Application of the internal protective layer from stainless steel to the surface of long-length pipes with an explosive welding

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Abstract. This study is devoted to obtaining long-length two-layer corrosion-resistant tube blanks by explosion welding for their subsequent rolling into tubing. The technological scheme of the process was developed, which allowed ensuring high-quality adhesion of the internal corrosion-resistant layer from austenitic stainless steel 08Kh18N10T with a tube blank made of 37G2F hollow structural steel. In the course of study on the experimental production of bimetallic pipes of 2.4 meters in length, the following problems were solved: 1) the choice of optimal collision regimes of the tube elements thrown on each other; 2) the development of the necessary technological equipment to maintain the alignment of the main elements; 3) ensuring full filling of the internal surface of the device with solid-liquid filler without contact with the welding gap (sealing with welded joints); 4) reducing the degree of lateral dispersion of the explosive due to the assembly enhancing in the ground and use a metal formwork; 5) estimation of the relative narrowing of the outer diameter of the bimetallic tube after explosion welding; 6) carrying out ultrasonic control of the continuity of connection of the obtained two-layer pipes in order to reveal the mistreatment zones along the length of the blanks.

1. Introduction

The ability of a metal to withstand corrosion in a given environment determines its specific application. Corrosion resistance is determined by the material of the cladding layer. 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 [1].

Using explosion welding, almost all metals or alloys used in industry can be joined together, with high bond strength of the layers [2-4]. The quality criterion for welding is to achieve a bond strength of the layers at the level of a less stable alloy.

Both flat and also cylindrical products are obtained by explosion welding [5-8]. However, the problems of obtaining by explosion welding the lengthy (more than 10 diameters) cylindrical products are not resolved to the end at present. The formation of a connection between two cylindrical blanks 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. Often you can observe damages in the process of cladding by the explosion of a clad thin-walled layer, and in some cases, complete destruction of the assembly. High-speed deformation along with the presence of turbulent flow, heated to several thousand degrees of gas in the welding gap [9, 10], are the determining factors affecting the formation conditions of the
joint. Thus, the larger the product, the more carefully it is necessary to approach the choice of welding modes and the development of the technological scheme.

2. Materials and experimental methods
We used pipes made of steel 37G2F (main layer – 12 mm thick) and steel 08H18N10T (cladding layer – 2.5 mm thick) as the raw materials. The chemical composition of the starting materials is given in table 1.

| Material       | Fe  | Ni  | Cr  | Mn  | C   | Mo | Si | W  | V   | Ti  | Cu  |
|----------------|-----|-----|-----|-----|-----|----|----|----|-----|-----|-----|
| 08Kh18N10T     | 9–11| 18  | 2.0 | 0.08| 0.5 |    |    |    | ≤0.2| 0.5 | -   |
| 37G2F          | 0.20| 0.22| 1.52| 0.35| -   | 0.28| -  | 0.15| -   | 0.01| -   |

The length of the initial blanks was 2.4 meters. A stainless steel pipe was installed inside a thick-walled outer pipe with a gap of 2 mm. Before assembling the elements, the outer surface of the stainless steel pipe was mechanically cleaned and degreased. The gap was fixed with the help of special top and bottom covers. The lower cover was welded to the stainless steel tube by argon-arc welding to prevent water from entering the welding gap. The assembly of the two pipes was placed on a flat steel base. Immediately at the site, the pipes assembled in this way were placed on a previously prepared site. After installation the internal hollow of the assembly was filled with a filler (support element) and a formwork for the explosive was installed (figure 1a). A solid-liquid medium in the form of fragments and water was used as supporting filler. The gap between welded pipes was filled with an inert gas – helium in order to reduce the heat input from the shock-heated gas, thereby minimizing the penetration depth of the welded surfaces. Due to the low density (0.00017846 g/cm$^3$), the gas was supplied in a “top-down” scheme. A mixture of microporous ammonium nitrate with diesel fuel was used as the explosive (figure 1b). This scheme was worked out by the authors of [8] and in conditions of large sizes of the assembly it was chosen as the most optimal for this experiment. At a given thickness of charge of the explosive, the velocity of the contact point was 2900-3000 m/s.

