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Quality of bimetal Al-Cu joint after explosive cladding

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ABSTRACT

Purpose: An analysis of quality of bimetallic joint between aluminium and copper layers of billet for extrusion process is the subject of the work.
Design/methodology/approach: For preparing the quality analysis of particular layer of bimetal, the shearing test were done. During the tests the maximal stress for particular sets of the bimetal was established. For chosen cases the metallographic research of Al-Cu joint were done.
Findings: The geometry of the cylindrical set and explosive cladding process parameters which allow to obtain the cylindrical bimetallic billets without cracks and delaminations and also with uniform cladded layer along and across the billet.
Research limitations/implications: The analysis is concerning the explosive joint of pure aluminium Al995 and electrolytic copper M1E 99,97 in cylindrical sets. In the future research the analysis of this kind of joints after direct extrusion process is planning.
Practical implications: The analysis could be helpful for more effective designing of the bimetal billets through the explosive cladding process and next for the plastic working processes.
Originality/value: During the extrusion process with high value of extrusion ratio the delamination of the billet layers especially on the boundary of the layers is observed, this fact causes that joint after the metal working processes has lower strength even than components of the bimetal billet. So very important task is establishing the geometry set and explosive parameters to obtain the best quality of the joint.
Keywords: Plastic forming; Explosive welding; Bimetal; EDX

1. Introduction

The electronic, telecommunication and power engineering are the very fast developing industries. They are consumers of large amount of bimetallic products like wires, rods with aluminium core and copper sleeve for electronic elements and electric wiring [1]. There are many methods to obtain the bimetal rods and one of them is the explosive cladding and plastic deformation. Apart from used schema production, the every stage of production process of bimetallic product should give high quality semiproducts and products which means good strength of joints and uniform cladded layer.

2. Methodology of research and materials used for investigation

The analysis of bimetal joint quality was proceeded in two stages. In the first one the maximum share stress on the boundary of the layers were determined, the analysis were performed from the final plastic deformation process (extrusion) point of view.

In the second stage the detailed metallographic researches were done, these analyses were prepared for samples with the lowest strength of joint.

Table 1.
Chemical composition of aluminium rods used for investigation

Grade alloy	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
1050A	0,060	0,180	0,002	0,003	0,002	0,008	0,020	99,740

Table 2.
Chemical composition of copper pipes used for investigation

Grade alloy	Al	Fe, Pb, Si, Zn	Sb, Bi, As, Ni, Sn	Cu
M1-E	0,1	0,005	0,002	99,96

Table 3.
Initial dimensions of components for explosive cladding process

Set number	Copper pipe			Aluminium rod
	Outer diameter, $\mathbf{d}_{cuzew}$[mm]	Pipe thickness, **g** [mm]	Inner diameter [mm]	Diameter $\mathbf{d}_{al}$[mm]
1	16,00	1,00	14	13
2	54,00	2,00	50	40
3	32,00	1,50	29	26
4	18,00	1,00	16	13
5	35,00	1,50	32	30
6	25,00	1,50	22	20
7	25,00	2,00	21	20
8	24,00	2,50	19	16
9	25,00	3,00	19	16
10	25,00	3,00	19	14
11	42,00	2,00	38	32

2.1. Materials used for investigations

In the work the initial materials to get bimetal billet were aluminium 1050A rods and electrolytic copper M1E pipes. The chemical composition of aluminium and copper used for investigation was presented in tables 1 and 2.

2.2. Explosive cladding process

For explosive cladding process the 11 pairs of samples (sets) were prepared (see table 3).

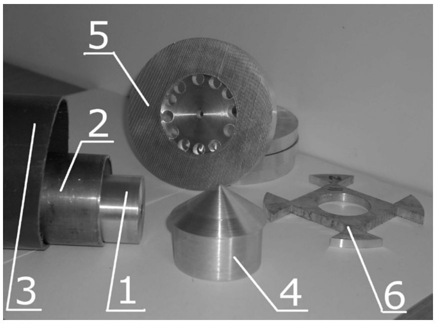

Fig. 1. Elements of explosive set 1 – aluminium rod, 2 – copper pipe, 3 - pvc pipe, 4 – upper cover, 5 – lower cover, 6 – distance ring

The range of copper pipe thickness and diameters of aluminium rods were chosen in special way to get the dimensions of final products (after plastic deformation) [2÷5], which correspond to the biggest producers of bimetallic wires and other bimetallic products [6].

For the process the cylindrical sets were prepared. The elements of the cylindrical set are presented in Fig. 1.

The methodology of the bimetal rod production method used for investigation was described in literature [7÷9].

For explosive cladding process „amonal-2" (detonation speed 1600 m/s) and "amonal-5" (detonation speed 1900 m/s) blowing materials were used.

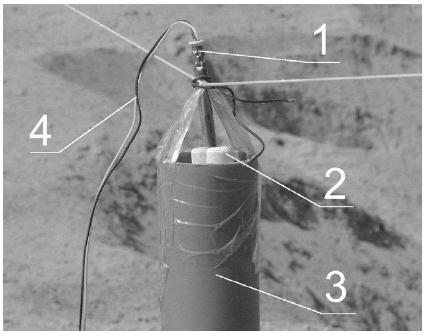

Fig. 2. Cylindrical set with explosive charge prepared to explosive joining 1-fuse, 2-detonator, 3- blowing charge, 4-detonation initialising wiring

Blowing materials contained crystalline ammonium nitrate (V) and flaky aluminium dust were used. The material was in shape of loose fine-grained powder, which although small distance between joining elements can be easily elaborated.

The set before shooting is presented in Fig. 2. The explosive cladding was performed in shooting area of one of the explosive material factory in Poland.

