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# THE THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE POSSIBILITY OF EMPLOYING THE GROOVE ROLLING PROCESS FOR THE MANUFACTURE OF Mg/Al BIMETALLIC BARS

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The paper presents the results of investigation into the possibility of employing the groove rolling process to produce round Mg/Al bimetallic bars. The feedstock were round 22,5 mm Mg/Al bars that had been produced using the explosive welding method. The average thickness of the aluminium layer amounted to 1,7 mm. The Mg/Al bars were rolled in the stretching rolling passes. The theoretical analysis was done using the Forge2011® computer program. Based on the theoretical and experimental analysis it has been found that one of the main rolling process parameters influencing the quality of bond between the bimetal components is the initial feedstock temperature.

*Key words:* Mg/Al bimetallic bars, groove rolling, temperature, stress, numerical analysis

## INTRODUCTION

Magnesium is characterized by low density and excellent ability to dampen vibrations. However, it exhibits poor strength and low deformability due to the fact that its crystal lattice has a limited number of slip systems at ambient temperature [1]. Another obstacle to its broader use in technology is relatively poor corrosion resistance and considerable abrasive wear. The increase in the corrosion resistance of Mg alloy products is achieved by employing various surface treatment methods [2]. One of the method to increase the corrosion resistance of Mg alloy products is, e.g., by applying Al cladding layers. Such a layer is distinguished by a greater thickness. Thus, a prospective solution is to produce Mg/Al bars that will provide increased corrosion resistance compared to magnesium bars produced by a different method. For this purpose, it is necessary to produce Mg/Al bars, in which the outer layer will be aluminium, with the individual layers being bonded together.

Aluminium layer clad Mg alloy products can be subsequently subject to further metal forming, if needed. This type of layer with the adequate thickness can be produced using, e.g., hot-pressing [3] or explosive welding [4] methods, in the rolling [5, 6] or extrusion [7] process.

Good bonding between layers in bimetallic feedstock does not guarantee the correct behaviour of the composite during groove rolling. With an unfavourable layer thicknesses ratio and inadequately selected technological parameters, delamination of individual components and a non-uniform outer layer distribution over the bar perimeter may occur. Thus, the aim of the study was to determine the possibility of using the groove rolling process to obtain round Al - clad magnesium bars from feedstock made by the explosive welding method.

## CONDITIONS ADOPTED FOR COMPUTATIONS

The thermo-mechanical simulation of the groove-rolling process was carried out with the use of a visco-plastic model in the triaxial state of strain by using the Forge2011® program, whereas the properties of the deformed material were described according to the Norton-Hoff [8, 9] conservation law.

Bimetallic bars with an outer diameter of 22,5 mm covered with 1,7 mm copper layer, after explosive welding (Figure 1), were rolled on a D 150 two-high rolling mill. The aluminium layer fraction of the bimetallic bar cross-section was approximately 28 %. The initial non-uniformity of the clad layer distribution in the feedstock obtained from explosion welding did not exceed 10 %, so its uniform distribution on the bimetallic feedstock perimeter was assumed for numerical

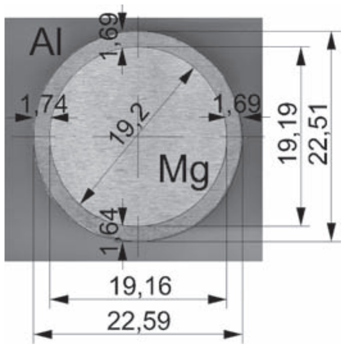


**Figure 1** The shape and dimensions of bimetallic feedstock after explosive welding (cross-section) [4]

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computations. The feedstock material was round AZ31 magnesium alloy bar covered with an AW-1050A aluminium layer.

The modified oval pass was used for rolling, which had been designed for rolling Al - Cu bimetallic bars [10]. The shape and dimensions of the pass are shown in Figure 2. Heating of the bimetallic feedstock of an initial length of 150 mm was carried out in a chamber furnace. Bars were heated up to a temperature of 300 and 400 °C, respectively. The theoretical analysis was performed for the real rolling conditions: the working roll diameter $D$ = 150 mm; coefficient of friction, 0,3; the coefficient of heat exchange between the material and the tool, a = 3000 W/Km$^2$; the coefficient of heat exchange between the material and the air, $a_{air}$ = 100 W/Km$^2$; tool temperature, 60 °C; and ambient temperature, 20 °C. The flow stress as dependent on the rolling process parameters was determined by hot compression tests. The tests were performed in the Gleeble 3800 simulator. The junction between the core and the cladding layer was defined as closely fitting. The nodes of both mesh were shared. In order to increase the speed and accuracy of computations, ¼ of the bimetallic band cross-section and the symmetric half of one of the rolls were used in the simulations.

