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# Study on Curve of Pe-heating Temperature Control in Selective Laser Sintering

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***Abstract*—Through selective laser sintering PSB powers, the influence of temperature control in SLS process on precision of sinter products was studied by orthogonal experiments and variance analysis means. The results show that the influence of pre-heating temperature of differ process on precision of products is different. The influence of pre-heat temperature before sintering first layer on warping degree is bigger, and the influence of beforehand warm temperature before sintering last layer on difference size between sample two end is bigger. The better curve of temperature control is first temperature of pre-heat phase($T_A$)is 85℃,and pre-heat temperature before sintering first layer ($T_B$)is 105℃,and pre-heat temperature before sintering last layer ($T_C$)is 85℃.**

***Index Terms*—selective laser sintering, pre-heating, curve of temperature control, precision**

## I. Introduction

Any complex parts can be quickly created by selective laser sintering （SLS）, which is a method to control the laser beam sintering, curing, and superimposing, point by point, line by line, layer by layer. In the process of SLS process, control system controls the laser beam to sinter a layer of powder; job piston shift to next layer after completion of previous layer, at the same time, powder paving system paves a new layer of powder. Because of lower density of powder layer, the parts shrink excessively, which lead to lower precision is in making parts. This is the bottleneck of SLS. In order to get higher precision, processing technology of SLS must be manipulation reasonably. Powder preheating is a very important process for improving the precision in SLS, which can decrease the temperature differences between sintering zone and non-sintering zone, elimination of thermal stress avoiding distortion. At present, few studies have been done in preheating temperature, constant preheating temperature results in low precision of molding parts or waste of energy and materials. Therefore, it is necessary to study the effects of preheating on the SLS molding, and develop a gradual changed preheating temperature in accordance with different stages of processing.

## II. Precision Analysis of Parts

Using precision-guided laser beam, SLS molding can make materials powder solidify after melted. Although the gap between the powders is propitious to the transmission of laser, with the increase of depth, energy inevitably attenuates. Reference [1] In each sintering layer, there obtains different energy in different depth. The energy of upper part was great, the energy of lower part was low, and there generates a thermal stress between upper and lower part. with heat transfer of air convection, the upper part cooled quickly, and then contracted largely. Reference [2]The lower part cooled slowly and shrank little because of thermal conductivity with powder bed. In this way, there generates a residual strength, and parts have a warping for the combined effect of thermal stress and residual stress.

During the molding, the biggest contraction layer is first layer. When sintering the second layer, in order to connect the first layer, second layer is bound to be burn through, and first layer melted a part also. Reference [3]Then, un-melted part of the first layer will treated as a support to retard the contraction of second layer. This retard to shrinkage was greater than the support or gridding. So, the contraction of second layer is small than the first layer, and the size is bigger. Thus, each layer will retard the contraction of subsequent layer, and the retard is bigger and bigger. With the Z-axis increase in size, the size of X, Y-axis gradually increased also, the shape of parts changes, because the amount of shrinkage is different at different sintered layers, the error will eventually affected the contour of parts. For example, a CAD model sample with rectangular cross-section will become a trapezoidal cross-section, as shown in Fig. 1.

Fig.1. Graph of sample distortion

Presently, most study focus on the contraction of parts size. The technique of improving parts' precision is mainly through the development of a reasonable contraction compensation coefficient. Few studies are concerned the precision of parts shape itself. It is difficult to improve the precision rate through contraction compensation. In the experiment, we found that precision of parts shape is mainly affected by distortion and section size error.

Pivotal achievement of this article is to discuss the warping and sample size variance at both ends affected by the preheating temperature curve. In this experiment, we use the temperature control system produced by Beijing Longyuan Co., Ltd. to control the preheating temperature. Three key parameters in the temperature curve are studied, the initial temperature in stage of preheating($T_A$), the preheating temperature in sintering the first layer of sample ($T_B$), and the preheating temperature in sintering the last layer of sample ($T_C$), as shown in Fig. 2.

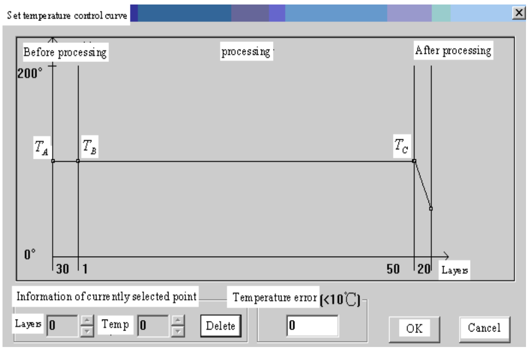


Fig.2. Graph of Temperature control

## III. EXPERIMENTAL METHODS

### *A. Experimental materials and equipment*

PSB powder developed by Beijing Longyuan Co., Ltd. are used as experiment Materials, AFS-320 machine (50W maximum output power) is employed as experiment equipment.

