Application of Selective Laser Melting Technology Based on Titanium Alloy in Aerospace Products

JING Li-qi, LI yu-hua, CHENG Ke wei, WANG Feng, SHI Jin Wen

China Academy of Space Technology (Xi’an), Xi’an 710000, China

Corresponding author’s e-mail: yhl4_1794@126.com

Abstract: Selective laser melting (SLM) is a key technology for direct forming of metal parts in 3D printing technology. SLM technology can realize the direct forming of parts with complex shape, high dimensional accuracy and excellent mechanical properties. It is especially suitable for rapid manufacturing of personalized and customized structures of aerospace difficult-to-machine parts. SLM forming process involves complex physical and chemical behavior of materials. Forming mechanism is quite different from traditional casting processes. The process parameters are complex and difficult to control. In this paper, a set of SLM forming process parameters suitable for Ti6Al4V alloy has been explored through the development of a SLM forming equipment of ESO M290 in Germany. The innovation of this product application design is the SLM printing design and process of minimal size dual-antenna, and the process method and design idea are universal. SLM forming technology based on Ti6Al4V alloy will be more and more widely used in aerospace field.

1. Preface

The so-called Selective Laser Melting (SLM) technology uses computer aided design (CAD) and manufacturing to selectively melt metal powder with high energy laser beam through the principle of layering-superposition. The designed workpiece is directly formed without tooling and dies, and is not subject to part structure for Diversity restrictions [1]. It is one of the fastest growing and leading technologies of Metal Additive Manufacturing (MAM) in the world [2]. Compared with the traditional method of manufacturing metal parts by subtracting material, MAM technology goes the opposite way. Based on the concept of Additive Manufacturing (AM), starting from the three-dimensional part model of computer aided design, the complex three-dimensional manufacturing is transformed into a series of two-dimensional flat by slicing software. Surface superposition manufacturing.

Reviewing the development history of SLM technology, its original idea is to combine the traditional processing with the selective Laser Melting (SLS) technology [3]. The idea of SLS technology was first put forward by Deckard C, a graduate student of Austin Distribution at Texas University in 1986. At that time, many people were interested in this technology, so they studied it deeply. In 1988, the first SLS machine in the world was developed [4]. In 1992, DTM Company of the United States was incorporated into the public of 3D Systems of the United States. We have developed a SLS device for commercial applications. In the early stage of SLM technology development, high power laser technology is not mature, and usually expensive. At the same time, the limited level of computer can not meet the control needs of large data. Therefore, in the early stage, metal parts were indirectly formed by metal powder coating and SLS technology [5]. With the improvement of laser manufacturing technology, the cost of laser production has been significantly reduced, and the level of computer has been continuously improved. The Fraunhofer Institute for Laser Technology (ITL) in
Germany first explored the SLM technology of laser fully melting metal powder forming. Soon afterwards, EOS in Germany developed the technology. Supported by the end of 1994, the first SLM equipment was produced. Subsequently, many commercial companies such as the United States, Britain and Germany began to produce commercial SLS equipment [6].

2. Technical Principle and Technical Characteristics of SLM

SLM technology is to selectively melt the images read by each slice layer by layer through the high energy of laser beam to achieve the purpose of forming metal parts [7]. The schematic diagram of SLM technology is shown in Figure 1.

![Fig.1 Sketch of SLM Technology Principle](image)

Laser selective melting deposition (SLM) technology was first proposed by Frauhofer Institute in Germany. This technology was developed on the basis of C.R. Dechard selective laser sintering (SLS). The principle of the two technologies is basically the same. The specific process is as follows: before scanning, the powder is laid horizontally. The roll lays the metal powder on the base plate; the laser beam melts the powder in a specific area according to the three-dimensional contour data to produce the contour of the current layer; and then reduces the thickness of a layer by lifting platform. The powder roll lays the metal powder on the front layer which has been processed. The control program calls in the next layer of data for processing, so that the layers of metal parts are repeated. The whole process is protected by inert atmosphere, which avoids the reaction between titanium alloy and impurity gas at high temperature, and ensures that the composition of titanium alloy parts meets the requirements.

The SLM process parameters include laser power P, scan speed V, single layer thickness t, scan interval h, scan strategy, etc. The comprehensive evaluation parameter energy density is introduced in the unit of J/mm$^3$. The results show that, low energy density tends to produce a large number of pores and poor fusion points at the top of Ti-6Al-4V forming parts, and the microstructure is dominated by lamellar alpha+beta phase; high energy density tends to cause material vaporization to form inner holes, and the microstructure is dominated by acicular martensite alpha'. Thijs et al. show that high energy density promotes the segregation of aluminium elements at the boundary of TC4 alloy molten pool, thus increasing the content of alpha 2-Ti 3 Al phase. Yadroitsev et al. observed that increasing laser power and prolonging laser irradiation time would increase the maximum temperature, geometric width and depth of molten pool by using optical monitoring system of CCD camera. In addition, in recent years, scholars have used hot isostatic pressing (HIP) with SLM technology to effectively reduce the porosity of SLM parts. The results show that the porosity of the alloy can be reduced from 0.501% as deposited to 0.012% as hot isostatic pressing by HIP treatment, and the properties of the alloy can be improved. Figure 1.2 is a schematic diagram of laser selective melting forming.
Study on SLM Forming Technology of Titanium Alloy and Parameter Optimization

Ti6Al4V alloy has good comprehensive properties, good structure stability, good toughness, plastic and high temperature deformation resistance. It is especially suitable for aerospace applications. This chapter optimizes the process of Ti6Al4V alloy to ensure that the workpiece has high density, good mechanical properties, stable sintering process and good surface quality.

