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The Multi-objective Optimization for the SLS Process Parameters Based on Analytic Hierarchy Process

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***Abstract*—**The forming process parameters of Selective Laser Sintering(SLS) directly affect the forming efficiency and forming quality. Therefore, to determine reasonable process parameters is particularly important. In this paper, the weight of each target of the forming quality and efficiency is firstly calculated with the Analytic Hierarchy Process. And then the size of each target is measured by orthogonal experiment. Finally, the sum of the product of each target with the weight is compared to the process parameters in each group and obtained the optimal molding process parameters.

***Keywords*—**Analytic Hierarchy Process, Multi-objective optimization, Orthogonal test, Selective Laser Sintering

I. INTRODUCTION

IN recent years, selective laser sintering (SLS) technology has been successfully used for manufacturing coated sand casting mold [1]. The strength and dimensional accuracy of sand molds are the main performance index in sand casting. But up to now, the process parameters using SLS to make sand mold has been determined by experience and feeling. Therefore, it is necessary to optimize for these process parameters.

II. SELECTIVE LASER SINTERING BASED ON COATED RESIN SAND

A. Coated Resin Sand

The coated resin sands used in SLS are syntheses that use the high-quality selected natural quartz as the raw sands, thermoplastic phenolic resin as film, urotropine and reinforcing agent as raw materials. The resin sands used in this test are ZFS-JND coated sand made by Beijing Renchuang Technology Group. The particles morphology of coated resin sand is shown in Fig. 1. The size distribution graph is shown in Fig.2. And the basic proportion of coated resin sand is shown in table I.

B. The Sintering Mechanism of Coated Resin Sand

In the SLS process, the laser energy melts the phenolic resin out of the coated resin sand, phenolic resin bonds the resin sand in the cooling process. Laser scans and sinters layer by layer, a layer bonds a layer, and the final parts are formed [2]-[8]. In generally, the strength of "green" made by SLS is very low (tensile strength 1-2Mp). Therefore, the after curing process is necessary to improve the strength.

Fig.1 The morphology of resin coated sand

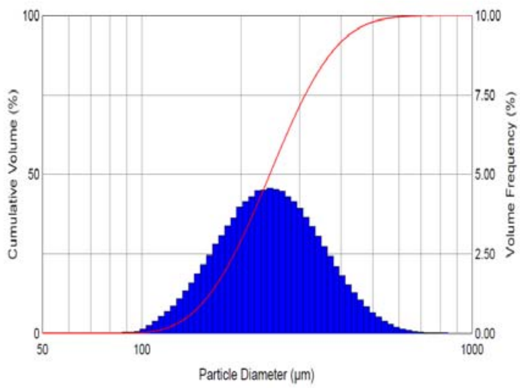

Fig.2 ZFS-JND particle size distribution of the coated

TABLE I
BASIC RATIO OF THE COATED SAND

INGREDIENT	MASS RATIO	EXPLANATION
Raw Sand	100	Scrub sand
Phenolic Resin	1.0-3.0	% Of sand weight
Methenamine	10-15	% Of resin weight
Calcium Stearate	5-7	% Of resin weight
Additive	0.1	% Of sand weight

III. OPTIMIZATION METHOD

The Analytic Hierarchy Process (AHP) is used to multi-objective optimize for SLS molding process parameters in this paper. The AHP is proposed by a professor of University

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of Pittsburgh. It is a multi-attribute decision analysis method combined qualitative with quantitative. And its character is to become the judge of the decision-makers by experience to quantify. This method is more practical under the case of the complex structure target (factor) and lack of data. In the AHP, many factors are gradually combined with personal factors of decision-makers through the establishment of pair wise comparison judgment matrix, logical thinking is done, and then it is expressed in quantitative form [3].

IV. The Multi-Objective Optimization for SLS

A. Calculation of the Target Weight for the Forming Parts

Besides the material properties of the coated resin sand, the main process factors, such as laser power, scanning speed, layered thick and scan spacing affect on SLS molding quality. The reasonable parameters for the target layer is set[4]-[5]. Molding quality is characterized by the strength, precision and warp deformation of the molded parts. Forming efficiency is reflected by the production time. So, set the strength, accuracy, warpage and production time as a criterion level; set the laser power, scanning speed, the thickness of stratification and scan spacing as program layer[6]-[7], shown in Fig. 3.

