Experimental Investigation of Process Parameter on Tensile Strength of Selective Laser Melting Built Parts

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Abstract— Selective Laser Melting (SLM) is an emerging, fast growing rapid prototyping (RP) technology due to its ability to build functional parts having complex geometrical shape in reasonable time period. The quality of built parts highly depends on many process variables in selective laser melting. In this study, three important SLM process parameters such as layer thickness, orientation angle and scan speed are considered. Their influence on tensile strength of test specimen is studied. Margining Steel having grade 1.2709 was the material, commercially named CL50WS, which is used for fabricate Tensile Specimen in SLM. The experiments are conducted based on Taguchi's L_8 orthogonal array. The validity of process parameter and response is tested by using analysis of variance (ANOVA). The multi linear regression model is developed in order to predict Tensile strength of test specimen. The experimental data and data obtained by regression equation is closely correlated which validated the models. The layer thickness and scan speed is highly affect the quality of SLM fabricated parts whereas orientation angle have little important.

Keywords: Selective Laser Melting (SLM), Rapid Prototype Technology (RPT), Taguchi Method, ANOVA, Tensile Strength and Regression Analysis

I. INTRODUCTION

Reduction of product development cycle time is a major concern in industries to remain competitive in the market place and hence, focus of industries has shifted from traditional product development Methodology to rapid fabrication techniques like rapid proto typing (RP). Selective Laser Melting (SLM) is an emerging powder based additive layer manufacturing technology that used to fabricate three-dimensional fully functional parts from metal powders by fusing the material in a layer by layer manner as per a CAD model. Selective Laser Melting (SLM) is gaining distinct advantage in manufacturing industries because of its ability to manufacture parts with complex shapes without any tooling Requirement and less human interface. Selective laser melting rapid prototype machine consist an Nd: YAG laser to melt the thin layer of powder. The laser head is attached to the x, y table controlled by a computer. A steel substrate is attached to the piston, which moves down one layer thickness of 0.05 or 0.1 mm (z direction) or as per requirement. The process is carried out in a closed chamber and argon is flushed continuously in order to minimize oxygen and nitrogen pick-up. SLM developed at the Fraunhofer Institute for Laser Technology ILT in Germany, so called basic ILT SLM.

The parts are fabricated from metal powders on a substrate so the initial step is to preheat the work surface (substrate) with help of the Nd:YAG laser after this first thin layer of powder is spread equally over the work surface. The powder on the substrate is selectively melted by energy of high intensity laser beam according to the sliced CAD model. When the laser melting of the spread layer is done the substrate plate is lowered, and new powder is deposited on top of the first layer. This new layer is selectively melted, and the layers (approximately 50µm) are metallurgic ally bonded. The final component is thus built of many single layers. At last part is removed from work. Produced parts have density about 100%, and the mechanical properties can even beat conventional manufacturing processes such as die-casting.

II. LITERATURE REVIEW

Literature reveals that properties of SLM fabricated parts are function of various process related parameters and can be significantly improved with proper adjustment. It will give the information about different optimization techniques used to process parameters optimization of SLM Machine and also suggest the main process parameters that affect the quality of SLM produced parts. It also provides the information about the different methods which are used for experimental design and prediction purpose. There are different methods of optimization of process parameter like factorial design, Taguchi method, central composite design, response surface methodology etc. From these different methods of optimization, Taguchi approach is more powerful technique. Currently high quality of the parts with low cost and in shorter time period is the demands from the users. This is the big challenge so it is necessary to optimize the process parameter of respective machines

III. METHODOLOGY

A. *Design of experiment (Taguchi method):*

Taguchi method is used for Design of Experiment. Full factorial design of experiments would require a large no. of runs; Hence Taguchi based design of experiment method was implemented. In Taguchi method Orthogonal Array provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a minimum experimental runs. Taguchi replaces the full factorial experiments with a lean, less expensive and less time consuming method concern to manufacturing.

