DISSIMILAR FRICTION-STIR WELDING OF AL ALLOY 1050 AND MG ALLOY AZ31

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ABSTRACT

Dissimilar friction stir welding of aluminum (Al) alloy 1050 and magnesium (Mg) alloy AZ31 was successfully done in the limited welding parameters. The dissimilar weld showed good quality and facility compared to conventional fusion weld. Transverse cross section perpendicular to the welding direction had no defects. The weld was divided into base material of Al alloy, an irregular shaped stir zone and base material of Mg alloy. The irregular shaped stir zone was roughly located around the initial weld center. The weld interface near plate surface shifted from initial weld centerline to the advancing side. Hardness profile of the weld was heterogeneous, and the hardness value of the stir zone was raised to about 150 Hv to 250 Hv. The mixed phase was identified to intermetallic compound $Mg_{17}Al_{12}$ using x-ray diffraction method, energy dispersive x-ray spectroscopy (EDX) and electron probe micro analysis (EPMA). The formation of intermetallic compound $Mg_{17}Al_{12}$ during FSW causes the remarkable increase in hardness value in the stir zone.

KEYWORDS

Dissimilar friction stir welding, Al alloy, Mg alloy, hardness distribution, intermetallic compound

1. Introduction

Friction stir welding invented by The Welding Institute (TWI, Cambridge, UK) in 1991 is a remarkable new process for joining workpieces in the solid phase, using a non-consumable rotating tool plunged into the joint line of the workpieces [1-3]. It has enabled us to butt-weld Al alloys, which are often difficult in fusion welding, without voids, cracking or distortion [4-13]. Furthermore, friction stir welds exhibit better tensile, bend and fatigue properties than fusion welds. Taking advantages of these positive factors, this process has already been applied to the construction of large Al structures [14,15]. Friction stir welding has also showed the feasibility for joining many types of materials such as Mg alloys, copper alloys, titanium alloys, lead, zinc, plastic and mile steel in addition to Al alloys [12,16,17].

As well as similar materials, friction stir welding has been examined for dissimilar material combinations [18-21] since dissimilar welding can achieve cost and weight reduction and high efficiency of production. In the present study, using light materials of Al alloy and Mg alloy, we investigated the relationship between microstructure and hardness distributions in a dissimilar friction-stir weld of Al alloy and Mg alloy.

2. Experimental Procedures

The materials used for dissimilar friction stir welding were Al alloy 1050 and Mg alloy AZ31, nominally 6 mm in thickness. The welding was performed such that Al alloy 1050 and Mg alloy AZ31 placed at retreating and advancing side, respectively, as shown in Figure 1. The two plates were friction-stir-welded at various welding parameters. The welding tool rotated counterclockwise and was tilted a few degrees from normal direction of the plate.

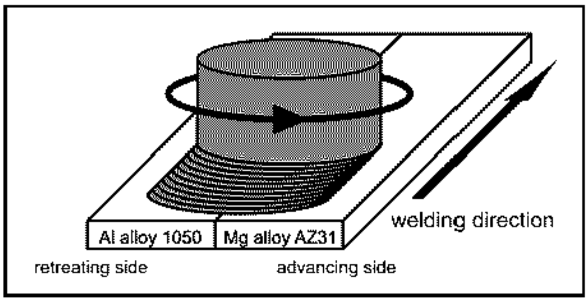

Fig. 1 Schematic illustration of dissimilar friction stir welding.

Following friction stir welding, transverse cross section was observed by optical microscopy (OM). The specimen for OM was cut perpendicular to the welding direction using an electro-discharge machine, and then was etched in a 5 ml acetic acid + 5 g picric acid + 10 ml water + 100 ml methanol solution. Vickers hardness profile of the weld was measured on the cross section perpendicular to the welding direction. In order to examine formation of new phase in the stir zone, some regions of the stir zone were analyzed by energy dispersive x-ray spectroscopy (EDX) and electron probe micro analysis (EPMA). In addition, x-ray diffraction method was used for the powder sample produced from the stir zone.

3. Results and Discussion

Dissimilar friction stir welding of Al alloy 1050 and Mg alloy AZ31 was allowed at the limited welding speeds and rotation speeds. The dissimilar welding was successfully done in case that Al alloy 1050 and Mg alloy AZ31 placed at retreating and advancing side. Exchanging the placement of Al alloy 1050 and Mg alloy AZ31, however, led to fail in the dissimilar welding. It is supposed that the welding parameters in dissimilar materials might be limited than those in similar material due to differences in material properties.

