Study of the Optimization of Laser Stereo Forming Process Based on the Orthogonal Experiment

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Abstract. Based on the problem that the supply of equipment spare parts on the battlefield is not timely, this paper studies the laser stereo forming technology. Combined with the characteristics of battlefield repair, 316L stainless steel is used as the printing material, based on the orthogonal experiment method, and the tensile properties are used as the evaluation index to optimize the process parameters. The results show that the optimal process parameters are as follows: the laser power is 400W, the scanning speed is 700mm/min and the powder feeding rate is 1.6rpm. The degree of the influence on the tensile properties is as follows: the powder feeding rate > the laser power > the scanning speed, the range of the laser power and scanning speed is almost the same, and the powder feeding rate is the most important factor.

1. Introduction

With the rapid development of the 3D printing technology, it has been applied in more and more fields due to its advantages such as the short production cycle, no waste of the materials, and the ability of manufacturing the complex components. The laser stereo forming technology has a good application prospect in the field of the weapon equipment support as the 3D printing technology for medium metals. Applying this technology, only the printing materials are needed to prepare and the 3D model of the parts is transferred to print directly when needed. The laser stereo forming provides a new model and a new way for supplying of the equipment and improving the capabilities of the battlefield equipment in wartime.

At present, most of the materials studied using in the laser stereo forming are mainly aerospace materials such as titanium alloys and nickel-based alloys, which are expensive and not suitable for the rapid manufacturing equipment. Considering the physical and chemical properties, the mechanical properties, the environmental factors and the economic parameters, the 316L stainless steel is selected as the printing material in this paper. Based on the orthogonal experimental method, the tensile properties under different process parameters are tested, and the process parameters are optimized by the intuitive analysis and the variance analysis.
2. Experimental Materials and Methods

2.1. Experimental Materials
The 316L stainless steel is selected as the experimental material, and the elemental composition of this material is shown in Table 1. The size of the powder has a great impact on the printing parts. The powder with small particles is easy to stick together, because of the poor fluidity, it is not easy to be transported uniformly and continuously. While the powder with larger particles has relatively better fluidity, which is convenient to be transported, but the much larger particles affect the accuracy of the printed parts. Based on the above considerations, the particles size of the 316L stainless steel powder used in this experiment is -150/360 mesh, and the 316L stainless steel is also selected as the matrix material.

![Table 1. The composition of 316L stainless steel](image)

2.2. Experimental Methods
Orthogonal Design is a highly efficient experimental design method that rationally analyzes the multi-factor experiments and seeks the optimal level combination. The orthogonal test design replaces the comprehensive test with the partial representative test, which can know the comprehensive experiment from the less representative test results, obtaining the degree of influence and the optimal parameters.

The idea of orthogonal experiment is to use the partial representative experiment instead of the comprehensive experiment, which cannot be possible to analyze the effects and interactions of various factors as the comprehensive experiment does. When there is an obvious interaction between the factors, there may be a mixture of interactions. On the basis of a small number of experiments, the fairness and justice of the experiments should be reflected as much as possible, which needs a reasonable arrangement for the experiments.

The main factors affecting the properties of the laser cladding layer of the automatic powder feeding include: the laser power, the spot diameter, the scanning speed, the powder feeding rate, the defocusing amount and the gas flow rate, etc. In this experiment a fixed 1mm spot is used, and the defocusing amount and the gas flow rate are also the fixed parameters. So only the changes of the three parameters of the laser power, the scanning speed, and the powder feeding rate are considered. Based on the previous experimental experience, the range of laser power variation is set for 400 ~ 700 W, the scanning speed is 400 ~ 700 mm/min, and the powder feeding rate is 1.0-1.9 RPM. Within this range, the experiment parameters are selected, and the number of tests is considered to be excessive. The orthogonal experiment with five factors and four levels is designed, two factors of which are set to empty columns, the number of experiments is 16 for L16 (45). The data for the orthogonal experiment is shown in Table 2.

