FRICTION WELDING OF Al-Cu-SiC COMPOSITE TO AISI 304 AUSTENITIC STAINLESS STEEL

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Original scientific paper

The present study investigates the feasibility of joining an aluminium matrix composite reinforced with 5, 10 and 15 vol. % of SiCp particles to AISI 304 austenitic stainless steel by using friction welding technique. In the present study, optical and electron microscopy as well as lap shear strength test and microhardness measurements were used to evaluate the quality of bonding of Al-Cu-SiC and AISI 304 austenitic stainless steel joints produced by friction welding

Keywords: *Friction welding, Aluminium metal matrix composite, Austenitic stainless steel*

1 Introduction

Aluminium based metal-matrix composites (MMCs) show improved specific stiffness and strength, better wear resistance and greater thermal stability in respect to the corresponding unreinforced matrix alloys, thus finding application mainly in the aerospace, automotive and motorsport fields [1–3]. Among Al-based MMCs, those reinforced with ceramic particles (such as Al2O3 or SiC) offer many advantages, such as: relatively simple and cost saving production routes, suitability to be processed by conventional secondary processes (forging, extrusion, etc.), as well as isotropic mechanical behaviour [4–6]. One of the main limitations in the use of these materials concerns their joining, since traditional fusion welding techniques (TIG, MIG, and laser) generally lead to microstructural defects, which in turn result in a decrease in their mechanical properties. In particular, the addition of the ceramic reinforcement causes higher viscosity in MMCs melts, particle segregation, evolution of the occluded gas and undesired matrix-reinforcement reactions [7,8], besides the typical defects commonly found in Al alloy fusion welds, such as solidification shrinkages, oxide inclusions and gas pores [8].

Friction welding is a solid-state joining process and one of the most effective processes for joining similar and dissimilar materials with high joint integrity. The present trend in the fabrication industries is the use of automated welding processes to obtain high production rates and high precision. To automate a welding process it is essential to establish the relationship between process parameters and weld quality [1]. Friction welding (FW) is preferred over other methods of welding of dissimilar materials because of its inherent qualities like easy control of process variables, high quality and prevention of atmospheric contamination of welding interface [2]. With the growing emphasis on the use of automated welding systems, FW is employed in semiautomatic or automatic mode in industry [3]. In such automated applications, a precise means of selection of the process variables and control of the amount of materials which is flash out in the welding interface has become essential. [2,3]. The acceptable or appropriate flash geometry and axial shortening on factors such as rotating speed, friction time, friction pressure, forging time and forging pressure, etc. Moreover, in the friction welding with the increase of rotation speed, the axial shortening quantity increases at the short friction time. In other words, the axial shortening speed is increases with increasing the rotation speed. It is because that increasing the rotation speed could enhance the input power of friction welding, leading to the shorter time for the heat generation, softening, plastic deformation and axial displacement. Hence, study and control of flash geometry and axial shortening is very much essential. To do this precise relationship between the process parameters controlling the axial shortening is to be established. This may be achieved by the development of mathematical expressions, which can be fed into a computer relating the flash geometry and axial shortening dimensions to the important process control variables affecting these dimensions. Also, optimization of the process parameters to control and obtain the required shape and quality of weld is possible with these expressions. Several studies have been recently focused on friction welding of aluminium alloys and some data are also reported on FW of aluminium-based composites. The application of this solid state welding technique to particles reinforced composites seems very attractive, since it should eliminate some typical defects induced by the traditional fusion welding techniques, such as: gas occlusion, undesired interfacial chemical reactions between the reinforcement and the molten matrix alloy, inhomogeneous reinforcement distribution after welding. The aim of this investigation is to evaluate the effects of process parameters on joint strength.

2 Materials and Experimental Process

2.1 Preparation of metal matrix composites

The test materials used in the present work were SiCp reinforced aluminium alloy metallic matrix composites manufactured by means of powder metallurgical method. Specimens were prepared using 99.8% pure aluminum, 99.5% pure silicon carbide (SiCp) and 99.9 % Cu powders. Metal matrix composite specimens were produced in the reinforcement volume fractions of 5%, 10% and 15% SiCp and 5% Cu. The Al powder has average particle size of 230 μm, SiC and Cu powder has average size 325 μm. The powders were blended by a motorized mixer to produce a homogeneous particle distribution, and were cold pressed.

