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Investigation of Layer Thickness and Orientation on Mechanical Strength of CL20 ES Material by Selective Laser Sintering Process

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Abstract: Selective Laser Sintering is one of the rapid prototyping process, 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. In this present work important process parameters of the SLS process such as layer thickness and orientation of part is taken as input parameter. Specimens are prepared for Tensile testing as per ASTM standards. Their influence on responses such as Tensile strength and Yield point strength is found.

After results and analysis, it is concluded that layer thickness is more significant parameter for SLS process than orientation. If we increase layer thickness and orientation mechanical property like tensile strength and yield point strength decreases. So for better result of fabricated part layer thickness and orientation should be lesser as SLS is layer wise manufacturing process.

Keywords: Selective Laser Sintering (SLS), Rapid Prototyping, CL20 ES (SS316L) Materials, Layer thickness, Orientation.

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. Selective laser sintering (SLS) is an additive manufacturing technique that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (direct metal laser sintering), ceramic, or glass powders into a mass that has a desired 3-Dimensional shape.

The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered b y one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed. Because finished part density depends on peak laser power, rather than laser duration, a SLS machine typically uses a pulsed laser. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point to make it easier for the laser to raise the temperature of the selected regions.

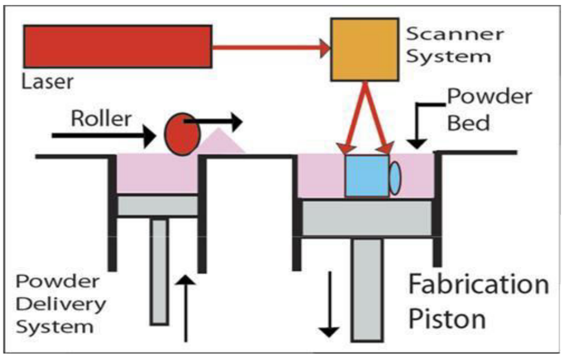

Figure 1 Selective Laser Sintering (SLS)

This process can be applicable for building fully functional prototypes and cast metal parts. Now days SLS is also used as rapid tooling for manufacturing parts. Unlike other Rapid Prototyping techniques SLS does not require any support structure for fabricating parts.

II. LITERATURE REVIEW

YAN Yongnian al. [1] presented a brief review on Rapid Prototyping and Manufacturing Technology: Principle, Representative Techniques, Applications, and Development Trends and also given flow of process of SLS.

A.N. Chatterjee al. [2] published paper on An experimental design approach to selective laser sintering of low carbon steel. They had concluded relation between Hardness and Layer thickness of fabricated part.

Fangxia Xie al. [3] published paper on Structural and mechanical characteristics of porous 316L stainless steel fabricated by indirect selective laser sintering. The effect of processing parameters on pore characteristics and mechanical properties were analyzed in their paper and also given relationship between stress & strain.

Edson Costa Santosa al. [4] published paper on Rapid manufacturing of metal components by laser forming. They concluded that direct fabrication of metal products of high density and excellent mechanical properties is possible by using laser based layer manufacturing techniques. The aeronautic, automotive and medical industries are the main markets.

Y. Tang al. [5] published paper on direct laser sintering of a copper-based alloy for creating three-dimensional metal parts. The density, surface roughness and mechanical properties of the laser sintering parts due to variation of process parameters were measured and analyzed. They concluded that the final density also increases when the laser power increases, and the scan speed and scan spacing decreases.

D. King al. [6] published paper on Rapid tooling: selective laser sintering injection tooling. They had concluded variations in dimensions of part made by different process like CAD model, Z- Corp part, SLS part and plastic parts.

III. METHODOLOGY

3.1 Design of Experiments

DOE is a technique for defining and finding out all the possible combinations in an experiment involving multiple variables and to identify the best combination. Total 9 experiments were designed for investigation of input parameters layer thickness and orientation.

Specimen is designed for tensile testing on Pro-Engineering software as per ASTM E8/ E8M-11 (60mm length X 12mm height x 4mm thickness) as shown in below figure 2.

