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Strength Analysis of rapid-solidifying Selective Laser Melting Forming Hydraulic Manifold Block

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Abstract: The complex flow channel structure inside the hydraulic manifold block and the very large pressure and impact during the work have higher requirements for its strength and molding accuracy. Selective laser melting technology is not sensitive to complex internal structure, especially suitable for processing hydraulic manifold block, such as complex internal structure of parts, as much as possible to improve the strength of the hydraulic manifold block after SLM forming is the key of the scheme. Therefore, this paper proposed a scheme of SLM forming hydraulic manifold block with rapid-solidifying, and analyzed the influence of various process parameters and coupling volume energy density on the microstructure and strength of the ultra-hard aluminum manifold block. The results show that the change of volume energy density is the key factor affecting the microstructure and mechanical properties of the superhard aluminum blocks. By changing the effect of different process parameters on the formation, microstructure, mechanical properties and crack of hIC formed by SLM, The strength of formed hydraulic manifold block was improved by heat treatment.

1. Introduction

Hydraulic manifold block is the concentrated embodiment of complex flow channel, its various channels directly connected with a variety of control components, so as to achieve the required hydraulic circuit. The internal flow channel of hydraulic manifold block usually works under high pressure, which has a high demand on the strength of manifold block. In the traditional machining of hydraulic manifold block, drilling is usually used to form the flow channel on the blank. For some complicated places of the flow channel, drilling process is also needed, which makes the machining of hydraulic manifold block very complicated, and the burr generated by drilling at the intersection of the channels is difficult to remove in the process of drilling. With the development of technology, in the manufacturing process of manifold blocks, the manufacturing technology is not only required to be efficient and fast, but also to meet the requirements of higher strength and the adjustment ability that changes with the design of manifold blocks [1], the traditional manufacturing technology is approaching the limit.

Additive manufacturing technology through the three-dimensional model of parts, the principle of discrete accumulation of layered melting powder material to form entities, is not sensitive to the complexity of parts. Compared with traditional casting process, additive manufacturing technology can form parts without mold, and the more complex the parts are, the more significant the forming efficiency is [2]. At present, aluminum alloy material manufacturing technology main have laser gain material manufacture, electron beam increases, arc material manufacturing, such as high energy density of electron beam increases material manufacturing technology, part of the light is easy to cause the alloy gasification, arc added material manufacturing technology for formation of the molten pool is uniformity, make its forming precision is low, the surface roughness is high [3]. Selective laser melting technology uses laser as a heat source, which has the advantages of high forming precision, good density, and high cooling speed after forming molten pool, which can form excellent microstructure and mechanical properties. Compared with traditional casting, forging, smelting and other additive manufacturing technologies, selective laser melting has higher density, mechanical properties and forming accuracy during forming, which has obvious advantages in the forming of hydraulic manifold blocks.

2. Introduction of SLM forming scheme for hydraulic manifold block

The processing process of SLM is "powder laying -- laser sintering -- substrate descent -- powder laying". A layer of superduralumin powder with a considerable thickness is laid on it, and then the powder is selectively heated and melted by laser according to the model to form a molten pool and fast solidification to form, and the parts are finally formed through layer upon layer processing [4]. In order to reduce the influence of stress on the forming parts, the substrate can be rotated 90° while the substrate is falling after finishing one layer. This scanning method can increase uniform shrinkage during rapid-solidifying and thus reduce residual thermal stress. That is, the final processing process is "powder - laser sintering - substrate down - substrate rotation 90° - powder again".

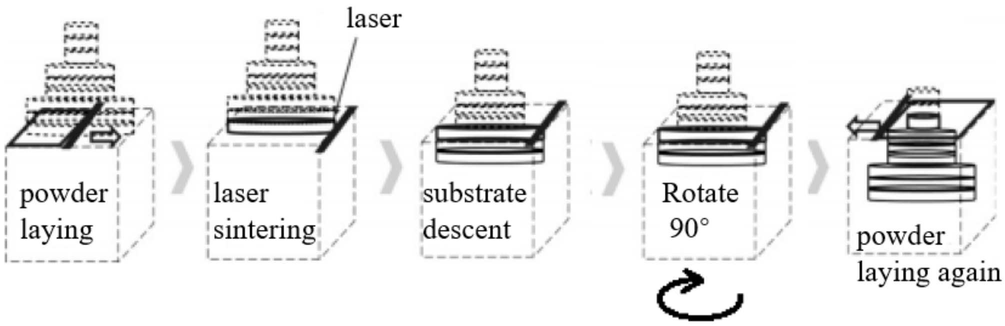

Figure 1: SLM forming scheme

To sum up, this scheme of hard aluminum alloy powder materials, use of SLM technology and rapid-solidifying technology required by the oil duct shape and size of hydraulic manifold blocks, in the process of forming pores, cracks and other generation mechanism and suppression strategies, and by adjusting the process parameters and forming the post-processing to improve the alloy microstructure, improve the strength of hydraulic manifold blocks.

