

THE ANALYSIS OF THE PLASTIC DEFORMATION OF TWO-LAYERED MAGNESIUM – ALUMINIUM ALLOYS (AZ31 – Al)

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The paper presents the results of physical modelling of the plastic deformation of the two-layered AZ31 - Al alloys. The AZ31 - Al feedstock was produced using the diffusion bonding method. Heating under pressure led to the formation of a continuous layer of the intermetallic phases at the bond interface of AZ31 - Al. A compression test was used to determine the plastic deformation of the two-layered AZ31 - Al alloys. Based on the analysis of the investigation results it has been found that, as the strain rate decreases and temperature increases, the intermetallic phase yields, and a distinct thinning of the intermetallic phase layer has occurred in the zone directly affected by the anvil.

Key words: magnesium – aluminium alloys, microstructure, plastic deformation, diffusion bonding, physical modelling

INTRODUCTION

In recent years, many surface treatment methods have been developed and applied to improve surface properties magnesium and its alloys [1]. A promising surface treatment method for improving the corrosion and wear resistance is the fabrication of alloyed layers enriched in Al on a Mg - based substrate. Laser surface alloying [2] and thermochemical treatment [3] are among commonly used techniques for the fabrication the Al - enriched layers. There are also a lot of studies concerning the fabrication of Mg - Al bimetallic or Al - Mg - Al multi-layered materials by hot-pressing [4], extrusion [5], hot-rolling [6, 7], explosive welding [8], twin-roll casting [9], in which the outer layer being either of pure aluminium or an Al alloy offers effective anti-corrosive protection to the Mg substrate. During the fabrication of Al - Mg multilayer products, a transition diffusion zone of Mg - Al intermetallic phases may be formed at the bond interface. As shown in the literature [5, 7], this intermetallic zone, being composed of the Al_3Mg_2 phase (on the Al side) and the $Mg_{17}Al_{12}$ phase (on the Mg side), is hard and brittle, enhancing further the durability of such materials.

Thus, the purpose of the study is to determine the effect of temperature and strain rate on the possibility of plastic deformation multilayer Mg - Al alloys without losing the continuity of the intermetallic phase layer.

EXPERIMENTAL PROCEDURE

The two-layered AZ31 - Al material was prepared by the diffusion bonding method. 40 x 20 x 10 mm sam-

ples were cut out from an AZ31 magnesium ingot. Sheets 40 x 20 mm in size were cut from 1,0 mm - thick 1050A aluminium sheet, which was used as the cladding material. The joining surfaces of the metals were ground with SiC paper with a grit size increasing progressively to 800, then cleaned with ethanol and, finally, dried in air. The AZ31 and Al samples were placed in a vacuum furnace and heated up from room temperature to 430 °C for 30 minutes, kept at that temperature for 20 minutes, and cooled down in the furnace to room temperature. The vacuum furnace used in this study, as shown in Figure 1, was equipped with a pressure pad. A pressure of 5 MPa was used to ensure good contact between the AZ31 substrate and the aluminium sheet during the heat treatment process.

The microstructure of the AZ31 - Al material was observed using a Nikon ECLIPSE MA 200 optical microscope and a JEOL JSM-5400 scanning electron microscope (SEM). A chemical composition analysis was conducted using an Oxford Instruments ISIS 300 X-ray energy dispersive spectrometer (EDS) attached to the SEM.

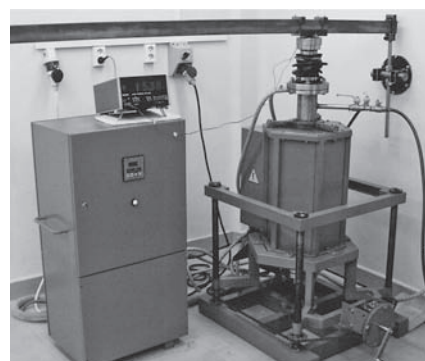


Figure 1 The Vacuum furnace equipped with a pressure pad used for diffusion bonding of the AZ31 substrate with the Al sheet.

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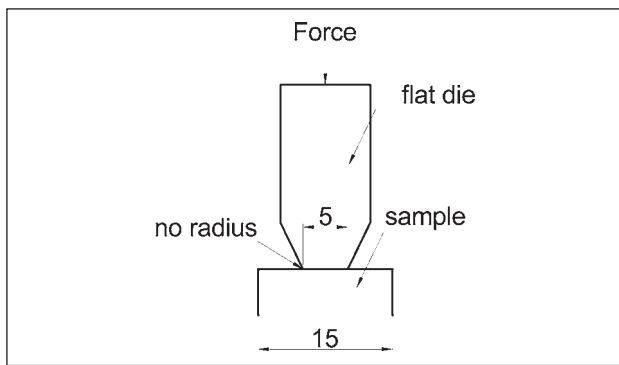


Figure 2 The schedule of the compression test using the Gleeble 3800 simulator.

