X.B. LU, X.D. SHU, S.Y. CHEN, C. XU, Z.X. LI, H.J. XU

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EFFECT OF PROCESS PARAMETERS ON FORMING QUALITY OF SiCp/TC11 TITANIUM MATRIX COMPOSITES BY SELECTIVE LASER MELTING (SLM)

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In this paper, SiCp/TC11 titanium matrix composites were prepared by selective laser melting. The influence of laser process parameters on the forming quality of composites was studied by control variable method. The results show that the process parameters have a significant effect on the forming quality of the composite material. The laser power has the greatest influence on the density, followed by the scanning spacing, and the scanning speed has a relatively small influence. When the laser power is 160 ~ 180 W, the scanning speed is 1 000 ~ 1 200 mm/s, and the scanning spacing is 0,1 mm, the forming quality of the sample is better.

Key words: TC11 titanium alloy, SiCp, SLM, process parameter, surface morphology

INTRODUCTION

In recent years, countries have continuously strengthened the construction and development of aerospace industry, and there is an increasing demand for titanium alloys and titanium matrix composites with high strength, low density and high temperature resistance. Titanium matrix composites have become the focus of research in recent years because of their combination of the strong plasticity of the matrix and the high strength and high modulus of the reinforcing phase. Selective laser melting (SLM) 3D printing technology is based on the forming concept of ‘discrete + accumulation‘. Under the control of the computer, the high-energy laser beam melts the automatically laid powder layer by layer according to the path specified by the layered software, and finally realizes the precise forming of complex components through layer-by-layer accumulation[1]. However, at the same time, the defects such as holes, cracks, splashes, and spheroidization that cannot be avoided in the forming process are important factors restricting the development of SLM technology. Therefore, optimizing the process parameters in the forming process, reducing defects such as pores, cracks, and spheroidization, and obtaining specimens with excellent performance are the basis of the laser selective melting forming process.

At present, Zimeng Ye et al. [2]studied the influence of process parameters on the mechanical properties of TiB/Ti6Al4V titanium alloy, and pointed out that the grain size of TiB decreased with the increase of laser power, which affected the microhardness of the material. Ran Jiangtao et al. [3]studied the influence of process parameters on the forming quality of TA32 titanium alloy, and pointed out that the increase of scanning speed, spacing and power will lead to the decrease and then increase of roughness of titanium alloy. Bai et al. [4]studied the influence of process parameters on the forming quality of TC11 titanium alloy, and pointed out that the microhardness of the formed sample increased with the increase of laser power.

In order to obtain titanium matrix composites with good forming quality, TC11 titanium alloy was selected as the matrix and SiCp was used as the reinforcement to prepare the composites. The control variable method was used to explore the influence of process parameters on the forming of samples, which provided parameter support and theoretical reference for the further development of SLM formed titanium matrix composites.

EXPERIMENTAL MATERIALS AND METHODS

The matrix of this experiment is titanium alloy TC11, and its microstructure is shown in Figure 1 (a). The sphericity of the powder is good, the surface of the particles is smooth, and there are no satellite particles. SiCp with an average particle size of 500 nm was selected as the reinforcing phase. The micro-morphology is shown in Figure 1(b), which is an irregular triangle,

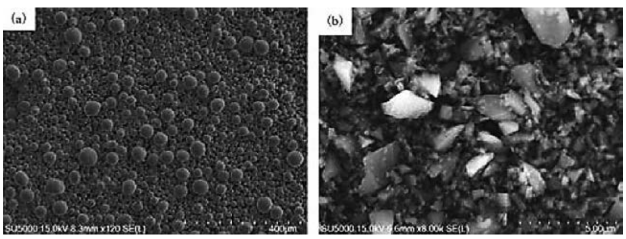

Figure 1 Microstructure:(a)TC11,(b)SiC

X.B. Lu, X.D. Shu, S.Y. Chen, C. Xu, Z.X. Li, H.J. Xu, Ningbo University, School of Mechanical Engineering and Mechanics, Ningbo, China; X.D. Shu (Email: shuxuedao@nbu.edu.cn)

which is conducive to adhesion to the surface of the substrate.

