Study of the Process Parameters of the Laser Stereo Forming on Forming Quality

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Abstract. Based on the supply problem of the equipment spare parts in the poor timeliness and the low accuracy during the wartime, this paper studies applying the laser stereo forming technology in the weapon parts for the supply. The 316L stainless steel is selected as the printing material in the experiment. And based on the control variable method, it takes the three major parameters of the laser power, the scanning speed and the powder feeding rate as variables to study the influence on the rule and mechanism of the processing parameters on macro forming quality. The results show that the height decreases with the increase of the laser power and the scanning speed, and the height increases with the increase of the powder feeding rate. The width is basically unchanged, which is mainly affected by the size of the spot.

1. Introduction
The laser stereo forming technology has been widely researched and developed since the 1980s. It is a new high technology that has been developed from the rapid prototyping technology and the laser cladding technology, which can rapidly make the rapid prototyping of dense metal parts without models become a reality. At present the laser stereo forming technology is widely used in the aerospace field. The research is mostly focused on using the expensive titanium alloy materials, with which the printed products have good performance and can meet certain application requirements.

For the emergency manufacturing of spare parts, it is necessary to consider the economy of produced spare parts as well as it’s the performance. Obviously, aerospace materials are not suitable for the emergency manufacturing of spare parts. It is necessary to study the performance of the laser stereo forming printing parts from the cheap and good performance materials. The 316L stainless steel is selected as the experimental materials to study, with the consideration of the parameters such as the physical and chemical properties, the mechanical properties and the environmental and economic factors.

The dense metal parts made directly by using the laser stereo forming technology are influenced by many process parameters, and the different teleological parameters have a great influence on the forming and properties of the final formed parts. The laser stereo forming is a process of the rapid melting and the rapid directional solidification. The parameters that have a great influence on the printed parts include: the laser power, the scanning speed, the powder feeding rate, the spot size, the Z-axis feed, the flow rate of the protective gas and so on. In this paper, the three main parameters -- the laser power, the scanning speed and the powder feeding rate are studied to affect the influence law and mechanism on the forming.
2. Experimental Materials and Methods

2.1. Experimental Materials

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.

| C    | Mn  | Si | S   | P    | Cr   | Ni   | Mo  | Fe  |
|------|-----|----|-----|------|------|------|-----|-----|
| 0.025| 1.19| 0.64| 0.013| 0.016| 17.13| 12.53| 2.14| Bai |

2.2. Experimental Methods

In this paper, the laser stereo forming technology is selected for parts processing. The laser solid forming technology is a typical 3D printing technology for directly forming metal parts. Its printing principle is the accumulation into the surface by using lines and then a body formed by overlapping the surface. So the forming quality of each printing line will affect the subsequent overlapping process. These effects will be expanded and eventually affect the quality of the printed parts in the overlapping forming, so it is necessary to study the forming conditions of each printing line.

The factors that have a great influence on the molten pool are taken as the index to study the influence on the height and width of the final formed parts. The laser power changes the energy size of the laser beam, which mainly affects the shape of molten pool and the depth of remelting. The laser scanning speed mainly affects the moving speed of the solid-liquid interface of the molten pool. And the powder feeding rate mainly affects the amount of the solute entering the molten pool and the depth of remelting. In this paper, based on the control of the variable method the study focuses on the influence on the forming height and width with the laser power, the scanning speed and the powder feeding rate by changing a single forming parameter and keeping other parameters unchanged.

3. Experimental Results and Discussion

3.1. The Influence of the Laser Power on the Forming Height and Width

When the parts are processed by the laser stereo forming technology, the laser and the metal powder interacts, some of the energy is absorbed by the metal powder, some of the energy is transferred to the substrate for heat transfer, and the rest is reflected by the material and diffused into the air, causing the energy loss. The laser power mainly affects the size and depth of the molten pool. In this experiment, the laser scanning speed is 400mm/min, the powder feeding speed is 1.3RPM, and the laser power is selected to be 400W-800W. The result is the average of three repeated experiments performed. Figure 1 shows the effect of the laser power on the height and thickness of the printed layers.

