Obtaining two-layered pipes and rods using explosion energy and hot deformation

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Abstract. In this work, experimental studies were carried out to obtain bimetallic pipes and rods using explosion welding and hot deformation. The cladding layer was made of 08Cr18Ni10Ti stainless steel. It was found that explosion welding provides high-quality adhesion of the bimetal layers. Subsequent hot plastic deformation did not affect the ratio of the component layer thicknesses and the quality of the welded joint, which is confirmed by studies of the microstructure and mechanical tests of samples for flattening. Based on the results obtained, a combined technology for the production of bimetallic pipes and rods with a combination of layers of steel 20 + 08Cr18Ni10Ti was developed and tested.

1. Introduction

The production of bimetallic pipes and rods can be achieved through different processes such as rolling (cast-rolling) [1, 2] and diffusion bonding [3], explosion welding [4-6], extrusion [7] and centrifugal casting [8]. There are also complex technologies combining some of the above methods. Explosion welding (EXW) is used to create a metallurgical bond between two or more similar or dissimilar materials. Production of bimetallic clad cylindrical billets by means of EXW is one of the prospective trends. For the production of long corrosion-resistant bimetallic pipes, it is advisable to use the combined technology "EXW + rolling". Pipes made of double-layer steels have high strength, toughness and corrosion resistance, therefore they are recommended for operation in the oil and chemical industry, for the production of underwater pipelines, transporting the water-and-gas mixture, and other main pipelines [9].

The formation of a joining between two cylindrical billets is influenced by a number of factors, each of which can lead to a loss of process stability and to the formation of defects in the near-weld zone. Important in this case is compliance with all welding modes and assembly accuracy.

The aim of the study was to demonstrate that the use of the combined technology "EXW + rolling" for corrosion-resistant pipe production and study the influence of process parameters, scheme and hot rolling on the properties of the joining zone in bimetallic pipe specimens.

2. Materials and Methods

In this study, we developed and tested a method for producing double-layer rods and pipes with external corrosion-resistant layer. The billets was made up of type the austenic stainless steel pipes and carbon steel pipes and rods. The system and its individual components are illustrated in Figure 1. The raw materials used were rods made of steel 20 (diameter 20 mm) and pipes 08Cr18Ni10Ti steel
(cladding layer 2.5 and 5.0 mm thick). The outer diameter of the pipe was 28 mm and 34 mm. The pipes and rods were 0.8 and 1.5 meter long.

![Figure 1](image)

**Figure 1.** Schematic (a) and actual view (b) of systems used for EXW of bimetallic stock: 1 – detonator; 2 – explosive; 3 – upper centering element; 4 – outer steel pipe 08Cr18Ni10Ti; 5 – inner steel 20 rod; 6 – bottom centering element

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According to the diagrams, a rod 5 of steel 20 was installed inside a pipe 4 made of 08Cr18Ni10Ti corrosion-resistant steel. To ensure a uniform detonation front, a welding gap and to prevent explosive detonation products from getting into it, special centering elements 3 and 6 were used. The assembly was placed on a sand base. Before assembling the elements, the outer surface of the stainless steel pipe was mechanically cleaned and degreased.

According to the presented diagrams, the charge of ESs (a mixture of ammonium nitrate with diesel fuel) 2 was placed on the outer surface of a 08Cr18Ni10Ti steel pipe. The speed of the contact point was 2300 and 3350 m/s. At the explosive ground, assemblies that were 5 meters apart were simultaneously undermined.

In the present work, ultrasonic continuity monitoring of the connection was carried out using a UD2V-P45 device with separately combined converters of the P112-2.5 and P112-5 type. Metallographic studies of the initial blanks and the bimetallic materials obtained from them were carried out using a METAM LV-34 metallographic inverted microscope. The microscope images were taken with a TC-500 camera. The microstructure of the samples was studied using an ultrahigh-resolution Zeiss Ultra plus field-based scanning electron microscope on the base of an Ultra 55 together with an X-ray microanalysis unit INCA 350 (Oxford Instruments).

