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Interface reaction in aluminium matrix composite at laser welding ①

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[Abstract] Interface reaction of SiC_w/6061Al aluminium matrix composite subjected to laser welding was studied. It is pointed out that the main reason for bad weldability of the material is concerned with the interface reaction during the welding. Effects of welding parameters on interface reaction were also investigated. The results show that the interface bonding state can be improved by laser beam, and the main welding parameter affecting the strength of weld is laser output power. The smaller the output power, the lower the extent of interface reaction and the better the mechanical properties.

[Key words] aluminium matrix composite; laser welding; interface reaction
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1 INTRODUCTION

Aluminum matrix composites have many outstanding properties, such as high specific strength, specific modulus, elevated temperature properties, radiation resistance and size stability, so they have attracted great attentions from material scientists. By replacing gradually partial traditional metal materials, they will be widely used in aerospace, aviation and automobile, and become the major developing and studying direction of metal matrix composite[1~5]. Due to the huge differences in physical and chemical properties between aluminium matrix and reinforced phase, it is difficult to gain an ideal welded joint of aluminium matrix composite by ordinary fusion welding methods[6]. With high power density and adjustability, laser beam welding has attracted great attentions and is hoped to restrain the interface reaction in welding[7~9]. In the present paper, the interface behavior of SiC_w/6061Al aluminium matrix composite during laser beam welding and effects of welding parameters on the interface behavior are investigated.

2 EXPERIMENTAL

The material used in this study was SiC_w/6061Al aluminium matrix composite manufactured by squeeze casting. The mean diameter of SiC whiskers used as reinforced phase was 0.5 μm, and volume fraction was 20%. The tensile strength of the composite under annealed condition was 220 MPa. The SEM morphology of the composite is shown as Fig. 1, and the chemical compositions of matrix 6061Al alloy is listed in Table 1.

Fig. 1 Microstructure of SiC_w/6061Al composite

Table 1 Chemical composition of 6061Al alloy (mass fraction, %)

Cu	Mg	Mn	Fe	Si	Zn	Ti	Ni	Al
0.34	0.75	0.22	0.36	1.26	< 0.15	< 0.05	< 0.05	Bal.

The material were machined into 2 mm × 10 mm × 30 mm welding specimens by wire cutting, then were butt-welded in the downwind position. The welding equipment was the YAG laser machine (made in USA), whose technical parameters are giv-

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en in Table 2. Tensile test was carried out on an electronic universal test machine (made in Instron Company, USA) at a deformation speed of 0.5 mm/min. The analyses on microstructure and the interface reactant of the composite were accomplished by optical microscopy, SEM and TEM.

Table 2 Technical parameters of YAG laser machine

Pulse frequency/Hz	Maximum power/W	Length of wave/μm	Stability	Width of pulses/μm
1~200	400	1.06	±5%	0.3~7.4