Figure 2 shows transverse cross section perpendicular to the welding direction in dissimilar weld produced at welding parameters, 2450 rpm and 1.5 mm/s. The weld consisted of the two base materials of Al alloy 1050 and Mg alloy AZ31, and irregular shaped stir zone, which was located between the two base materials. The irregular shaped stir zone, whose boundary was observed distinctly, was roughly corresponding to the recrystallized zone known to a typical characterization of friction-stir welded Al alloys [4,9]. The weld interface near the upper surface was shifted from initial weld centerline to the advancing side.

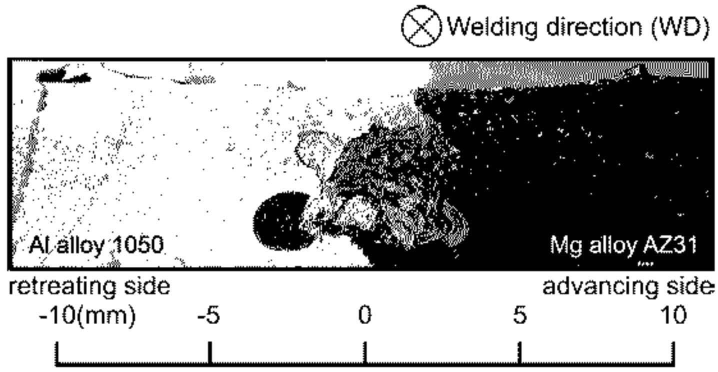

Fig. 2 Transverse cross section perpendicular to the welding direction.

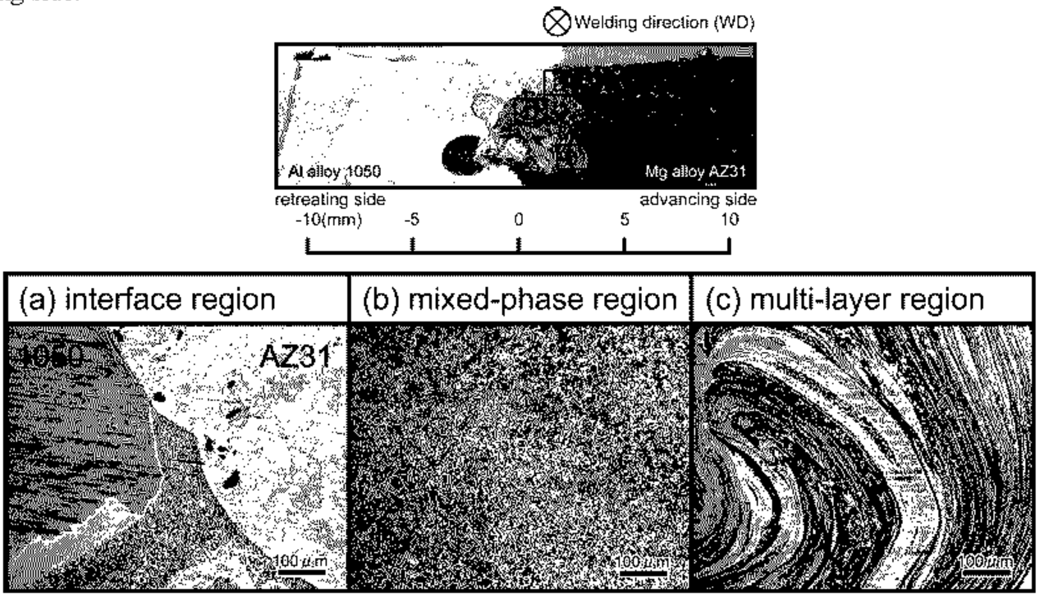

Fig. 3 Optical micrographs of (a) interface region, (b) mixed-phase region and (c) multi-layer region.

Figure 3 shows optical micrographs of three regions indicated in the cross section of the dissimilar weld: The three regions could be roughly classified as (a) "interface region" between the two base materials near the upper surface, (b) "mixed-phase region" and (c) "multi-layer region" within the stir zone. The stir zone had heterogeneous structures, i.e., both mixed-phase region and multi-layer region. The two base materials were divided distinctly in the interface region. The mixed-phase region was formed from edge of the interface region and broadly extended to the whole stir zone, as shown in figure 3(a) and (b). The multi-layer region had some phases that included Al alloy 1050, Mg alloy AZ31 and mixed-phase region. Figure 4 shows detailed microstructure of the mixed-phase region, which looks experienced partial-melting.

