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## ANALYSIS OF BIMETALLIC PLATE ROLLING AFTER EXPLOSIVE WELDING

### ANALIZA PROCESU WALCOWANIA BLACH BIMETALOWYCH PO POŁĄCZENIU METODA ZGRZEWANIA WYBUCHOWEGO

This work presents the effect of plastic deformation and heat treatment on the properties of joint area of AL99,8 + M1E bimetallic plate. The joining zones were analyzed after rolling in three variants: directly after joining, after joining and annealing at 300°C, and after joining and annealing at 400°C.

*Keywords:* Explosive welding, copper-aluminum clad, rolling, annealing

Praca przedstawia wpływ przeróbki plastycznej oraz obróbki ciepła na własności złącza blach bimetalowych Al99,8+M1E. Analizie zostanie poddany obszar złącza próbek po walcowanych według trzech wariantów: tj. bezpośrednio po spojeniu, po spojeniu i wyżarzaniu w 300°C oraz po spojeniu i wyżarzaniu w 400°C.

#### 1. Introduction

Based on a review of literature concerning the joining of metals by explosive welding, this method has still many new applications. There is observed rapid growth of interest, both in the country and the world, and the use of multi-layer materials becomes a very important and vital issue for the industry.

Initially it was thought that an explosive welding is a process in which the connection should take place as a result of surface layers melting and diffusion process in layers. Such diffusion gave the opportunity of the transition continuity between material. In the merging area the intermediate layer was observed which character is non-diffusional. Later, it was assumed that a sufficient condition for joining with the explosive welding method is a very large plastic deformation and diffusion occurring during its duration. However, studies have shown that the maximum pressure in the explosive welding method is very small, and even the diffusion coefficient is too low, that it could appear. It is now believed that the most advisable is to assume that the explosive weld is formed during overlapping of many interlinked processes of the collision area, either during its formation and after the collision. In the welds obtained with the explosive merging process are observed both diffusion and recrystallization. These processes, however, do not significantly affect the formation of connections, but they are very important for the properties of obtained connection [1].

#### 2. The purpose and scope of work

The aim of the study was to determine the properties of Al99.8 + M1E bimetallic plate connection area. Because the explosive welding method does not always allow to obtain the desired thickness of the sheet, it essential to apply the second stage of the production which is the rolling process [1-4]. In the paper were made studies of explosive welding, annealing and intermediate rolling process impact to the Al99.8 + M1E (Fig. 1.) bimetallic plate connection area.

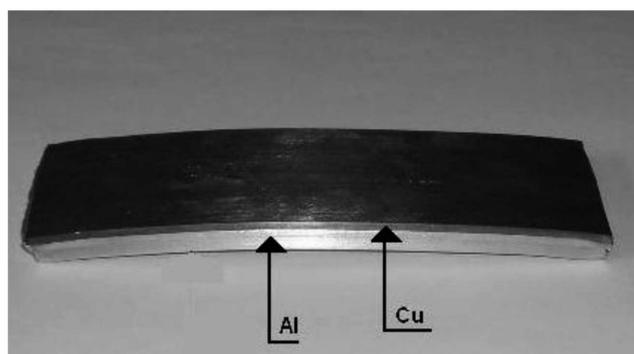


Fig. 1. Bimetallic plate after rolling process

In the Table 1 is presented the chemical composition of analyzed materials.

Within this work will be carried out metallographic tests that will allow for the evaluation of the metal joint directly after merging, after interoperation annealing and after the rolling process (using the asymmetry of peripheral speeds work roll).

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TABLE 1

Chemical composition M1E- PN-87/H-82120, A199,8 - PN-79/H-82160

Type of material		Chemical composition [%]									
		Cu	Al	Zn	Sn	Pb	Fe	Sb	Si	Ni	S
M1E (Cu)	minn	99.90	–	–	–	–	–	–	–	–	–
	max	Resta	–	0.003	0.002	0.005	0.005	0.002	0.001	0.002	0.004
A199,8 (Al)	min	–	99.8	–	–	–	–	–	–	–	–
	max	0.02	Resta	0.05	–	–	0.15	–	0.13	–	–

The rolling process will be carried out in three variants: Variant I – samples directly after welding, variant II – after the annealing process at the temperature  $T = 300^{\circ}\text{C}$  and variant III after annealing at  $400^{\circ}\text{C}$ . After the rolling process there will be determined the quality of the connection area, depending on the asymmetry of the work roll peripheral speeds. The rolling process was carried out on a rolling mill roll duo 150 mm diameter at the Institute of Forming and Safety Engineering in the Czestochowa University of Technology. The rolling mill scheme is shown in Figure 2.