### *B. Experimental sample design*

A cuboid sample (40×20×10mm) is test in this experiment, and $C_f$ is the warping degree of sample, L is the variance of size.

$$C_f = \delta_1 - \frac{\delta_2 + \delta_3}{2} \quad (1)$$

$$L = L_1 - L_2 \quad (2)$$

$\delta_1$ is the central thickness of the sample, $\delta_2$ and $\delta_3$ are the thickness of the sample at both ends, as shown in Fig. 3. $L_1$ is the length of upper section; $L_2$ is the length of underside section, as shown in Fig. 4.

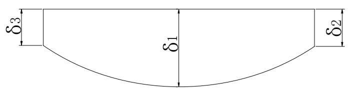


Fig.3. sketch map of sample warp

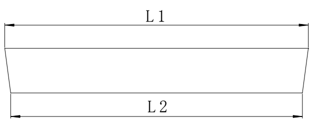


Fig.4. sketch map of difference size of sample two end

### *C. Orthogonal experimental design*

In the circumstances of sintering process parameters for laser power 15w, scanning speed1.4mm/s, and slice thickness 0.15 mm, L9($3^4$) orthogonal pilot for three key parameters, $T_A$, $T_B$, $T_C$ is shown in tableⅠ. Results of orthogonal experiments is shown in table Ⅱ.

TABLE I. VALUES OF FACTOR AND LEVEL USED IN ORTHOGONAL DESIGN

| NO. | TA (℃) | TB (℃) | TC (℃) |
|---|---|---|---|
| 1 | 85 | 85 | 85 |
| 2 | 95 | 95 | 95 |
| 3 | 105 | 105 | 105 |

TABLE II. RESULTS OF ORTHOGONAL EXPERIMENTS

| No. | parameters | | | | $C_f$ (mm) | L(mm) |
|---|---|---|---|---|---|---|
| | $T_A$ (℃) | $T_B$ (℃) | $T_C$ (℃) | error | | |
| 1 | 85 | 85 | 85 | 1 | 0.34 | 0.35 |
| 2 | 85 | 95 | 95 | 2 | 0.09 | 0.55 |
| 3 | 85 | 105 | 105 | 3 | 0.04 | 0.61 |
| 4 | 95 | 85 | 95 | 3 | 0.31 | 0.54 |
| 5 | 95 | 95 | 105 | 1 | 0.03 | 0.91 |
| 6 | 95 | 105 | 85 | 2 | 0.01 | 0.25 |
| 7 | 105 | 85 | 105 | 2 | 0.18 | 0.91 |
| 8 | 105 | 95 | 85 | 3 | 0.08 | 0.37 |
| 9 | 105 | 105 | 95 | 1 | 0.01 | 0.30 |

### *D. Variance analysis of Orthogonal pilot*

Variance analysis for warping degree shown as table Ⅲ (F0.01 (2, 2)=99, F0.05 (2, 2)=19).

TABLE III. VARIANCE ANALYSIS OF WARPING DEGREE

| | $T_A$ (℃) | $T_B$ (℃) | $T_C$ (℃) | error | $C_f$ |
|---|---|---|---|---|---|
| M1 | 17.6 | 29.6 | 15.9 | | T= 1.09 |
| M2 | 11 | 7 | 14 | | |
| M3 | 9 | 2 | 8 | | |
| K1 | 52.7 | 88.7 | 47.7 | | |
| K2 | 34 | 20 | 41 | | |
| K3 | 27 | 5 | 25 | | |
| R | 8.6 | 27.6 | 7.9 | | |
| Sj | 0.0234 | 0.1444 | 0.0207 | 0.0039 | |
| DOF | 2 | 2 | 2 | 2 | |
| Mean square | 0.0117 | 0.0722 | 0.0104 | 0.0020 | |
| F | 6 | 37 | 5 | | |
| significance | | * | | | |

From the compare of F values and the critical value, factor B is the significant factors. By comparison of significance, we can find $F_B > F_A > F_C$, that is to say, the significance sequence of each factors is TC, TB, and TA. By comparing the size of K values, we can conclude that optimal preheating temperature for better intensity is $T_A3$, $T_B3$, $T_C3$, That is, the initial stage of preheating temperature is 105 ℃, preheating temperature of sintering sample in first layer is 105 ℃, and preheating temperature of sample in last layer is 105 ℃.

