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PARAMETRIC INVESTIGATION ON SELECTIVE LASER SINTERING PROCESS BY AHP/MOORA METHOD USING PA2200 MATERIAL

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Abstract: *The Selective Laser Sintering (SLS) is a one of the rapid prototyping (RP) technology by which physical objects are created directly from CAD model using layer by layer deposition of extruded material. SLS produces higher strength and surface finish parts. 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, Tensile Modulus, and Elongation of the test specimens will be studied. The application of Analytical hierarchy process (AHP) method and multi objective optimization on the basis of ratio analysis (MOORA) method for selecting the optimal value of output parameters of Selective laser sintering machining process. The current study reveals that the results obtained using the AHP with MOORA methods are satisfactory and it prove the applicability, and potentiality of these methods. After results, 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 Tensile Modulus decreases.*

Keywords: *Rapid Prototyping, Selective Laser Sintering (SLS), PA2200 Materials, Analytical Hierarchy process(AHP), Multi Objective Optimization on the Basis of Ratio Analysis (MOORA) Method.*

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 by 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.

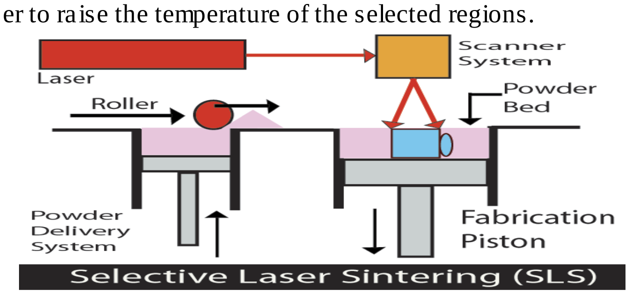

Figure 1 Working of SLS process

Now a 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

Ratandeep paul, et al. [1] published paper on “Process energy analysis & optimization in selective laser sintering”. This paper presents a mathematical analysis of the laser energy required for manufacturing simple parts using the SLS process.

B. Caulfield, et-al. [2] had published their research on “Dependence of mechanical properties of polyamide components on build parameters in the SLS process”. The present paper investigates the influence of the energy density on physical and mechanical properties of parts produced using polyamide.

R.D. Goodridge, et-al. [3] had published their research on “Laser sintering of polyamides and other polymers”. Parts built in the x-axis orientation had the highest tensile and compressive results; however y-axis had the highest flexural result.

Anish Sachdeva, et-al. [4] had published their research on “Investigating surface roughness of parts produced by SLS process”. This study investigates surface roughness (SR) of parts produced by SLS process.

Shankar Chakraborty [5] had published their research on “Applications of the MOORA method for decision making in manufacturing environment”. MOORA method to solve different decision making problems as frequently encountered in the real-time manufacturing environment.

T. Jollivet, et-al. [6] had published their research on “Rapid manufacturing of polymer parts by selective laser sintering” This article presents an analysis carried out to better understand the advantages and drawbacks of SLS for Rapid Manufacturing.

Ivan Pogarcic, et-al.[7] had published their research on “Application of AHP method in traffic planning” there are different methodologies and techniques of planning in field of traffic. The choice of technology usually depends upon business management. This paper analyses possibilities of applying AHP method in making decisions regarding planning and implementation of plans in traffic and ensuring the qualitative business logistics.

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 D638 (115mm length X 19mm 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, Tensile modulus and Elongation. Some parts made by PA2200 material is shown in below figure 3.

Figure 3 Components made by SLS process

3.2 Mechanical Properties of PA2200 material

Table 1 Mechanical Properties of PA2200 material

Tensile Modulus [N/mm^2]	1700 ± 150
Tensile Strength [N/mm^2]	45 ± 3
Elongation [%]	20 ± 5
Flexural Modulus [N/mm^2]	1240 ± 130
Izod- Impact Strength [KJ/m^2]	32.8 ± 3.4
Izod- Notch Impact Strength [KJ/m^2]	4.4 ± 0.4
Charpy - Impact Strength [KJ/m^2]	53 ± 3.8
Charpy - Notched impact Strength [KJ/m^2]	4.8 ± 0.3
Ball indentation hardness [N/mm^2]	77.6 ± 2

IV. RESULT OF EXPERIMENTS AND ANALYSIS OF RESULTS

4.1Results of Tensile testing

Tensile testing was carried out on Universal Testing Machine for measuring Tensile strength, Tensile Modulus & Elongation 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.