3.1 Laboratory equipment and materials

In the process of this research, the SLM forming equipment used is ESO M290 in Germany. The maximum forming size of the forming cylinder is 250 mm*250 mm*325 mm as shown in figure 3. This system is compatible with two kinds of protective gases, nitrogen and argon, thus making the system compatible with a variety of metal materials from light metal to stainless steel, from die steel to superalloy.

SLM forming has a high quality of powder itself. Generally speaking, the higher the sphericity of powder and the better the fluidity of powder, SLM forming will be relatively simple. Ti6Al4V alloy parameters and particle size micro-appearance are as follows:

| Project                        | Parameter        |
|--------------------------------|------------------|
| Loose packing density          | 2.19g/cm³        |
| Vibration compaction density   | 2.74g/cm³        |
| Angle of repose                | 38.66°           |
| Flat angle                     | 52.41°           |
| Mobility                       | 76.00            |
| Collapse angle                 | 25.00°           |
3.2 Optimization of Filling Process Parameters

SLM is an augmentation manufacturing process from scanning line to surface and from surface to surface by laser welding. Therefore, the optimization of filling parameters should start with single track scanning and then multi-layer scanning to form the bulk. There are many factors affecting the quality of SLM forming workpiece (laser power, scanning speed, filling distance, scanning strategy and powder layer thickness), among which laser power, scanning speed and scanning distance are the three most important factors. Their energy density with the laser beam can be expressed as follows:

\[ E = \frac{P}{\pi d^2} \times \frac{2d}{v} \times \frac{2d}{s} \]

In the above formula, E denotes energy density, P denotes laser power, V denotes scanning speed, D denotes spot diameter, s denotes scanning spacing. From the above formula, we can see that increasing laser power, reducing scanning speed and reducing scanning spacing can improve laser beam energy density to a certain extent.

According to the actual demand, the process identification test is carried out, the spline sintering test is applied, five splines are sintered, the tensile test is carried out, and the performance data of five splines are sorted out as shown in Fig. 5.

| No. | Tensile Strength (MPa) | Elongation after Breaking (%) |
|-----|------------------------|------------------------------|
| 1   | 1071                   | 6                            |
| 2   | 1055                   | 8.5                          |
| 3   | 1116                   | 11                           |
| 4   | 1143                   | 9.5                          |
| 5   | 1170                   | 8.5                          |
Based on the experimental research of SLM forming, the better forming process parameters are determined: filling process parameters, contour process parameters and upper and lower surface process parameters. Finally, with this set of parameters, a representative metal workpiece and sample spline are formed and sent to the detection quantity. The following conclusions are drawn: through the actual measurement of upper and lower surface parameters. The experimental optimization and result analysis show that better process parameters are obtained, in which the upper surface parameters are $P=220w$, $v=1m/s$, and the lower surface parameters are $P=140w$, $v=1.6m/s$.

4. Printing Application of SLM Formed Spaceflight Products of Powder Titanium Alloy

In view of the practical application of a 140 mm *140 mm single-feed and double-biased Grigori reflector antenna for a space product, the main and secondary feedback and feed are small in size and compact in structure, and can not be processed by conventional methods. Because of its high precision and difficult technology, there is no precedent in engineering application. Combining SLM equipment with small spot diameter, low single layer thickness and small powder particle size, it has the best surface quality and is suitable for the preparation of porous materials, small titanium alloy parts with complex geometrical structure and other net forming parts. Therefore, the process method is chosen to realize.

Sinusoidal, random and thermal vacuum tests were carried out to verify the antenna. The main reflector surface RMS $= 0.04mm$, the secondary reflector surface RMS $= 0.027mm$, the bottom mounting surface flatness $0.005mm$ and the feed mounting surface $0 \rightarrow +0.03mm$ all meet the design requirements.
5. Concluding remarks
In this paper, selective laser melting technology can realize the direct forming of parts with complex shape, high dimensional accuracy and excellent mechanical properties, especially suitable for the rapid manufacturing of personalized and customized structures of aerospace difficult-to-machine parts. Through exploring the SLM forming process identification test and exploring the basic parameters, a certain antenna of aerospace product has been successfully applied, and it meets the performance index. This process method and design idea are universal. SLM forming technology will be more and more widely used in the aerospace field.

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