Effects of selective laser melting process parameters on powder formability of Ti6Al4V

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Abstract: Taking Ti6Al4V titanium alloy powder as the research object, on the basis of single layer scanning and single channel scanning experiment, this paper studies the influence of selective laser melting (SLM) process parameters on Ti6Al4V alloy material formability, and block forming experiment is carried out. Through the design of orthogonal experiment, morphology observation of sample and density analysis, results show that the best block molding parameters of SLM technology in Ti6Al4V alloy powder are laser power of 400 W, lap rate of 1 and the scanning speed of 750 mm/min, density can up to 96.17%.

Key words: selective laser melting (SLM); Ti6Al4V powder; powder formability; density

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0 Introduction

With the rapid development of aviation and space industry[1], titanium alloy has been obtained more attention because of its high strength, good corrosion resistance, chemical activity, thermal conductivity and other excellent performance[2]. Selective laser melting (SLM) is one of the rapid prototyping technology (RP), which can achieve high-performance complex structure of metal parts without mold fast and accurately to almost near the final shape, so in recent years, rapid material forming technology has become a very important molding method[3].

In the process of SLM, there are complex physical and chemical reactions[4]. Metal powder material is easy to produce common spheroidizing effect due to the surface tension of melting liquid metal from melt to re-solidification, which makes the surface of the molded part not even or even unable to mold in serious cases. The thermal conductivity of the metal material is high and a large temperature gradient is easily generated during the forming process to cause large residual stress after the liquid metal is solidified, which leads to deformation, fracture and other defects. Based on this, to get molding with high density and good performance, research of forming process parameters on the density mechanism has become particularly important[5].

In this study, Ti6Al4V[6] titanium alloy powder is used as the research object. On the basis of single-layer scanning and single-channel scanning experiment, the effect of SLM process parameters on the moldability of Ti6Al4V alloy is studied, and the block forming experiment is carried out. And the optimum process parameters of Ti6Al4V alloy powder SLM block are obtained by morphology observation and density analysis of the sample.

1 Experimental materials, equipment and methods

1.1 Experimental materials

The microstructure of Ti6Al4V alloy powder is shown in Fig. 1. In this experiment, Ti6Al4V alloy powder with near spherical, smooth surface and low porosity is prepared by rotating electrode method. The chemical composition of Ti6Al4V alloy powder is shown in Table 1.

Table 1 Chemical composition of Ti6Al4V alloy (wt %)

Element	Al	V	Fe	C	O	N	H	Ti
Content	6.1	4.2	0.12	0.01	0.08	0.01	0.002	Bal.

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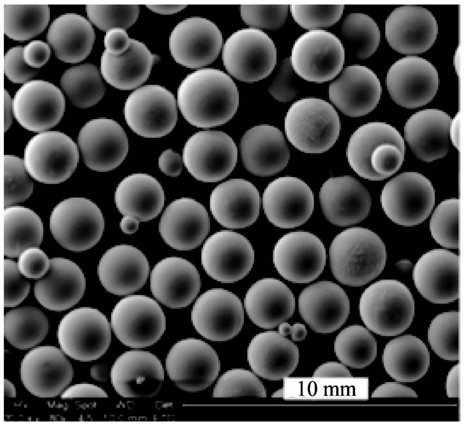


Fig. 1 SEM morphology of Ti6Al4V alloy powder

1.2 Experimental equipment

Wuhan Huagong Laser Company's pulsed Nd : YAG laser rapid prototyping machine is used in this experiment, the maximum output power is 400 W, the minimum diameter of laser beam is 0.15 mm, the maximum single pulse energy is 70 J, the maximum scanning speed is 1 600 mm/min, and the maximum forming size of the studio is 220 mm × 220 mm × 400 mm.

1.3 Experimental methods

Based on the study of single-layer scanning and single-channel scanning experiments, the experiment of block formation is carried out, the level of various factors are shown in Table 2.

Table 2 Level of various factors

Level	Elements		
	Laser power (W)	Lap rate	Scanning speed (mm/min)
1	400	0.6	600
2	375	0.8	675
3	350	1.0	750

There are many factors to be taken into account in block forming. The optimal process parameters are determined by block forming experiment to explore the density, mechanical properties and microstructure fabricated by SLM.

2 Experimental results and analysis

2.1 Sample density analysis

Experiment is carried out by orthogonal design method. The experimental parameters of each group are tested. Each batch of process parameters corresponds to one sample. The density of the sample is measured by the sample size. The density test method is the sealing wax method, the way for backfill is phase scanning.

It can be seen from Table 3 that the density can reach 96.17% when the laser power is 400 W, the lap rate is 1 and the scanning speed is 750 mm/min. The experimental parameters are the optimal process parameters. Using the optimized process parameters for SLM experiment, the mechanical properties test pieces are obtained[7]. Under the same lap rate and scanning speed, the density of the molded parts increases with the laser power increasing. In the laser power range of 300—400 W, the density of the molded parts increases with the increase of the laser power.