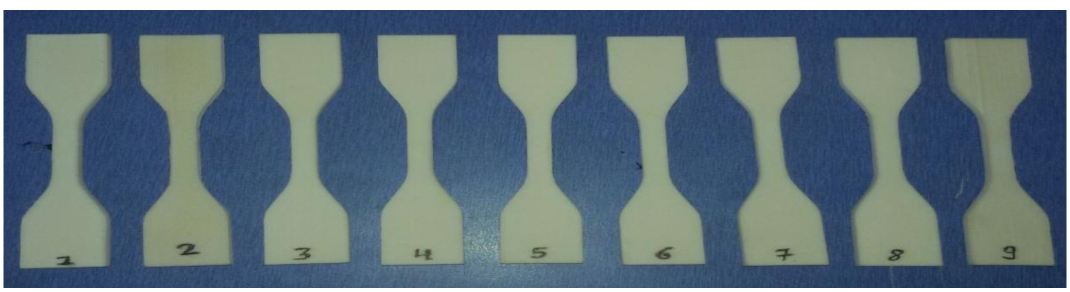

Figure 4 Tensile test Specimens

Table 2 Results of experiment

	Input parameters		Output parameters		
Part	**Layer Thickness**	**Orientation**	**Tensile Strength**	**Tensile Modulus**	**Elongation**
No.	**Micron**	**Degree**	**N/mm^2**	**N/mm^2**	**%**
1	120	30	47.702	2078	6.866
2		45	48.420	1801	6.494
3		60	41.334	1634	5.716

4.2

4	150	30	41.767	1370	10.827
5		45	40.966	1392	11.712
6		60	40.322	1557	10.249
7	180	30	42.282	1608	12.098
8		45	29.215	1236	10.944
9		60	43.412	1900	14.714

AHP/MOORA Methods

Step-1: Define the problem.

This step is associated with to define the objective and identification of all the possible alternatives and its attributes. Let A = {Ai for i = 1,2,3,…m} be a set selective laser sintering machine alternative, B = {Bj for j =1,2,3,…,n } be a set of decision criteria or attributes of Selective laser sintering machine alternative selection problem, and mij is the performance of alternative Ai when it examined with criteria Bj.

Step-2: Formulate the decision matrix.

Generally, solution of any multi attribute decision making process is start with preparation of decision matrix. In the decision matrix all the performance measure of attributes are represented into quantitative form or in numerical value (x_{ij}) as shown in fig.5.

$$X = \begin{bmatrix} X_{11} & X_{12} & . & X_{1n} \\ X_{21} & X_{22} & . & X_{2n} \\ . & . & . & . \\ X_{m1} & X_{m2} & . & X_{mn} \end{bmatrix}$$

Figure 5 Decision matrix

Step-3: Generate pair wise matrices.

A pair wise comparison matrix is constructed using a scale of relative importance as shown in Table 3. Let, there are M attributes are involved in the decision making, the pair wise comparison of attribute i with attribute j yields a square matrix A1 =M x M =[a_{ij}] M x M. Where a_{ij} denotes the comparative importance of attribute i with respect to attribute j. In the matrix, a_{ij} = 1 when i = j and a_{ji}= 1/a_{ij}.

$$A1_{MxM} = \begin{array}{c} B1 \\ B2 \\ B3 \\ \vdots \\ BM \end{array} \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1M} \\ a_{21} & 1 & a_{23} & \cdots & a_{2M} \\ a_{31} & a_{32} & 1 & \cdots & a_{3M} \\ \vdots & \vdots & \vdots & 1 & \vdots \\ a_{M1} & a_{M2} & a_{M3} & \cdots & 1 \end{bmatrix}$$

Table 3 Scale of Relative Importance

Scale	Importance	Meaning of attributes
1	Equal importance	Two attributes are equally important
3	Moderate Importance	One attribute is moderately important over the other
5	Strong Importance	One attribute is strongly important over the other
7	Very Importance	One attribute is very important over the other
9	Absolute Importance	One attribute is absolutely important over the other
2,4,6,8, compromise importance between 1,3,5,7 and 9		

Step -4: Determination of relative normalized weight.