Using planetary high-energy ball mill, the reinforcement SiCp is uniformly dispersed and attached to the surface of TC11 powder particles to obtain titanium-based composite powder. The mass ratio of the two materials is 99.5 : 0.5. In order to explore the influence of SLM process parameters on the forming quality of the sample and its variation law, the 8×8×6 mm block sample was printed as the research object, and the experimental scheme shown in Table 1 was designed. The printing results are shown in Figure 2.

Table 1 **Experimental scheme of different process parameters**

Laser power /W	Scanning speed /m·s^{-1}	Scan spacing /mm
140/160/180/200/220	1,2	0,1
180	0,8/1,0/1,2/1,4/1,6	0,1
180	1,2	0,08/0,09/0,10/0,11/0,12

Figure 2 Printing results of block specimens

RESULTS AND ANALYSIS

The density of the block samples under different laser power, scanning speed and scanning spacing was measured after grinding and polishing, as shown in Figure 3.

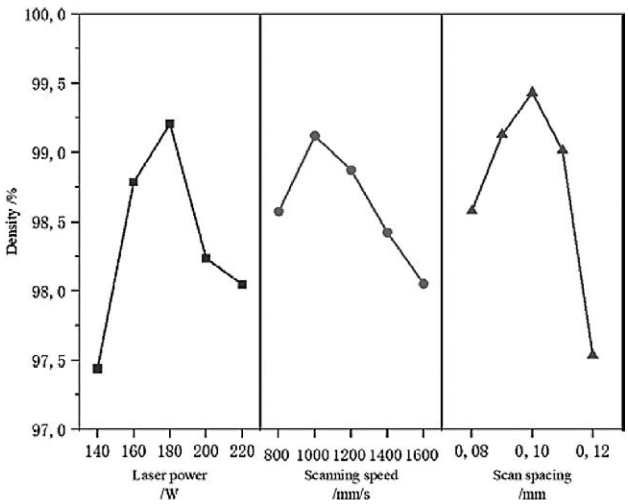

Figure 3 Single factor block density measurement results

The fixed scanning speed is 1 200 mm/s, the scanning spacing is 0,1 mm, and the laser power is changed in the range of 140 W ~ 220 W. The density of the sample shows a trend of increasing first and then decreasing. The surface morphology of the sample is shown in Figure 4. When the laser power is 140 W, the energy input of the powder is less, only 38,889 J/mm^3. The resulting molten pool is shallow, the melt flow is not sufficient, and it is not fully spread before solidification. The incompletely melted powder also appears in the melt channel, resulting in poor quality of the formed melt channel, which cannot form a good lap, resulting in low density. With the increase of laser power, the energy density of the body gradually increases, the powder melts more fully, the forming quality is improved, and the density gradually increases. When the laser power is too high to reach 200 W and above, the energy density of the body can reach 61,112 J/mm^3. The high energy leads to a sharp increase in the temperature inside the molten pool after the powder is melted, and the volatile elements are vaporized and escaped from the molten pool. At the same time, the large laser power will produce a large recoil pressure when forming the molten pool, resulting in the phenomenon of powder splashing. The spattered powder falls in the formed melt channel, making the powder uneven, causing defects such as holes, affecting the density and decreasing it. The metallographic observation of the sample is carried out, as shown in Figure 5, and the defect change form is consistent with the density. When the laser power is small, there are irregular pores due to incomplete melting of the powder. When the laser power is 200 W and 220 W, there are more circular pores and micropores, which corresponds to the spherical pores caused by powder splashing. When the laser power is 160 W ~ 180 W, the defects appear less, and most of them are regular pore defects, and the forming quality is better.