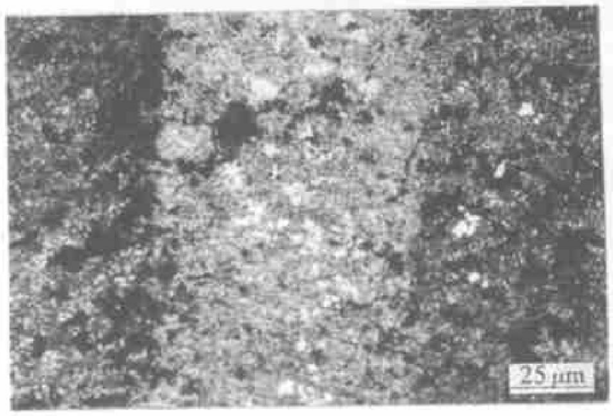

Fig. 2 Optical micrograph of SiC_w/6061Al welded joint

3 INTERFACE BEHAVIOR OF COMPOSITE

Fig. 2 shows the optical micrograph of SiC_w/6061Al welded joint. It can be seen that the weld and heat affected zone (HAZ) are evident. SEM morphologies of the welded joint (Fig. 3) shows that there are many needle shape phases. Electron diffraction analysis shows that such needles are made of Al element. In order to identify the phase of the needles, XRD analyses on the weld were carried out (XRD patterns are shown in Fig. 4). Besides the Al and SiC peaks, there are some strong Al_4C_3 peaks in the patterns, so the longer needles in Fig. 3 are considered Al_4C_3 which are the reactants of interface reaction between matrix and reinforcement. Furthermore, in Fig. 3(b), the burning loss of SiC whisker in weld is evident, moreover Al_4C_3 and SiC coexist in HAZ. The microstructure indicates that interface reaction reduces gradually and the reactant Al_4C_3 becomes fine at the transition zone from weld to HAZ. Fig. 5 shows micrograph between the weld and HAZ of laser welded joint for SiC_w/6061Al composite. It is found that the directivity of Al_4C_3 is evident and Al_4C_3 forms at the direction of heat flow. The microstructure of the parent far away from the laser spot becomes the original microstructure of the composite.

When Al matrix composite is welded under laser beam, the composite is melted by the heat absorbed from the laser beam, and the absorptivity is given as follows[3].

$$\alpha = 0.35\sqrt{\rho/\lambda} \quad (1)$$

where ρ is electrical resistivity of material, λ is wave length of laser.

Since the electrical resistivity of SiC reinforcement is much higher than that of Al matrix, the absorptivity of SiC under laser beam is much greater than that of Al matrix according to the equation mentioned above. When SiC_w/6061Al composite is welded, the SiC exposed to laser beam absorbs heat firstly and is heated to very high temperature, then the Al matrix alloy is heated by thermal transition. Such heating method make the temperature of the region around SiC is much higher than the average temperature of molten pool, therefore the following reaction takes place easily:

