PLASMA ARC FUSION-PRESSURE WELDING OF Al-ZrO_2 SYSTEM COMPOSITE SYNTHESIZED BY XD METHOD

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Abstract:

In this paper, an Al-ZrO_2 system composite synthesized by XD method is welded by a new plasma arc fusion-pressure welding method. Their joint forms and microstructures are investigated. The results show that the optimum process parameters for the Al-ZrO_2 System composite (Φ7mm) are as follows: welding current is 150A and welding time is 2s, no adding filling materials, spring upset force is 2.45N. There are no defects such as large gas pore, micro-hole, or incomplete fusion in the joint. During the solidification of the molten pool, the melted Zr_3Al grows fully along the minimum growing energy direction <110>, thus the slender stick precipitates of Zr_3Al appear in the weld. The joint form and the microstructure are affected by the processing parameters such as welding current. For example, a larger current will cause the defect of micro-hole in the joint.

1 Introduction

The reinforced phase of in-situ composites is produced directly by in-situ reaction in the matrix, with advantages of the clean surface without contamination, excellent compatibility with the matrix, thermodynamically stable and high bonding strength at the interface. In-situ synthesizing technique has become a new method of preparing composites [1-4]. However, due to the great difference of the thermal physical property between the matrix and the reinforced particles of aluminum matrix composites, together with the poor fluidity of the molten pool, and the secondary growth of particles, it is difficult to obtain weld with excellent appearance by general fusion welding. There are few reports about successfully welding discontinuous reinforced aluminum matrix composites using fusion welding [5-8].

At present, the diffusion welding and friction welding are the most effective methods for the welding of aluminum matrix composites [9-13], but those methods are both limited by the welding equipment, the shape and size of the work. The main problem of the fusion welding of aluminum matrix composites is how to eliminate or inhibit the formation of the interface reaction products [14-15]. In this paper, a new method of plasma arc fusion-pressure welding is used to weld in-situ aluminum matrix composite. During welding process, a certain upsetting force is imposed on the molten pool to squeeze the products and remove the defects out of the weld. The combination of fusion welding and pressure welding is used to obtain excellent appearance of the weld with no defects. The effect of processing parameter exerted on the quality of the joint is elaborated in this paper.

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2 Material and method

Composite containing 80% (volume fraction) of Al and 20% (volume fraction) of Al_2O_3 and Al_3Zr particles is prepared by means of XD method in Al-ZrO_2 system. The specimen is a round bar with the diameter of Φ7mm and the length of 100 mm. Fig. 1 shows the microstructure of the substrate. It is found that Al_2O_3 appears as a tiny particle, while Zr_3Al is presented as lamella.

The welding system is composed of a plasma arc welding machine, welding robot and welding positioner. The design of special fixture should meet two demands: the first is that the bar should be fixed, the other is that the specimen should be upset. For high energy beam fusion-pressure welding, the designed special fixture is composed of a base, spring, baffle plate, static and dynamic pressure board. A structure diagram is shown in Fig. 2.

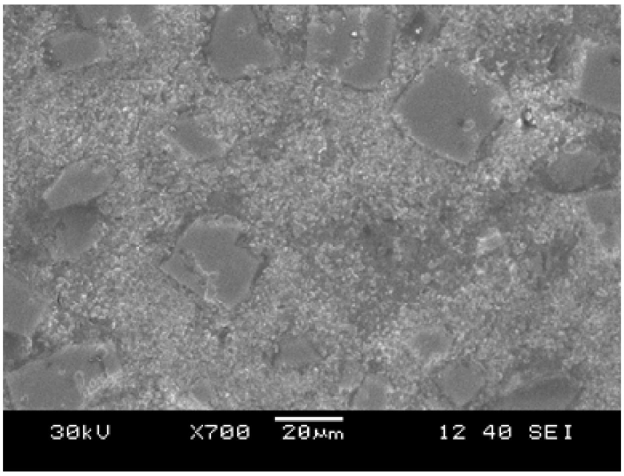

Figure 1. The microscopic photos of the Al-ZrO_2 System composite synthesized by XD method.

During welding, the upsetting force is provided by a dynamic pressure board (produced) and a compression spring. The maximum compression displacement of the spring from the top is 6 mm. The upsetting force of the spring is 2.45 N. The welding process is as follows: preliminary gas shielding → striking arc and welding → upsetting→ continue gas shielding → end of welding.

