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Production of Bimetallic Bars Steel – Steel Resistant to Corrosion of the Method Explosive Cladding

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In the paper the analysis of production of bimetallic bars steel-steel resistant to corrosion by explosive cladding. Method explosive cladding is the affirmed process the receipt the bars plated is characterizing the large strength of bond two different metals. Moreover, in this study, the author presents the bond strength of interface of bimetallic joint of the cross section on the test bar.

Keywords: BIMETALLIC ROUND BARS, STEEL RESISTANT TO CORROSION, EXPLOSIVE CLADDING

Introduction

The production of steel – steel resistant to corrosion bimetallic bars is a relatively complex process and is associated with many technological problems. The most important of them include obtaining a bimetallic stock of proper joint strength in the region of core and cladding layer bonding, and assuring a uniform plastic flow of both bimetallic layers during the rolling process. Failure to meet the above conditions may results in a delamination of the bimetallic strip during rolling or the formation of other defects. One of the bimetallic bar manufacture methods is the method explosive cladding [1÷7].

Materials used for research

The accuracy of calculations performed by means of computer program is dependent on the accurate determination of the properties of materials used for tests. Plastometric tests were performed on a Gleeble 3800 plastometer owned by the Institute of Modeling and Automation of Plastic Working Processes, Częstochowa University of Technology, using strain rates of 0.1 s-1, 1.0 s-1 and 10 s-1 respectively. Chemical composition of materials used for tests is given in **Table 1**, whereas **Figure 1** illustrates the example testing results in the form of flow curves for steel C45E and for steel X2CrNi18-10.

When analyzing the data in **Figure 1** it can be found that the yield stress values for the X2CrNi18-10 steel are much higher than for the C45E steel. This difference has a considerable influence on the process of rolling bimetallic bars in passes. The higher yield stress values in the clad layer reduce the effect of the clad layer "flowing down" from the bimetallic bar core [3, 6].

Explosive welding of bimetallic stock

For explosive welding of bars, sets composed of X2CrNi18-10 corrosion-resisting steel pipes and C45E steel bars were prepared. The system and its individual components are illustrated in **Figure 2**. Whereas, **Figure 3** shows finished bimetallic bars obtained after explosive welding. Based on the testing of bimetallic bars after explosive welding it has been found that by changing the initial dimensions of pipes and bars and the initial distances between them, bimetallic bars of the desired inner diameter and the required cladding layer thickness can be obtained [1, 2].

Microstructure of the joint zone in bimetallic bars after explosive welding

Samples for microstructural examinations were taken from bimetallic bars obtained after explosive welding.

The analysis of changes in the microstructure was performed both for the core and for the clad layer. **Figure 4a** and **4b** show the microstructure of the joint regions in the bars examined. It was found that the core after explosive welding exhibited a ferritic-pearlitic structure (with a majority of pearlite of approx. 80%) with the ferrite grain size in the standard class of 9.0, and the pearlite grain size of 8.0÷8.5 (acc. to the EN-ISO 643:2003 standard). At the joint zone, pearlite grains were in the standard class of 8.0, whereas the ferrite grains in the standard class of 9.0 (acc. to the EN-ISO 643:2003 standard). The clad layer, in turn, had an austenitic structure with the grain size in the standard class of 9.0. It was found that the area of the core-clad layer joint was wavy, with no oxides or fraying. No presence of any impurities was found in this zone.

Table 1. Chemical composition of materials used for tests [%]

Gatunek stali	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Sn
C45E	0,45	0,64	0,21	0,015	0,031	0,13	0,14	0,04	0,25	0,015
X2CrNi18-10	0,03	2,00	0,24	0,045	0,03	19,0	10,0	0,75	-	-

