Effect of pulse frequency on laser welding on SiCp/6061 aluminum alloys with powder

Yongchao Jian 1,a, Yan Shi 2,b*

1 School of Mechanical and Electric Engineering, Changchun University of Science and Technology, Changchun130022, P. R. China
2 School of Mechanical and Electric Engineering, Changchun University of Science and Technology, Changchun130022, P. R. China
a-e-mail: 929845510@QQ.com
*b Corresponding author: blasercust@hotmail.com

Abstract—Because of the uneven distribution of reinforcement particles in the molten pool during laser welding of SiCp/6061Al composites with powder, the effect of pulse frequency on the homogenization was studied in this paper. The pulse frequency of welding is changed and the macro morphology of the weld is studied by metallographic microscope. The particle uniformity of reinforcing phase and the porosity of molten pool at different frequencies were compared. The tensile strength of welded joints at different frequencies was tested by universal tensile machine. Finally, when the pulse frequency is 160Hz, the particle distribution of reinforcing phase is the most uniform and the tensile strength is the largest. The tensile strength reaches 267.06MPa, reaching 69.1% of the base metal. When the pulse frequency is 320Hz, the porosity of the weld is the lowest, reaching 1.75%.

1. INTRODUCTION

SiCp/6061Al composites are widely used in aerospace, automotive, medical and other fields because of their light weight, high strength and good thermal conductivity [1-3]. However, the connection of SiCp/6061Al composite has the problem of uneven particle distribution [4,5]. Therefore, the connection technology of SiCp/6061Al composites has attracted extensive attention of scholars.

At present, there are few studies on the uneven distribution of reinforcing phase particles in the molten pool. Al and Si powders are used as interlayer, and a certain amount of SiC particles are added as reinforcing phase. Diffusion welding was used to weld the composites, and the weld with uniform reinforcement phase dispersion was obtained [6]. Paola Bassani welded SiC/A359 with CO2 laser, it was found that SiC was seriously poor at the laser keyhole. Increasing the stirring effect on the molten pool can solve the problem of reinforced phase segregation and make the reinforced phase evenly distributed in the molten pool. At the same time, a large cooling rate can make the reinforced phase difficult to be moved [7]. Friction stir welding is the most studied method. The successful application of friction stir welding in welding composites has solved the problem of uniform distribution of reinforcing phase particles [8-10].

However, adding interlayer or using friction stir welding has certain limitations. It is difficult to implement when the shape of weldment is complex or working conditions are special. Therefore, the pulsed laser welding with powder is used in this paper. The flow and cooling rate of the molten pool...
can be changed to achieve the purpose of uniform distribution of reinforcing phase particles by changing the pulse frequency.

2. MATERIALS AND METHODS

2.1 Materials
In this study, the material used for laser welding with powder is SiCp/6061Al composite with 10% volume fraction cast by Shanghai Jiaotong University. Plates of dimension 32mm×30mm×2.5mm were cut from a block by wire cut EDM and a 20° groove shall be machined on the welding surface. The specific chemical composition is shown in Table 1.

| Cu  | Mg  | Mn  | Fe  | Si   | Zn  | Ti  | Al   |
|-----|-----|-----|-----|------|-----|-----|------|
| 0.2-0.6 | 0.4-0.9 | 0.15-0.35 | 0.5  | 0.5-1.2 | 0.2 | 0.15 | Bal. |

The powder used is 6061 aluminum alloy powder produced by Changsha Tianjiu. The particle size of the powder is ~150~300 mesh. The chemical composition of the powder is shown in Table 2. The filling powder is a mixed powder of 6061Al alloy powder and 8% Si powder.

| Cu   | Mg   | Mn   | Fe  | Si  | Zn  | Ni  | Ti  | Fe+Si | Al |
|------|------|------|-----|-----|-----|-----|-----|-------|----|
| 0.2~0.6 | 0.4~0.9 | 0.15~0.35 | 0.5  | 0.5  | 0.3  | 0.1  | 0.15 | 0.7  | Bal. |

2.2 Laser welding with powder
TruDisk8002 laser is used in the experiment. The wavelength of the laser is 1.06um, the maximum power is 8000w, and the beam quality is 8mm ꞏ mrad. A-RC-PGF-D-2-type powder feeder was used to feed the side shaft powder. The carrier gas was nitrogen gas, and its flow rate was fixed at 400L/h and the protective gas was nitrogen gas, and its flow rate was fixed at 14L/h. Welding parameters is shown in Table 3. The schematic of laser welding with powder equipment is shown in Fig. 1.

| Welding power(W) | Speed(mm/min) | Defocusing amount (mm) | Duty Ratio (%) |
|------------------|---------------|------------------------|----------------|
| 4000             | 420           | +7                     | 50             |

Fig.1. schematic of laser welding with powder equipment
3. RESULTS AND DISCUSSION
A very important parameter of pulsed laser is pulse frequency, which determines the number of light output per unit time. Changing the pulse frequency is changing the time interval of the laser. The temperature gradient of the molten pool is changed by light and no light, which affects the flow of the molten pool, and finally affects the distribution of reinforcing phase particles [7]. Macrostructure of weld joint with different pulse frequencies is shown in figure 2. It can be seen from the figure 2 that with the increase of pulse frequency, the welding morphology gradually shows the characteristics of continuous laser. When the frequency is 320Hz and 640Hz, the distribution of reinforcing phase particles in the weld center shows uneven distribution. When the pulse frequency is small, the weld bottom fusion is not very sufficient. When the pulse frequency is 160Hz, the weld formation is better and the particle distribution of reinforcing phase is more uniform.

Figure 2. Macrostructure of weld joint with different pulse frequencies
(a)40Hz (b)80Hz (c)160Hz (d)320Hz (e)640Hz
The porosity detection is shown in the figure 3. It can be seen from the figure that the porosity first decreases and then increases with the increase of pulse frequency, and reaches the lowest value at 320Hz. However, compared with the weld morphology at 160Hz, the decrease of porosity at 320Hz is due to the increase of melting area. Therefore, considering that the base metal may melt less, the pulse frequency of 160Hz is conducive to the discharge of pores.

![Figure 3. Porosity ratio with different pulse frequencies](image)

The tensile strength at different pulse frequencies is shown in Figure 4. It can be seen from the figure 2 that under the condition of low pulse frequency, there is no fusion at the lower end of the weld. The results show that the tensile strength of incomplete fusion weld is very low compared with that of fully fusion weld. With the continuous increase of pulse frequency, the mechanical properties of welded joints show a downward trend, which is caused by the uneven distribution of reinforcement phase in the weld center [11]. Therefore, the pulse frequency of 160Hz is more appropriate, and the mechanical properties of the welded joint reach 69.1% of the base metal. This is due to the uniform distribution of reinforcing phase particles in the center of the weld. Relevant literature points out that the particle separation zone is the crack source [11].

![Figure 4. Tensile strength with different pulse frequencies](image)
Figure 5 shows the fracture location of the joint under different pulse frequencies. After the tensile strength test, the fracture locations all occur in the joint, indicating that the strength of the joint is still lower than that of the base metal.

4. CONCLUSIONS
A. When the pulse frequency is 160Hz, the tensile strength reaches 69.1% of the base metal which is achieve 267.06MPa.
B. The change of pulse frequency will change the fluidity of molten pool, and then affect the distribution of reinforcing phase particles.
C. When the pulse frequency is 320Hz, the porosity of molten pool is the lowest which is achieve 1.75%.

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