For the assessing the influence of the conditions for finding the external stemming from the sand on the degree of transverse deformation of the pipe, two schemes were used with the use of bulk sandy soil: with a partial depth of 1.5 meters by immersing the assembly in a pre-made hole and simply filling with sand by the diameter of the assembly. The measurements were made in two perpendicular planes of the outer diameter of the original pipes to determine the relative radial narrowing of the outer tube along the length of the blank and to estimate the possible loss of cylindricality after explosion welding. The measurement points were arranged as follows: the first 21 marks were applied in steps of 100 mm, then closer to the end of the tube; the marks were applied in length of 50 mm. The marks were applied by the shock method. The obtained bases were measured with an accuracy of 0.1 mm twice. After the explosion welding the measurements were made at the same points, thereby evaluating the change in the outer diameter along the length of the bimetallic blank. Based on the fact that the gap between the pipes was 2 mm, it is clear that, from the point of view of preserving the original shape of the surface, the outer diameter of the pipe will narrow by 4 mm (3.7%) along the entire length.

Since the quality of the explosion welding is determined by the state and structure of the joint boundary, it was precisely the weld area of the welded materials that was exposed to a detailed analysis. The quality of welding was determined metallographically on polished sections. We used for
this purpose the METAM LV-34 metallographic inverted microscope (the image was taken from the microscope by TC-500 model camera) and Zeiss Ultra plus high-resolution field-scanning electron microscope based on Ultra 55 with X-ray microanalysis device INCA 350 Oxford Instruments. Ultrasonic control of the continuity of the connection was made using UD2V-P45 device with separately-combined P112-2.5 and P112-5 converters.

![Image 1](image1.jpg)

**Figure 1.** External view of the assembly: a - formwork cavity before filling with explosive; b - after filling with explosive and stemming installation.

3. **Results and discussion**

3.1. **The samples obtained by explosion welding**

After the experimental work on the developed schemes two-layer tube blanks of 2.4 meters in length were produced (figure 2).

![Image 2](image2.jpg)

**Figure 2.** Bimetallic tube blanks obtained by explosion welding: a – blank obtained with partial deepening of the assembly in the ground; b – blank received according to a scheme filled with sand.

After visual inspection there were no defects on the outer and inner surfaces of the pipes. The support element (shot+water) was extracted directly at the test site and used in further experiments.
Ultrasonic inspection revealed zones of border (initial and final parts of the blank) of short-welding on both pipes with a length of 20 to 50 mm.

3.2. **Measuring the transverse deformation of a bimetallic tube**

After ultrasonic testing, the outer diameter of the bimetallic tube blanks was measured at the same points as before welding. The results of the measurements are presented on the graph of the dependence of the value of the relative narrowing of the outer diameter of the tube blank from the length starting from the point of the collision beginning (figure 3). The pipe obtained by a scheme with partial immersion in the ground is designated as pipe №1; the second pipe is referred to as №2, respectively.

![Graph](image)

**Figure 3.** Dependence of the relative narrowing of outer diameter along the length of the blank from the method of piling.

From the data obtained it can be concluded that a 1.5 meter deep of assembly in the ground permits to maintain the degree of transverse deformation of the pipe within the prescribed limits of 3.7–4.0%. The deformation along the length of the blank in this case is more even, therefore such a scheme is promising from the point of view of welding by explosion of long pipe structures. Apparently, in conditions of greater constraint, the support environment efficiently works when the welded layers collide and does not allow deformation of the inner tube. Moreover, additional experiments are needed to finally establish the advantages of this scheme.

3.3. **Metallographic studies of the bond edge**

For carrying out metallographic studies from the double-layer tube blank, ring templates were made at a distance of 100 mm from the beginning and end of the pipes. The ring samples were then divided into 4 parts, microsections were made and the bond edge in each sample was examined.