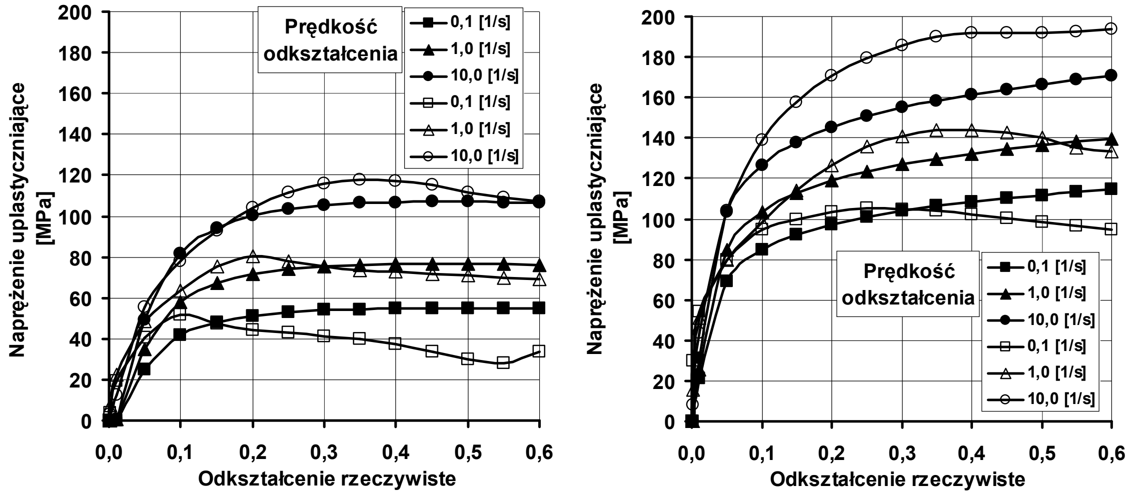

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Figure 1. The flow curves for: *a* – steel C45E; *b* – for steel X2CrNi18-10, for a temperature of 1100°C

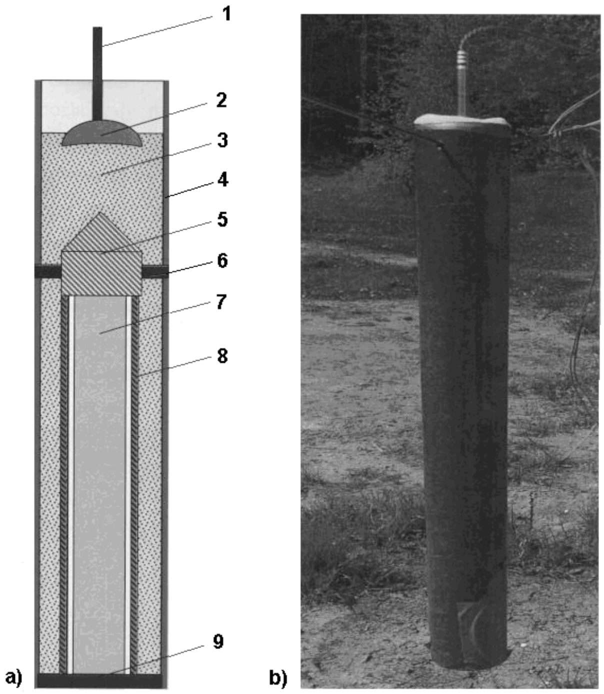
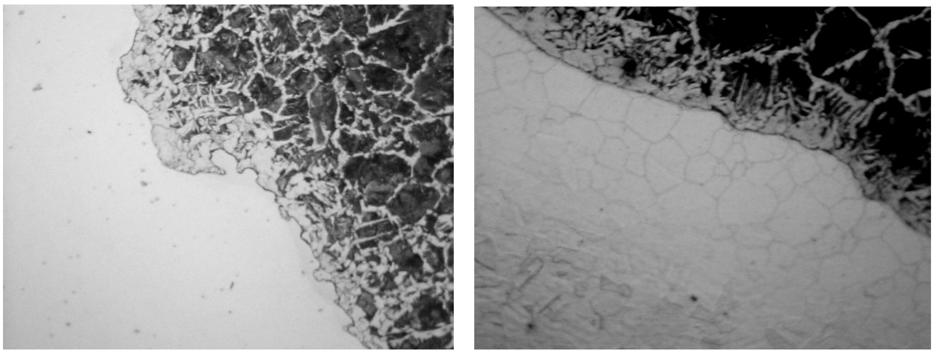


Figure 2. Schematic (*a*) and actual view (*b*) of systems used for explosive welding of bimetallic stock: *1* – detonator; *2* – primary explosive; *3* – loose explosive; *4* – PCV tube; *5* – centring plug; *6* – element aligning the system in the container; *7* – steel bar; *8* – corrosion-resisting steel pipe; *9* – bottom centring disk

Figure 3. Bimetallic bars after explosive welding



a b

Figure 4. The microstructure in the joint region of a bimetallic bar after explosive welding: *a* – the core, zoom 100x, etched with Nital; *b* – clad layer, zoom 100x, etched with 45ml H_2O, 30ml HNO_3, 15ml HCl, 10ml HF

The analysis of the presented testing results shows that different bars after explosive welding exhibited comparable cladding layer and core structures in the joint region. No differences in grain sizes between ferrite and pearlite were observed. A wavy joint area was found to occur in both cases.