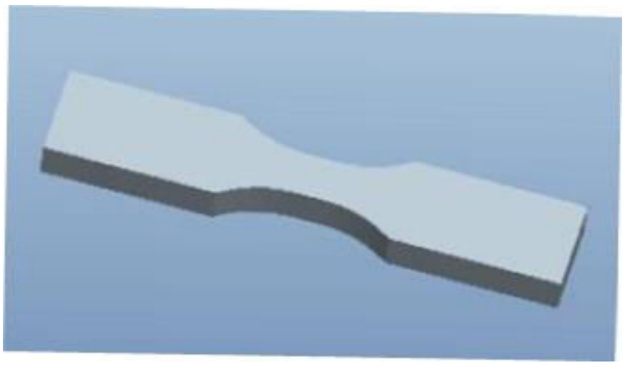

Figure 2 3-D CAD model Specimen for Tensile testing

Above shown CAD model will be fabricated by SLS process by varying Input parameters are Layer thickness and Orientation. And output parameters are Tensile Strength and Yield point Strength.
SLS part were made on M1 Cusing machine at Indo-German Tool Room (IGTR) at Ahmedabad, Gujarat. Some parts made by this machine is shown in below figure 3.

Figure 3 Components made by SLS process

3.2 Mechanical Properties of CL20 ES material

Table 1 Mechanical Properties of CL20 material

Yield Point [N/mm^2]	470
Tensile Strength [N/mm^2]	570
Hardness [HRC]	20
E-modulus [N/mm^2] at 20° C	-
Elongation [%]	>30
Thermal conductivity [W/mK] at 20° C	15

IV. RESULT OF EXPERIMENTS AND ANALYSIS OF RESULTS

4.1 Results of Tensile testing

Tensile testing was carried out on Universal Testing Machine for measuring Tensile strength as well as Yeild point strength for input parameters of layer thickness and orientation. Below figure 4 shows the parts made for tensile testing and table 2 shows the results of tensile testing.

Figure 4 Tensile test Specimens

Table 2 Results of experiment

	Input parameters		Output parameters	
Part no.	**Layer Thickness**	**Orientation**	**Tensile Strength**	**Yield Point Strength**
	in Micron	**in Degree**	**N/mm^2**	**N/mm^2**
1	35	0	522.87	477.94
2		15	518.79	473.85
3		30	494.28	457.51
4	40	0	506.53	461.6
5		15	494.28	469.77
6		30	498.36	473.85
7	45	0	502.45	465.68
8		15	498.36	482.02
9		30	490.19	469.77

4.2 Analysis of Variance terms and notations

n = Numbers of trails
C.F. = Correction factor
E = Error
F = Variance ratio
f = Degree of freedom
f_E = Degree of freedom of error
f_T = Total degree of freedom
r = Number of repetition
P = Percent contribution
T = Total of results
S = Sum of squares
S'= Pure sum of squares
V = Mean squares (variance)
бyᵢ = sum of all output values

Total number of runs, **n = 9**
Total degree of freedom f_T **= n-1 = 8**

Three factor & their levels

Layer Thickness A – A1, A2, A3
Orientation B – B1, B2, B3

Degree of freedom

Factor A – Number of level of factor A – 1 = 2
Factor B – Number of level of factor B – 1 = 2
For error $f_e = f_T - f_A - f_B = 8 - 2 - 2 = 4$

4.3 Calculations of Analysis of Variance

Correction factor C.F. = (T^2 / n)

Total Sum of Squares

$$S_T = \sum_{i=1}^{n} y_i^2 - C.F.$$

Factor sum of squares

$$S_A = A_1^2 / N_{A1} + A_2^2 / N_{A2} + A_3^2 / N_{A3} - C.F.$$
$$S_B = B_1^2 / N_{B1} + B_2^2 / N_{B2} + B_3^2 / N_{B3} - C.F.$$
$$S_E = S_T - (S_A + S_B)$$

Mean Square (variance)

$$V_A = S_A / f_A$$
$$V_B = S_B / f_B$$
$$V_E = S_E / f_E$$

Variance ratio F

$$F_A = V_A / V_E = 3.325076$$
$$F_B = V_B / V_E = 3.518017$$
$$F_E = V_E / V_E = 1$$

Percentage contribution

$$P_A = S_A / S_T$$
$$P_B = S_B / S_T$$
$$P_E = S_E / S_T$$

4.4 Analysis of variance for Tensile Strength

Output result is analyzed by taguchi method on Minitab 16 software and then by ANOVA method for verification that result. Result is obtained as shown in below table for tensile strength of input parameters.

