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IMPROVEMENT OF TECHNOLOGY AND EQUIPMENT FOR WELDING VERTICAL JOINTS WITH FORCED WELD FORMATION

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ABSTRACT

The paper presents the results of design and experimental studies carried out to modernize welding equipment to increase the reliability of operation in site conditions and improve ergonomic performance. The results of improving the technology and technique of welding vertical joints with forced weld formation in order to increase the efficiency of the process and expand its technological capabilities, as well as improve the sanitary and hygienic working conditions of the welder-operator are presented. The A-1150 and AD343 machines were modernized and prototypes of the machines were manufactured to create new specialized assembly welding equipment based on a modern element base in compliance with ergonomic requirements. The study of the macrostructure of the welded joints showed that the weld metal is dense, and no defects in the form of lacks of fusion, cracks, pores, nonmetallic inclusions, etc. were found. The main advantages of the proposed method compared to ESW and the method of welding with forced flux-cored wire formation are shown. The technology and equipment for submerged arc welding with forced formation of vertical joints of low-carbon low-alloy steels with a thickness of 12–80 mm have been developed and successfully implemented in factory and site conditions.

KEYWORDS: electroslag welding, electric arc welding with forced weld formation, assembly machines, low-carbon low-alloy steels, fluxes, heat input, impact toughness

INTRODUCTION

At present, in Ukraine, one of the important areas of performing welding works in the workshop and field conditions are the works on the creation and restoration of metal structures manufactured of metal of medium (different dimensional values) and large range of thicknesses. Other indices of welding conditions causing the choice and application of welding and technological process may be: speed of work performance, availability of qualified performers and the possibility of quick production of filler material, technological equipment available in the designated place of works.

In the modern production, vertical welds with forced metal formation are performed mainly with the use of two technological processes: electroslag welding (ESW) and an electric arc process with forced weld metal formation (EAW). Electroslag welding from the time of its invention has become widespread all over the world [1, 2].

ESW is the most widespread in the manufacture of parts of machines and metal structures of large thickness (more than 50 mm), such as housings of rolling mills, frames of jaw crushers, oversized bands of rotary fire kilns, housings blast furnaces, etc. [3]. This is predetermined by the high performance (in terms of melting rate of filler metal, ESW is out of competition) and the stability of the process, deep metallurgical treatment of weld metal (absence of defects in the form of pores and slag inclusions), possibility of welding metal of excessively large thicknesses, cost-effectiveness of the process, low sensitivity to the quality of edge preparation, relatively low cost of welding consumables, which are not scarce, etc.

However, the use of ESW during the construction of large metal structures of large thickness in the field conditions is not always acceptable due to the high heat input of the process that leads to growth of grains of weld metal and heat-affected-zone (HAZ). As a result, the mechanical characteristics of a joint are reduced, especially, impact toughness is noticeably reduced at low temperatures. The situation can be improved by the following high-temperature treatment (HTT), but it requires large-sized furnaces, the use of which for welding of large metal structures, especially in site conditions, is unrealistic.

All this facilitated the development of alternative processes of mechanized welding of small thickness metal in a one pass. One of them turned to be electric arc welding using flux-cored wire with forced weld formation by water-cooled copper shoes, both self-shielding and with additional gas shielding [4]. The method not only provides high performance of wire melting, but also became non-alternative to produce welds in a one/two passes in different spatial positions, both circumferential on pipelines, gas holders, spherical tanks, as well as “on the overhead” when welding horizontal girths of structures of the metal of at least 25 mm thick. However, the method required additional measures to protect the welding zone from drafts, especially at the height, and was too sensitive to side deviation from the vertical. Welding of metal of more than 30 mm thick using two flux-cored wires turned to be complicated because of the difficulties with the positioning of the wire in depth due to intense radiation and emission of fumes. In addition, production of flux-cored wire is non-serial, it has a high price and a short storage period because of its hygroscopicity.

Therefore, PWI conducted research on the development of welding method with forced formation of vertical welds under a thin layer of molten slag using solid-section wires [5]. The first experiments on practicing of such technique of weld performance showed the prospect of the method, since it combined a stable process course and reliable protection of the welding pool, which was an urgent task.