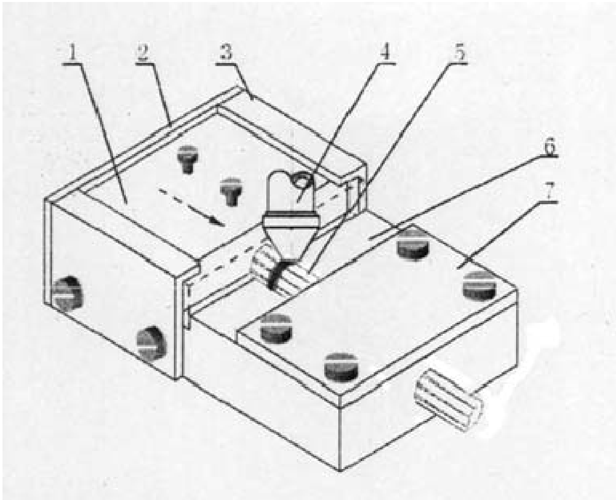

Figure 2. Aluminum alloy / aluminum matrix composites welding fixtures (1 dynamic pressure board ; 2 backboard; 3 right and left board; 4 plasma torch; 5 composite; 6 the base; 7 static pressure board).

3 Results and analysis

3.1 Effects of welding current of 150A on joints

Due to the effect of pinning on the reinforced particles during fusion welding, the fluidity of molten pool is very poor. Thus, in order to improve the fluidity of molten pool, the heat input should be increased, by using a large current. The macroscopic appearance of the fusion-pressure welded joint of the Al-ZrO_2 system aluminum matrix composite bar is shown in Figure 3, whose process parameters are: welding time t=2s and welding current I=150A.

Figure 3. Appearance of joint during I=150A.

It is found in Fig. 3 that the joint form is fine during the above optimum parameters, while the width of the weld is about 5 mm. The molten metal is squeezed around the joint. Eventually a firm and impervious joint is formed. There are no large deformations, such as bending, expansion, et al. in the joint that contribute to the excellent strength and stiffness properties of an aluminum matrix composite.

Fig. 4 is the macroscopic photograph of the joint. It is found that the microstructure of joint is found to be compact with welding current 150A. The weld width is about 5 mm, and the reinforced particles of Al_2O_3 in the matrix are distributed homogeneously and randomly.

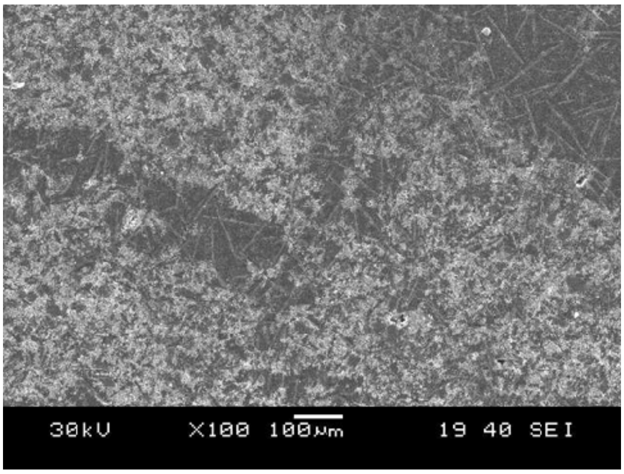

Figure 4. The macroscopic photograph of the joint during I= 150A.

Due to the effect of drastic extrusion, little molten metal of weld is remained in the joint area. The microstructure of joint shows irregular shapes while the weld and bond area are staggered to some extent. In comparison with ordinary plasma arc welding, there is no apparent weld zone in joint of plasma arc fusion-pressure welding. The microstructure of the whole joint area is compact and the transition from substrate is natural. Above all, there are no defects such as large blowholes, holes and the incomplete fusion. Under the upsetting force, an irregular semi-solid pressure area occurred. By means of the upsetting force, the products that are harmful to property of joint can be squeezed out as much as possible, and thus the fine microstructure of joint is formed. This welding method is applicable to aluminum matrix composites of Al-ZrO_2 systems by XD synthesis.

Fig. 5 is the microstructure of the weld by fusion-pressure welding with plasma arc. It is found in Fig. 5 (a) that besides some lamella Zr_3Al intermetallic compounds and Al_2O_3 particles, some stick products are generated as larger bulk factor in the weld center and there are few Al_3Zr flakes surrounding the stick products. Analyzed by using EDX, there are 76.62% of Zr and 23.38 % Al (atomic fraction) in the stick products, which can be virtually ascertained as Zr_3Al, being proved with the result of X-ray analysis of the joint area. Some remaining Zr_3Al sticks are broken, which shows that Zr_3Al has been melted in the molten pool. The Al_2O_3 particles are homogeneously distributed in the center of welded zone, but is less in quantity compared with the substrate. It is found in Figure 5 (b) that the quantity of Zr_3Al sticks melted is obviously reduced at the edge of the weld, thus the amounts of lamella Zr_3Al bulk are significantly greater than those of stick products in this area.