Table 3 Percentage contribution of process parameter for Tensile Strength

Sources of variation	DOF	Sum of squares S	Variance (mean Square)	Variance ratio F	Percentage contribution P
Factor A	2	382.0428	191.0214	3.325076	37.6008
Factor B	2	404.2108	202.1054	3.518017	39.7826
Error E	4	229.7949	57.44873	1	22.6165
Total	8	1016.04899			100

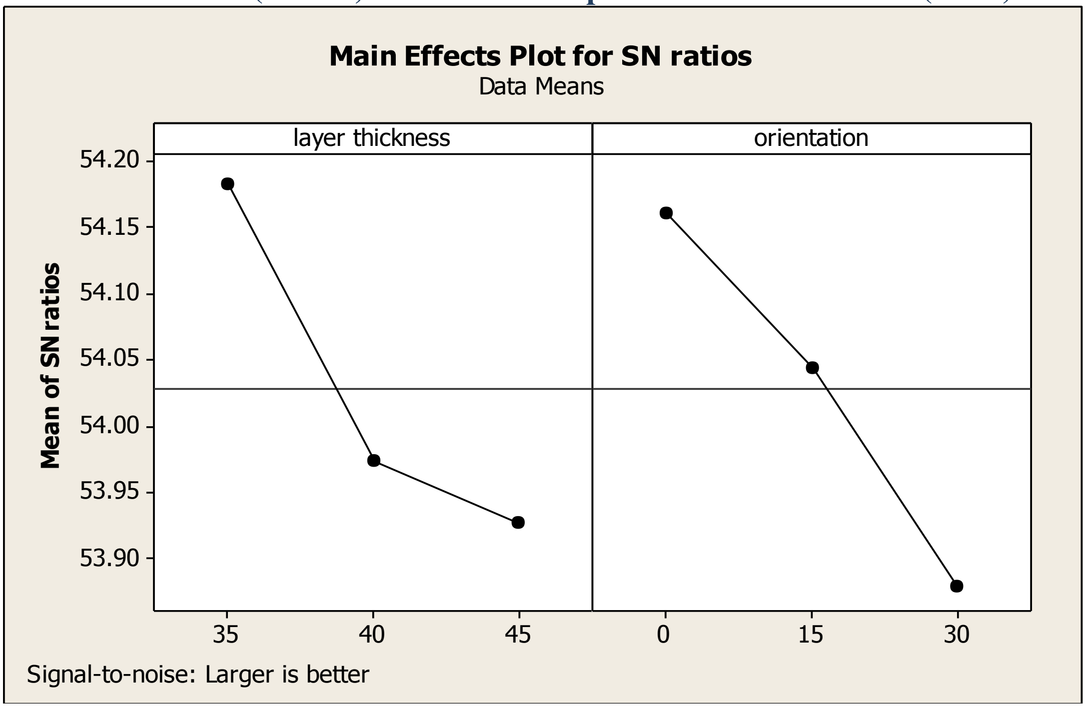

Figure 5 Print Screen of ANOVA Minitab software for Tensile Strength

Above figure 5 shows that as we increase layer thickness and orientation of part for fabrication by SLS, tensile strength is decrease of fabricated part. So lesser the layer thickness and orientation higher the tensile strength of fabricated part may be obtained.

4.5 Analysis of variance for Tensile Strength

Output result is analyzed by taguchi method on Minitab 16 software and then by ANOVA method for verification that result. Result is obtained as shown in below table for yield point strength of input parameters.