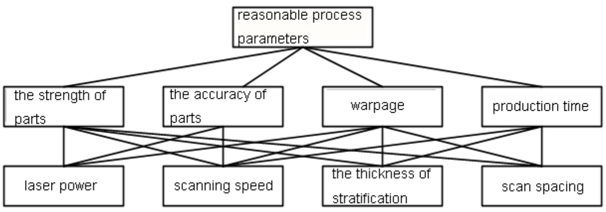

Fig.3 The Hierarchy of a reasonable process parameters

According to the effect of process parameters on the forming quality, strength, accuracy, warpage and the production time, we obtain the judgment matrix G for target layer on rule layer, and the judgment matrix C for the various factors of rule layer on the program layer depending on the distribution in Figure 3., such as the matrix (1) - (5)

$$G=\begin{pmatrix} 1 & 2 & 2 & 3 \\ 1/2 & 1 & 1 & 2 \\ 1/2 & 1 & 1 & 2 \\ 1/3 & 1/2 & 1/2 & 1 \end{pmatrix} \quad (1)$$

$$C_1=\begin{pmatrix} 1 & 1 & 1/2 & 1/2 \\ 1 & 1 & 1/2 & 1/2 \\ 2 & 2 & 1 & 1 \\ 2 & 2 & 1 & 1 \end{pmatrix} \quad (2)$$

$$C_2=\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \quad (3)$$

$$C_3=\begin{pmatrix} 1 & 1 & 1/3 & 1/2 \\ 1 & 1 & 1/3 & 1/2 \\ 3 & 3 & 1 & 2 \\ 2 & 2 & 1/2 & 1 \end{pmatrix} \quad (4)$$

$$C_4=\begin{pmatrix} 1 & 1/3 & 1/2 \\ 3 & 1 & 2 \\ 2 & 1/2 & 1 \end{pmatrix} \quad (5)$$

Then the right weight of the target layer on the rule layer, rule layer on the layer of the program, respectively, is

$$X=(0.4236,0.2270,0.2270,0.1223)^T \quad (6)$$

$$X_1=(0.3750,0.1250,0.2500,0.2500)^T \quad (7)$$

$$X_2=(0.5,0.5)^T \quad (8)$$

$$X_3=(0.1409,0.1409,0.4554,0.2628)^T \quad (9)$$

$$X_4=(0.1634,0.5396,0.2970)^T \quad (10)$$

Supported

$$B=\begin{pmatrix} 0.3750 & 0.1250 & 0.2500 & 0.2500 \\ 0.5000 & 0.5000 & 0 & 0 \\ 0.1409 & 0.1409 & 0.4554 & 0.2628 \\ 0 & 0.1643 & 0.5396 & 0.2970 \end{pmatrix} \quad (11)$$

So the right weight of the target layer on the layer of the program is,

$$W=X^TB=(0.3043,0.2184,0.2753,0.2019) \quad (12)$$

Consistency of the test shows that it meets the inspection requirements of the AHP. Then the right weight of the laser power, scanning speed, slice thickness and scan spacing for the program layer on the target layer, respectively, is: $\lambda 1=0.3043$, $\lambda_2=0.2184$, $\lambda_3=0.2753$, $\lambda_4=0.2019$。

B. Design of Orthogonal Test

The process parameters affected on molding quality and forming efficiency are mainly laser power, scanning speed, layer thickness and scan spacing. The reasonable choice of molding process parameters can not only guarantee the quality of the molded parts, but also can improve processing efficiency. Here we use the orthogonal table with four factors and three levels to study the impact on the quality and efficiency of parts. The following table II shows the orthogonal table of four process parameters.

TABLE II
ORTHOGONALTABLE WITH FOUR FACTORS AND THREE LEVELS

Test No.	Laser Power (W)	Scanning Speed. (mm/s)	Layer Thickness (mm)	Scan Spacing (mm)
1	35	2500	0.25	0.2
2	35	3000	0.27	0.25
3	35	3500	0.3	0.3
4	40	2500	0.27	0.3
5	40	3000	0.3	0.2
6	40	3500	0.25	0.25
7	45	2500	0.3	0.25
8	45	3000	0.25	0.3
9	45	3500	0.27	0.2

C. Definition of Optimized Routes

In order to consider the impact of the four targets, weighted comparison is done for each target of each group achieved by experiment, and then an optimal set of process parameters are select through the comparison of the size of the sum of the target weighted in each group. Optimizing the target value is:

$$Q = \lambda_1 P + \lambda_2 A + \lambda_3 \mathrm{L} + \lambda_4 \mathrm{T} \qquad (13)$$

V. EXPERIMENTS AND OPTIMIZATION

A. The Experimental Platform

The experimental machine is the SLS rapid prototyping machine which was jointly developed by Shaanxi Hengtong Intelligent Co., Ltd. and the Advanced Manufacturing Institute of Xi'an Jiaotong University.