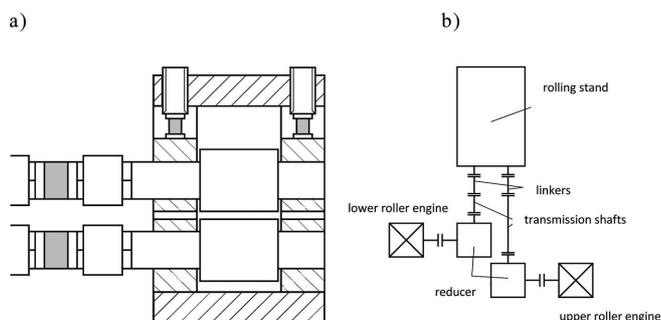


Fig. 2. Scheme of the laboratory duo 150 rolling mill

Because the rolling mill is equipped with two drive rolls, which drive the rollers individually, it is possible to introduce variations in peripheral speeds. The laboratory mill is also equipped with a frequency converter ACS-601 ABB Company; it is possible to control the peripheral speeds of the rolls.

### 3. Initial metallographic studies

Geometric and structural composition of explosively welded connections depends primarily on the type of merged metal and connecting parameters such as thickness of metals layers, collision geometry, type and surface preparation, speed and strength of detonation wave.

Metallographic examination of the tested samples was performed using an optical microscope Zeiss Axiovert 25 with digital image storage adapter. Figure 3 present the A199.8 + M1E connection area after explosive welding.

After direct connection A199.8 + M1E intermetallic phases were observed. To identify what type of intermetallic phases appeared in the merged area the chemical analysis was made. On the base of chemical analysis and based on the phase equilibrium of Al – Cu it was possible to identify those phases. In areas marked in Fig. 3 was made a point EDS chemical analysis and the following phases were identified: I –  $\theta$  ( $\text{Al}_2\text{Cu}$ ), II –  $\eta_1$  ( $\text{CuAl}$ ) and III –  $\eta_1$  ( $\text{CuAl}$ ). Intermetal-

lic phases presented in the weld area of Al –Cu are fragile. Therefore, it is necessary to specify the conditions of A199.8 + M1E bimetal rolling process. For this purpose, laboratory tests were performed with use of 150 mm duo rolling mill. The rolling process was performed at a speed of 100 mm/s. Samples were rolled after the immediate welding and after annealing at temperatures of  $300^{\circ}\text{C}$  and  $400^{\circ}\text{C}$  for 0.5 h. All samples were rolled in several passages, until the delamination of the joined layers.

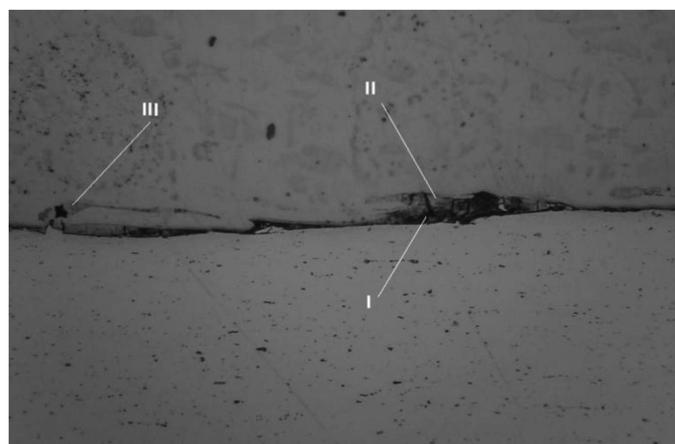


Fig. 3. Sample after direct connection – not etched, mag. 200x

### 4. Results of laboratory tests

In the work were carried out also research on the plastic deformation of bimetal A199.8 + M1E sheet until the total lost of layers connection. Table 2 shows the results after rolling in three variants.