A relative normalized weight at each level of Hierarchy structure is calculated using Equation (1) and Equation (2).

$$GM_j = \left[\prod_{j=1}^{M} a_{ij}\right]^{1/M} \quad \text{......... (1)}$$

$$W_j = \frac{GM_j}{\sum_{j=1}^{M} GM_j} \quad \text{..........(2)}$$

If the judgment matrix or comparison matrix is inconsistent then judgment should be reviewed and improved it to obtain the consistent matrix. Hence, consistency test will be carried out using following steps.

- Calculate matrices: A3 = A1 x A2 and A4 =A3/A2
  Where; A1=[aij]M×M
  A2 = [W1, W2... Wj] ^{T}
- Calculate Eigen value λmax (average of matrix A4)
  Calculate the consistency index: CI = (λmax- M) / (M - 1)
- Calculate the consistency ratio: CR = CI/RI, select value of random index(RI) according to number of attributes used in decision-making.
- If CR < 0.1, considered as acceptable decision, otherwise judgment of the analyst about the problem under study

Step-5: Find the dimensionless number or normalization value.

$$X^*_{ij} = X_{ij} \Big/ \sqrt{\sum_{i=1}^{m} X^2_{ij}} \quad \text{.........(3)}$$

Where X^*ij is a dimensionless number which belongs to the interval [0, 1] representing the normalized performance of i^{th} alternative on j^{th} attribute.

Step-6: Determine the normalized performance of alternative.

In this step, the normalized performance of alternatives is determined with considering weightage of selection criteria involved in the decision making process. For multi-objective optimization, these normalized performances are added in case of maximization (for beneficial attributes) and subtracted in case of minimization (for non beneficial attributes).

$$Y_i = \sum_{j=1}^{g} W_j X_{ij} - \sum_{j=g+1}^{n} W_j X_{ij} \qquad \text{.............(4)}$$

Where, g is the number of attributes to be maximized, (n-g) is the number of attributes to be minimized, w_j is the weight of j^{th} attribute, which can be determined applying analytic hierarchy process method as described in step3 and step 4, and y_i is the normalized performance value of i^{th} alternative with respect to all the attributes.

Step-7: Ranking and selection of alternative.

The y_i value can be positive or negative depending of the totals of its maxima (beneficial attributes) and minima (non beneficial attributes), A ranking of alternative will be carried out based on value of y_i and finally, the best alternative is considered who has the highest y_i value or ranked first while the worst alternative has the lowest y_i value or ranked last.

4.3 Illustration of Example Using AHP/MOORA Method

Step 1: A Selective Laser Sintering process parameters selection problem can be decomposed procedure described in the hierarchy structure shown in Figure 6.