Figure 5(a) shows two-dimensional hardness distributions on the cross section of the dissimilar weld. Hardness profile on the dotted line indicated in Figure 5(a) is shown in Figure 5(b). Average hardness values of the two base materials were

Fig. 4 Optical microstructure of mixed-phase region.

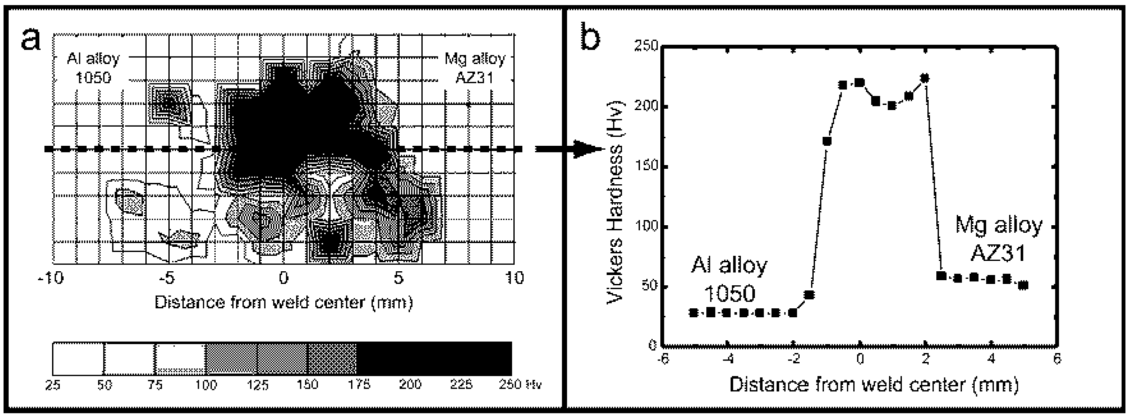

Fig. 5 Hardness distributions on the cross section of the dissimilar weld.

about 27 Hv and 55 Hv in Al alloy and Mg alloy, respectively. The hardness values in the stir zone, where the hardness was heterogeneously distributed, were measured to about 5 times higher than those of the two base materials, i.e., 150 - 250 Hv. These increased hardness values suggest formation of other phases in the stir zone including mixed-phase region during friction stir welding.

In order to investigate the reason for great increase in hardness values in the stir zone, EDX, EPMA and x-ray diffraction method were performed for the dissimilar weld. Figure 6 shows EDX images for interface region, mixed-phase region and multi-layer region, which are corresponding regions to Figure 3(a), (b) and (c), respectively. Al-rich or Mg-rich phase is indicated as bright region in each EDX image. EDX analysis for three regions is roughly coincident with optical microstructural observation. It should be noted that the mixed-phase region has heterogeneous microstructure, which is similar to optical microstructure as shown in Figure 4. Closer investigation using EPMA was carried out in the interface region including the mixed phase formed between the two base materials. As shown in Figure 7, the mixed phase mainly contained Mg-rich phase although it has heterogeneous microstructure, which is the same result as EDX analysis. Figure 8 shows x-ray diffraction pattern for the powder sample produced from the irregular shaped stir zone. It was detected that the stir zone had large amounts of intermetallic compound $Mg_{17}Al_{12}$.

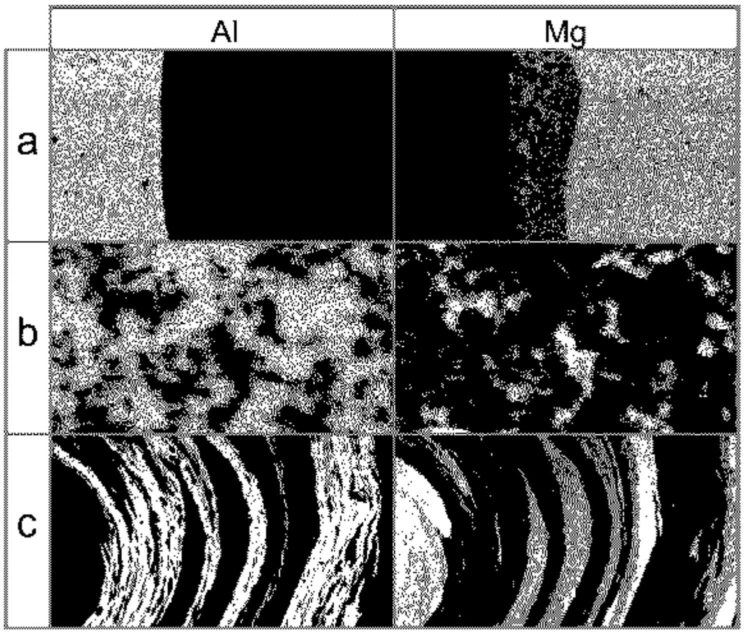

Fig. 6 EDX images in (a) interface region, (b) mixed-phase region and (c) multi-layer region.