3. Analysis of strength influencing factors

In the process of forming hydraulic blocks by the rapid-solidifying SLM process, the laser beam scanning process stays on the powder of the forming part for a short time, which is heated, melted, fused, cooled and solidified in a short time. The manifold block formed has higher tensile strength and requires less later processing, but due to the higher temperature gradient and surface tension of the molten pool, it is easy to form defects such as pores and cracks [6]. Moreover, the solidification rate of the molten pool is much faster than the diffusion rate of solute atoms, leading to the phenomenon of insufficient solute diffusion at the solid-liquid interface.

However, the point-by-line forming characteristics of the rapidly solidified SLM make the molten pool formed during the forming process very small, which leads to the extremely high solidification rate and refine the microstructure to a large extent. By controlling the parameters of SLM during the forming process, the superduralumin manifold blocks with good microstructure can be obtained, and then the strength of the superduralumin manifold blocks can be greatly improved by post-treatment.

3.1 Influence factors of process parameters on microstructure of superduralumin

In order to improve the strength of the manifold block after forming, the microstructure should meet the requirements of small grain size, high density, low residual stress, high solution degree and as far as possible, no element burning loss. In the process of SLM forming manifold blocks, set the laser power (P), scanning velocity (V), temperature (T), spread powder thickness (h), (T), laser wavelength scanning spacing (lambda) and gas atmosphere that 7 process parameters, and require observation grain size, density, degree of solid solution, the five elements loss and crack propagation microstructure characteristics. These technological parameters affect the microstructure and strength of superhard aluminum blocks during forming. Volume energy density (Ev) is introduced here to determine the laser energy input per unit volume, and its calculation formula is [5]:

$$Ev = P/(hTv)$$

In SLM process, preheating temperature, powder thickness and other parameters are set first, and the volume energy density (Ev) is changed mainly by changing the scanning speed (V) and laser power (P).

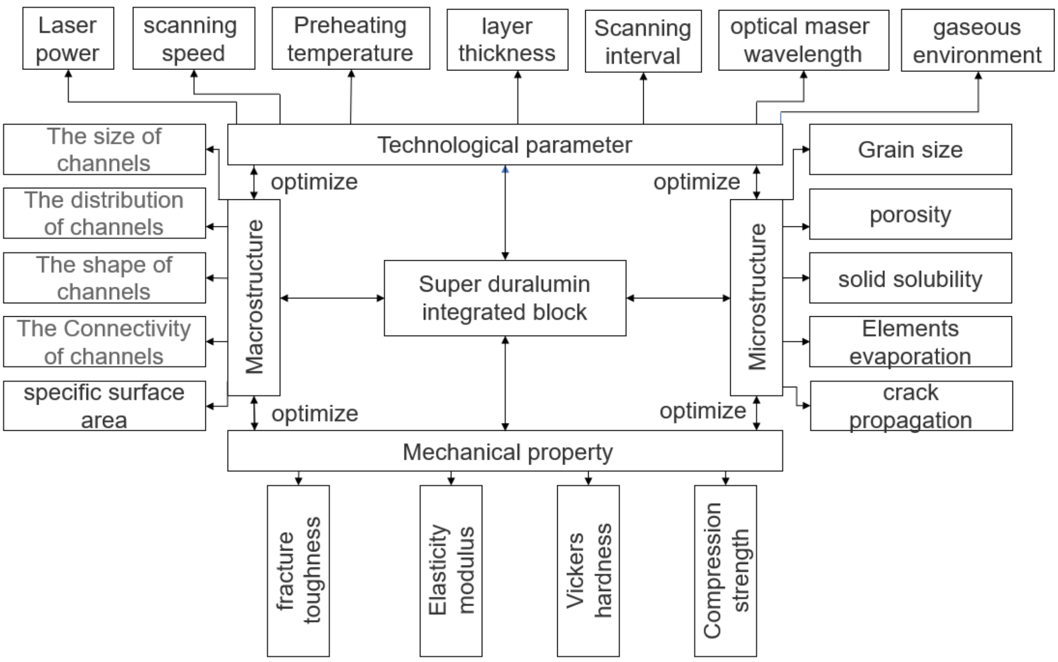

Figure 2: The overall framework of the research plan for additive manufacturing of high-strength aluminum alloy hydraulic manifold blocks

Under the condition of fixed cooling mode, the change of volume energy density directly determines the microstructure of SLM forming superhard aluminum manifold block. The larger the volume energy density is, the more heat accumulates in the laser scanning process of aluminum alloy powder, and the slower the cooling rate after melting and forming molten pool, which will lead to the longer growth time of the grain, thus making the grain larger. When the energy density is too high, not only the grains become larger, but also some elements with lower boiling points in the superduralumin powder evaporate, resulting in element burning loss. The bubbles formed by the evaporated elements rapidly expand to form a recoil pressure on the surrounding powder, and in serious cases, some of the surrounding superduralumin powder will be washed away, which makes the formed superduralumin manifold block have defects, which will greatly reduce the strength of the manifold block. Therefore, the volume energy density needs to be controlled within a range.