Table 4 Percentage contribution of process parameter for Yield Point

Sources of variation	DOF	Sum of squares S	Variance (mean Square)	Variance ratio F	Percentage contribution P
Factor A	2	25.93976	12.96988	0.152059	5.3811
Factor B	2	114.9383	57.46914	0.673771	23.8433
Error E	4	341.1792	85.28481	1	70.7757
Total	8	482.0573			100

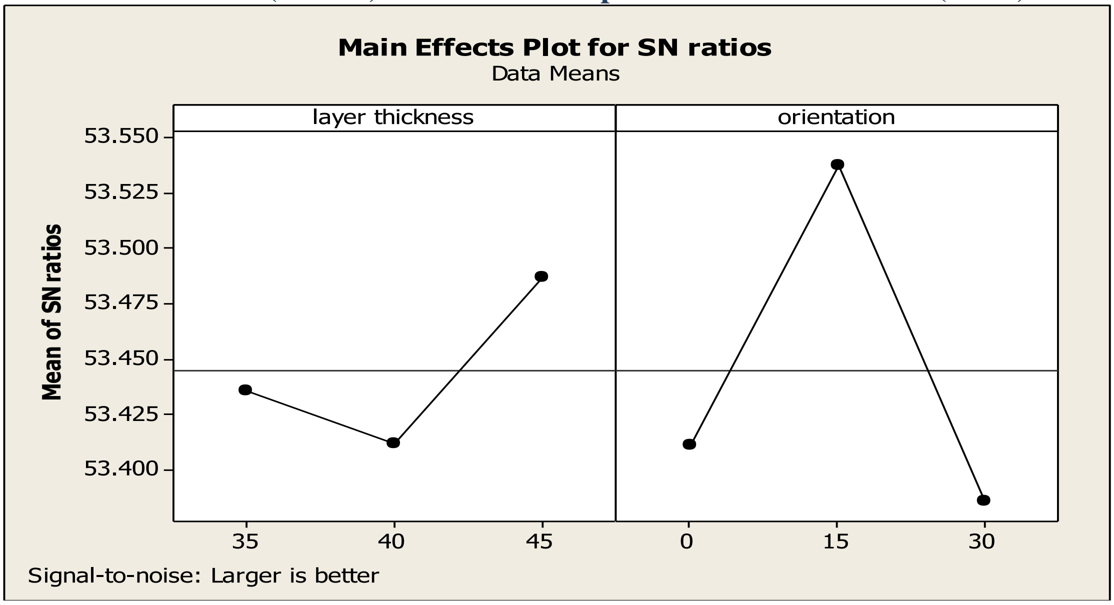

Figure 6 Print Screen of ANOVA Minitab software for Yield Point Strength

Yeild point strength is not much more affected by layer thickness or orientation of part and it can be seen by figure 6.

V. CONCLUSION AND FUTURE SCOPE OF WORK

5.1 Conclusion

Selective laser sintering is more promising method of Rapid Prototyping Technology (RPT). Mainly it is suitable for powder based metal material for part fabrication, so it is also known as Metal RP process. It gives higher possible strength of material and consumes less material & time. Also it does not require any other material for support structure as other process of RPT.

Following results are obtained for different input parameters as discussed below:

5.1.1. Layer Thickness

In general aspects of obtained results, it can be clearly found that as we increase layer thickness there is decrease in tensile strength and yield point strength. Thus, if we go for smaller layer thickness our output results would be high but it will take more time of fabrication because it is layer wise manufacturing technique. From all results, layer thickness of 35 microns is better value than rest of two.

5.1.2 Orientation

From obtained results, it can be clearly defined that tensile strength and yield point reduced with change in orientation. Also consumption of material and time are dependable on orientation taken for fabricating part. If we increase its inclination than it require more support material. From all results, orientation of 15 degree is better value for Yeild point strength. And 0 degree is best value for higher tensile strength.

For getting better value of output parameters best value of layer thickness is 35 microns and orientation is 0 and 15 degree.

5.2 Future Scope of work

In this research work I had taken two input parameters, Layer thickness and Orientation, for fabrication part by SLS process. There is a better scope for taking other input parameters like: Laser power, Focus diameter, hatching distance, Laser speed, Speed of roller etc.

Also other output parameters can be measured, by SLS process, like: Thermal conductivity, Hardness, Dimensional accuracy, Surface roughness etc.

Thus future work can be done by taking or considering any of following points/variables: Different input parameters, Different output parameters, Different methods/process of rapid prototyping, using different materials etc.

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