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Original Research Article

Effects of the process parameters on the formability of the intermetallic zone in two-layer Mg/Al materials

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ABSTRACT

This paper discusses experimental results concerning the plastic deformation of the bonding zone in a two-layer AZ31/Al material subjected to compression loads. The specimens were fabricated by diffusion bonding method. The 50 μm thick transition zone at the AZ31/Al interface contained Mg–Al intermetallic phases. The physical modelling of the deformation behaviour of the intermetallic zone was performed using a Gleeble 3800 system. The compression tests were carried out at two temperatures (300 and 400 °C), two strain rates (0.1 and 1.0 s^{-1}) and a true strain of 0.15 applied in one or two stages. The metallographic examinations and microhardness measurements were performed to assess the influence of the selected process parameters on the forming behaviour of the intermetallic zone. The experiments revealed that the main factors affecting the formability of the intermetallic zone in the two-layer AZ31/Al material were the strain rate and the temperature. It was found that when the deformation occurred at a strain rate of 0.1 s^{-1} and a temperature of 400 °C, there was no loss of continuity of the intermetallic transition zone; such conditions induced its plasticization.

1. Introduction

In recent years, there has been considerable interest in bimetals and metallic layered composites [1–3] because of their unique properties unattainable in single metals. The growing demand for lightweight structural materials to be used in the automotive industry has led to more intensive research to develop new aluminium and magnesium based alloys. Two-layer (Mg/Al) or multi-layer (Al/Mg/Al) materials are a promising solution to expand the application of these light metals in the transport sector. Various methods can be used to bond Al with Mg in order to produce a one-body solid material; these include casting [4–6], friction stir welding [7],

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explosive welding [8,9], hot-pressing [10–12], extrusion [13–16], hot-rolling [17–20], and cold-rolling [21].

From the literature it is evident that bimetallic Mg/Al or multi-layer Al/Mg/Al products are generally fabricated at elevated temperatures and the bonding zone forms between Al and Mg as a result of diffusion. The microstructure of the bonding zone, which affects the properties of bimetal elements, is dependent on the fabrication method. As shown in [4–6], the bonding zone in Al/Mg bimetals formed by casting was thick and had a non-homogeneous structure; there was a eutectic ($Mg_{17}Al_{12}$ and a solid solution of Al in Mg) on the Mg side and Al–Mg intermetallic phases in the area adjacent to Al. In [7], Sato et al. examined the microstructure of the Al alloy 1050 and Mg alloy AZ31 joints produced by friction stir welding. They found that the bonding zone was irregular in shape and had a eutectic structure ($Mg_{17}Al_{12}$ and a solid solution of Al in Mg). In [8,9], the explosive welding method was used to produce Mg–Al bimetallic bars. The microstructural analysis showed that metallurgical bonding was achieved and the Al/Mg interface had a wavy morphology. Locally, a thin $Mg_{17}Al_{12}$ intermetallic phase transition zone was found. The fabrication of Mg/Al bimetals by hot metal forming processes proceeds at a temperature below the eutectic temperature of the Mg–Al system (437 °C). In this case, the bonding zone is thin and continuous; it is composed of two layers of Mg–Al intermetallic phases: Al_3Mg_2 on the Al side and $Mg_{17}Al_{12}$ on the Mg side. As the bonding zone is hard and brittle, cracks are very likely to appear while further plastic deformation takes place. The Electron Backscatter Diffusion (EBSD) analysis presented in [15] reveals that the two-layered intermetallic zone in Mg/Al compounds fabricated by extrusion has a specific columnar structure, with columnar grains oriented perpendicular to the Mg/Al interface. The detailed microstructural analysis of the intermetallic zone in bimetallic Mg/Al rods described in [16] confirms the occurrence of a columnar grain structure. There are several studies concerning the behaviour of Mg–Al intermetallic phases in Mg/Al materials. In [18], which deals with the fabrication of Al(5052)/Mg(AZ31)/Al(5052) laminated composites using two-pass hot rolling, the test results show that during the first pass no new phases formed at the Mg/Al interface. The formation of a continuous transition layer composed of Mg–Al intermetallic phases was observed during heating before the second pass. During the second rolling pass, cracks occurred in the intermetallic layer and they were perpendicular to the Mg–Al interface. After the process, broken fragments of intermetallic phases were observed at the interface. Luo et al. [18] suggest that the fine intermetallic particles at the interface may strengthen the bonding of the layers in Al/Mg/Al laminated composites. Feuerhack et al. [14,15] attempted to determine the formability of the intermetallic zone in Mg/Al compounds. In their studies, co-extruded Mg/Al specimens were formed using the following subsequent die forging processes: upsetting, spreading and rising to achieve different load conditions for the Mg/Al interface. It was found that, depending on the load direction, the intermetallic zone was more or less susceptible to plastic deformation with no crack formation. In spreading and rising, the load acted along the long columnar grains. The combination of elongation and high shear stresses led to fracture; the intermetallic zone was cracked in several places. By contrast, the load applied during upsetting was perpendicular to the columnar grains so they were under compression. In that case, the intermetallic zone of a deformed specimen did not show any fracture or crack. Another article on this subject [20] investigates the relationship between the parameters of deep drawing and the formability of multilayer Al/Mg/Al composite sheets fabricated by accumulative roll-bonding. The microstructural analysis of the intermetallic zone at the Mg/Al interface of a deep drawn cup shows that the propagation of cracks in this zone could be suppressed by increasing the deformation temperature. Fewer cracks were observed after deformation at 200 °C than at 150 °C.

This study is a continuation of research on the deformation behaviour of the intermetallic transition layer in Mg/Al materials; the preliminary results were presented in [22]. The material tested was a AZ31/Al bimetal fabricated by diffusion bonding. The investigations involved compression tests using a Gleeble 3800 thermo-mechanical testing system. The purpose of this study was to determine the effects of selected process parameters, i.e. the temperature, the strain rate and the deformation procedure (one or two stage process), on the forming behaviour of the intermetallic zone. The hardness test results and the flow curves were used to analyze the influence of the process parameters on the strengthening of the bimetallic material. The microstructure of the intermetallic zone in deformed specimens was studied to determine how much the assumed parameters contributed to the plasticization of this area.

2. Experimental materials and procedures

AZ31 magnesium alloy and 1050A aluminium alloy were used in the experiments. $40 \times 20 \times 10$ mm AZ31 and $40 \times 20 \times 0.8$ mm 1050A specimens were joined by diffusion bonding. Prior to that, the surfaces were ground with SiC paper progressively to 800 grit, cleaned with ethanol and dried in air. The AZ31 and Al pieces were placed in a vacuum furnace, where they were heated from room temperature to 430 °C for 30 min, kept at that temperature for 20 min, and cooled down to room temperature. During the heat treatment process, a pressure of 5 MPa was applied to bond the two metals.

The forming behaviour of the intermetallic zone in the two-layer AZ31/Al material produced was studied using compression tests performed with a Gleeble 3800 system. The specimens used in the simulation were cuboidal in shape with dimensions of $10 \times 15 \times 20$ mm. It should be noted that a rectangular base prism specimen normally employed in a compression test yields a three dimensional state of stress and a plane strain condition [23]; the process conditions resemble those reported during flat product rolling [24]. This assumption, however, generally applies to homogeneous materials [23,24]. The compression method employed in this study to deform the two-layer material could disturb the plane strain state; with this in mind, the tests were conducted not only to determine the plastic flow curves for the AZ31/Al material but mainly to analyze the behaviour of the intermetallic transition zone during plastic deformation.