After detonation the straight bimetallic rods with stable joints were obtained [10].

2.3. Analysis of strength of bimetal joint

The quality of joining between copper cladded aluminium rods was investigated in testing matrix in shape and dimensions properly chosen for the dimensions of investigated samples according to literature [7,11].

From research results it can be stated that differences between the lowest values of shear stresses (69÷74 MPa from samples taken out from sets 3, 6÷10), and the highest (82÷98 MPa - from samples taken out from sets 1, 2, 4, 5, and 11), excided 30%. In the samples which were characterized by minimal value of shear strength during the test the crack in joint was appeared as a consequence of it delamination of sleeve from core [10].

Moreover on the basis of the analysis it can be concluded that on the quality of bimetal joint the initial thickness of cladded layer has influence because delamination (decohesion) appears in samples from 7÷10 sets characterized by the higher initial thickness of the cladded layer.

Also it could be observed that less distance between copper pipe and aluminium rod was applied the higher quality of joint is obtained.

2.4. Metallographic research of joining area

In this part of analysis the Zeiss Axiovert 25 optical microscope and JEOL JSM-5400 scanning microscope equipped with EDX analyser, which enable the analysis of chemical composition of microarea on the boundary of bimetal layers, was used. The microhardness tests were performed by using FM7 device of Future Technic Company with 245,2 mN (HV0,025) load.

To obtain the cladded layer with suitable strength, the joint area should be plasticly displaced and heated. The increase of temperature into micrometric surface layers is estimated on 2200-3500ºC for speed of detonation 2000-2500m/s, mainly due to adiabatic compression of bimetal components and air and also due to friction phenomena between joined components. The cumulative type wave, which accompanying the explosive cladding process, causes also the selfcleaning of surface and significant removing partial melted layer. The residues trapped into the joint area build more or less continuous intermediate layer.

The literature research pointed that in dependence on material of joining components and explosive parameters the joints can have flat character or wavy character, direct or with intermediate layer. From the strength of joint point of view the most advantageous are wavy joints [10,12÷15].

Photography of joints after explosive joining presented in Figs 3 and 4 revealed that for Al-Cu composition appears very clear and different from component materials intermediate layer with specified waviness.

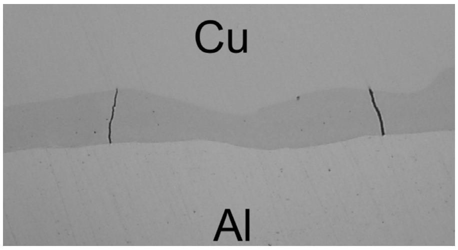

Fig. 3. Character of joint in sample from set nr 6 after explosive cladding (Mag. 200x without etching)

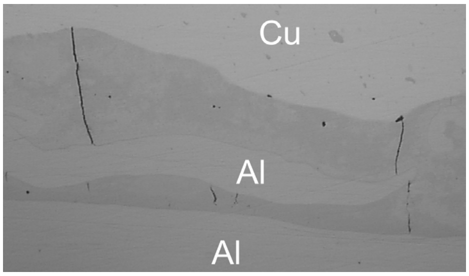

Fig. 4. Character of joint in sample from set nr 7 after explosive cladding (Mag. 200x without etching)

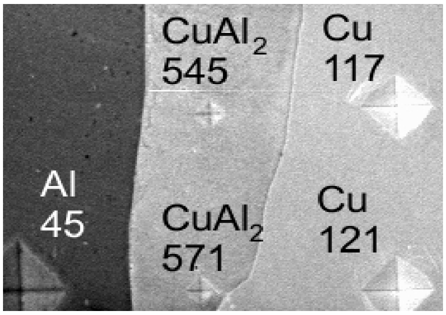

Fig. 5. Microstructure of EDX analysis area

Presented results (Figs. 5 and 6 and table 4) of microanalysis obtained by EDX method pointed that intermediate area is characterized by very stable, on the cross-sections, chemical composition with Al fraction from range 61- 63 % (atom) and Cu fraction ~35-36%. So it should be stated that during the microsecond duration of the explosive cladding in the narrow area of joint the increase of temperature which caused partial melting and stirring of the layers enables getting the layer of 20-40 μm with stoichiometric composition adequated to intermetallic phase $CuAl_2$.

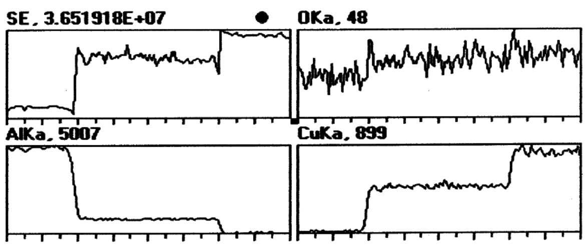

Fig. 6. Distribution of chosen chemical elements in area from figure 5

Table 4.
Percentage fraction of chemical elements in area from figure 5 [mass % / at%].

Analysis location	Cu	Al	O
Middle of layer	56,81/35,63	42,61/62,94	0,58/1,44
3 µm from Al. side	57,73/36,33	41,28/61,19	0,99/2,48
3 µm from Cu side	57,30/36,08	42,08/62,39	0,61/2,54

3. Conclusions

The analysis enables formulation of following remarks and conclusions:

Higher values of initial cladded layer causes asymmetrical decohesion of joint layers.

Small distances between aluminium rod and copper pipe increases quality of joint.

The joint appeared during the explosive cladding of Al-Cu sets is characterized by typical wavy shape. However into the area of the joint very hard intermediate layer occurs with thickness about 20-40 µm and stoichiometric composition adequated to intermetallic phase $CuAl_2$.

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