The laser power is fixed at 180 W, the scanning spacing is 0,1 mm, and the scanning speed is selected to

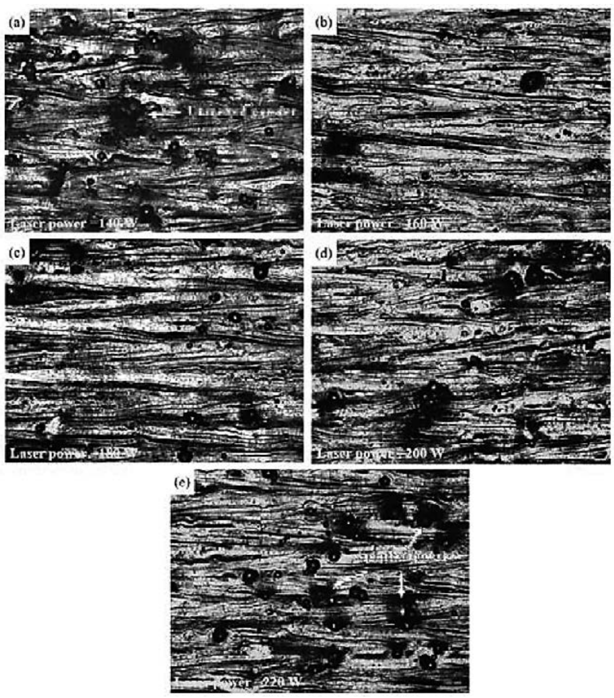

Figure 4 Surface morphology under different laser power

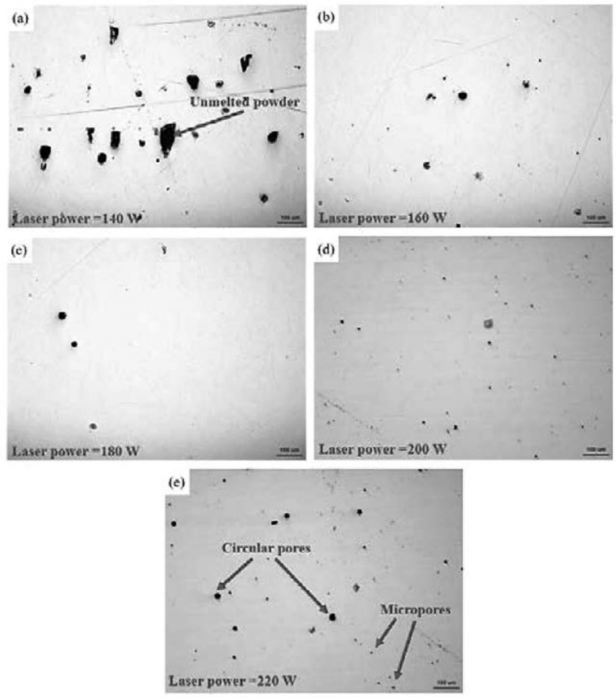

Figure 5 Metallographic diagram under different laser power

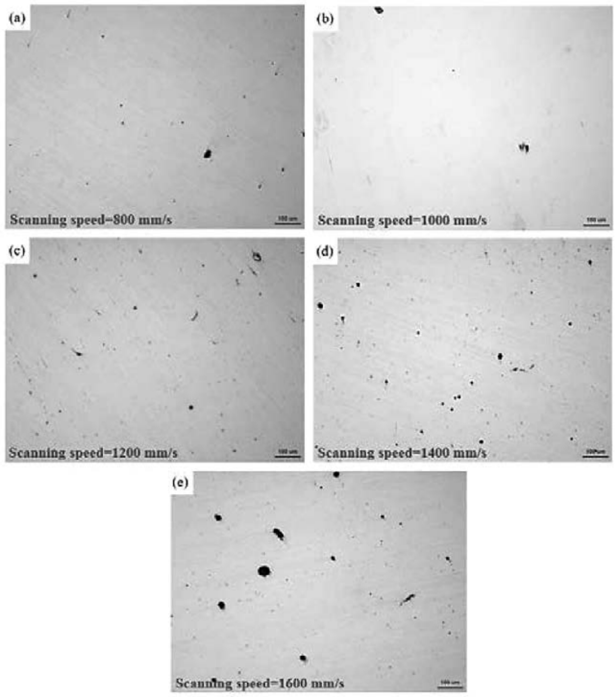

Figure 7 Metallographic images at different scanning speeds

change in the range of 800 ~ 1 600 mm/s. The density shows a trend of increasing first and then decreasing gradually. Combined with the analysis of surface morphology (Figure 6) and metallographic diagram (Figure 7), it can be concluded that as the scanning speed gradually increases from 800 to 1 600 mm/s, the energy density decreases from 75 J/mm^3 to 37,5 J/mm^3. Excessive energy density causes the viscosity of the metal liquid phase to increase after the metal melts, resulting in overburning, poor fluidity of the melt channel, and easy to produce heat accumulation and other phenomena, resulting in internal defects and low density. Too fast

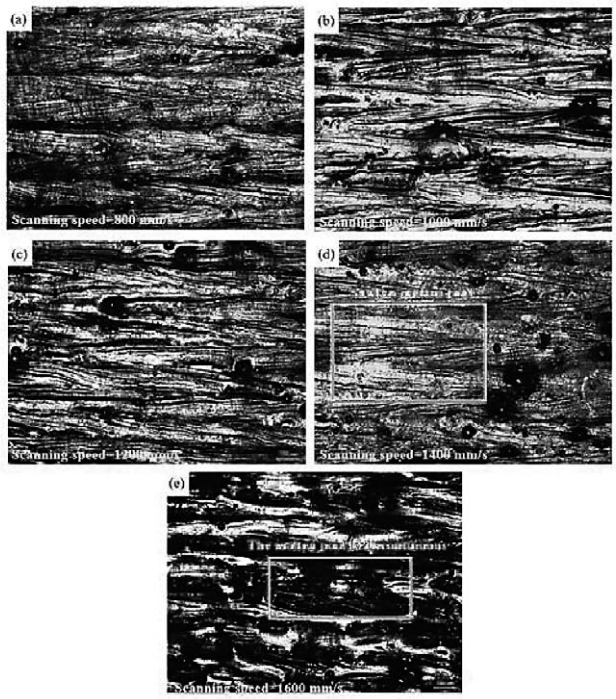

Figure 6 Surface morphology at different scanning speeds

scanning speed reduces the energy density of the body, and the time of laser action on the powder is very short, resulting in more unmelted powder. At the same time, it will also elongate the molten pool, resulting in a shallow molten pool, resulting in discontinuous phenomena such as discontinuous or even separation of the molten pool, making the forming surface uneven, affecting the quality of the lower layer powder, and more circular and irregular pores. This results in a decrease in density. When the scanning speed is 1 000 ~ 1 200 mm/s, the melting channel presents a continuous and stable state, and the defects in the metallographic diagram are also less, showing a dense state.

The laser power is fixed at 180 W, the scanning speed is 1 200 mm/s, and the scanning spacing is selected to change within the range of 0,08 ~ 0,12 mm. The density generally shows a trend of increasing first and then decreasing, which indicates that too small and too large scanning spacing are not conducive to the good forming of the sample. The scanning spacing directly affects the overlap between the sample melts. It can be seen from Figure 8 that when the scanning interval is 0,08 mm, the overlap rate of the two melt channels is greater than 50 %, showing excessive overlap, which makes the surface undulate and seriously affects the subsequent powder laying. In addition, it will also lead to an increase in the remelting area and a relative concentration of energy, resulting in vaporization, overburning, and spheroidization of the powder. When the scanning spacing is 0,09 ~ 0,11 mm, the overlap of the melt channel is improved, the surface is relatively flat, and the quality of the subsequent powder laying is improved. When the scanning spacing is 0,12 mm, due to the excessive distance between the melting channels, the adjacent melting channels are not completely con-

