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The Effect of the Friction Pressure on the Friction Welding of AZ91 and Fe_3Al Alloys

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Abstract: In this study, Fe_3Al and AZ91 magnesium alloys were welded by friction welding method. The samples were machined to a cylindrical form having a diameter of 8 mm and 40 mm in length. Friction welding processes were carried out for 20, 40 and 60 MPa friction pressures under a friction time 12 s, 100 MPa forging pressure, 10 s forging time and 1000 rmp rotational speed. A continuous drive friction welding was used for friction welding process. After welding, the microstructures of welding interfaces of the welded samples were examined with optical microscopy and scanning electron microscopy (SEM). The optical microscopy and SEM investigations were revealed that the welding interfaces of the friction welded of AZ91 magnesium and Fe_3Al alloys have a smooth morphology without any crack or pore. Diffusion zone was occurred in the interfaces of the welded samples. The mechanical properties of welding interfaces were determined using a specially designed shear test apparatus. The samples inserted in the apparatus were cut on the universal tension-compression testing machine. The hardness values were measured from the center of the welding interface to both sides. The micro hardness measurements of the welding interfaces showed that the hardness values differ slightly at welding interface.

Keywords: Friction welding, AZ91 Magnesium alloy, Fe_3Al, Hardness

Introduction

Magnesium alloys have attracted much interest in academic studies, space, automobile and electronics industries in recent years due to its low density, dimensional stability, good machinability and low casting cost. In order to expand the use of these alloys, welding with other materials is of great importance (Sun et al. 2004, Fernandus et al. 2011, Elthalabawy et al. 2011). Recently, many automobile and space components are manufactured using magnesium alloys Therefore, the joining of these alloys is critical in the manufacture of parts. The combination of magnesium alloys and other materials presents various problems by conventional melt welding methods due to the different physical and metallurgical properties (Campell, 2006). In the literature, there are many studies on the weldability of Mg alloys, especially AZ91 alloys. AZ91 alloys can be welded by conventional melt welding methods such as laser welding, MIG welding and TIG welding. In addition, these alloys can be welded by solid state welding methods such as diffusion welding, spot welding, friction stir welding (Çelikyürek and Önal, 2016). On the other hand, Mg alloys have some problems arise from the nature of magnesium during the melt welding. The most important problems are the affinity of magnesium alloys to oxygen and nitrogen. Most of these problems disappear because of the lack of melting in solid state welding techniques.

Fe_3Al based iron aluminides have recently received considerable attention in engineering area. The ordered structure is found to exhibit low diffusion and lower creep rate. The formation of Al_2O_3 scales causes excellent corrosion resistance at high temperatures in oxidizing and sulfidizing environments (David et al. 1996). The welding is an important fabrication technology for iron aluminides to be used widely in engineering applications. Investigations of welding of Fe_3Al alloys have mainly focused on fusion weldability using gas tungsten arc (GTA) and electron beam welding (EB) processes (Santella 1997, David et.al 1993 and David et. Al 1998). Friction welding is one of the applicable solid-state welding techniques and is widely used in metals

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and alloys (Özdemir 2005, Lee et al. 2004, Sketchley et al. 2002). In this study, AZ91 magnesium alloy and Fe_3Al alloy were welded for different the friction pressures by friction welding.

Method

Fe_3Al alloy was produced with vacuum arc melting in argon atmosphere from iron and aluminum with 99,99 wt.% and 99.7 wt.% purity, respectively. The AZ91 alloy was proved a private firm. The Fe_3Al and AZ91 alloys were machined as cylindrical, 8 mm diameter and 40 mm length, at lathe machine for friction welding process. The friction welding experiments were performed out by a continuous-drive friction welding machine for under constant a friction time, forging pressure, forging time, rotational speed for different the friction pressure (Table 1).

Table 1. Parameters of the friction welding.

