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PRODUCTION OF MAGNESIUM-ALUMINIUM BIMETALLIC BARS USING THE EXPLOSIVE CLADDING METHOD

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The paper presents the results of the preparation of semi-finished products in the form of magnesium-aluminium round bimetallic bars by the explosive cladding method. The system of samples consisted of an aluminium tube (1050 grade) and magnesium bar (grade AZ31) was prepared. The analysis of microstructure and mechanical tests of the joint quality was carried out. On the base of obtained results it was found that the explosive cladding parameters used to obtain the semi-finished bimetallic product characterized by a slight ovality and mechanical connection of the individual layers were correct.

Key words: magnesium – aluminium, bimetallic bars production, explosive cladding, bond strength

INTRODUCTION

There is high demand on the world's markets for magnesium alloy products intended for the automotive and aircraft industries. Such products can reduce the mass of a car or aircraft and might substitute for aluminium alloys being used currently [1]. A significant obstacle to a wider use of magnesium alloys in technology is the fact of the relatively poor corrosion resistance of magnesium [2].

Aluminium and its alloys exhibit considerably higher corrosion resistance than magnesium does. Hence, it can be expected that by producing a two-layered Mg-Al bar the advantages of the both materials, magnesium and aluminium, could be combined. The tightness of the cladding layer (Al) and its appropriate uniform thickness on the perimeter and along the length seem to be the key to the effective inhibition of corrosion of the even more chemically active core material (an Mg alloy).

Hence, the prospective solution is to manufacture magnesium-aluminium (Mg-Al) bimetallic bars which will ensure increased corrosion resistance compared to homogeneous magnesium alloys.

For many years, the explosive cladding method has been used for the production of multi-layer materials featuring high physico-mechanical and service properties [3, 4]. The method consists in obtaining a fast bond between two or more metals as a result of a high-speed collision of layers to be joined.

By using this method, very good mechanical and technological properties of joints are achieved, which are characterized by corrosion and high-temperature resistance [3-6].

The paper describes the investigation of the shape and properties of a joint of semi-finished products in the form of aluminium clad magnesium bars obtained by the explosive cladding method.

EXPLOSIVE CLADDING OF Mg-Al BIMETALLIC BARS

Two sets of samples were prepared for testing, each consisting of aluminium tubes (grade 1050A) and magnesium bars (grade AZ31), respectively. The initial dimensions of tubes and bars used for explosive cladding are summarized in Table 1.

Table 1 **The dimensions of tube and bars used for the explosive cladding**

Outer diameter of Al tube / mm	Inner diameter of Al tube / mm	Wall thickness / mm	Diameter of the Mg bar / mm	Distance between Al tube and Mg bar / mm
24	21	1,5	20,9	0,05
24	21	1,5	19,2	0,9

In the majority of studies published so far [4, 6], amonals was used for explosive cladding of bimetallic bars. In the present study, an explosive called saletrol was used for explosive cladding, which was composed of a mixture of ammonium nitrate and diesel oil. The casing of the prepared explosive cladding system was made of a 50 mm - inner diameter paper tube of a wall thickness of 5 mm. The aluminium tube was shielded by a polypropylene layer of a thickness of approx. 0,5 mm. The thickness of the explosive material was approx. 12 mm.

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EXAMINATION OF GEOMETRIC CHANGES IN THE BIMETALLIC BAR AFTER EXPLOSIVE CLADDING

After denotation, straight bimetallic bars with a durable bond over the entire length was obtained, with no curving and necking. The explosive cladding resulted also in a slight thickening of the aluminium layer in the samples, with a simultaneous reduction of the aluminium tube length, particularly visible in the lower part of the clad bar. An example shape of Mg-Al bimetallic bar after explosive cladding is shown in Figure 1.

The cross-section and dimensions of Mg-Al bimetallic bars after explosive cladding are shown in Figure 2 and in Table 2. The data in Figure 2 and in Table 2 indicates that only slight difference in aluminium layer thickness have were on the magnesium core perimeter after explosive cladding. The average thickness of the aluminium layer for sample no. 1 amounted to 1,58 mm and the share of the aluminium layer in the bimetallic bar cross-section was approx. 24%, while for sample no. 2, respectively, 1,69 mm and 28%.