However, this method did not find an industrial use for several reasons:

- absence of a compact mechanism of drawing two wires for welding in the site conditions, which would provide their reliable and stable feeding to the welding pool;
- lack of mechanism for positioning wires in the slit between welded edges;
- flux AN-47, under which the process was performed, did not ensure its stability.

AIM OF THE WORK:

designing of mobile equipment and industrial technology for joining metal in site conditions with the thickness from 10 mm to the maximum possible in site conditions during the manufacture of tanks of various purposes, bridge spans, etc.

TASKS OF THE WORK:

- modernization of welding equipment in order to increase the reliability of work in these conditions and improve ergonomic indices;
- improvement of technology and technique of welding vertical joints with forced weld formation in order to increase the efficiency of the process and expand its technological capabilities, as well as improve sanitary and hygienic conditions.

MATERIALS AND RESEARCH METHODS

Experimental studies of the process of two-electrode welding with forced formation were carried out as follows:

- welding of specimens of low-alloy structural 09G2 and 10KhSND steels of 12, 20 and 25 mm thick was performed with the use of a prototype of a two-electrode apparatus and VSZh-1600 DC power source;
- electrode wires of Sv-08G2C and Sv-10NMA grades were used;
- fluxes for the process performance were chosen based on the following criteria: electrical conductivity and toughness in the molten state; technological properties, such as stability of the process, wetting of a shoes with the cooled water, which requires the quality formation of the weld metal; visual signal about the need to add another portion of flux to the welding pool; welding was performed with the use of flux grades AN-47, AN-22, AN-60 and AN-67A;
- the main criteria for choosing electrode wire were its diameter, which ensures the stability of the process when welding metal of different thickness; chemical composition that guarantees obtaining of mechanical properties and impact toughness of welded joint, which meet the requirements of standard documentation;
- using the procedure given in [6, 7], in the welding process, the high-speed recording of electrical mode parameters (I_c, U_c, V_{wf}) was performed by means of the Hall sensors, the ADC E-140 module and the Power Graph software. Numerical values of electrical parameters of the welding process were recorded at a frequency of 10 thou records per second. To determine the efficiency coefficient of the process η, during welding, the temperature and water consumption for cooling the copper slider were measured. Water temperature was measured by means of the Doubl Laser Infra Red Thermometer, which provides the measurement accuracy of 0.1 °C;
- tests of the weld metal and HAZ on the impact bending of Charpy specimens were conducted.

PRESENTATION OF THE BASIC MATERIAL

To carry out two-electrode welding of vertical joints with forced weld formation, a complex of works was performed to create the mobile welding equipment. In the process of designing a new apparatus, the design of the apparatus A-1150 was selected as a base, which is trackless, i.e. it moves along the slit between the welded edges of the sheets.

Movement of this apparatus is realized by making cuts in the sharp ribs of the edges of steel sheets by the teeth of the cone-shaped running wheel of the apparatus trolley during its pressing by plate-like springs through the knife fixed to the trolley — the rear suspension on the back side of the joint. This suspension pulls and presses the rear shoes — one of two water-cooled copper shoeses forming a weld. Such an apparatus is the most used one in the construction works.

To provide a two-electrode submerged arc welding process, a compact mechanism for feeding two electrode wires (Figure 1) was designed, which by its sizes did not exceed the standard mechanism for welding using one flux-cored wire. Its joint traction gear has two conical grooves for wires. Each of these wires is pressed with its idle gear with the same conical groove in the teeth, which allowed feeding both wires reliably and at the same speed.