Rotational speed, rmp	Forging pressure (MPa)	Forging time (s)	Friction time (s)	Friction pressure (MPa)	Burn-Off (axial shortening) (mm)
1000	100	10	12	20	0,3
1000	100	10	12	40	1,8
1000	100	10	12	60	4,2

The friction welding principle is shown schematically in Figure 1. Four the welding process were performed for each a test condition. One of the welded samples was used for microstructure examinations. The shear tests were applied to the other welded samples to determine the shear strength of the joint and the results obtained were averaged. The shear strength tests were carried out at room temperature using a specially manufactured apparatus in a universal electromechanical tensile-compression device (Shimadzu AG-IS-250) (Figure 2).

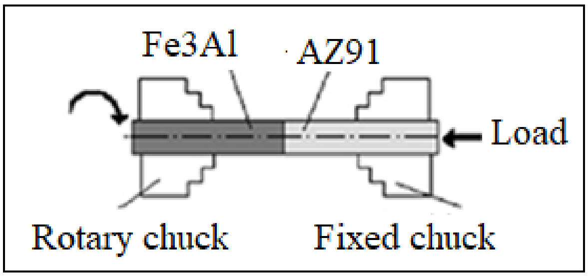

Fig. 1. Schematically illustration of the friction welding process.

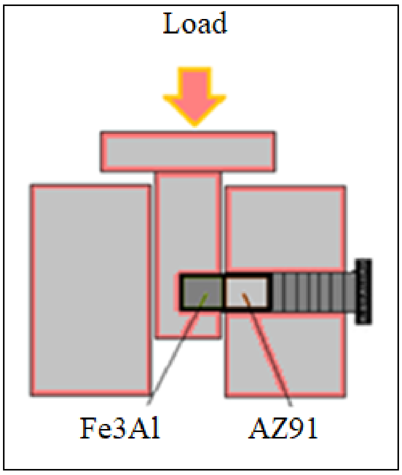

Fig 2. A specially designed specimen holder

The welded samples were cut perpendicular to the joint interface for microstructure investigations. The surfaces of the welded samples were ground with 600, 800 and 1200 mesh grinding paper and polished with a 3 µm diamond paste. Fe_3Al side of welded samples were etched with a mixture of H_2O (30 ml), HNO3 (30 ml), HCl (20 ml) and HF (20 ml). The AZ91 side was etched with 20 alcohol (20 ml), 2 H_2O and 1 gr $C_6H_3N_3O_7$. The interfaces of the welded samples were examined were optical microscopy. After the shear test, the surfaces of the fracture samples were examined by SEM and EDS analyzes were taken from these surfaces.

Results and Discussion

Flash formation was observed in all welded samples because of plastic deformation during the welding process. The friction pressure plays an important role in the flash formation. More plastic deformation occurs because of higher the friction pressure, which produces higher heat in the weld interface. Hence, the burn-off (axial shortening) increases with the increase in plastic deformation. The different physical and mechanical properties of the materials exhibit different deformation rates during the friction welding. Fe_3Al alloy has greater strength at high temperatures compared with AZ91. Therefore, Fe_3Al alloy does not show deformation during friction welding. All mass is transferred to the flash from the AZ91 side. Optical micrographs of the samples welded for 40 and 60 MPa the friction pressure are presented in Fig. 3. As seen micrographs, all of the welded samples were of sound quality and, they did not exhibit any pores or crack formation along the weld interface.