$$4Al(l) + 3Si(s) \longrightarrow Al_4C_3(s) + Si(s) \quad (2)$$

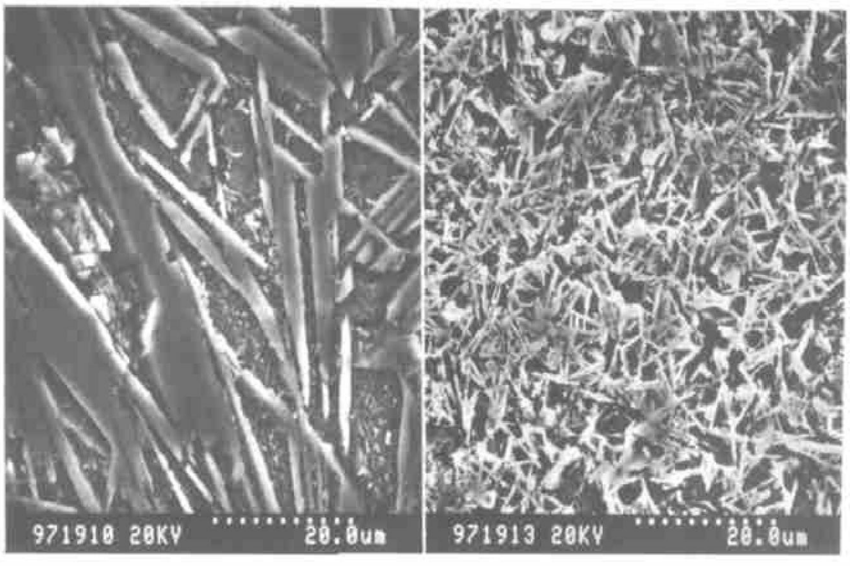

Fig. 3 Microstructures of welded joint
(a) —Weld; (b) —HAZ

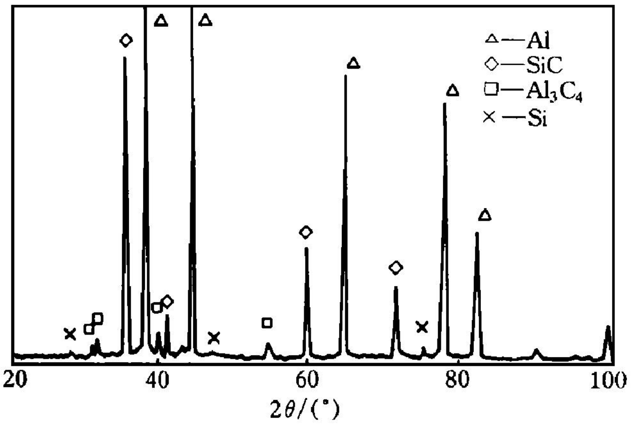

Fig. 4 XRD pattern of weld for SiC_w/6061Al composite

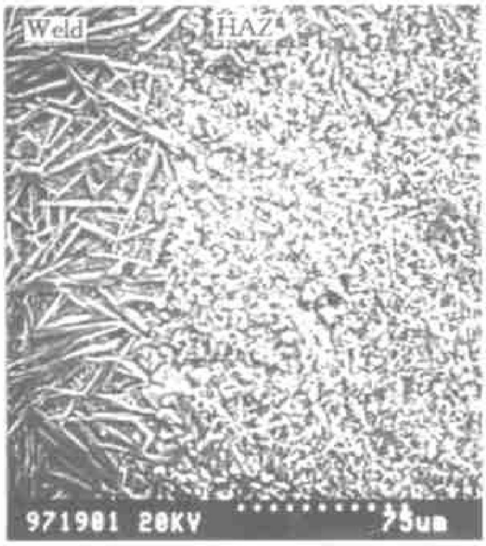

Fig. 5 Microstructure of weld and HAZ of laser-welded joint for SiC_w/6061Al composite

The Eqn. (2) is non-reversible. The reactants, such as fine needles or flakes of Al_4C_3 and Si blocks, form in the interface and destroy the good bonding way of interface between SiC and Al matrix. Thus, the strength of weld decreases.

Former study showed that the bonding between SiC and Al matrix in the composite manufactured by squeeze casting was very good, and the interface was clean[4]. But in the weld under laser beam, the bonding way of interface changes greatly, and the bonding way is shown as Fig. 6. It is clear that the brittle reactants Al_4C_3 like a interlayer inserted between SiC whisker and Al matrix. In the reacted region of SiC whisker and Al matrix, the transition ability of the load decreases, then cracks initiate and propagate easily as well. Therefore it is considered that the important reason for bad mechanical properties of the welded joint is the interface reaction between matrix and reinforcements in the weld.

In general, the main reasons for the degradation in mechanical properties of weld are shown as follows. When the reaction of Eqn. (2) takes place, the

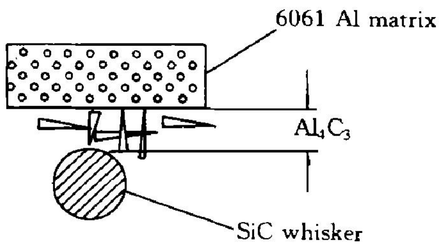

Fig. 6 Scheme diagram of interface of aluminum matrix composite under laser welding

amount of SiC whisker decreases and bonding way between the whisker and the matrix changes, consequently, the mechanical properties of the welded joint degrade. Otherwise, the microstructure of the matrix changes and contains many Si blocks, consequently, the plasticity of the matrix degrades.

4 EFFECT OF WELDING PARAMETERS ON INTERFACE REACTION

The free energy of the reaction shown as Eqn. (2) is given as follows[5]:

$$\Delta G/(\mathrm{J\cdot mol^{-1}}) = 113\,900 - 12.06T\ln T + 8.92\times10^{-3}T^2 + 7.53\times10^{-4}T^{-1} + 21.5T + 3RT\ln a_{[Si]} \quad (3)$$

where $a_{[Si]}$ is the activity of Si in liquid Al.