B. Analysis Of Variance (ANOVA):

Analysis of Variance (ANOVA) is a powerful analysing tool to identify which are the most significant factors. It calculates variations about mean ANOVA results for the each response. Based on F-value (Significance factor value) important parameters can be identified. ANOVA Table obtained by MiniTab15 software. ANOVA Table contains Degree of freedom (DF), Sum of Squares (SS), Mean squares (MS), Significant Factor ratio (F-Ratio) and Probability (P).

IV. EXPERINENT

Experiment work carried out in M1 laser cusing Selective Laser Melting Machine at Indo-German Tool Room, Vatva.

Fig. 1: SLM Machine

Three important SLM process parameters such as layer thickness, orientation angle and scan speed are considered. Their influence on tensile strength of test specimen is studied. Margining Steel having grade 1.2709 was the material, commercially named CL50WS, which is used for fabricate Tensile Specimen in SLM.

Component	Indicative value (%)
Fe	Balance
C	≤ 0.03
Si	≤ 0.10
Mn	≤ 0.15
P,S	≤ 0.010
Cr	≤ 0.25
Mo	4.50 – 5.20
Ni	17.0 – 19.0
Ti	0.80 – 1.20
Co	8.50 – 10.0

Table.1 Chemical Composition

The factors and their levels used in experimental work are shown in table.2.

Process parameter	Unit	Level 1	Level 2
Layer thickness	µm	0.03	0.04
Scan speed	mm/sec	500	600
Orientation angle	degree	0	90

Table. 2: Control factors and their level

The number of experiment run is eight based on Taguchi's L_8 orthogonal array that is produced in Minitab software.

Sr. No.	Layer thickness	Scan speed	Orientation angle
1	0.03	500	0
2	0.03	500	90
5	0.03	600	0
4	0.03	600	90
3	0.04	500	0
6	0.04	500	90
7	0.04	600	0
8	0.04	600	90

Table.3: Taguchi's L_8 orthogonal array

Specimen detail

Standard test specimen for tensile test as per ASTM E 8 is designed using pro-e software. Tensile test specimens having dimensions 100 mm x 10 mm x 5mm (Length*Width*Thickness) are prepared. Now control factor listed in table 1 is set as per experimental plan shown in table 2. Total 8 numbers of tensile parts are fabricated with the same material using concept laser SLM machine. The mean of the reading of tensile strength is taken to be repetitive value.

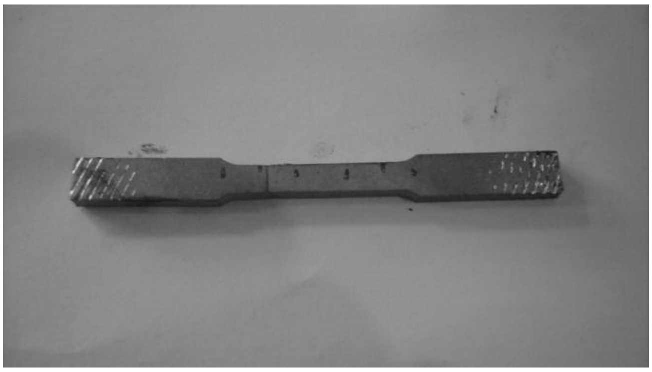

Fig. 2: Specimen for experiment

V. RESULTS AND ANALYSIS

After conducting experiment, the tensile strength of the specimens is measured at Divine Laboratory Services at Ahmedabad. The testing results are shown in table.4.

Sr. No.	Layer thickness	Scan speed	Orie. angle	Tensile Strength
1	0.03	500	0	1188
2	0.03	500	90	1176
3	0.03	600	0	1150
4	0.03	600	90	1139
5	0.04	500	0	1129
6	0.04	500	90	1122
7	0.04	600	0	1106
8	0.04	600	90	1097

Table. 4: Results of Tensile strength

The experimental Result is analyzed in Minitab Software for effect of all factors on tensile strength. Tensile strength preferred always higher is better. According to Taguchi technique Tensile strength calculated based on Higher is better. The S/N ratio is calculated based on response requirement. The analysis carried out on MINITAB 15 software.