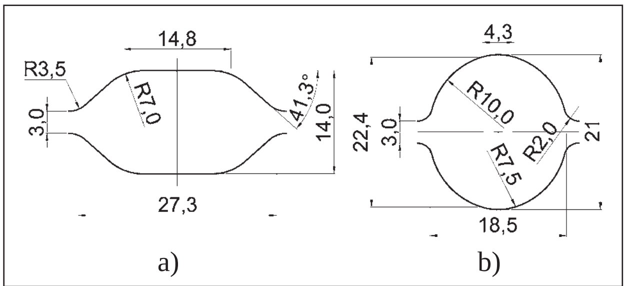


**Figure 2** The shape and dimensions of the modified grooves used for the process of rolling Mg/Al bimetallic bars: a) horizontal oval, b) vertical oval

## RESULTS AND DISSCUSION

A theoretical analysis of the distribution of temperature, effective strain and effective stress in the roll gap exit plane has been carried out in the study. The analysis was made for the first rolling pass. The results in the form of distributions of the examined parameters are represented in Figures 3-4.

The temperature of the rolling process significantly influences the effective strain and stress values and the plastic flow of individual components of the Mg/Al bimetallic band. Therefore, the numerical computations were performed for two temperature values, 400 and 300 °C (Figure 3).

When analyzing the data in Figure 3, a temperature drop in the aluminium layer can be found for both rolling variants, especially in the band regions in contact with the roll, and a temperature increase in the magnesium core.

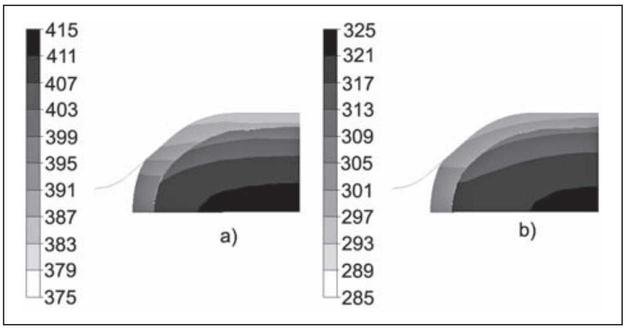


**Figure 3** Temperature distribution in the Mg/Al band cross-section after pass no. 1: a) rolling temperature 400 °C, b) rolling temperature 300 °C, ¼ of band.

Figure 4 illustrates the distribution of effective strain in the rolled Mg/Al band.

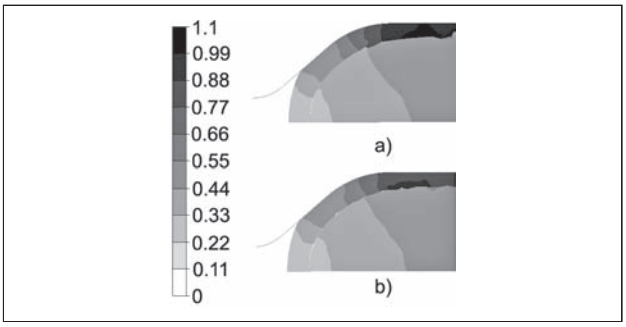


**Figure 4** Effective strain distribution in the Mg/Al band cross-section after pass no. 1: a) rolling temperature 400 °C, b) rolling temperature 300 °C, ¼ of band

The data in Figure 4 shows that lowering the initial feedstock temperature has an effect on the obtained effective strain values. This is especially visible for the soft clad layer, for the band regions situated in the immediate vicinity of the axis of symmetry of the pass, that is for the most intensively deformed band regions. In the region under examination, the effective strain has decreased from a level of approx. 1,1 mm - for the initial feedstock temperature of 400 °C (Figure 4a), to a value of approx. 0,8 - for the initial feedstock temperature of 300 °C (Figure 4b). The reduction of the effective strain value in the clad layer has resulted from the increase in the effective stress value, which is due to the lowering of the initial feedstock temperature (Figure 5). The increase of the effective stress value should also contribute to a reduced “flowing down” of the soft clad layer, and thus to a lesser “thinning” of this layer in the most intensively deformed band regions.