When the volume energy density is smaller, the heat accumulation of laser scanning aluminum alloy powder is less, and the cooling rate of molten pool is faster, which will reduce the size of formed grain and refine the grain. However, too low volume energy density may lead to aluminum alloy powder can not completely melt into molten pool, and the flow and diffusion of liquid will be greatly restricted, leaving a large number of unfilled voids, greatly reducing the density of the manifold block after forming.

The rapid-solidifying technology makes the cooling speed of the aluminum alloy powder after the formation of molten pool very high, this rapid-solidifying process can restrain the grain growth, this kind of inhibition occurs in the whole alloy rather than just the alloy surface, which will greatly optimize the mechanical properties of the manifold block. At the same time, rapid-solidifying technology can also explore the potential properties of superduralumin. During the rapid-solidifying process, many supersaturated cell crystals are formed with extremely high cooling rate. During the solidification process, solute element diffuses slowly, resulting in structural undercooling at the solid-liquid alternating interface, which leads to dendrite transformation to equiaxed crystal and grain refinement. Different aluminum content in superduralumin can affect the formation of supersaturated cell phase and the mechanical strength can be improved by solution strengthening.

3.2 Influence of scanning speed on forming phenotype

Scanning speed is an important parameter in SLM process, which directly affects the machining efficiency of SLM parts. At the same time, scanning speed is also an important factor of volume energy density, forming and forming strength. When the scanning speed is low, the powder accumulates more heat per unit time, and almost all the powder forms molten pool. After the powder forms liquid, it has high fluidity and is easier to form the required geometric shape. At the same time, according to statistics, the surface roughness of formed parts is also affected by scanning speed, when the scanning speed is low, the surface roughness of formed parts is smaller. However, too low scanning speed will cause the phenomenon of "spheroidization" in the forming process, which will worsen the surface roughness [7]. At the same time, due to more heat accumulation, the grain will also become larger during rapid-solidifying, and the strength will decrease when there is a good forming effect.

However, when the scanning speed gradually increases, the powder will not fully form the molten pool due to insufficient heating time. In the process of processing complex pore structure, the liquid formed by the powder is not liquid enough, which leaves gaps in some pore processing, which will greatly weaken the strength and density of the pore.

3.3 Post-processing to strength, hardness changes

Heat treatment is a method to improve the performance by changing the microstructure. In addition to improving the strength of the manifold block by changing the technological parameters of SLM during the forming process, it can also meet the strength requirements of the manifold block by heat treatment after the forming.

In the SLM process, the superduralumin powder is melted under a high-energy laser scan to form a pool, leading to complete melting first -- a rapid-solidifying process. In the formation stage of the molten pool, the temperature of the bottom, interior and upper regions of the pool is different, which makes the temperature gradient in different directions different. Under the same cooling environment, the cooling rate in each direction is different, which leads to the anisotropy of the microstructure in the manifold block. At the same time, the extremely high cooling speed of SLM process will also bring large residual stress, which will bring great harm to the compressive strength and fracture toughness of the manifold block. Therefore, heat treatment to reduce the anisotropy of microstructure and further reduce the residual stress can effectively improve the performance of manifold blocks. However, although heat treatment can reduce the thermal stress, long-term heat treatment will make the smaller grains generated during rapid-solidifying grow up, which will damage their mechanical strength to a certain extent.

Besides heat treatment, the hardness of the manifold block can be further improved by oxidation treatment, surface treatment and other post-treatment methods. Through electrochemical treatment, a dense oxide film is formed inside the cavity of the manifold block, which can prevent further oxidation of the manifold block in the process of use and improve the corrosion resistance and hardness of the cavity.

4. Conclusions

In this paper, the relationship between the process parameters and the microstructure, mechanical properties and macroscopic structure of the hydraulic manifold valve block formed by SLM technology with superdural-aluminum alloy powder is analyzed, and the method of improving the strength of the manifold block is discussed emphatically. Compared with the traditional way of machining hydraulic manifold blocks, SLM technology can realize the manifold block manufacturing under various hole optimization. The influence of different process parameters on the microstructure of the chip, the influence of scanning speed on the forming and surface roughness of the chip and the mechanical properties of the chip were analyzed by introducing volume energy density.

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