B. The Experimental Data

In order to test the strength, accuracy, warpage and production time of the specimens under the set of process parameters, we made respectively the strength specimens, the accuracy specimens, warpage specimens and record production time specimens. Fig. 4 and Fig. 5 are the strength specimens accuracy specimens and warpage specimens.

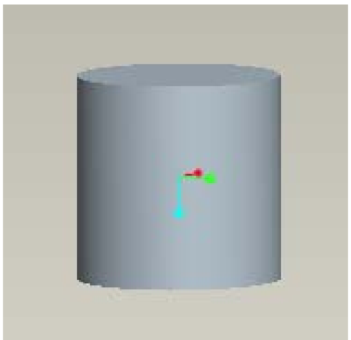

Fig. 4 The compressive strength specimens

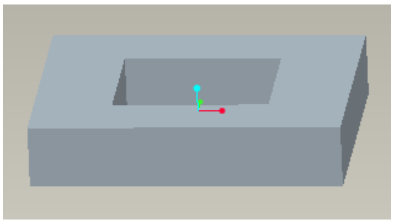

Fig.5 The accuracy specimens and warpage specimens

The compressive strength test was done in the universal testing machine made by INSTRON (USA). The test data is shown in Table III.

TABLE III
THE RESULTS OF THE STRENGTH AND PRODUCTION TIME FOR THE SAMPLE No. 1-9

SAMPLE	1	2	3	4	5	6	7	8	9
Load (kN)	5.45	2.53	1.03	2.51	4.14	2.59	4.14	2.11	3.08
Production Time (min)	170	130	108	130	125	140	125	133	133

For the errors in the XY direction, we firstly take the five positions in the XY directions respectively, measure the errors of the five positions in the XY directions respectively, and then compare them, the maximum value are the error in the XY directions under the set of parameters. For the war page in the Z direction, we firstly measure the warpage value of the highest point and lowest point, and the take the difference as the warpage under the set of parameters. The size error in the XY direction and the warpage amount in the Z direction of the sample are shown in Table IV.

TABLE IV
THE RESULTS OF THE ERRORS IN XY DIRECTION AND WARPAGE DEFORMATION IN THE Z DIRECTION FOR SAMPLE No. 1-9

SAMPLE	1	2	3	4	5	6	7	8	9
Error in XY	031	026	040	0415	0385	0285	0215	0225	0345
Warpage in Z	2.30	1.50	0.54	1.64	2.0	1.58	1.76	1.22	1.06

C. Experimental Results

In order to conveniently compare the four targets, we take the optimal value of in each target as 1, the value of the rest is calculated by comparing the ratio of the optimal value and the rest value. The following table 5 shows the intensity (P), , accuracy (A), warpage (L), the production time (T) and the optimization target value (Q) for the sample1-9. By calculating according to formula (2)-(13), the Q value is obtained. The results are shown in Table V.

TABLE V
THE RESULTS OF FOUR TARGET AND OPTIMIZATION FOR THE SAMPLE No. 1-9

SAMPLE NO.	STRENGTH	ACCURACY	WARPAGE	PRODUCTION TIME	OPTIMIZATION TARGET
1	1.0000	0.6935	0.2348	0.6827	0.6487
2	0.4642	0.8269	0.3600	0.8308	0.5887
3	0.1890	0.5375	1.0000	1.0000	0.6521
4	0.4606	0.5181	0.3293	0.8308	0.5117
5	0.7596	0.5584	0.2700	0.8640	0.6019
6	0.4752	0.7544	0.3418	0.7714	0.5592
7	0.7596	1.0000	0.3068	0.8640	0.7085
8	0.3872	0.9556	0.4426	0.8120	0.6123
9	0.5651	0.6232	0.5094	0.8120	0.6123

D. Analysis For Results

It can be seen from the table above, the optimization target value Q is biggest for the sample 7. So we determine that the process parameter for sample 7 is the optimal set of processing parameters on these 9 groups.

VI. CONCLUSION

In this paper, the process parameters for SLS were optimized with a method of combining the AHP and orthogonal. And the following conclusions are obtained:

It is simple, reliable and practical to use the method of the combining the analytic hierarchy process with orthogonal test to optimize for SLS process parameters.

The optimal process parameters for SLS molding were obtained by experiment and analysis: laser power is 45W, scanning speed is 2500 mm/s, layer thickness is 0.3 mm and scan spacing is 0.25 mm.

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