After cold pressing compacted powder mixtures were hot pressed uniaxially in a single-end circular die made of hot-work tool steel under a pressure of 50 MPa inside a protective argon atmosphere at a temperature of 550 0C for a sintering time of 20 min. Sintered parts were machined in a lathe to a diameter of 12 mm and a length of 50 mm for the friction welding. Immersion density measurements were performed according to Archimides' method. In this technique density is determined by measuring the difference between a specimen's weight in air and when it is suspended in distilled water at room temperature.

2.2 Friction welding

For dissimilar friction welding, AISI 304 austenitic stainless steel and Al/SiCp metal matrix composite used test materials. Joining of these two dissimilar metals was performed on a continuous drive friction welding machine. The main welding process parameters employed were rotational speed, friction pressure, friction time, upset pressure and upset time. Friction welded specimens were cut longitudinally parallel to the welding interface for investigating the microstructural changes carry out in the welding interface and were polished using different grades of emery paper. Final polishing was done using the diamond compound (2 µm particle size) in the disc-polishing machine. For the microstructure examination, AISI 304 austenitic stainless steel side was etched with electrolytically in a solution of Oxalic acid (90% H_2O+10% Oxalic acid) and Al/SiCp metal matrix composite was etched in Keller (3% HCl+2% HF+3% HNO_3+92% H_2O). Lap-shear test was carried out on a Shimadsu mark tensile testing machine. The hardness was measured perpendicular to weld interface on both sides of the weld at a load of 30 g.

3 Result and discussion

3.1 Evaluation Microstructure

A view of dissimilar metal friction weld combination is shown in Fig1 and 2. İt is observed that the amount of flash, which much higher on the MMC compared to AISI 304 stainless steel. When the photographs of these welded joints are analyzed; an increase is observed on the material quantity that effuses depending on the increasing friction pressure despite sharing similarity in principle. As a result of the axial shortening measurements taken after welding, the greatest shortening has been established to be 5 mm on the sample no S6. Axial shortening has occurred only on the side of MMC. The reason why axial shortening has occurred on the side of MMC is that the metal matrix composite's hardness is low, density is less and resistance is high. When the macro interface photographs are also analysed (Figure 1,2), it has been clearly observed that diameter of the material that flanges outside as a result of the temperature increase on the interface due to increased friction pressure has been increased and it has caused the stainless steel to sink more into composite side.

Fig.1 and Fig.2 show the micrographs of specimens welded under different welding conditions. The Friction processed joints were sectioned perpendicular to the bond line and observed through a scanning electron microscopy (SEM). SEM photos revealed three distinct zones across the specimens identified as base material (BM), heat affected zone (HAZ) and plastically deformed zone (PDZ). The grain refinement occurred in the PDZ region by the combined effect of thermal and mechanical stresses. The width and geometry of these regions changed as a function of rotational speed, friction pressure and friction time. The most microstructural changes took place in the DZ region. High rotational speed can cause local heating at the interface to reach a high temperature at a short time. This condition causes lower cooling rates and a wider heat affected zone (HAZ), as a consequence a greater volume of viscous material transferred out of the interface. High rotational speed leads to narrower HAZ. It is well known that pressure used to bring joint pair together by plastic deformation results in dynamic recrystallization leading to a grain refinement in the central region of the weld [5]. The effect of increasing rotational speed over the friction welding joint is that both temperature gradient and axial shortening increase as a result of more mass transferred out of at the welding interface