It can be seen from Figure 1 that the height of the printing layer increases with the increase of laser power, in the later it tends to be stable and even has the trend of declining. The width of the printing layer is basically the same, with a slow growth trend. Now the analysis of the above phenomenon is as follows: the energy of the laser beam appears Gaussian distribution, the energy in the middle of the light spot is the largest, and it decreases outward in turn. When the laser energy is small, it is difficult to melt all metal powders, which is bound to cause large amount of the metal powders without melting in the molten pool, resulting in the poor mechanical properties of the forming parts, eventually leading to the failure of the forming. In this case, there are little powder materials used to increase the thickness, which caused the thickness of the print layer to be lower.
When the laser power increases, the amount of the melted powder can be increased, which can effectively increase the powder of the printing layer that can increase the thickness of the printing layer. At the same time, the laser power increased will make the molten pool larger synchronously, so that more powders can enter the molten pool, which is beneficial to increase the solidification thickness of the single layer. When the laser power continues to increase, the height of the molten pool will continue to increase. When it reaches a certain level, the powder has basically reached the upper limit of melting. The main factor of limiting the thickness of the printing layer becomes the quantity of the powder feeding, which makes the thickness of the printing layer basically stable. If the powder feeding quantity is enough, when the tension of the metal liquid surface is not enough to balance with the action of the gravity, the liquid will flow to both sides of the molten pool, which will reduce the height of the cladding layer, and at this time the uneven flow of the liquid metal can cause the irregular shape of the accumulated layer.

3.2. The Influence of the Laser Scanning Speed on the Forming Height and Width

When the laser stereo forming technology is used to process parts, the laser scanning speed mainly affects the moving speed of the molten pool on the substrate. When the laser beam advances, the metal at the front of the molten pool is melted, and the liquid metal at the end of the molten pool solidifies rapidly because it is far away from the high-energy laser beam. When the scanning speed the printed parts. In this experiment, the laser power is 500 W, the powder feeding rate 1.3 RPM and the laser scanning speed is 400 mm/min, 500 mm/min, 600 mm/min and 700 mm/min respectively. The result is the average value of three repeated experiments performed, which can reduce random errors. The effect of the scanning speed on the height of printing layer is shown in Figure 2.

From Figure 2 it can be seen that with the scanning speed increasing, the height becomes smaller and smaller. When the scanning speed is smaller, the degree of reduction is larger, and with the increase of the scanning speed, the change trend of the height reduction is slowing down. When the parts are printed, the increase of the scanning speed mainly affects two factors: one is the amount of metal powder entering the molten pool affected, if the amount of the powder feeding is constant, the molten pool moves faster with the increase of the scanning speed, so the reduction of the total time to print a line directly causes the reduction of the powder feeding, as a result the height of the printed.
Figure 2. The influence for height of scanning rate

Layer is reduced with the increase of scanning speed. The other is to affect the heating time. When the speed is slow, the metal powder can be fully melted in the molten pool and transformed into the effective forming quality. However, when the scanning speed becomes faster, the energy input is insufficient, and a large amount of powder directly jumps out of the working area, which cannot be combined with the molten pool to form the cladding layer, finally this leads to the reduction of the height of the printing layer. The effect of the scanning speed on the width is shown in Figure 3. With the increase of the scanning speed, the width of printing tends to decrease, but its change is not large, which can be neglected as compared with the change of height.

Figure 3. The influence for width of scanning rate

3.3. The Influence on the Height and the Width of the Powder Feeding Rate

When the laser stereo forming technology is used to manufacture parts, it is necessary to maintain the uniformly continuous powder feeding. The uneven powder feeding will affect the height of the molten pool after solidification, resulting in uneven cladding layer, and the accumulation layer by layer will significantly affect the shape of the parts. DPSF-2 powder feeder is selected in this experiment, a double-barrel pneumatic powder feeder, which can provide better powder flow and ensure the accuracy of the printing parts. In this experiment the laser power is 500W, the laser scanning speed is 400 mm/min, and
the powder feeding rate is 1.0 RPM, 1.3 RPM, 1.6 RPM and 1.9 RPM. The experiments are made three times repeatedly. And the average value is taken. The influence of the powder feeding rate on the height and the width is shown in Figure 4.

From the analysis of Figure 4, it can be concluded that with the increase of the powder feeding rate, the height of the printing layer increases obviously, and the width of the printing layer increases slightly, but the change is not significant. When the laser power is large enough, with the increase of the powder feeding rate, on the one hand, the forming materials in the molten pool are increased, more powder is not transformed into the effective printing layer quality, on the other hand, the size of the molten pool is increased, which leads to the increase of the forming height. The width also increases slightly because of the increase of the size of the molten pool. When the metal powders melted by the laser power do not reach the limit of energy, the increase of the powder will not have much effect on the height and width.

![Figure 4](image.png)

**Figure 4.** The influence for height and width of deliver powder rate

4. Conclusion
This paper studies the effects of the laser power, the powder feeding rate and the scanning speed on the macro-shape of parts printed by the laser rapid forming technology. The laser power mainly affects the printing temperature, the scanning speed mainly affects the heating time and the powder feeding rate mainly affects the height of molten pool. The height decreases with the increase of the laser power and the scanning speed while the height increases with the increase of the powder feeding rate. The width is basically unchanged, which is mainly affected by the size of the spot. In this paper, the range of the technological parameters is provided for the study of the forming structure, and the macroscopically control of the formed quality. It has a high reference value for the further study of the forming properties.

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