The two-layer rods obtained by explosion welding were broached using the following technology: before broaching, a centering recess with a diameter of 12 mm was drilled at the front end of the billets to improve secondary capture and increase the accuracy of the ends of the sleeve. Then, the initial billets were heated in a chamber furnace of electrical resistance. The heating temperature is 1160…1180 °C. The firmware was carried out on a twin-roll piercing mill for screw rolling MISIS-130D with barrel-shaped biconical rolls. The feed angle is 15 degrees. Biduloid cast iron rulers were used as a guiding tool. The firmware was carried out on a mandrel with a diameter of 19.5 mm with a conical shape of the working part. The bars were rolled on a three-roll minivan of radial-shear rolling 14-40 along the route 24 → 22 → 19 → 16 mm. The feed angle of the work rolls is 18 degrees. After
each pass, a template was cut from one end on a band saw. Before the next pass, the bar was heated in the furnace to the rolling temperature.

In the study, we calculated the ratios of the volumes of the constituent layers per 1 cm of the length of the bimetallic billets after each technological stage. The quality of the connection layers in bimetallic pipes was determined by testing the control samples for flattening.

**Results and Discussion**

After the experiments on the developed schemes two-layer pipe billets of 0.8 and 1.5 meters in length were produced. For further rolling, samples 250 mm long were taken from the middle of two-layer rods (Figure 2).

![Figure 2. Bimetallic rods divided into parts](image)

Figure 2. Bimetallic rods divided into parts

Figure 3a shows the microstructure of the welded joint in a bimetallic rod 1.5 meters long (detonation velocity 2300 m/s), and Figure 3b shows the microstructure of a bimetallic rod 800 mm long (detonation velocity 3350 m/s). Microstructure studied on transverse microsections. The results of the metallographic study are as follow: 1. No macrodefects of the joint are found, 2. Local microdefects are of formed in explosion welding, but they are don’t form a continuous layer.

![Figure 3](image)

Figure 3. Morphologies of the joint surface: a – bimetallic rod 1.5 meters; b – 0.8 meter length; c and d – element lines scanning near the joint surface

Figures 3c and 3d shows the element line scanning near the joint surface under different explosive welding conditions. The transition from a steel base to a clad metal is a narrow strip with uneven
edges. The width of the transition zone in the studied area of the connection varies from 1 to 150 microns. The features of the distribution of chemical elements in the transition zone, shown in Figures 4a and 4b, indicate diffusion from the cladding layer into the main chromium, the content of which decreases from 50% to 20% with distance from the layer.

![Figure 4](image)

Figure 4. Element distribution: a – bimetallic rod 1.5 meters; b – 0.8 meter length

Figure 5 shows the specimens after hot deformation - screw firmware and radial-shear rolling. The total wall thickness of the bimetallic pipes after flashing was 5.3–5.5 mm with an extraction coefficient $\mu_{pr} = 1.8$ and a relative compression of the pipe cross section of 44%. The results of measurements of the outer diameter of the samples after explosion welding showed that there was a uniform deformation of the outer pipe during welding by the value of the welding gap. The ratio of the volumes of the constituent layers in all samples after explosion welding and hot deformation remains the same.

![Figure 5](image)

Figure 5. Specimens after hot deformation

Figure 6 shows the microstructures of the joint surface of the specimens after rolling and broaching. During metallographic studies of the specimens, no hardening was revealed; a decarburization zone was observed at the joint boundary in steel 20, which was formed as a result of thermal action during hot plastic deformation. It was found that in steel 20 in the joint there are layers of recrystallized ferrite grains.
Figure 6. The microstructure of the joint surface in bimetallic rods and pipes steel 20 + 08Cr18Ni10Ti after hot deformation: a – bimetallic pipe; b – rod

As a rule, when welding by explosion of steels, the hardness in the joint increases [10]. This is due to the hardening of the welded surfaces under the action of the pressure of the detonation products, as well as plastic deformation during the collision of the welded surfaces.

The microhardness measurements of the layers at the joint boundary after each technological stage showed that at the heating temperature corresponding to the technological process, the hardening in the joint is removed due to recrystallization, there by improving the plastic properties of the finished product.

At the final stage of the work, mechanical tests of control samples for flattening were carried out. Visual control of flattened specimens showed that cracks and delamination were not detected.

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