Table 3 Orthogonal experimental design

Serial number	Laser power (W)	Lap rate	Scanning speed (mm/min)	Density (%)
1	400	0.6	600	90.82
2	400	0.8	675	93.43
3	400	1.0	750	96.17
4	375	0.6	600	86.92
5	375	0.8	675	87.84
6	375	1.0	750	89.93
7	300	0.6	600	84.88
8	300	0.8	675	86.75
9	300	1.0	750	87.43

2.2 Mechanical properties analysis

The SLM experiment is carried out under optimized process parameters to obtain the mechanical properties test piece[8], the test results are compared with the mechanical properties of the traditional Ti6Al4V alloy[8]. The results are shown in Table 4.

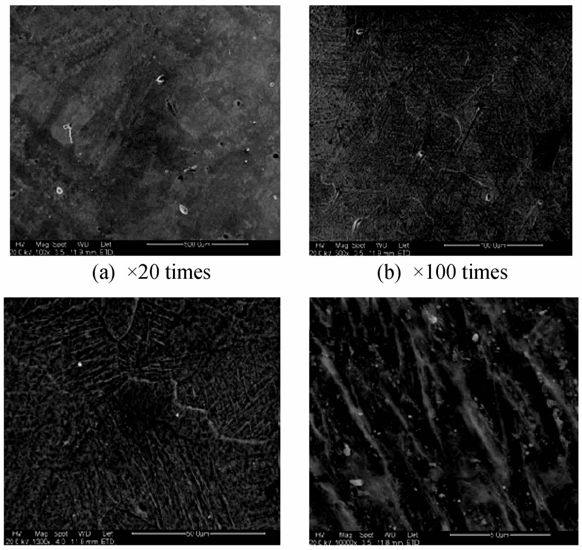
Table 4 SLM sample compared with traditional alloy performance

Performance	Hardness ($HV_{0.5}$)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
SLM Samples	409	1 082	976	4.9
Ti6Al4V	340—395	1 200	1 100	10

It can be seen from Table 4 that the tensile strength, yield strength and elongation of the SLM molded parts are lower than those of the conventional Ti6Al4V alloy. The reason for this phenomenon is due to the low density of the titanium alloy. The microhardness of the microstructure is significantly higher than that of the conventional Ti6Al4V alloy[9], which may be due to the high cooling rate during the SLM process.

2.3 Microstructure and phase analysis

Fig. 2 shows the SEM image of Ti6Al4V alloy surface produced by SLM.



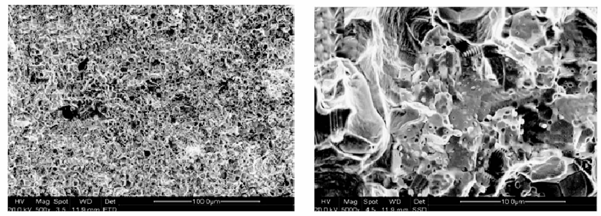
(a) ×20 times (b) ×100 times (c) ×200 times (d) ×2 000 times

Fig. 2 Surface SEM morphology of SLM sample at different magnifications

From the Figs. 2(a) and (b), it can be seen that the titanium alloy samples formed by the SLM optimization process have high density, and no microcracks occur. From Figs. 2(c) and (d), the titanium alloy structure is still a two-phase structure of $\alpha+\beta$ after the SLM process. Due to rapid heating and cooling of the SLM process, α' acicular martensite can be found[10].

Fig. 3 presents the SEM image of the SLM specimen fracture of Ti6Al4V alloy, which shows the trace of ductile fracture.

It can also be seen that cracks are generally not observed when forming a titanium alloy by the SLM method, but metallurgy defects such as stomata and poor fusion occur clearly in the formed sample. Stomata is formed by the gas in the powder gap or the gas produced by the powder gas, which is not overflowed in the process of the solidification in the pool, so the stomatal morphology is mostly spherical or spherical. Different from the stomata, the poor fusion leads to the irregular shape of the stomata and the uneven size.



(a) ×100 times (b) ×1 000 times

Fig. 3 Fracture SEM morphology of SLM sample at different magnifications

3 Conclusion

1) After the SLM process, the titanium alloy has a two-phase structure of $\alpha+\beta$, and α' needle-like martensite exists.

2) The mechanical properties of SLM sample of Ti6Al4V alloy powder are analyzed. The hardness is improved to 409 $HV_{0.5}$, the other properties are reduced, the tensile strength is 1 082 MPa, the yield strength is 976 MPa and the elongation is 4.9%.

3) The Ti6Al4V alloy powder is subjected to block formation experiment on the basis of single-layer scanning and single-channel scanning. The optimum process parameters of SLM block of Ti6Al4V alloy powder are obtained by the comparison of the density: laser power of 400 W, lap rate of 1 and scanning speed of 750 mm/min, the density can reach 96.17%.

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选区激光熔化工艺参数对 Ti6Al4V 粉末成型性的影响

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摘　要： 以 Ti6Al4V 钛合金粉末为研究对象，在单层扫描和单道扫描实验的基础上，研究 SLM 工艺参数对 Ti6Al4V 合金材料成型性的影响，并进行了块体成型实验，通过设计正交试验及观察试样的形貌和致密度分析，最终得到 Ti6Al4V 合金粉末 SLM 块体成型的最佳工艺参数为：激光功率 400 W、搭接率 1、扫描速度 750 mm/min，其致密度可以达到 96.17％。

关键词： 选区激光熔化；Ti6Al4V 粉末；粉末成型性；致密度

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