Variance analysis for difference in dimension shown as table IV (F0.01 (2,2)=99, F0.05 (2,2)=19, F0.1(2,2)=9)

TABLE IV. VARIANCE ANALYSIS OF DIFFERENCE DIMENSION

| | TA (℃) | TB (℃) | TC (℃) | error | L |
|---|---|---|---|---|---|
| M1 | 0.50 | 0.60 | 0.32 | | T=4.79 |
| M2 | 0.57 | 0.61 | 0.46 | | |
| M3 | 0.53 | 0.39 | 0.81 | | |
| K1 | 1.51 | 1.8 | 0.97 | | |
| K2 | 1.7 | 1.83 | 1.39 | | |
| K3 | 1.58 | 1.16 | 2.43 | | |
| R | 0.7 | 0.22 | 0.49 | | |
| Sj | 0.0062 | 0.0955 | 0.3767 | 0.0067 | |
| DOF | 2 | 2 | 2 | 2 | |
| Mean square | 0.0031 | 0.0478 | 0.1884 | 0.0034 | |
| F | 0.9118 | 14.0588 | 50.4 | | |
| significance | | (*) | * | | |

From the compare of F values and the critical value, factor C is the significant factors. By comparison of significance, we can find $F_C > F_B > F_A$. By comparing the size of K values, we can conclude that optimal preheating temperature for accurate Shape is A1B3C1. That is, the initial stage of preheating temperature is 85℃, preheating temperature of sintering sample in first layer is 105 ℃, and preheating temperature of sintering sample in last layer is 85 ℃.

## IV. ANALYSIS AND DISCUSS

We can conclude from the results of variance analysis that impact, preheating temperature on the warping degrees and shape errors, are inconsistent at different stages.

### A. The effect of $T_A$ on the precision

Initial preheating temperature plays its role before the molding in SLS processing. After preheating in higher temperature for a long time, the temperature of powder bed arise , powder in the lower part obtains thermal radiation by powder bed, which can reduce temperature difference and warping degree to some extent. But preheating temperature in the initial stage had little impact on the precision. From the point of energy conservation, temperature at A point should give priority to the size difference, that is, to choose 85 ℃.

Generally, before the sintering, polymer powder should be evenly preheated 1 hour. We can get better result when we use the preheating temperature control software. We preheated each layer of powder by spread powder layer by layer while heating. The first stage of preheating can be defined as 30-storey powder. After half-hour's heating, requirements can be met well.

### B. The effect of $T_B$ on the precision

Reference [4] In the process of SLS, because of material compensation and restriction between layers, there exists a decreases trend of warp. For general polymer materials, preheating temperature must be 5~10℃ lower than glass transition temperature. PSB powder glass transition temperature is to 100 ℃, sample warped seriously in 95℃. Therefore, for PSB powder, only the preheating temperature is higher than glass transition temperature of itself, PSB powder showed soft and flexible high-elastic state. At the same time, powder's density increased, sintering shrinkage stress decreased, and warping degree decreased.

As for shape error, optimal temperature of $T_B$ is 105℃. In this temperature, the powder around sample sintered together by laser, which makes sample bigger in first layer and diminishes the size difference between upper and lower surfaces.

### C. The effect of $T_C$ on the precision

After completing the sample processing, we still need to warm-up powder bed in order to avoid deformation because of cold. The preheating temperature using 85 ℃ in the processing of the final layer, in which powder around sample can be avoided melting together with the sample because of the high preheating temperature, thus ensuring the accuracy of the sample, reducing the sample size difference between upper and lower surfaces.

Therefore, a better preheat temperature curve for selective laser sintering is 85-105-85℃. By using this preheat temperature curve, no significant deformation of the sample occurred, and get a better accuracy. As shown in Figure 5.

Fig.5. Graph of sample

## V. CONCLUSIONS

Increase of preheating temperature can effectively eliminated the warping in SLS. At preheat temperature of 105 ℃, warping degree is 0, and it is easy to clean-up because powder agglomeration around sample was not obvious. In high-low preheating temperature sequence, the size error of sample between upper and lower surfaces can be reduced. Preheating temperature curve of 85-105-85 ℃ is better.

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