Moreover, there were added mechanisms for adjusting the position of electrode wires in the slit between the edges (and distances between them) both separately and

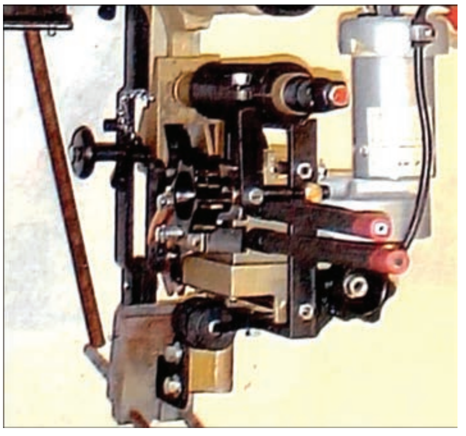

Figure 1. Appearance of upgraded drive for feeding electrode wires

together across the thickness of the joint, and at an angle relative to the weld axis. This, in combination with a standard corrector on the suspension axis, allowed almost plane-parallel displacing of the wires without the danger of "short-circuiting" the tips of the nozzles on welded edges, which would lead to their damage.

The welding voltage supply in such a mechanism is common to both wires, that is, welding is carried out by the so-called "split" arc with power from one current source with remote control.

To ensure the possibility of installing an additional coil with an electrode wire, the design of the coil bracket was changed. Taking into account the twice increased weight of the electrode wire and a load on the running trolley, certain changes were introduced into its design.

For a dosed flux supply, a flux-hopper with a spring-loaded shutoff rod was designed, which makes it possible to use a solenoid and a time relay to determine a portion of flux. The operator had only to determine the moment and frequency of charging, but when the joint deviated from the vertical position at more than 20°, such a flux-hopper did not completely block the flow of flux. Therefore, a flux-hopper was designed with a spring-loaded gate-valve, which reliably blocked the flow of flux during welding of joints when they deviated from the vertical.

Figure 2. Appearance of prototype of mounting apparatus for welding vertical joints

As a result of the carried out design and experimental works, a prototype of the mounting apparatus for two-electrode welding of vertical welds using solid cross-section wires was designed and manufactured (Figure 2).

Vertical welds and welds inclined to vertical (to 30°) were produced under the minimum possible layer of molten flux, which allowed closing the welding arc from its escaping outside (into the atmosphere). This enabled a visual control (in the gas-cutter glasses) of the positioning of welding wires in the slit-gap between the welding edges, which is important when feeding two wires simultaneously.

The required depth of the molten flux layer depended only on the arc voltage required to melt welded edges at a gap sufficient for safe passing of the nozzle tips, and was determined after stopping the process after the slag solidified above the weld metal. A fairly accurate dependence (approximate equality) of the required height of the molten flux layer and a gap at the joint was noted. Supporting the minimum possible molten flux layer allowed solving two tasks:

● receive a signal about the need in charging the next portion of flux;

● significantly, compared to ESW, reduce the heat input and, as a consequence, increase the impact toughness of welded joint to 27 %.

If slag spattering is absent, the flux during welding was spent only for the formation of a thin (about 1.4–1.5 mm thick) slag crust on the weld surface and proportionally depended on the gap in the joint, and therefore on the voltage. The dependences of flux consumption on an increase in the outlet of welding wires was not observed.

Fluxes, that maintained the electroslag process were not used for conducting research, since the main task of developing the technology was to obtain the process that is as close as possible to the electric arc process. This allows reducing the heat input into the base metal and thus increasing the impact toughness of welded joint, especially at low temperatures. The latter is important when welding metal structures in site conditions, where HTT is impossible.

The first studies of welding with forced formation were performed using fluxes of grades AN-47 and AN-60. Flux AN-60 provided satisfactory results during welding metal of 30–50 mm thick but low stability of the process on the metal of smaller thicknesses. In this case, both in the first and second cases, a tendency to leaking of a melt from under the shoes was observed. During welding under the flux AN-22,

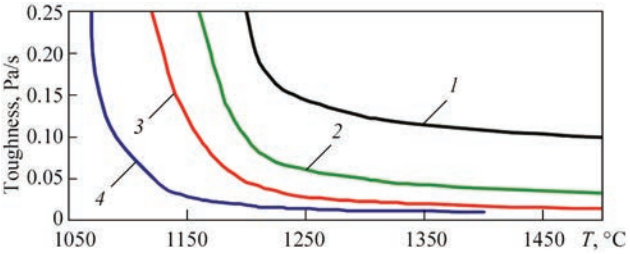

Figure 3. Dependence of flux toughness on temperature [8]: *1* — AN-67A; *2* — AN-348; *3* — AN-60; *4* — AN-22

a high stability of the process and satisfactory (without undercuts) weld surface formation were observed.