The distribution of effective stress in the rolled Mg/Al band is shown in Figure 5.

The data in Figure 5 indicates that the differences in the obtained effective stress values between the clad layer and the core are much greater for the bands rolled at 400 °C (Figure 5a), compared to the values obtained for rolling at 300 °C. The greater difference in the obtained effective stress values contributes to a more non-uniform plastic flow of individual bimetal band compo-

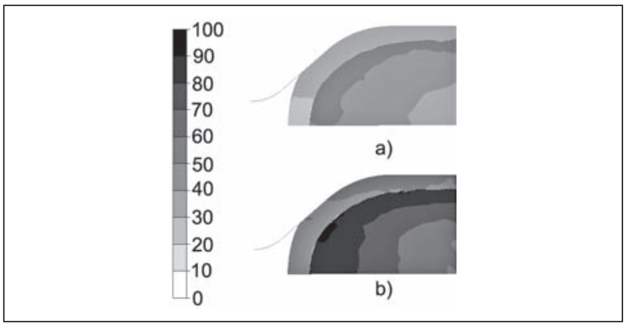


**Figure 5** Effective stress distribution in the Mg/Al band cross-section after pass no. 1: a) rolling temperature 400 °C, b) rolling temperature 300 °C, ¼ of band.

nents, which might cause a delamination to occur at the bond boundary.

Figure 6 shows the shape and dimensions of templates taken after respective rolling passes.

As shown by the data in Figure 6, a delamination at the bimetal component bond boundary has occurred in each pass. In each pass, cracks at the bond boundary are observed, which are indicated with the arrows. In spite of the fact that the employed bimetallic feedstock, produced by the explosive welding method, was characterized by high bond strength, microcracks formed at the bond boundary in the first pass, which were subsequently „transferred" to successive passes.

The analysis of the data in Figure 6b has found that the reduction of the initial feedstock temperature to 300 °C influences the band deformation mode, as compared to the process of rolling at a higher temperature. This is especially visible for the soft clad layer, for the band regions situated in the immediate vicinity of the axis of symmetry of the pass, that is for the most deformed band regions.

In the analyzed region, the effective strain during rolling of bimetallic specimens at 300 °C is lower (Figure 4b) compared to the rolling of bimetallic specimens at the initial temperature of 400 °C (Figure 4a). The reduction of the effective strain values in the clad layer resulted from the increase in the value of yield stress in this layer due to the lowering of the initial feedstock temperature. The more uniform effective stress distribution had the effect of eliminating the possibility of cracks occurring at the bond boundary in the rolled band.

## SUMMARY

The initial parameters (temperature) of the Mg/Al bimetallic bar groove rolling process significantly influence the bond strength quality of the bimetal component joint. The analysis of the theoretical study and experimental test results has demonstrated that more favourable conditions for Mg/Al bimetallic bar deformation exist at a lower rolling temperature. The observed discontinuities between the bimetal components were less numerous.

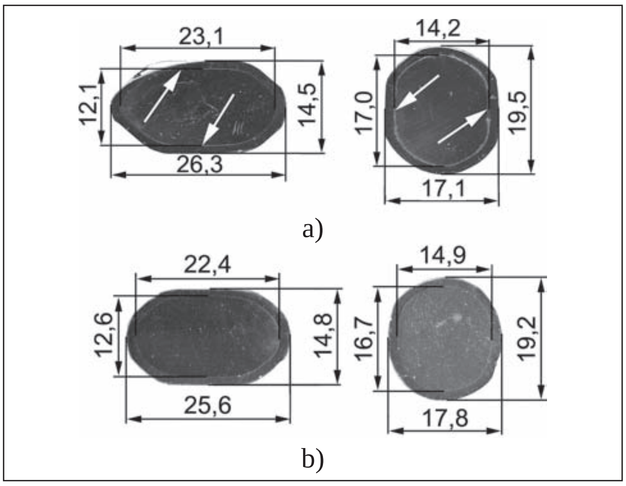


**Figure 6** A view of the Mg/Al templates taken from the band after particular passes: a) rolling temperature 400 °C, b) rolling temperature 300 °C.

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**Note:** The professional translator for English language is Czesław Grochowina, Studio-Tekst, Poland.