The physical modelling to determine the possibility of plastic deformation the two-layered AZ31 - Al material was carried out using the Gleeble 3800 in the rectangular prism sample compression test. It should be noted that the rectangular prism sample compression test yields a three dimensional state of stress and a plane state of strain. This is a good approximation of the flat product rolling conditions. This assumption applies to homogeneous materials. By contrast, using the aforementioned method for two-layered samples might cause a disturbance of the plane strain state. However, the compression method employed in the study was not used to determine the plastic flow curves for the material under examination, but only to establish the possibility of plastic deformation of two-layered materials. The compression parameters, i.e. temperature, deformation and strain rate, were selected based on references [6, 7], where the Al - Mg - Al multi-layer material rolling process was investigated. The compression tests were conducted for the parameters: temperature 300 and 400 °C, strain rate 0,1 and 1,0 s⁻¹, and the true strain up to 0,15.

The tests measured the value of stress causing permanent deformations, which can be defined as the resistance to the plastic flow of the two-layered material. The schedule of the compression test is shown in Figure 2.

RESULTS AND DISCUSSION

Figure 3a shows the microstructure transition zone formed at the AZ31 - Al interface after the heat treatment process conducted at 430 °C for 20 minutes. The zone was about 50 μm thick. The high-magnification SEM image presented in Figure 3b illustrates the details of this zone. Two layers could be distinguished in the transition zone. The thinner layer (denoted as 1 in Figure 3b) in the vicinity of the AZ31 and the thicker one (denoted as 2) adjacent to the Al. The results of the quantitative EDS analysis indicate that the composition of layer 1 (61,75 at. % Mg and 38,25 at. % Al) is similar to that of the Mg₁₇Al₁₂ intermetallic phase. The composition of layer 2 (41,12 at. % Mg and 58,88 at. % Al) suggests the presence of the Mg₂Al₃ intermetallic phase. Solid state diffusion during the heat treatment process resulted in the growth of a continuous zone composed

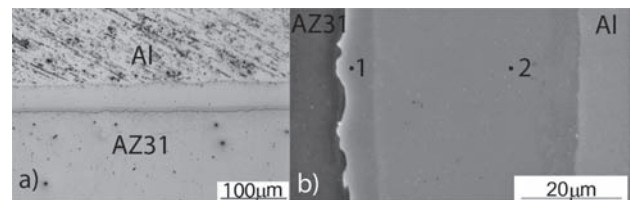


Figure 3 The microstructure of the bond region in the AZ31 - Al feedstock material - a) and SEM image of the bond region - b).

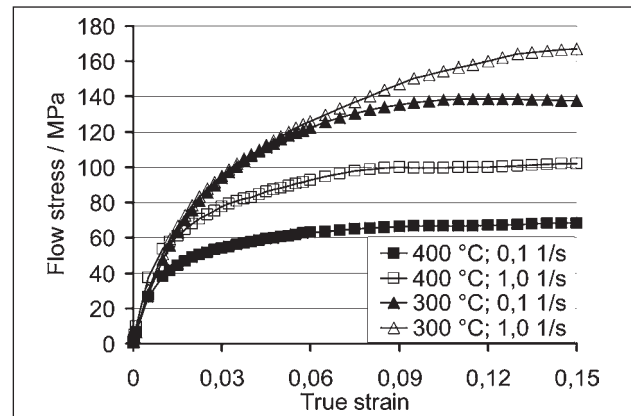


Figure 4 The plastic flow curves obtained from the compression tests of AZ31 - Al samples.

of Mg - Al intermetallic phases at the interface. As shown in the literature, Mg - Al intermetallic phases are characterized by high hardness. The microhardness reported for the Mg₁₇Al₁₂ and Al₃Mg₂ was 250 HV and 275 HV, respectively [10]

Comparison of the obtained plastic flow curves is shown in Figure 4.

From the data represented in Figure 4 it can be noticed that the temperature and strain rate have a considerable influence on the values of stress recorded during the deformation of the material tested. By examining the effect of strain rate on the plastic flow resistance it has been found that with the increase in strain rate the plastic flow resistance of deformed two-layered AZ31 - Al samples increases, regardless of the temperature applied. By analyzing the effect of temperature on the behaviour of the plastic flow variation curves, a considerable effect of this parameter on the obtained plastic flow resistance values has also been found. Increasing the value of strain rate causes an increase in plastic flow resistance, while raising the temperature from 300 to 400 °C results in a decrease in the plastic flow resistance.