It is clear from Eqn. (3) that both temperature and $a_{[Si]}$ affect ΔG and ΔG decreases with increasing T. In order to investigate the effect of the welding heat input on interface reaction in weld and the path to restrain the reaction, XRD was used to analyze the relationship between the content of the reactant in weld and the laser welding parameters. As listed in Table 3, the strength of the joint decreases with increasing laser output power. That is, the larger the laser output power, the higher the temperature of molten pool, the smaller the ΔG, the larger the extent of reaction, and the more the reactants, then the more the decrease of mechanical properties in weld under laser beam.

On the basis of this, the main factor affecting interface reaction is laser output power in welding aluminum matrix composites. Furthermore, it is shown that using lower heat input is an important way to gain a good weld of SiC_w/6061Al composite by fusion welding.

5 FRACTURE BEHAVIOR OF COMPOSITE

Fig. 7 shows the fracture appearance of welded joints with different welding parameters. As shown in Fig. 7(a), at lower laser output power (190W), although the interface reaction takes place and the reactants (Al_4C_3) changes the bonding way between the whiskers and the matrix, no evidence of naked

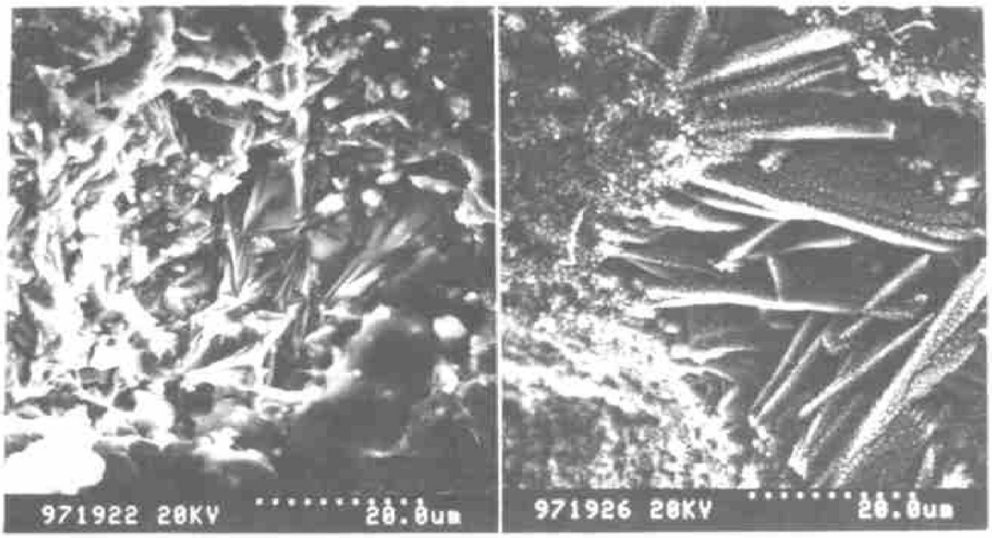

Fig. 7 Fracture appearance of welded joint at different laser output powers
(a) —190 W; (b) —250 W

Table 3 Relationship between content of reactant in weld and laser welding parameters

Laser out power /W	Strength of welded joint /MPa	$w(Al_4C_3)$ /%	w(Si) /%
300	105	< 3	< 3
350	101	< 3	< 3
400	74	5	8
450	61	7	13
500	57	7	13
600	49	7	16

whisker is found in the fracture appearance. It indicates that because extent of reaction is lower, effect of reactant Al_4C_3 which exists in weld beam on tensile strength of welded joint is small, so fracture does not form at interface. In a sense, whiskers act still as reinforcements. However, when laser output power increases (250 W), naked whisker is found in fracture appearance of the weld (as shown in Fig. 7(b)). It indicates that extent of interface reaction is high and the amount of reactant increases, so whisker is difficult to act as reinforced phase and fracture in welded joint originates in the interface between whisker and matrix, consequently, mechanical properties of the weld decreases evidently.

6 CONCLUSIONS

1) When SiC_w/6061Al composite is welded under laser beam, the main reason for bad weldability of the material is the interface reaction during welding.

2) The main parameter affecting the strength of weld is laser output power. The lower the output power, the smaller the extent of reaction, and the better the mechanical properties.

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