5. The quality of the bimetallic bar bond joint

For the quality assessment of bimetallic bars, a method relying on the maximum shearing stress at the joint boundary was used. In **Figure 5a** shows the shape and dimensions of samples, while **Figure 5b** shows the shape and dimensions of the matrices used for quality testing. The results of the quality examination of the steel – corrosion-resisting steel joint (maximal shearing stress) after explosive welding are represented in **Figure 5**. The data in **Figure 6** show that the difference between the lowest (test piece no. 2; 140 MPa) and the highest (test piece no. 3; 230 MPa) stress values does not exceed 40%. For all of the test pieces examined, the quality of the joint was good enough so that no breaking of individual layers occurred, but only squeezing out of the bimetallic bar through the test die.

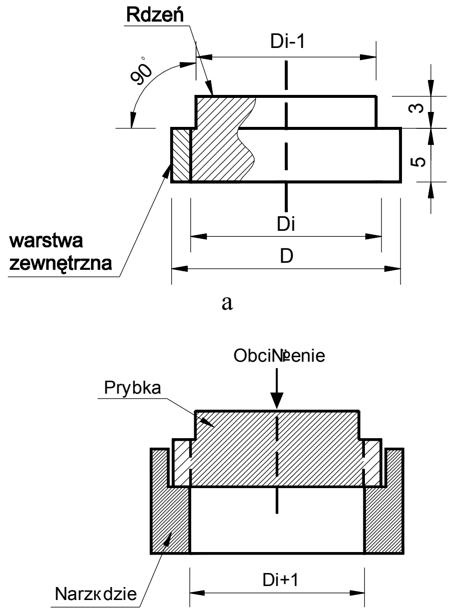


Figure 5. Dimensions of test specimens (*a*) and testing dies (*b*) used for quality testing of the bimetal bar joint after explosive cladding

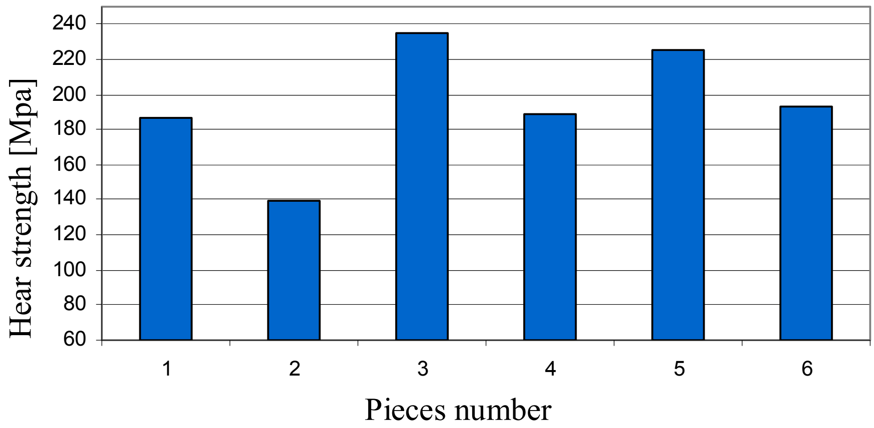


Figure 6. The hear strength of bimetallic test pieces after explosive welding

To examine the quality of the joint between bimetallic layers more precisely, microanalysis of the joint region was made by the EDX method. The results of this microanalysis are given in **Figures 7, 8** and in **Table 2**.

From the results of the EDX analysis of a bimetallic sample after explosive welding it can be found that locally, at the joint boundary, a 35 µm wide transitory film has formed – region 2, which consist of a mixture of mainly nickel, chromium and iron, with the following contents: 10% Cr, 5% Ni and 83% Fe. For region 1 – the core of the bimetallic sample, the contents of these elements are as follows: 0% Cr, 0% Ni and 99% Fe; whereas, in region 3 – the clad layer, these are: 19% Cr, 10% Ni and 69% Fe.

Microhardness tests of layers in respective joint regions were carried out for 3 selected samples obtained after explosive welding. The results of these tests are represented in **Figure 9**. The hardness tests were performed by the Vickers method according to the PN-ISO 6507-3 standard.

