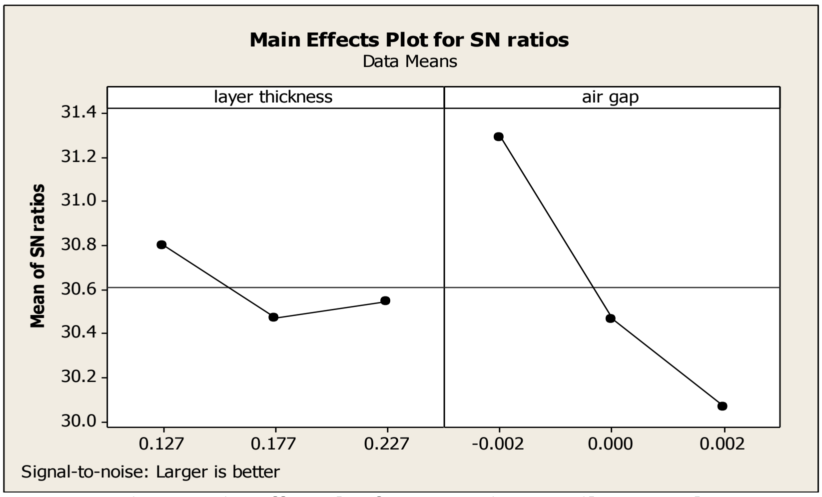

Fig.3. Main Effect plot for SN Ratios Tensile Strength

Table 9. Response Table for Means of Tensile Strength larger is better

Level	Layer Thickness (mm)	Air Gap (mm)
1	34.76	36.70
2	33.52	33.38
3	33.75	31.94
Delta	1.24	4.76
Rank	2	1

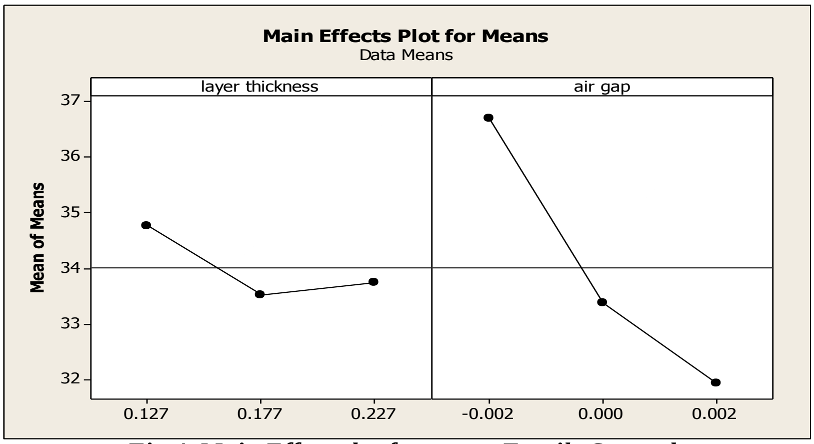

Fig.4. Main Effect plot for means Tensile Strength

Percentage of Elongation

Table 10. Experimental data of Percentage of Elongation.

Sr No.	Layer Thickness (mm)	Air Gap (mm)	Elongation (%)	SN Ratio
1	0.127	-0.002	4.453	12.97305
2	0.127	0	3.994	12.02816
3	0.127	0.002	4.234	12.53502
4	0.177	-0.002	5.996	15.55723
5	0.177	0	5.678	15.08391
6	0.177	0.002	5.08	14.11727
7	0.227	-0.002	7.553	17.56239
8	0.227	0	7.185	17.12854
9	0.227	0.002	4.573	13.20402

Table 11. Response Table for Signal to Noise Ratios of Percentage of Elongation larger is better

Level	Layer Thickness (mm)	Air Gap (mm)
1	12.51	15.36
2	14.92	14.75
3	15.96	13.29
Delta	3.45	2.08
Rank	1	2

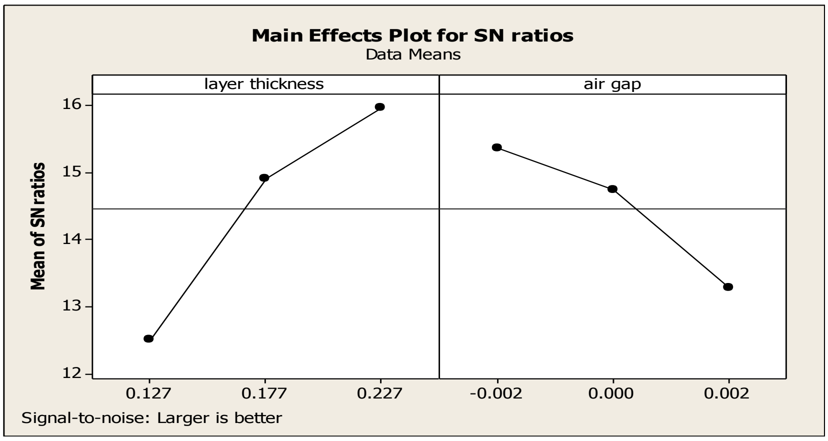

Fig.5. Main Effect plot for SN Ratios Percentage of Elongation

Table 12. Response Table for Means of Percentage of Elongation larger is better

Level	Layer Thickness (mm)	Air Gap (mm)
1	4.227	6.001
2	5.585	5.619
3	6.437	4.629
Delta	2.210	1.372
Rank	1	2