However, when using the mentioned flux, leaking of the liquid flux from under the working surface of the shoes was periodically observed, apparently due to the low temperature of its melting, which is unacceptable.

Studies have shown that flux AN-67A has satisfactory technological properties to produce welded joints with forced formation using solid cross-section wires. It provides a high stability of the process, presence of a clear signal about the need in adding another portion of flux, satisfactory formation of the weld surface and easy separation of a skull crust.

The only disadvantage of the flux was its tendency to form undercuts-indents at the edges of the weld due to its high toughness. The problem was solved by changing the configuration of forming weld of the shoes groove.

Thus, fluxes having high electrical conductivity and required toughness are the best for welding vertical joints (Figure 3) [8].

The first studies of submerged arc welding of metal with a thickness of 16 mm were performed using wires of 2 mm diameter [5]. However, a relatively small volume of welding pool did not allow increasing the feed rate of electrode wires of this diameter when welding metal of 14–20 mm thick in order to reduce the heat input, and an increase in the welding gap is not rational from the economic point of view.

It was experimentally established that satisfactory stability of the process can be ensured by using wires of 1.6 mm. Therefore, welding of smaller thicknesses involves the use of electrode wires of even smaller diameter. The use of electrode wires of 2 mm diameter can be recommended for welding metal of more than 20 mm thick.

The use of electrode wires alloyed only by Ni and Mo (for example, Sv-10NMA) did not allow reaching the level of impact toughness of the weld in accordance with regulatory documents. It was experimentally determined that about 1 % Mn should be introduced into the weld metal to provide the required impact toughness. This was achieved by mixing the metal of two electrode wires of Sv-08G2S and Sv-10NMA grades in a joint welding pool. In this case, the weld metal by its chemical composition approaches the surfacing using the wire Sv-08G1NMA.

Figure 4. Submerged arc welding of vertical joint of 20 mm thick with forced formation

Welding of specimens of 12–20 mm thick was performed at the calculated specific input energy E_w = 53.8–60.6 kJ/cm^2 (Figure 4).

Visual inspection of welds showed that the quality of weld formation is satisfactory, undercuts and corrugations are absent (Figure 5).

The examination of welded joint macrostructure showed that the weld metal is dense, no defects in the form of lacks of fusion, cracks, pores, nonmetallic inclusions were detected (Figure 6) [9]. The average depth of the base metal penetration is 7 mm and HAZ width does not exceed 7–8 mm.

The oscillograms of the high-speed recording of electrical mode parameters are shown in Figure 7.

In order to increase the values of impact toughness of welded joints, the technique of welding metal with the thickness of 40 mm in two passes at X-edge preparation was practiced (Figure 8).

In order to expand the technological capabilities of the process, the specimens of a steel of 50 and 64 mm thick were welded (assembled of two sheets of 32 mm thick). Welding of 50 mm thick metal was satisfactory, and for a metal of 64 mm thick, the heat of the arcs was not enough for rapid flux melting — its certain amount remained on the pool surface between the wires. To prevent this, the design of the wire feed mechanism was adjusted for feeding three electrode wires (without changing the dimensions), and the nozzles were replaced by a one solid with the ability to adjust all or one wire

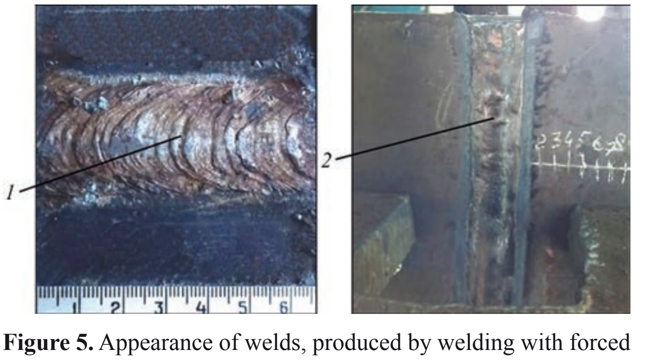

Figure 5. Appearance of welds, produced by welding with forced formation: *1*, *2* — rewelded specimens of 12 and 20 mm thick, respectively