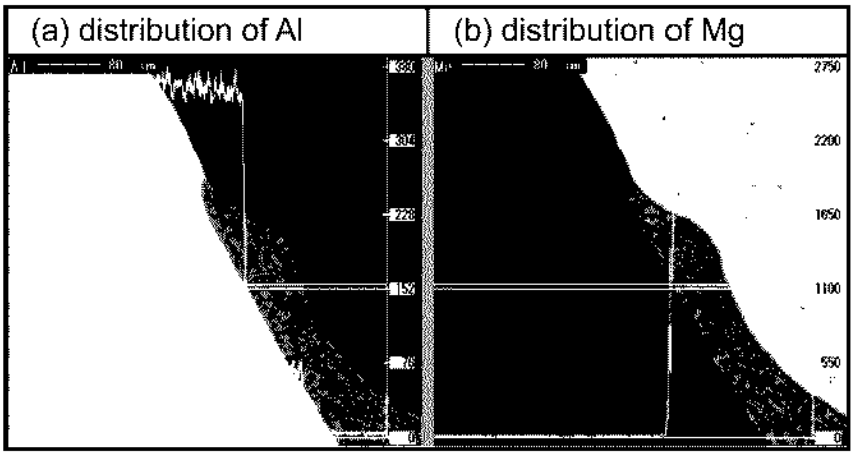

Fig. 7 EPMA analysis in the interface region and mixed-phase region.

During the welding, stirring could make layered phase of Al alloy and Mg alloy, as shown in Figure 3(c). At elevated temperatures achieved by friction heating, there is a possibility that mutual-diffusion between the two alloys could be activated. It is known that peak temperature in similar conditions to the present study rises over 723K during the welding [4,13]. According to the phase diagram of Al-Mg system [22], intensive mutual-diffusion during the stirring can form constitutional liquid phase at this temperature. As a result, it is supposed that these periodical stirring and activated diffusion led to the liquid phase in the stir zone during the present dissimilar welding, so that solidification from the liquid phase made extensive formation of $Mg_{17}Al_{12}$ possible. This result also reveals that great increase in hardness values in the stir zone is attributed to formation of intermetallic compound $Mg_{17}Al_{12}$ during friction stir welding.

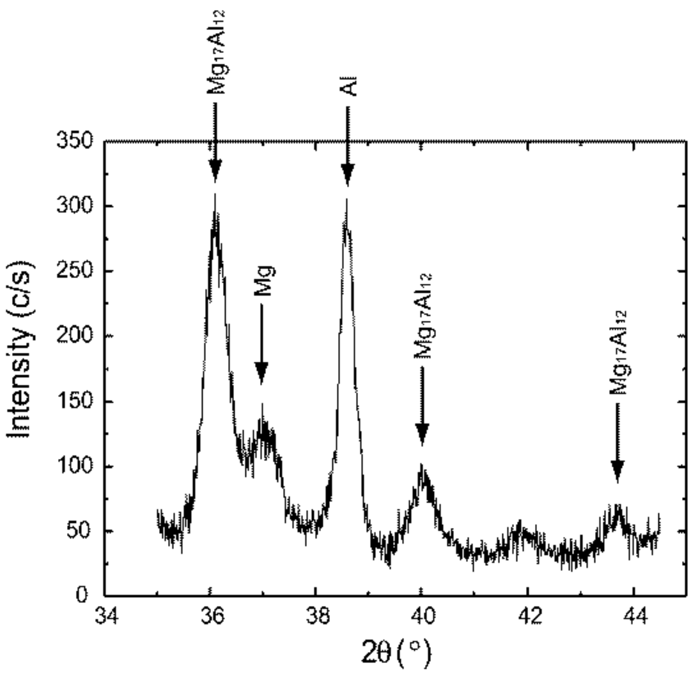

Fig. 8 X-ray diffraction pattern of irregular shaped stir zone.

4. Conclusion

Dissimilar friction stir welding of Al alloy 1050 and Mg alloy AZ31 produced the irregular shaped stir zone without defects near the weld center. The stir zone including mixed phase showed remarkable rise of hardness values, which is caused by extensive formation of intermetallic compound $Mg_{17}Al_{12}$ during friction stir welding.

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