![Table 2. Technological parameters](image)

3. Experimental Results and Discussion.

3.1. Analysis of Experimental Results
With the laser power, the scanning speed and the powder feeding rate as the parameters and the tensile strength as index, the results of the tensile strength obtained by 16 orthogonal experiments are shown in Table 4-4. It can be seen from the results that the maximum strength is 667 MPa, the minimum strength is 563 MPa, the average value is 625 MPa. And the tensile properties can reach the 480 MPa standard
of 316L stainless steel parts, which is higher than that of conventional 316L stainless steel parts. It can be concluded that the tensile properties of dense metal parts directly formed by metal 3D printing meet certain requirements.

3.2. Intuitive Analysis Method

Intuitive analysis method, also known as the range analysis method, is the most commonly used method for analyzing the results of orthogonal experiments. This method is simple and easy to operate. By summing and analyzing each level of a single column, the optimal test results can be obtained. Through the range analysis of different columns’ levels, the influence order of each factor on the test results can be obtained. At the same time, the trend of the factor’s level is drawn to get the influence trend of each level on the factor, which more intuitively show the optimization situation.

### Table 3. The results of the orthogonal experiment

| No. | Laser power | Scanning speed | Powder feeding | Tensile Strength |
|-----|-------------|----------------|----------------|-----------------|
| 1   | 400         | 400            | 1.0            | 634             |
| 2   | 400         | 500            | 1.3            | 636             |
| 3   | 400         | 600            | 1.6            | 637             |
| 4   | 400         | 700            | 1.9            | 640             |
| 5   | 500         | 400            | 1.3            | 630             |
| 6   | 500         | 500            | 1.0            | 624             |
| 7   | 500         | 600            | 1.9            | 614             |
| 8   | 500         | 700            | 1.6            | 637             |
| 9   | 600         | 400            | 1.6            | 667             |
| 10  | 600         | 500            | 1.9            | 573             |
| 11  | 600         | 600            | 1.0            | 636             |
| 12  | 600         | 700            | 1.3            | 620             |
| 13  | 700         | 400            | 1.9            | 563             |
| 14  | 700         | 500            | 1.6            | 641             |
| 15  | 700         | 600            | 1.3            | 619             |
| 16  | 700         | 700            | 1.0            | 629             |

The range analysis of the above results shows that the greater the range, the greater the influence on the test index when the level of this factor changes. The column with the greatest range has the greatest influence on the test index when the level of that factor changes. So tables 4-5 are given.

### Table 4. Results of range analysis

| K1  | 2547 | 2394 | 2523 |
|-----|------|------|------|
| K2  | 2505 | 2474 | 2505 |
| K3  | 2496 | 2506 | 2582 |
| K4  | 2352 | 2526 | 2290 |
| k1  | 636.75 | 598.5 | 630.75 |
| k2  | 626.25 | 618.5 | 626.25 |
| k3  | 624 | 626.5 | 645.5 |
| k4  | 588 | 631.5 | 572.5 |
| R   | 36 | 33 | 73 |

The factor level trend graph is obtained from the analysis of range results, as shown in Figure 1. It can be seen that the degree of influence on the tensile properties is: powder feeding rate > laser power >
scanning speed, the laser power is almost the same as the scanning speed. The powder feeding rate is the most important factor to be considered because the tensile strength belongs to the benefit index, the bigger the better. So it needs to take the maximum value from K value. For factor A: A1 > A2 > A3 > A4, for factor B: B4 > B3 > B2 > B1, and for factor C: C3 > C1 > C2 > C4. Therefore, the optimum process parameter is A1B4C3, that is, laser power is 400 W, scanning speed is 700 mm/min and powder feeding rate is 1.6 RPM.

4. Conclusion
In this paper, the mechanical properties of the laser forming parts are analyzed by orthogonal experiment, and the optimal process parameters and the effects of different processes on the mechanical properties are obtained. The optimal process parameters are A1B4C3, that is, the laser power is 400 W, the scanning speed is 700 mm/min, and the powder feeding rate is 1.6 RPM. The degree of influence on the tensile properties is: powder feeding rate > laser power > scanning speed. The laser power is almost the same as the scanning speed. The powder feeding rate is the most important factor affecting the tensile properties.

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