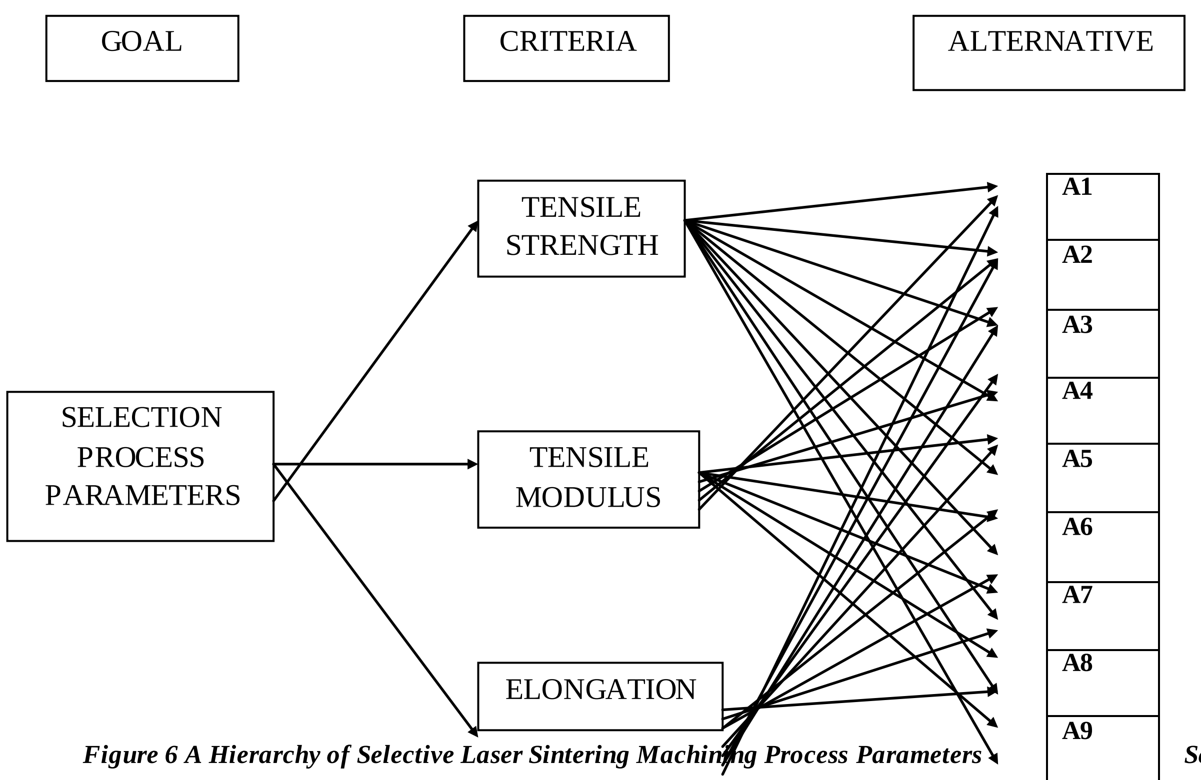

Figure 6 A Hierarchy of Selective Laser Sintering Machining Process Parameters Selection Problem

Step 2: A relative importance of between attributes is assigned with respect to the goal. The judgments are entered using Scale of Relative Importance of the AHP method as shown in Table 4.

Table 4 Pair Wise Comparison Matrix for Different Criteria

Attribute	B_1	B_2	B_3
B_1	1	2	4
B_2	1/2	1	4

B_3	1/4	1/4	1

Step 3: A relative normalized weight of attributes is calculated using Eq.1 and Eq.2 and its values are shown in the following Table 5.

Table 5 Relative Normalized Weight of Attribute

Attributes	W_i
(B1)= Tensile Strength	W_1 = 0.5469
(B2)= Tensile Modulus	W_2 = 0.3445
(B3)= Elongation	W_3= 0.1085

Step 4: Now, this step demonstration of consistency test of the taken judgment is illustrated and its calculated values are given below.

$$A_3 = A_1 \times A_2 = \begin{bmatrix} 1 & 2 & 4 \\ \frac{1}{2} & 1 & 4 \\ \frac{1}{4} & \frac{1}{4} & 1 \end{bmatrix} \times \begin{bmatrix} 0.5469 \\ 0.3445 \\ 0.1085 \end{bmatrix} = \begin{bmatrix} 1.6702 \\ 1.0521 \\ 0.3314 \end{bmatrix}$$

$$A_4 = \frac{A_3}{A_2} = \begin{bmatrix} 1.6702 \\ 1.0521 \\ 0.3314 \end{bmatrix} \div \begin{bmatrix} 0.5469 \\ 0.3445 \\ 0.1085 \end{bmatrix} = \begin{bmatrix} 3.0538 \\ 3.0537 \\ 3.0533 \end{bmatrix}$$

λmax= Average of matrix A4 = 3.0536

CI = (λmax- M) / (M-1) = (3.0536 -3)/(3-1) = 0.0536/2 = 0.2681

CR = CI /RI = 0.2681 /0.52 = 0.05
As the value of CR is less than 0.1 the judgments are acceptable.