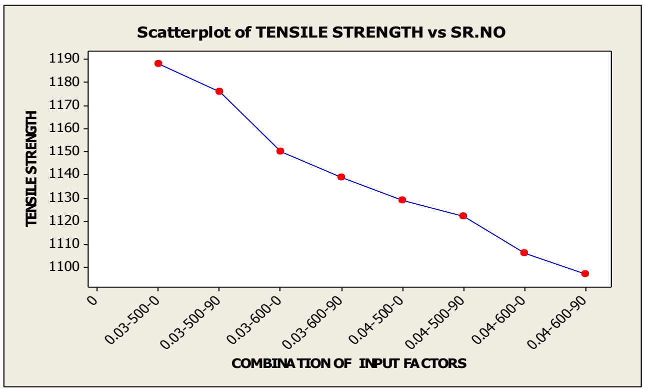

Fig. 3: Scatter plot for Tensile Strength

From above graph say that Tensile Strength is higher at lower value of layer thickness, scan speed and orientation angle. The highest result of tensile strength got from combination at 0.03 (Layer Thickness), 500 (Scan speed), 0 (Orientation Angle).

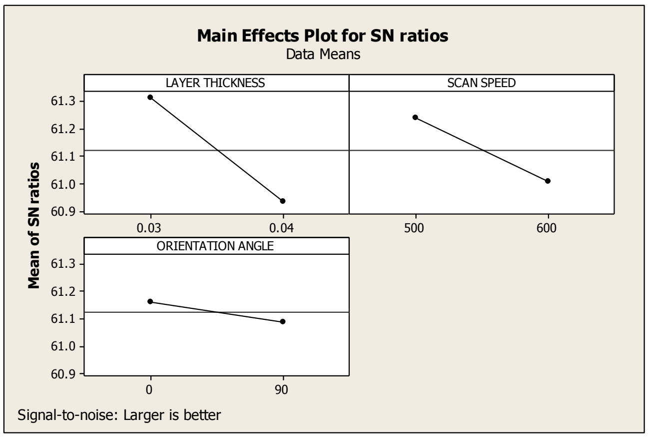

Fig. 4: Main Effect plot for SN Ratios (Tensile Strength)

From the graph we can say that tensile strength is decrease with increase in layer thickness and scan speed. It also shows that layer thickness and scan speed is highly significant factors which affect tensile strength whereas orientation angle have little importance.

Factor	df	Seq SS	Adj SS	Adj MS	F value	P (%)
A	1	4950.13	4950.13	4950.13	201	69.42
B	1	1891.12	1891.12	1891.12	76.8	26.60
C	1	190.12	190.12	190.12	7.72	2.67
Error	4	98.50	98.50	24.63	1	1.31
Total	7	7129.88				100

Table.6: ANOVA for tensile strength

The F value factor A and B is comparatively higher than Factor C, so they are significant for tensile strength.

A multiple linear regression models are developed in order to predict the values of Tensile strength of test specimen in SLM process. The developed models are reasonably accurate and can be used for prediction within limits. The regression equation for the Tensile strength was generated with the help of MINITAB 15 software is as:

Tensile Strength = 1486.5 - 4975 Layer Thickness - 0.3075 Scan Speed - 0.108333 Orien. Angle

The comparison of experimental data and regression data is shown below in table. 7.

Sr No.	Experimental Results	Regression results
1	1188	1184
2	1176	1174
3	1150	1152
4	1139	1143
5	1129	1133
6	1122	1124
7	1106	1103
8	1097	1093

Table. 7: comparison of experimental and regression data

VI. CONCLUSIONS

This paper presents analysis of various process parameters and drawn following conclusions from the Experimental study:

Tensile strength is maximum at lower level value of layer thickness, scan speed and orientation angle. The highest result of tensile strength got from combination at 0.03 (Layer Thickness), 500 (Scan speed), 0 (Orientation Angle). From the ANOVA analysis we can say that layer thickness and scan speed is most significant to performance characteristics whereas orientation angle have little importance. Experimental results and regression results are closely correlated with each other which validated the regression model developed.

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