During the plasma arc fusion-pressure welding, the temperature of molten pool is high. Especially, the temperature of the molten pool below the arc can be higher than the melting point of Zr_3Al, and as a result the area of Zr_3Al would be melted. At the edge of molten pool, Zr_3Al is either little melted or only part of Zr_3Al is melted due to low temperature of molten pool. The Zr_3Al stick without melt keeps the original shape after welding thermal cycle and the Zr_3Al flakes are regularly distributed in Figure 5 (a) and Fig. 5 (b).

In the molten pool, the weldability between the matrix of aluminum liquid and Al_2O_3 particles is poor, macro and micro segregation can be easily discovered in the aluminum liquid. Compared with that in the preparation of composite, the effect of inhibition exerted on the growth of Zr_3Al was greatly debased in subsequent solidification, and consequently, Zr_3Al fully grew along the direction of its minimum growing energy<110>[6]. After solidification, the slender Zr_3Al sticks were precipitated in the weld as shown in Figure 5.

Otherwise, the molten pool of plasma arc welding is rapidly cooled, which is consequentially accompanied with an inhomogeneous fusion of Zr_3Al. Therefore, Zr_3Al sticks precipitated in the center of weld more than those at the edge of the weld after fusion-pressure welding.

In the fusion welding process of the Al_2O_{3p}/Al composites, due to floating and segregating of the particles, the quantity of the Al_2O_3 in the weld is lower than that of the substrate, and homogenization of the distribution of the particles is significantly reduced [7]. In addition, in plasma arc welding of composite synthesized with XD method in Al-ZrO_2 System, not only the above-mentioned problems existed, but also brittleness of the weld joint is undoubtedly increased by too much precipitated Zr_3Al stick and the properties of the joint are thus poor. Based on the above analysis, the most liquid metal in the molten pool is squeezed out and the harmful products in the joint are significantly reduced. The size of the weld is also greatly decreased, which can effectively improve the properties of the joint.

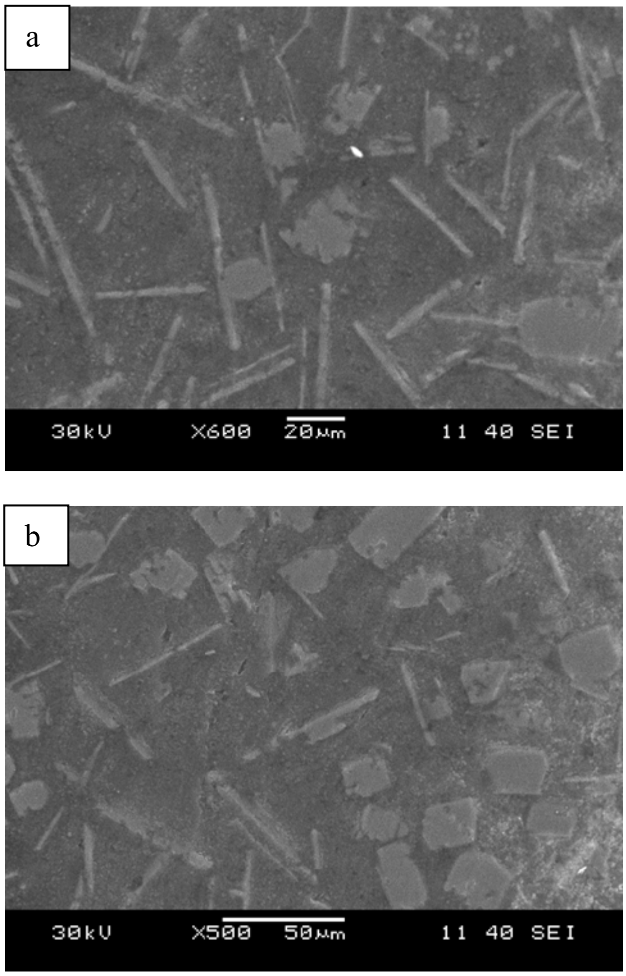

Figure 5. The microstructure of weld during I=150A (a) Weld center; (b) Weld edge.

3.2 Effects of welding current of 180A on joints

Figure 6. shows the typical form of Al-ZrO_2 system composite joint welded with plasma arc fusion-pressure method. Welding parameters are as follows: welding current I=180A, welding time t= 2s.

Figure 6. Joint form during I=180A.