Also the cladding layer non-uniformity distribution factor, K_{plat}, which is defined as the maximum to minimum Al layer thickness ratio (g_{Almax} / g_{Almin}), has been determined in the study. The coefficient enables the assessment of the non-uniformity of cladding layer distribution on the bimetallic bar perimeter. For the examined Mg-Al bimetallic bars, a uniform Al layer distribution on the magnesium layer was obtained: K_{plat} = 1,05 for sample no. 1 and K_{plat} = 1,06 for sample no. 2. The obtained values indicate a great uniformity of cladding layer distribution on the perimeter of the magnesium core.

Moreover, the obtained Mg-Al bimetallic bars were characterized by a slight ovality, which will not have, however, any adverse effect during their use in subsequent plastic working. The difference in difference for sample no. 1 amounted to 0,22 mm, while for sample no. 2 a mere 0,07 mm.

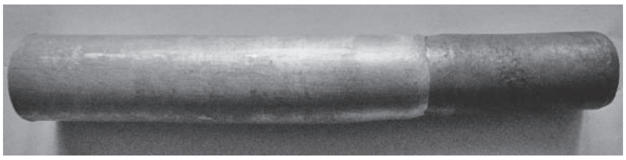
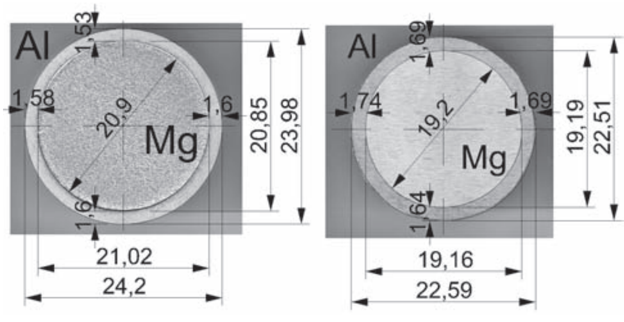


Figure 1 Shape of Mg-Al bimetallic bar after explosive cladding (sample no. 1)



a) b)

Figure 2 Shape and dimensions of bimetallic bars after explosive cladding (cross-section): a) sample no. 1, b) sample no. 2

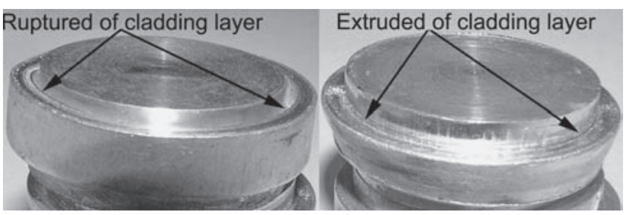
Table 2 **The dimensions of bimetallic bars after explosive cladding**

Av. outer diam. / mm	Share of cladding layer in the cross-section of the sample / %	Av. thickness of Al layer / mm	Change of the cladding layer thickness / mm	Deform. of cladding layer / %
24,1	24	1,58	0,08	5,1
22,6	28	1,69	0,19	11,2

EXAMINATION OF THE QUALITY OF THE BIMETAL BAR JOINT AFTER EX-PLOSIVE CLADDING

In order to examine the quality of the joint between the layers of bimetal bars taken from a sample obtained by the explosive method the strength tests were performed on the bars (to determine the joint shear strength). The quality of the joint of bimetal layers with the magnesium cores clad with aluminium was tested on testing dies [4]. Figure 3 shows the shape of samples after testing for maximum shearing stresses at the joint interface.

The examination of the quality of the bond found that the bond quality was significantly influenced by the initial distance between the aluminium tubes and the magnesium core of the bar. During conducting the examination of Mg-Al bond quality for sample no. 1, the maximum shearing stress was approx. 26 MPa (Figure 3a). The quality of the bond was so poor that the individual components were torn apart. The poor bond quality was caused by too small the initial distance during welding the magnesium core with the aluminium tubes, which was 0,05 mm, while in studies [4, 6] distances from 1 to 2 mm were used, which provided high bond quality. In the studies quoted above, squeezing of the cladding layer through the mould was observed during bond quality examination. Therefore, the initial distance between the magnesium bar and the aluminium tube for sample no. 2 was increased to 0,9 mm during explosive cladding. For sample no. 2, the quality of the bond turned out so good that the individual components



a) b)

Figure 3 Shape of Mg-Al samples after the examination of the joint quality of bimetal bars after explosive cladding: a) sample no. 1, b) sample no. 2

did not break apart, but instead the aluminium layer was squeezed through the test mould (Figure 3b). The shearing stress value of approx. 58 MPa obtained for sample no. 2 corresponds, from the plasticity condition, to 0,57 σ_p of the yield stress for aluminium (approx. 100 MPa). The tearing of the cladding layer off the magnesium layer in the case of sample no. 1 might suggest a mechanical nature of the bonding of the bimetallic components.