Step 5: Here 9 (Alternatives A1Up to A9) process parameters of SLS. Table 6 shows the response process parameters of the SLS such as Tensile Strength, Tensile Modulus, Elongation.

Table 6 Decision Matrix Table

Alternative	Layer thickness (Micron)	Orientation (Degree)	Tensile strength (N/mm^2)	Tensile modulus (N/mm^2)	Elongation (%)
A1	120	30	47.702	2078	6.866
A2	120	45	48.420	1801	6.494
A3	120	60	41.334	1634	5.716
A4	150	30	41.767	1370	10.827
A5	150	45	40.966	1392	11.712
A6	150	60	40.322	1557	10.249
A7	180	30	42.282	1608	12.098
A8	180	45	29.215	1236	10.944
A9	180	60	43.412	1900	14.714

Step 6: Normalization procedure.

where X_{ij}* is a dimensionless number which belongs to the interval [0,1] representing the normalized performance of i^{th} alternative on j^{th} criteria.

Table 7 Dimensionless Numbers (xi) for Each Alternative

Alternative	Tensile Strength (N/mm^2)	Tensile Modulus (N/mm^2)	Elongation (%)
A1	0.3782	0.4224	0.2211
A2	0.3839	0.3662	0.2092
A3	0.3277	0.3322	0.1841
A4	0.3312	0.2785	0.3488
A5	0.3248	0.2830	0.3773
A6	0.3197	0.3165	0.3301
A7	0.3352	0.3269	0.3897
A8	0.2317	0.2513	0.3525
A9	0.3442	0.3863	0.4740

Step 7: Evaluation of positive and negative effects.

For optimization, these normalized performances are added in case of maximization (for beneficial criteria) and subtracted in case of minimization (for non beneficial or cost criteria) by solving the following equation:

where g is the number of criteria to be maximized, (n−g) is the number of criteria to be minimized, and yi is the normalized assessment value of i^{th} alternative with respect to all the criteria. Tensile Strength & Tensile Modulus are considered as beneficial attribute (i.e. higher values are desirable), Elongation is considered as non beneficial attribute (i.e. lower values are desirable).

Using Eq.4 the weight of each attribute i.e. WTS= 0.5469, WTM= 0.3445, WE = 0.1085. An ordinal ranking of yi shows in table 8 final preferences. Thus, the best alternative has the highest yi value, while the worst alternative has the lowest yi value.

Table 8 Weighted Assessment Values (yi) and Ranking for Selection of the Process Parameters of SLS machine

Alternative	Tensile Strength (N/mm^2)	Tensile Modulus (N/mm^2)	Elongation (%)	yi	Rank
A1	0.2068	0.1455	0.0239	0.3284	1
A2	0.2099	0.1261	0.0226	0.3134	2
A3	0.1792	0.1144	0.0199	0.2737	3
A4	0.1811	0.0959	0.0378	0.2392	7
A5	0.1776	0.0974	0.0409	0.2341	8
A6	0.1748	0.1090	0.0358	0.2480	6
A7	0.1833	0.1126	0.0422	0.2537	5
A8	0.1267	0.0865	0.0382	0.1750	9
A9	0.1882	0.1330	0.0514	0.2698	4

V. CONCLUSION AND FUTURE SCOPE OF WORK

5.1 Conclusion

Selective laser sintering is more promising method of Rapid Prototyping Technology (RPT). 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 Tensile Modulus. 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 120 microns is better value than rest of two.

5.1.2 Orientation

From obtained results, it can be clearly defined that by increasing orientation so Tensile strength, Tensile Modulus reduced. 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 30 degree is best value for Tensile strength &Tensile Modulus.

- For getting better value of output parameters best value of layer thickness is 120 microns and orientation is 30 degree.
- It has been observed that AHP/MOORA method is very simple, stable and robust. It requires minimum Mathematical calculations and computational time.

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, Laser beam diameter, Energy density, hatching distance, Laser speed, Speed of roller, bed temperature 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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