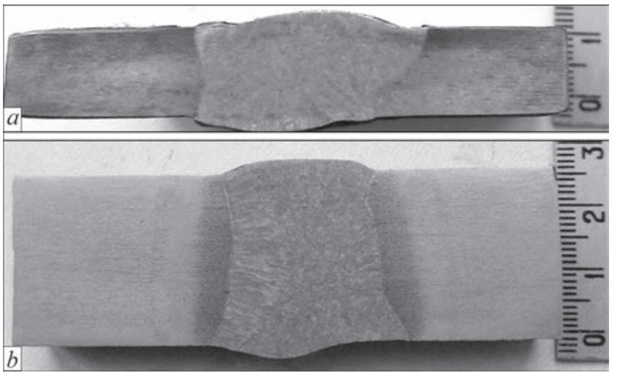

Figure 6. Transverse macrosections of welded joints of 12 (*a*) and 25 mm (*b*) thick

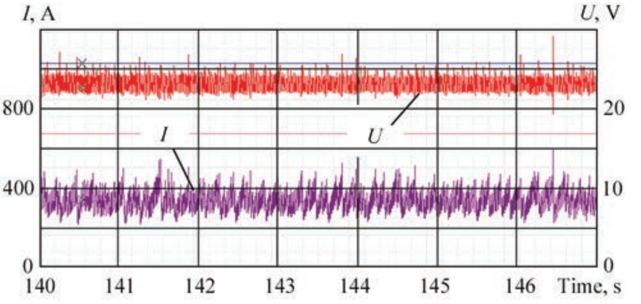

Figure 7. Fragment of welding oscillograms with a stable process

in a depth of the slit simultaneously. The feed mechanism was mounted on the designed suspension already of the rail apparatus on the base of the mechanism for movement of the apparatus AD343. This allowed the Elita-Burji Plant (Tbilisi) to manufacture structural elements of the concert hall Ureki-Natanebi (Figure 9) of 60 and 80 mm thick without angular deformations. The technology of manufacturing square-section pipes with a wall of 20 mm thick with radius rounding along the length was also practiced there.

At present, submerged arc welding was used to produce vertical welds and welds inclided at 30° from the vertical on about 20 span structures of non-standard bridges, overpasses, tunnel walls. Moreover time, the normative service characteristics of joints,