STRUCTURE OF JOINT REGIONS

The mechanical properties of the joint are determined by the nature of the bonding of the bimetallic bar layers and the microstructure of the bond [4]. In order to analyze the structure in particular areas of the material making up the core and the cladding layer and to determine the changes occurring in the structure, examinations were carried out using light microscopy and electron microscopy. For the assessment of the bond quality on both etched and not etched microsections, a Nikon Eclipse Ma 200 light microscope was employed. During the examinations, the thickness measurement of the intermediate layer observed after picric acid etching was also done. The microanalysis of chemical composition was made on a JSM5400 scanning microscope supplied by JEOL. The microscope is equipped with an integrated (EDS) X-ray spectrometer system. In the study, the analysis was limited to the joint of sample no. 2, for which high bond quality had been achieved.

Figure 4 shows example microphotographs of the joint region. It can be seen from the data in Figure 4 that no discontinuity regions occur at the joint interface. The analysis of the non-etched microsections revealed also a zone differing in colour from the both layers, as seen in Figure 4a. Therefore, in the subsequent part of the study it was determined that for the full analysis of the test sample, its etching was necessary. For etching, picric acid was used, which helped to reveal both the transition layer occurring in the joint zone, as well as the magnesium grain boundaries. After disclosing the intermediate zone, the measurement of its thickness was made. The average thickness of the intermediate layer amounted to approx. 33,5 µm.

At the next stage of the study, the examination of the chemical composition of the observed intermediate layer was carried out using electron microscopy and an EDS attachment. Figure 5 shows example result of chemical composition analysis of the intermediate layer which is shown in Figure 5.

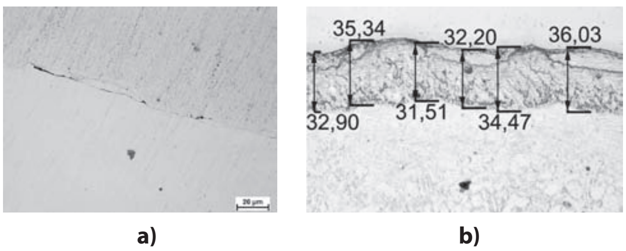


Figure 4 The zone of the Mg-Al joint region, a) non-etched microsection, b) etched microsection of the intermediate layer measurements, magn. 500x

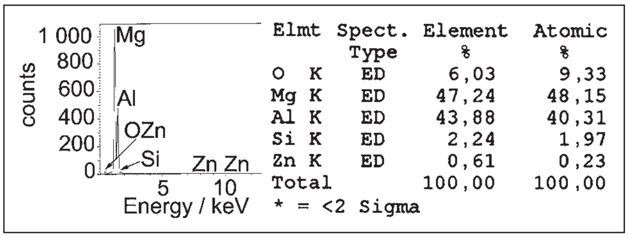


Figure 5 Example results of the examination of intermediate layer chemical composition, magn. 500x

The obtained chemical composition of the intermediate layer suggests the occurrence of the γ ($Al_{12}Mg_{17}$) phase formed probably as a result of a localized fusion of the welded materials. According to the results of studies [7, 8], the process of formation of the γ phase at the cladding layer – substrate interface must have occurred with the participation of a liquid phase as a results of high temperature and long time of process. The use of the explosive cladding technology, thanks to its quickness, probably do not enter in the full liquid state.

SUMMARY

The investigation carried enables the following observation to be made and conclusions to be drawn:

- The application of the explosive cladding has resulted in a semi-finished product in the form of Mg-Al bimetallic bar that is characterized by a uniform distribution of the cladding layer on the core perimeter.
- The initial parameters of explosive cladding (the distance between the Al tube and the Mg core) significantly influence the strength of the bonding of the individual layers.
- The application of the explosive cladding method results in the occurrence of the $Al_{12}Mg_{17}$ intermetallic transition layer of an average thickness of 33,5 µm.

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