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Joining mechanism and modeling of vacuum-free semi-solid stirring joining

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ABSTRACT

A new process of vacuum-free semi-solid stirring joining on SiCp/A356 composites was investigated. The experimental setup and mathematical model of fixed-point stirring experiment were developed to study the influence of stirrer rotating upon the distribution of flow field and mechanical effect during semi-solid stirring joining. Numerical simulation and experimental results showed that the stirrer rotates to drive semi-solid filler alloy convection, so that a greater alternating pressure and wall shear stress were generated at the brazing interface, which increased the extrusion effect and broken effect to the surface oxide film on the brazing side, and further, removed the oxide film and increased the bonding rate of the brazing interface.

1. Introduction

In many joining processes of aluminum metal–matrix composites, transient liquid phase (TLP) bonding [1,2], diffusion bonding [3,4] and brazing [5,6] are attracting considerable attentions because they can avoid the detrimental interfacial reaction between SiC particles and Al matrix that is associated with fusion welding. However, the joining processes above are usually conducted in a vacuum environment, which reduces their design flexibility. If brazing the composites using flux in air, it is difficult to remove the residual flux after brazing, and results in a corrosion problem [6]. To overcome the problem, some researches about vacuum-free joining processes have been performed. AS Zuruzi [7,8] et al. and Lee [9] et al. have used a surface rotation treatment technique to remove the oxide film during diffusion bonding of Al-MMCs and 6061Al, and have performed successfully vacuum-free bonding. Yan [10] has succeeded in ultrasonic vibration brazing of Al-MMCs in air by applying ultrasonic vibration to the removal of the oxide films on the composites. According to the existing technical literatures and researches, the semi-solid joining technology has been proposed to realize the jointing of several materials [11–13].

In previous study, a new process of vacuum-free semi-solid stirring joining on SiCp/A356 composites was proposed, and the experimental setup of fixed-point stirring was developed. Accordingly, the influence of rotational speed on materials flow in experiment was studied [14]. In this study, the mathematical model about the filler metal fluid was developed and the numerical simulation was used to study the influence of stirrer rotating to the distribution of flow field and mechanical effect during semi-solid stirring joining, which will be helpful to study the process parameters effects and the

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optimization design of joining process. This joining process was not required to provide a vacuum environment and easy to operate. Experimental results showed that it can be applied to the joining of aluminum matrix composites successfully.

2. Joining mechanism

The process of vacuum-free semi-solid stirring joining on SiCp/A356 composites is shown in Fig. 1. The filler metal is pre-placed between the two substrates and heated up to semi-solid state by a resistance heating plate. When the filler metal is melted to semi-solid state, the stirrer is introduced into the mushy weld seam and rotates to provide mechanical stirring force. With the affecting of mechanical stirring, the solid crystal grains in semi-solid filler metal will extrude, break and remove the surface oxide film on the brazing side. At the same time, some of the liquid phases in the semi-solid filler metal are diffused and dissolved with composites matrix, which will increase the wettability of semi-solid filler metal to composites. The mechanical agitation homogenizes the reinforcement particles in composite material and refines the grains in the weld. The reinforcement particles are captured by the existing solid–liquid interface during solidification, which is helpful to achieve a composite joint with evenly distributed reinforcement particles.

3. Modeling

3.1. Experimental materials

The base materials used in this work contain 15% volume of SiC particles, which diameters are about 12.6 μm. The A356 aluminum alloy compositions are shown in Table 1. And, the matrix has undergone T5 heat treatment. The filler metal is Zn–Al alloy. The chemical compositions and the melting rang of the filler metal are listed in Table 2. The specimen is the plates in shape with 50 mm × 40 mm × 3 mm.

3.2. Experimental setup

In order to facilitate the study of process parameters, an experimental setup of fixed-point stirring is established in Fig. 2 [14]. The test plate of aluminum metal–matrix composites is drilled in diameter of 2 mm, as shown in Fig. 2a.

The semisolid range of Zn–Al filler metal is 440–495. The aim of the experiments is to study the joining effect of Zn–Al filler metal in semisolid state. But the joining effect of filler metal in liquid state is a comparison. Therefore, the experimental process is as follows in detail: The Zn–Al alloy is filled into the hole, which is heated up to 445–500 °C together with the specimen by a resistance heating plate. When the filler metal is melted to a semi-solid state, a stirrer is introduced into the mushy weld seam, and rotates to achieve brazing effect, as shown in Fig. 2b. The cross sections of bonded joints are prepared for metallographic analysis by standard polishing techniques after joining experiment.

In order to simulate the joining process of fixed-point stirring, a two-dimensional calculation model is developed, as shown in Fig. 3. The cross section of stirrer in experiment is shown in Fig. 3. It can be seen that the radius of exterior margin is 0.9 mm and the radius of hole is 1 mm, which is consistent with the actual experimental setup. The fluid phase between the stirrer and the hole wall is Zn–Al filler metal, which physical property is presented in Table 3. The physical properties mentioned in Table 3 are essential data, which was got by experiment. The kinetic viscosity was measured as the temperature ranged from 445 °C to 500 °C.

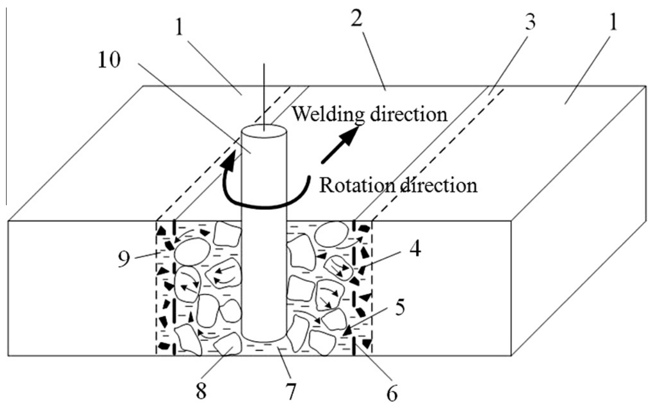

Fig. 1. Schematic of the semi-solid stirring brazing, 1—composites, 2—bond, 3—dissolved zone, 4—SiC particles in the dissolved zone, 5—SiC particles in the weld, 6—oxide film on surface of composites, 7—interdendritic liquid phase, 8—solid crystal grain, 9—dissolved liquid phase, 10—stirrer.