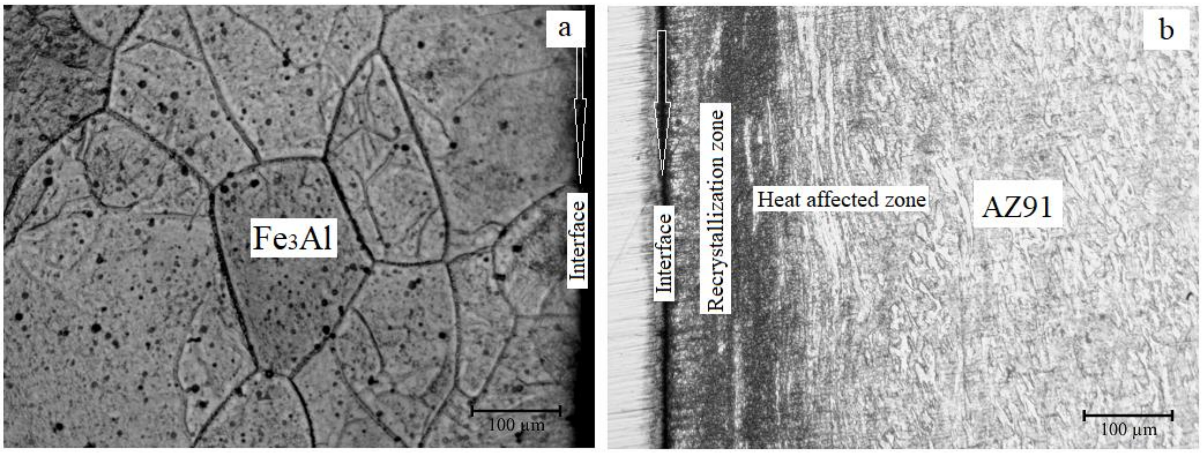

Fig. 3. Optical micrograph of the sample welded for 40 MPa friction pressure.

Two main regions are observable on the AZ91 side of the interface of all of the welded samples: a dynamically recrystallized zone with very fine grains and heat affected zone (Fig. 3b). The width of the dynamically recrystallized zone for all of the welded samples was approximately 190-200 μm. The micrographs demonstrated a slight variation in the width of dynamically recrystallized zone dependent on the friction pressure. There was not any change on the Fe_3Al alloy side (Fig. 3a).

The shear strengths of the welded samples and the base alloys are shown in Fig. 4. The results showed that the values of the shear strength of the welded samples increase with increase in the friction pressure. Under these experimental conditions, it can be said that the shear strength of the welded samples was depend on the friction pressure.

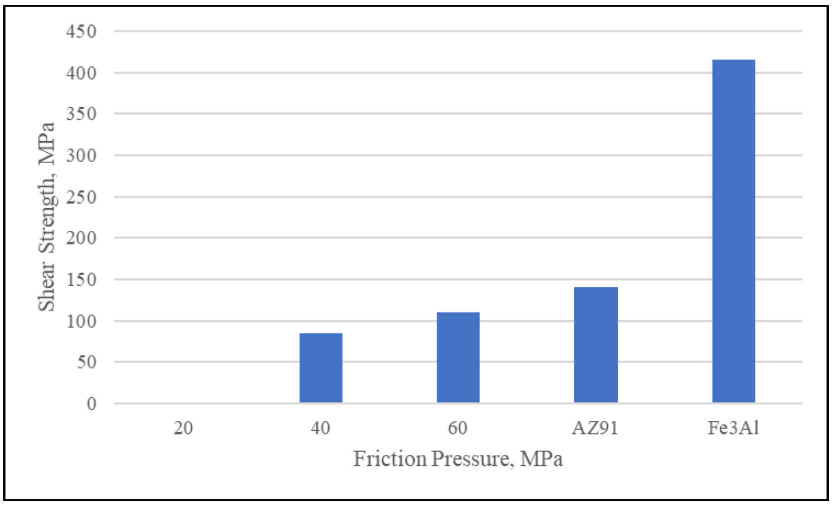

Fig. 4. The shear strengths of the welds and the base alloys

Microhardness values were measured in the direction from the center of the weld to both sides of the welded samples. The micro hardness profiles for all of the friction welding pressure were found to be similar. Fig. 5 shows the hardness values obtained from all the welded samples. The hardness of the dynamically recrystallized zone and heat affected zone is higher than that of the base alloy on the AZ91 side. The hardness of the dynamically recrystallized zone is higher the heat affected zone because of its fine-grained microstructure. There was not any changing on hardness of Fe_3Al alloy side.