Compared with Fig. 3, it is found that the joint form shown in Fig. 6 became poor when the heat input was increased. The joint width is about 10mm. Much substrate is melted and some liquid aluminum is extruded around the joint. However, there are some pits in the joint and some concavity defects are found in the weld center due to the larger current.
The macrograph of joint Fig. 7 shows the comparability of the joint compared and contrasted with that in Fig. 4. Due to the upsetting force, there is no regular weld in the joint, and there is a phenomenon of interlacing between the substrate and the weld. For the current increasing to 180A, heat input increases, which leads to the increase of the melting aluminum. Compared with 150A, the weld becomes wider and the poor zone of the reinforced phase becomes larger. It is also found that more blowholes and long needle-like products appear.
It can be found that the more needle-like products appear, the more defects such as micro-holes are present in Figure 8 (a). The reason is that the anchoring of precipitated Al_3Zr causes the high viscosity of molten pool. Thus the fluidity of the liquid aluminum gets worse. Otherwise, due to the different physical properties of the reinforced phase and the matrix, the defects of micro-holes are easily formed by/through shrinking during the solidification. Due to the rapid cooling of molten

pool and its high viscosity, the gas or impurity of the molten pool can hardly be entirely overflowed, which leads to the blowholes and inclusions, even the porosities after solidification.

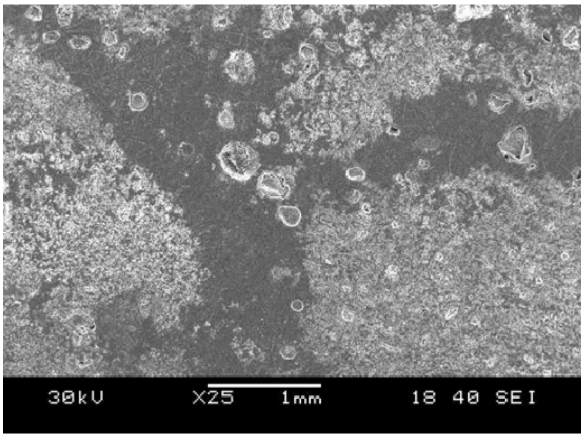

Figure 7. Macrograph during I=180A.

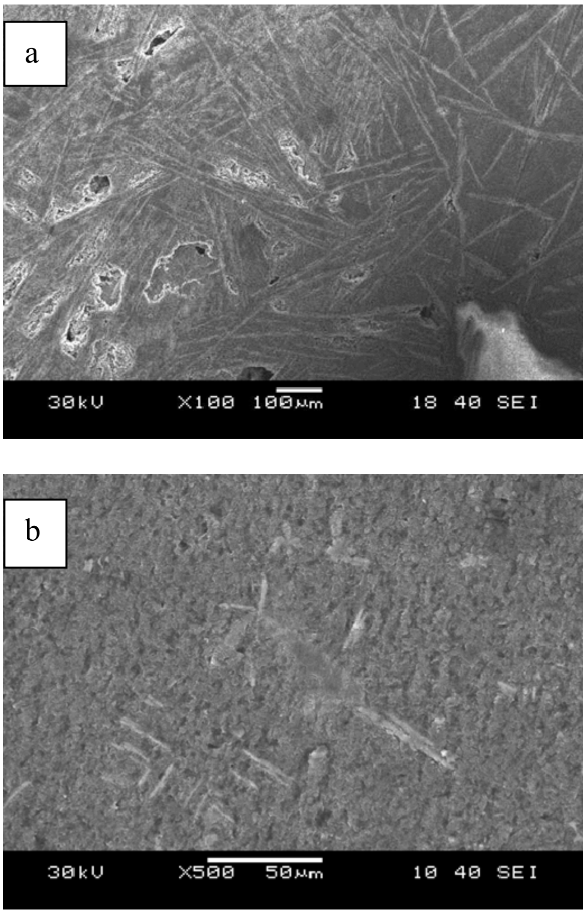

Figure 8. Microstructure of weld during I=180A (a) Weld center; (b) Weld edge.

In addition, Fig. 8 shows that when the heat input increases, the fluidity of molten pool is also increased, which is favorable for eliminating blowholes and porosity. However, by increasing the temperature of molten pool, there rarely exist blocks of Zr_3Al intermetallic compound in the weld due to melt of Zr_3Al. Instead, there are more needle-like Zr_3Al precipitates in the center of weld. Generally, the viscosity of molten pool becomes rather higher. Compared with Fig. 5, the quality of weld becomes/gets worse.

4 Conclusions

(1) Plasma arc fusion-pressure welding of composite synthesized in Al-ZrO_2 System by XD method has been considered. The process parameters are: welding current I=150A, welding time t= 2s, no fillers, spring pressure force is 2.45N. The joint is in good form and the microstructure is fine. In the irregular weld zone of the welded joints, there are neither regular welds in the joint nor severe defects such as pore, micro-hole, porosity and incomplete fusion,. During solidification of the molten pool, the melted Zr_3Al grew fully along the minimum growing energy direction <110 >, which resulted in the slender stick Zr_3Al precipitates in the weld.
(2) The variation of process parameters, such as welding current, has exerted effects on the joint form and the microstructure. A larger current will cause more needle-like Zr_3Al products and defects of micro-holes in the joint and the quality of weld becomes worse.

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