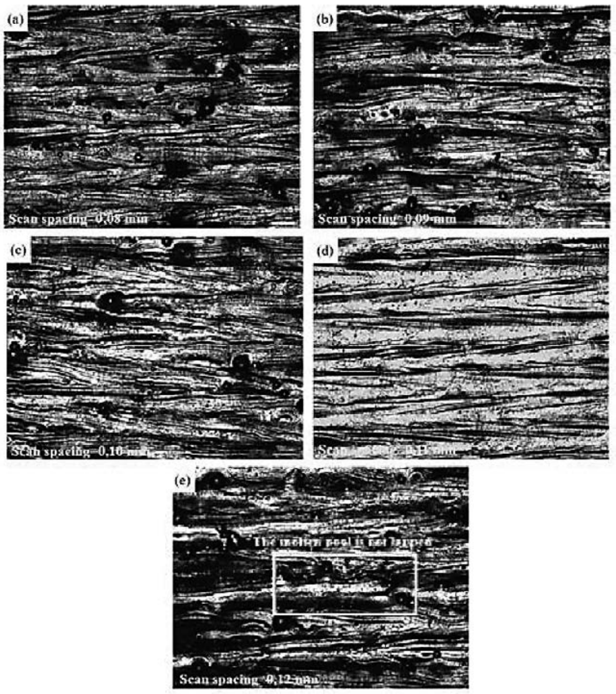

Figure 8 Surface morphology at different scanning distances

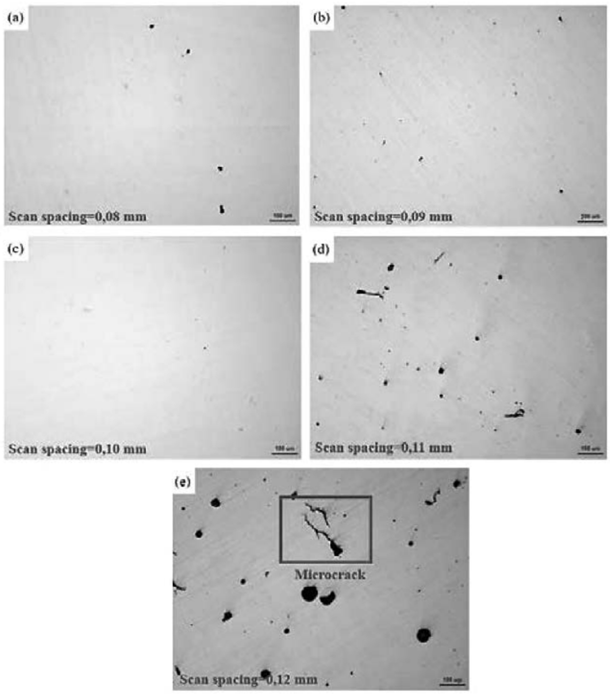

Figure 9 Metallographic images under different scanning spacings

tacted, and some of the melting channels have less or even no overlapping areas, which also leads to uneven surface. In the middle of the melting channel, unmelted powder also appeared, resulting in a decrease in the quality of the powder laying. In the metallographic diagram of Figure 9, cracks, pores and other defects also appeared under the large scanning spacing parameters, which affected the density of the sample.

CONCLUSIONS

In this paper, the influence of process parameters on the forming quality of composite materials is explored by changing the process parameters, and the following conclusions are obtained:

(1) Too low laser power will lead to incomplete melting of the powder and poor quality of the melt channel. Too high laser power will cause the temperature of the molten pool to rise, resulting in gasification and powder splashing, affecting the density of the sample. The range of good forming quality is 160 W ~ 180 W.

(2) If the scanning speed is too low, the viscosity of the powder will increase after melting, and the fluidity will be poor. If the scanning speed is too high, the melt channel will be discontinuous, which will cause defects in the sample. The range of good forming quality is 1 000 ~ 1 200 mm/s.

(3) Too small scanning spacing will lead to too high overlap of the melt channel, overburning and spheroidization of the powder. Too large scanning spacing will lead to incomplete overlap of the melt channel, which will lead to uneven surface and affect the density. The better scanning spacing is 0,1 mm.

Acknowledgments

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Note: The responsible translator for English language is X.B.LU, Ningbo, China