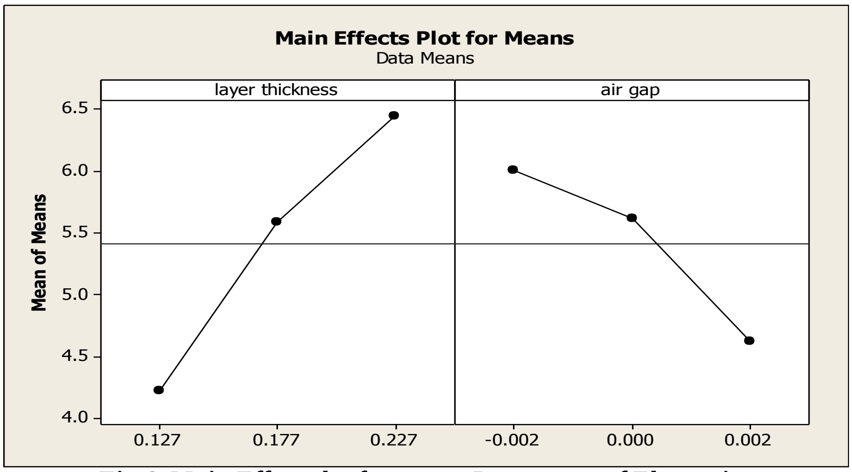

Fig.6. Main Effect plot for means Percentage of Elongation

IV. ANALYSIS OF VARIANCE (ANOVA)

Analysis of Variance was employed in order to analyze the experimental results. The analysis of variance is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each factor. The purpose of the ANOVA is to investigate which process parameters significantly affect the performance characteristics.

Table 13. Analysis of Variance for surface roughness, using Adjusted SS for Tests

Sources of Variation	DOF	Sum of Squares S	Variance (Mean Square)	Variance Ratio F	Percentage Contribution P
Factor A	2	32.07	16.035	18.22	86.18
Factor B	2	3.31	1.655	1.88	8.92
Error E	4	1.76	0.88	18.22	4.72
Total	8	37.14			100

Table 14. Analysis of Variance for Tensile Strength, using Adjusted SS for Tests

Sources of variation	DOF	Sum of squares S	Variance (Mean Square)	Variance ratio F	Percentage contribution P
Factor A	2	2.61	1.305	0.135654	3.75
Factor B	2	35.72	18.86	1.960498	62.04
Error E	4	19.24	9.62	1	33.42
Total	8	57.57			100

Table 15. Analysis of Variance for Percentage of Elongation, using Adjusted SS for Tests

Sources of variation	DOF	Sum of squares S	Variance (Mean Square)	Variance ratio F	Percentage contribution P

Factor A	2	7.462	3.731	2.66309	56.18
Factor B	2	3.016	1.508	1.07637	22.70
Error E	4	2.802	1.401	1	21.09
Total	8	13.28			100

V. RESULTS & DISCUSSIONS

The following conclusions can be drawn based on the results of the experimental study on ABS P430 material parts made of Fused Deposition Modeling.

- The significant parameters can be easily identified and rank the parameter as per the response table for S/N Ratio and Means.
- The rank order is clearly seen from the response table 5, Layer Thickness is on 1 rank and Air Gap is on 2 rank for surface roughness.
- The rank order is clearly seen from the response table 8, Air Gap is on 1 rank, Layer Thickness is on 2 rank for tensile strength.
- The rank order is clearly seen from the response table 11, Layer Thickness is on 1 rank and Air Gap is on 2 rank for Percentage of Elongation.
- Analysis of Variance table shows the effect of parameter on surface roughness. From this table the significant parameters can be easily identified. Layer Thickness is a most significant factor for surface roughness and it has p-value<0.05.
- The optimum condition for the minimum surface finish is Layer Thickness (0.127 mm) and Air Gap (-0.002 mm).
- The optimum condition for maximum Tensile Strength is Layer Thickness (0.127 mm) and Air Gap (-0.002 mm).
- The optimum condition for maximum Percentage of Elongation is Layer Thickness (0.227 mm) and Air Gap (-0.002 mm).
- The Analysis of Variance table can also justify the rank order of significant parameter as Layer Thickness (86.18) and Air Gap (8.92). It is clearly seen from the Analysis of variance that Layer Thickness is the most significant parameter for Surface Roughness.
- The Analysis of Variance table can justify the rank order of significant parameter as Air Gap (62.04) and Layer Thickness (3.75). It is clearly seen from the Analysis of variance that Air Gap is the most significant parameter for Tensile Strength.
- The Analysis of Variance table can justify the rank order of significant parameter as Layer Thickness (56.18) and Air Gap (22.70). It is clearly seen from the Analysis of variance that Layer Thickness is the most significant parameter for Percentage of Elongation.

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