The next stage of the investigation involved the metallographic analysis of the bond regions of AZ31 - Al samples after compression tests. Figure 5 shows the cross-section of an example AZ31 - Al sample after a compression test at a temperature of 300 °C and a strain rate of 0,1 s⁻¹. The shape of the employed anvil (no rounding at the location of the working portion transition into the lateral surface – Figure 2) causes the greatest tensile stresses to occur in the sample being deformed, as the anvil penetrates into the material tested, in regions close to the anvil edge. Therefore, for all

AZ31 - Al samples, microscopic observations of this region (the region A - Figure 5), as the most prone to the occurrence of cracks, were made in the zone of the diffusion bond composed of Mg - Al intermetallic phases.

Figure 6 shows the microstructure of the region A in two-layered AZ31 - Al samples deformed in the compression test. When analyzing the data in Figure 6 it can be found that the use of the temperature 300 °C and the strain rate 1,0 s⁻¹ (Figure 6a) has caused a considerable fragmentation of the Mg - Al intermetallic phase layer. This result shows that the transition layer consisting of Mg - Al intermetallic phases is characterized by high brittleness. Decreasing the strain rate value to 0,1 s⁻¹, with the temperature unchanged, also causes the fragmentation of the intermetallic phase layer (Figure 6b).

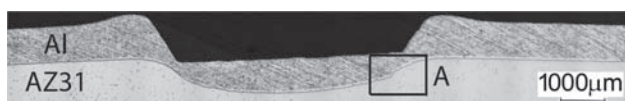


Figure 5 A two-layered AZ31 - Al sample after the compression test at a temperature of 300 °C and strain rate of 0,1 s⁻¹.

In both cases analyzed above, no plastic deformation (thickness reduction) of the intermetallic phase layer was observed. To minimize the possibility of cracks occurring in the intermetallic phase layer, the compression test temperature was increased. Figure 6c shows a microphotograph of a sample deformed at a temperature of 400 °C at a strain rate of 1,0 s⁻¹. In this case, a smaller number of cracks in the intermetallic phase layer and a slight thinning of this layer was observed, which suggests its plastic deformation. Using an even lower strain rate of 0,1 s⁻¹, with the deformation temperature unchanged (Figure 6d), caused the examined Mg - Al intermetallic phase layer to deform plastically. In the deformed AZ31 - Al sample, no intermetallic phase layer cracks were observed in the region A. The layer underwent an appreciable thinning (deformation) without losing its integrity.

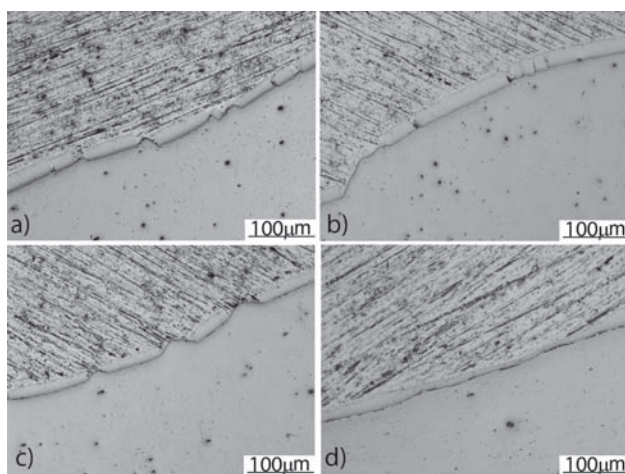


Figure 6 The microstructure of the region A after compression tests: a) 300 °C, strain rate 1,0 s⁻¹, b) 300 °C, strain rate 0,1 s⁻¹, c) 400 °C, strain rate 1,0 s⁻¹, d) 400 °C, strain rate 0,1 s⁻¹.

SUMMARY

Based on the analysis of the investigation results it can be stated that the diffusion heating method enables two-layered AZ31 - Al feedstock to be produced, which is distinguished by diffusion bonding through the transition layer of Mg - Al intermetallic phases. The physical modelling of deformation in the compression test has demonstrated that the plastic flow resistance of two-layered AZ31 - Al samples is dependent on the process parameters (temperature and strain rate). The obtained results indicate the possibility of deforming the two-layered AZ31 - Al alloys, while preserving the intermetallic layer integrity, using low strain rates and high deformation temperatures.

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Note: The professional translator for the English language is Czesław Grochowina, Studio Tekst, Czestochowa, Poland