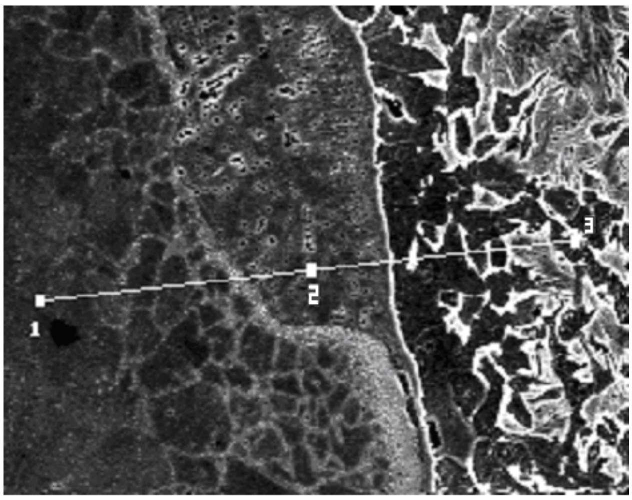


Figure 7. The microstructure of the joint region of bimetallic bar after explosive welding, zoom 320x - EDX analysis

Table 2. Percentage fractions of elements in particular regions of the joint from **Figure 7** [wt% / at%]

Area	Si	Mn	Fe	Cr	Ni
1	0,27 / 0,53	0,66 / 0,67	99,07 / 98,80	---	---
2	0,48 / 0,95	1,17 / 1,18	83,08 / 82.27	10,00 / 10,64	5,27 / 4,96
3	0,58 / 1,14	1,73 / 1,74	68,68 / 67,66	18,85 / 19,95	10,15 / 9,51