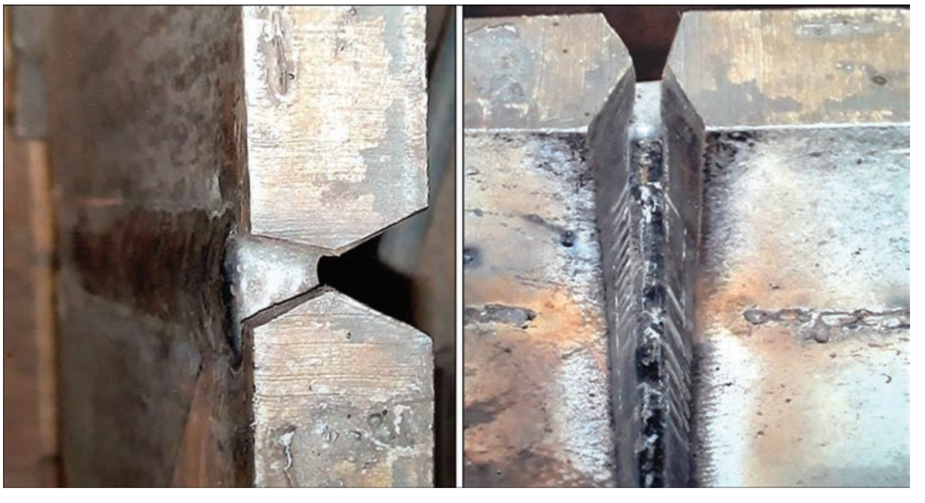

Figure 8. Appearance of weld after the first pass on the metal of 40 mm thick

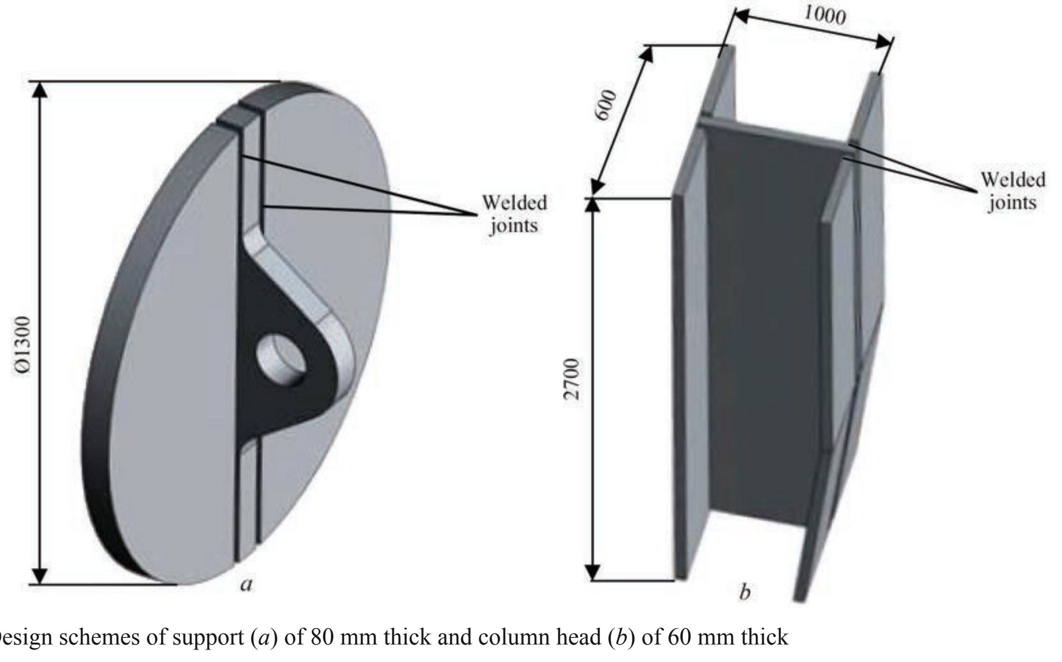

Figure 9. Design schemes of support (*a*) of 80 mm thick and column head (*b*) of 60 mm thick

including impact toughness at temperatures of up to –45 °C were provided.

The main advantages of the proposed method compared to ESW and the method of arc welding using flux-cored wire with forced formation:

● the possibility of refusal from further HTT of welded metal structures due to the low heat input in the base metal [9, 10];

● the possibility of defect-free renewal of the process after an unforeseen (emergency) stop;

● high economical efficiency of the process by more than twice decrease in the welding gap and reduction in flux consumption;

● high efficiency of welding due to a significant increase in the melting coefficient of the electrode wire (welding speed reaches 10 m/h instead of 2.5 m/h when using flux-cored wire);

● providing the quality protection of the welding pool and stable performance of welding process in site conditions in the presence of wind load;

● high cost effectiveness due to the use of non-scarce, not hygroscopic and relatively inexpensive welding consumables;

● improved sanitary and hygienic working conditions of the welder-operator due to the absence of intense radiation and a significant decrease in the volume of emissioned harmful fumes.

CONCLUSIONS

1. As a result of the performed works, the process of welding with forced formation of vertical welds using solid cross-section wire of low-carbon low-alloy steels of 12–80 mm thick was improved in the laboratory conditions. Welding consumables were selected, that provide the necessary mechanical properties of welded joints.

2. A-1150 and AD343 apparatuses were updated and prototypes of apparatuses were manufactured for the creation of a new specialized site welding equipment on a modern elemental base that complies with the requirements of ergonomic indices.

3. Technology and equipment for submerged arc welding with forced formation of vertical joints of low-carbon low-alloy steels of 10–80 mm was developed and successfully implemented in the factory and site conditions.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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