TABLE 2  
Dimensions of the samples after successive deformation

Pas- sage no	Wariant I		Wariant II		Wariant III	
	Initial thickness mm	Final thickness mm	Initial thickness mm	Final thickness mm	Initial thickness mm	Final thickness mm
1	12	10.8	12	10.8	12	10.8
2	10.8	9.7	10.8	9.7	10.8	9.7
3	9.7	8.7	9.7	8.7		
4	8.7	7.7	8.7	7.7		
5	7.7	6.5				
6	6.5	5.5				
7	5.5	4.7				
8	4.7	4.0				

For the Al99.8 + M1E samples a rolling process was carried out for the same conditions of strain until the appearance of torn or delamination of the joint layers. In the case of rolling after direct bonding delamination of layers was not observed or lack of connection of the bimetal. Samples were ready to continue in the rolling process. Much less favorable situation was observed on samples for variant with annealing. For samples annealed at 300°C delamination appeared after the fourth pass while in the case of samples annealed at 400°C the delamination appeared after the second pass. Results are shown in Fig. 4. Samples for metallographic analysis were polished with an aqueous suspension of aluminum oxide Al<sub>2</sub>O<sub>3</sub>. The microscopic analysis was made with magnification of 200x, that gave possibility to check the interconnection of the layers and to detect possible defects.

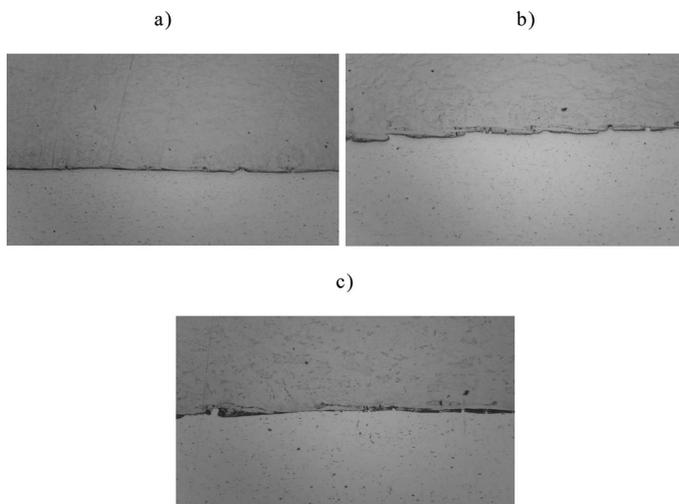


Fig. 4. Not etched samples observed at magnification 200x, a) rolled after 8 pass according to variant I, b) after 4 pass rolling according to variant II, c) after 2 pass rolling according to variant III

On the base of the metallographic analysis it was found that in the case of samples rolled according to variant I, it is possible to continue the process of sheets deformation. There were no cracks and tears in the joint area. There was observed wave height decrease, while the intermediate layer was not deformed. However, in the case of samples rolled according to variant II after four pass appeared cracks in the joints, and in the case of variant III cracks appeared after the second pass. Moreover, after heat treatment accumulation of intermetallic

phases was observed in the joint area. Those phases mainly contribute for arising crackings in the intermediate layer and delamination of bimetal layers.

## 5. Summary and conclusions

On the basis of research made for the area of Al99.8 + M1E plates connection area the following conclusions can be drawn:

- The rolling process of bimetallic samples after direct connection for variant ‘I’ do not cause break of consistency of welded area. However it can be considered that rolling of annealed samples according to variant ‘II’ and ‘III’ decrease joint durability with an increase of annealing temperature. For samples rolled according to the variant II delamination appeared after pass no 4 while in the case of the variant III rolling delamination was observed after the second pass.
- Intermediate layer did not undergo plastic deformation. It cracks as a result of forces occurring in the rolling process. The reason for this phenomenon is the presence of Al<sub>2</sub>Cu and CuAl intermetallic phases in the welded area. Those phases are hard and brittle, and taking into account fact that in the rolling process forces act strongly on the bonding area of the bimetallic plate most often brittle cracking of those phases takes place.

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