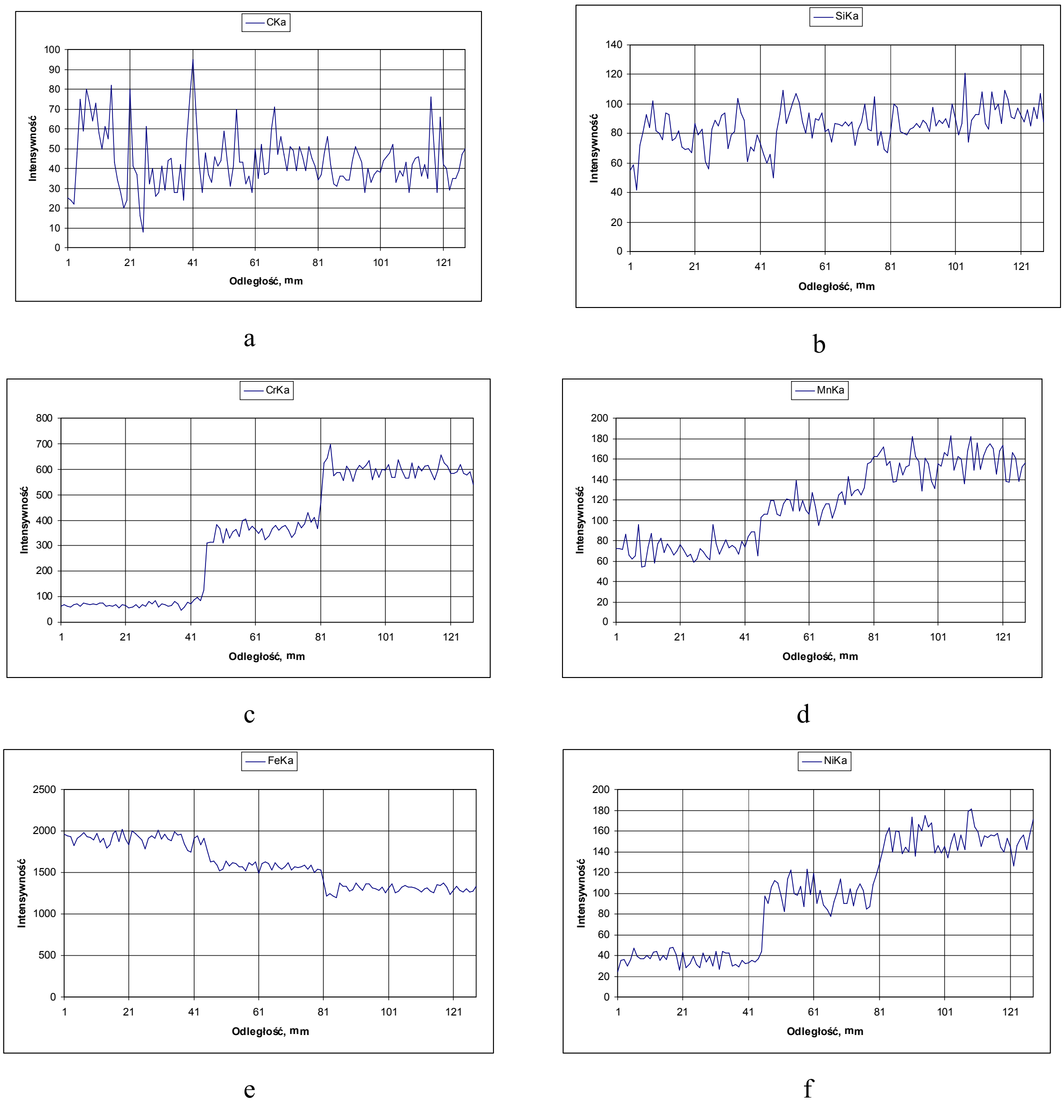


Figure 8. Linear distribution of selected elements in the bonding interface shown in **Figure 7**: *a* – carbon; *b* – sulphur; *c* – chromium; *d* – manganese; *e* – iron; *f* – nickel

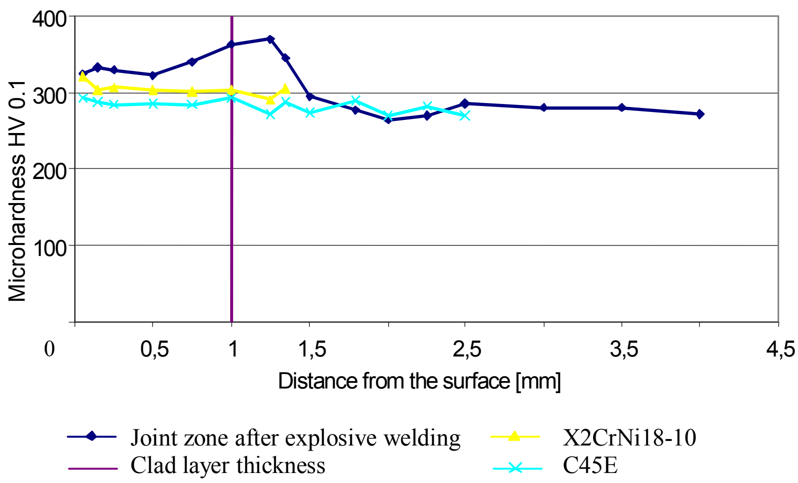


Figure 9. The distribution of microhardness for stock materials and in bimetallic bars after explosive welding: with a clad layer thickness of: *a* – 1,0 mm; *b* – 1,5 mm; *c* – 2,0 mm

When comparing the obtained microhardness values for the initial materials and the bimetallic bars after explosive welding it can be found that an increase in the microhardness of the materials examined has occurred. This microhardness increase was caused by hardening of the material during explosive welding and the deformation of the clad layer. A high increase in microhardness was observed in the joint zone. The highest microhardness increase in the joint zone (25% to 30%) was obtained for a bimetallic sample, which had a clad layer thickness of 1.0mm (**Figure 9**).

The microhardness increment for steel C45 explosively welded averaged out at about 5%. The increment in the microhardness of the clad layer after explosive welding was approx. 10% on the average. Microhardness values for homogeneous materials were, respectively: for steel C45, an average of 282 HV0.1; while for the corrosion-resisting steel, 305 HV0.1 on the average.

Conclusions

On the basis of the performed tests it was found that by the proper selection of explosive welding parameters for the metals tested, a bimetallic semi-finished product was obtained, which was characterized by a fast joint between bimetallic layers with regular waves, meeting the conditions imposed on feedstock to be hot rolled. The good quality of the joint between the bimetallic layers is indicated by the existence of a transitory layer between the bimetallic feedstock layers joined.

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Производство корозионностойких биметаллических прутков сталь-сталь, получаемых сваркой взрывом

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В статье дан анализ производства корозионностойких биметаллических прутков сталь-сталь, получаемых сваркой взрывом. Такой способ является одним из основных для получения таких прутков и характеризуется большой прочностью соединения двух различных металлов. Также приведен анализ прочностной связи биметаллического соединения в поперечном сечении экспериментального прутка, полученного экспериментальным путем.