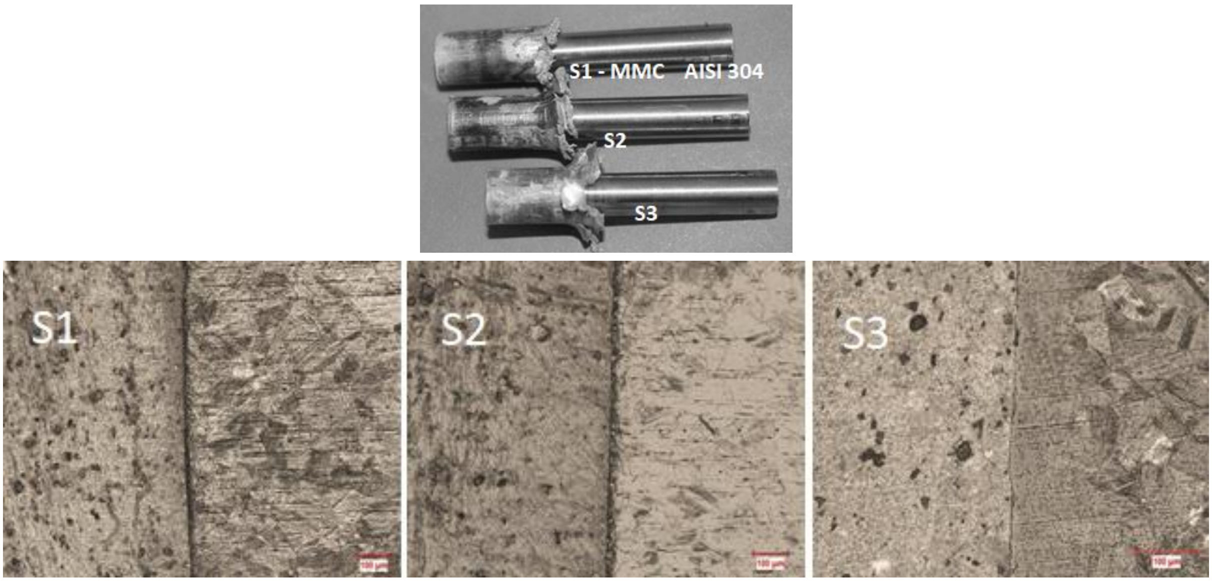

Figure 1. The microstructure in the welding zone of the friction welds by using 1500 rpm. rotation speed.

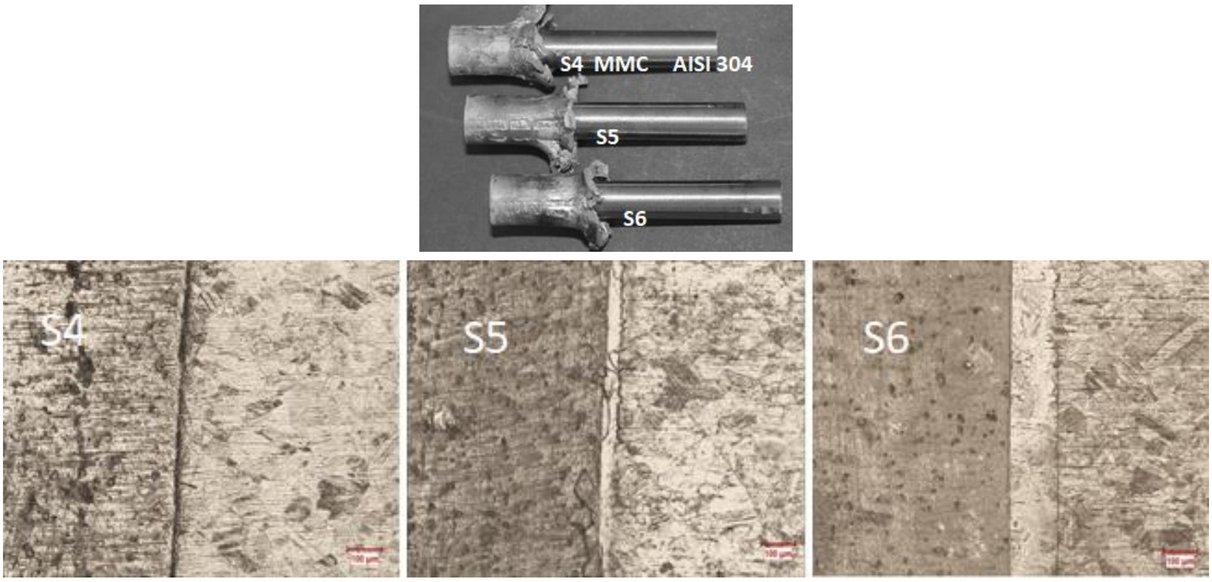

Figure 2. The microstructure in the welding zone of the friction welds by using 1500 rpm rotation speed.