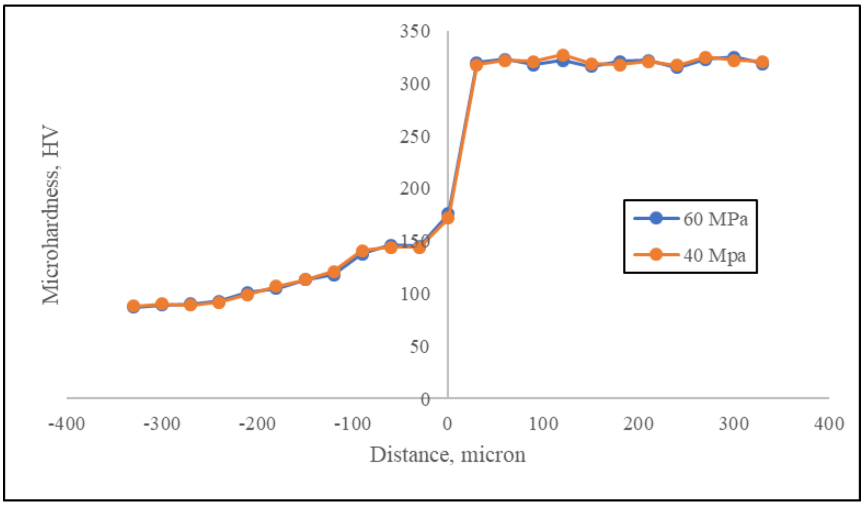

Fig. 5. The hardness values obtained from the welded samples for 40 and 60 MPa the friction pressure

Fig. 6 the SEM fractographs belonging to Fe_3Al side and AZ91 side of the welded sample that were treated for 60 MPa the friction pressure. The SEM and EDS analysis indicated that the failures took place in different zones, including interface of welded samples and the recrystallized zone of AZ91 side during the shear test. However, this situation was observed for all of the welded samples.

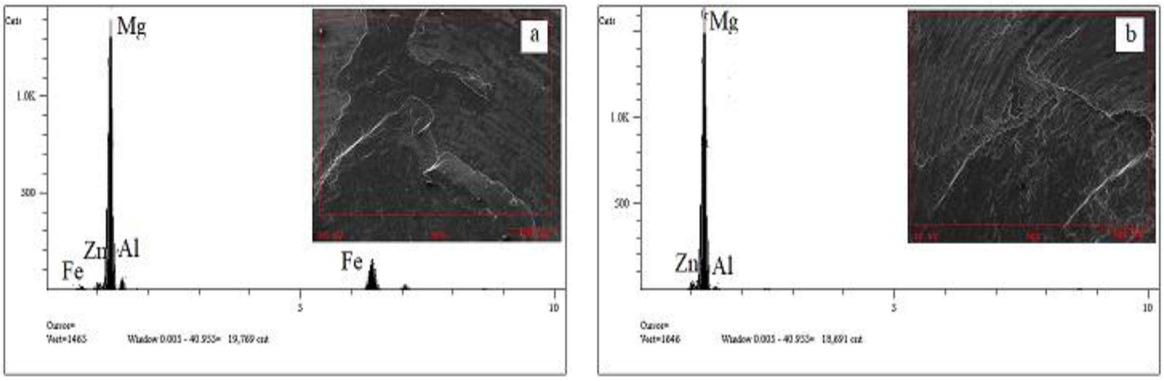

Fig. 6. SEM fractographs and EDS analysis of Fe_3Al side and AZ91 side

Conclusion

Fe_3Al and AZ91 alloys were welded by friction welding method. All of the welded samples were of sound quality, and they did not exhibit any pores or crack formation along the weld interface. The friction pressures play an important role in flash formation and welds shear strength. The welds shear strength and Burn-Off increase with increase in the friction pressure. After welding, while two different zone observed in the AZ91 side, there was not any difference on the Fe_3Al side. The hardness profiles for all friction pressure are similar. It was observed that AZ91 side has different hardness values. EDS analysis indicated that the failures took place in different zones during the shear test.

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