Metallographic studies have shown that, at a length of 100 mm from the beginning, the melted areas are practically absent, and if they are present in the near-weld zone, they have small sizes. The shape of the joint boundary is an almost straight line with a weakly expressed wave profile (figure 4a).

A different picture is observed in the near-weld zone on the final (100 mm from the end of the blank) sections. A continuous interlayer was found on the boundary of the compound (figure 4b), and on different samples from the same template the thickness of this interlayer was different. And in some samples there was no continuous layer at all. Apparently, this is due to the loss of stability of the process at a certain length, which leads to a loss of uniformity of the gap between the pipes.
The energy-dispersive analysis of the compound zone showed that the composition of the intermediate cast interlayers mainly consists of iron (~80%), chromium (~10%), and nickel (~6%). The microhardness of the transition zone was 650-700 HV, 480-470 HV and 380-400 HV for the layers of stainless and structural steel, respectively.

![Image](image1.png)

![Image](image2.png)

**Figure 4.** Bond edge of 08X18H10T (upper layer) and 37G2F (lower layer) steel at initial section of bimetallic pipe.

The unevenness of welding of the surfaces of welded pipes in the final zone can be related to the fact that in the welding gap, a piston of shock-compressed gas is formed ahead of the point of contact, which is displaced at a hypersonic speed exceeding 5-7 flaps, which leads to aerodynamic heating of welded surfaces, dissociation of oxides and melting of thin surface layers [10] Uneven compression along the length and diameter of the cylindrical blank leads to the formation of radial flows of shock-compressed gas, which shift to large gaps, which in turn leads to uneven heating of the welded surfaces and formation of a local cast inclusions arranged as narrow strips along the direction of welding. The use of an inert helium gas apparently does not prevent the intensification of the process of uneven heating of the surfaces to be welded, however, further studies and additional experiments are needed in this direction.

### 4. Conclusion

Based on the conducted experiments and studies of the bimetallic tube blanks produced by explosion welding, the following conclusions can be drawn:

1. The used explosion welding modes are optimal for obtaining long (more than 20 diameters) double-layer pipes. In this case, it should be noted that this mode can be considered as the maximum for high-quality adhesion of the layers and with further increase in the parameters there will be an increase in the thickness of the interlayer and the degree of deformation of the pipes, which will negatively affect the quality of the obtained product.
2. The applied explosion welding scheme made it possible to throw a thick-walled pipe without forming a conicity of the outer surface and maintain a level of transverse deformation within the set limits.
3. The supporting element (steel shot+water) facilitated the obtaining of an even connection over the entire length of the pipe blank, maintaining the integrity of the thin-walled cladding layer and uniform deformation of the outer tube. Particularly worth mentioning is the processability and possibility of reusing this type of support element for explosion welding of long tubes.
4. The conducted ultrasonic testing of the continuity of the joint showed that the adhesion of the layers occurred over the entire surface of the controlled pipes, except for insignificant in length edge areas.
5. The study of the transverse deformation of the outer tube after explosion welding showed that to ensure a minimum narrowing of the outer diameter of the blank, it is necessary to use a scheme with a deepening of the assembly into the ground.

6. Metallographic studies of the bond zone along the four bimetallic tube guides showed that when explosion welding of long pipe blanks in the initial section (100 mm from the beginning of the collision), the joint boundary does not have a regular wave form, the wave profile is poorly expressed and the wave parameters do not have regularities. A continuous layer of the melt with an intermediate elemental content was found at the end zone (100 mm from the end of the blank) at the edge of the compound, and the thickness of this layer was different for different samples from the same temperature, and in some samples there was no continuous interlayer at all. Apparently this is due to the loss of stability of the process, which led to a loss of uniformity of the gap between the pipes.

7. Based on the above conclusions, it can be said that the two-layer tube blanks obtained with explosion welding with a corrosion-resistant layer of stainless austenitic steel 08Kh18N10T can be processed through further technological redistribution (hot rolling).

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