3.2 Hardness test results

In this study, the micro-hardness distribution of the friction welded joints changes in two zones in accordance with the literature (see Fig.3). These zones are referred to as deformed zone and excessively zone. It has been observed that the hardness distribution increases in DZ and EDZ closer to welding interface and then decreases and reaches the main metal hardness value. The existence of a band that has deformation hardness as a result of the thermo-mechanical effect on the AISI 304 austenitic stainless steel side had been detected in the interface microstructure analysis of these welded joints. In the same way, the zone which is adjacent to the joint interface on MMC side, which has hardened as a result of thermo-mechanical effect and in which SiCp carbide build up has increased, has been identified in the SEM analysis photographs. The obtained hardness values are parallel to the structural change on the joint interface of the welded joints. The highest micro-hardness value has been recorded as 283 Hv on the AISI 304 austenitic stainless steel side and 104 HV on the MMC side. As can be clearly seen from the results, an increase has been recorded in the hardness on the joint interface depending on the increased friction time. When a comparison is made between the hardness values taken from all these samples, it has been observed that the rotational speed, friction time and friction pressure have a significant effect on the hardness values reached on the interface. It has also been observed that the hardness increases on MMC side depending on SiCp reinforcement ratio. The main reason for this can be related to the fact that the material cannot be sufficiently viscous in order to be ejected from the interface since the MMC's plastic deformation ability decreases as SiCp reinforcement ratio increases.

3.3 Evaluation of lap-shear test results

The lap-shear test has been performed on the welded joints joined by friction welding through the usage of 15 s friction time specified in the experimental design table. The lap-shear test has been primarily performed on unprocessed AISI 304 austenitic stainless steel and MMCs. When the lap-shear test results are analysed, it has been observed that all fractures display brittle fracture behaviour on the MMC side adjacent to the interface. As can be clearly seen from the results, the maximum shear strength of the welded joints reduces depending on the increased reinforcement ratio. In the literature related to the subject, it has been specified that in metal matrix composites, the hardness increases together with the increase of the reinforcement ratio but the shear strength reduces.

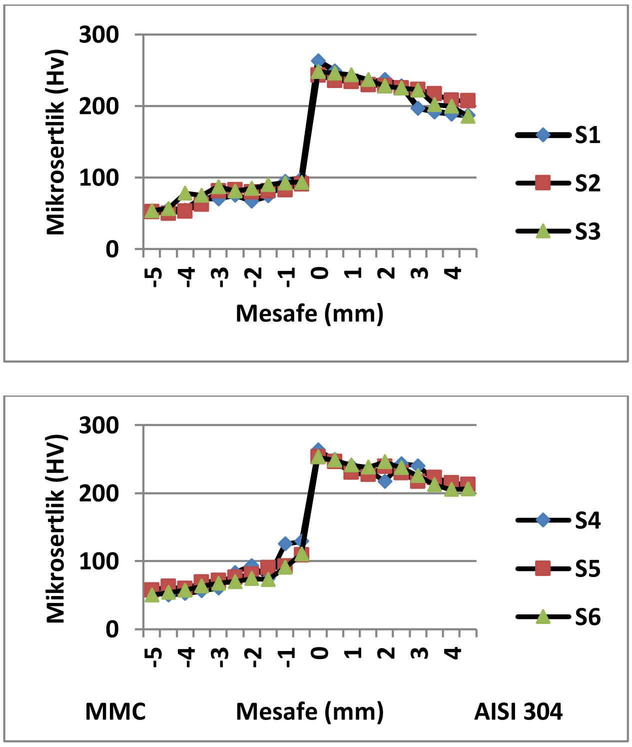

Figure 3. HV microhardness x distance bonding interface.

Table 1. Mechanical properties of friction welded samples.

Sample No	Rotation speed (rpm)	Friction presure (MPa)	SiC_p fraction rate (% Wt)	Shear strenght (MPa)
S1	1500	5	5	96
S2		10	10	108
S3		15	15	98
S4	1700	5	5	153
S5		10	10	197
S6		15	15	118

4 Conclusion

1. Al-Cu-SiC composite was successfully FS welded with to AISI 304 austenitic stainless steel with different parameters and material configurations.
2. The maximum tensile strength of the welding joints could reach up to 70% of the strength of the Al-Cu-SiC composite base metal. The joints strength increased up to a certain value and then decreased slightly with the applied friction pressure increasing.
3. The hardness at the interfaces was higher than that of the base material due to the presence of IMCs at the joints interfaces. The microhardness of Al side was almost no change under the welding parameters. Additionally, the microhardness distribution had slight variation from that of the base metals in the Mg side.

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