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DEVELOPMENT OF TECHNOLOGY OF SEALING HEAT EXCHANGER PIPES BY AUTOMATIC WET UNDERWATER WELDING

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One of the alternative sources of energy is heat pumps. The heat exchangers, included into their composition, represent pipes with a diameter of 140–190 mm, going into the ground to the depth of 200 m and filled with a heat-carrying agent: a mixture of water with 25 % of special coolant FXC2 based on antifreeze with corrosion inhibitors. For the heat exchanger sealing a technology for welding-in bottom was developed using automatic flux-cored wire underwater welding. The influence of coolant and depth on the formation and structure of weld metal were determined, the main parameters of welding process were selected: wire feed speed, rotation speed of automatic machine, inclination angles of torch, optimal gap between the pipe wall and the end of welded-in bottom. A pilot industrial inspection was carried out. 2 Ref., 8 Figures.

Keywords: *wet arc welding, low-carbon steel, heat pumps, welding-in of bottom, flux-cored wire, process automation*

The constant increase in the cost of oil products and gas forces many countries to turn their attention to the methods of obtaining the so-called renewable energy. One of the typical solutions in this industry is heat pumps. In particular, the system «Geoscart™» developed by the Company «Greenfield Energy Limited» is operated on their base [1]. It is designed to control heat flows of public and commercial buildings and enterprises with continuous energy consumption of high density: modern supermarkets, high-class hotels, stationary hospital complexes, food and pharmacological industry enterprises. At the same time, geothermal heat exchangers of special design for quick and efficient transfer of surplus or deficit heat are applied, using high density and heat capacity of geological formations located much lower than the surface soils. The standard depths for heat exchange process are the intervals reaching 200 m below the surface level of the earth. Each complex consists of more than a dozen of heat exchangers, which represent pipes with a diameter of 140–190 mm filled with a mixture of water containing 25 % of special coolant FXC2 based on antifreeze with corrosion inhibitors. The lower end of pipes is sealed with a rubber plug of a special design. The practice of operating heat exchangers showed that after several years as a result of aging of plug material, a leakage of heat-carrier appears, leading to decrease in the efficiency of heat pumps.

Figure 1. Welding with coolant FXC2

The aim of the work was the development of technology of sealing the pipes of heat exchangers by automatic wet underwater welding using flux-cored wire in solution of antifreeze at the depth of 200 m.

The investigations were carried out in two stages: in the laboratory installation based on the tractor TS-17 and in a hydro-pressure chamber with a depth simulation. At the first stage, the surfacing was carried out using experimental flux-cored wires in antifreeze solution. The welding speed was 6.8 m/h, the wire feed speed was 250 m/h. The vapors formed at dissociation of the coolant solution, escaping to the water surface, were flamed (Figure 1).

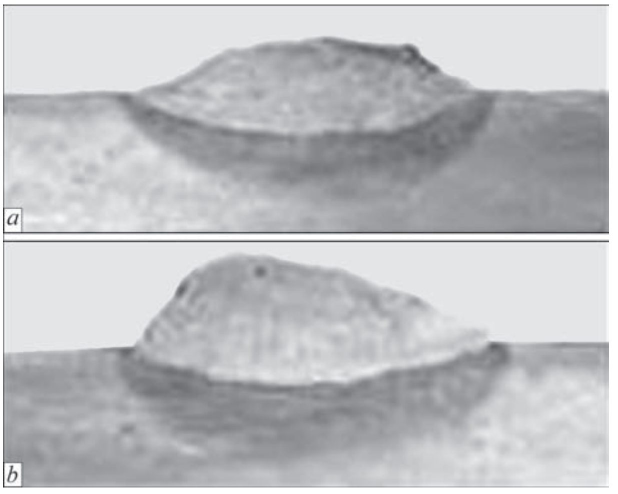

Figure 2. Macrosections of deposits produced in fresh water (*a*) and in 25 % solution of coolant FXC2 (*b*)

The macrosections of deposits produced by the flux-cored wire and selected for further investigations are shown in Figure 2. The presence of coolant did not actually have a noticeable effect on deposited bead formation.

To determine the effect of welding conditions on the structure of weld metal, the surfacing at the depth of 200 m was additionally performed. The metallographic examinations of specimens were carried out in the microscopes «Neophot-32» and Poluvar at different magnifications. The hardness was measured in the micro-durometer M-400 of the company LECO. The digital image was obtained with the help of the camera Olympus-5050. The results showed that the structure of weld metal during welding in fresh water represents ferrite with an ordered second phase (Figure 3, *a*), at the maximum hardness *HV*10 of 1950 MPa. During welding in 25 % solution of the coolant FXC2 a polygonal ferrite is formed in the weld metal, sometimes with a Wiedmanshtett orientation and finely-dispersed perlite precipitation along the boundaries of crystallites, the grain size is somewhat increased. In the body of crystallites several modifications of ferrite are formed: polyhedral and two modifications of a lamellar one with an ordered second phase and with a disordered one (Figure 3, *b*). The hardness is somewhat decreased (*HV*10 — 1820 MPa). During welding at the depth of 200 m, the structure of weld metal represents a fine-grained granular perlite and the areas of free ferrite (Figure 3, *c*). The separate large pores appeared. The hardness decreased to *HV*10 — 1600 MPa. Thus, the addition of the coolant FXC2 does not lead to a significant degradation of the microstructure of weld metal.

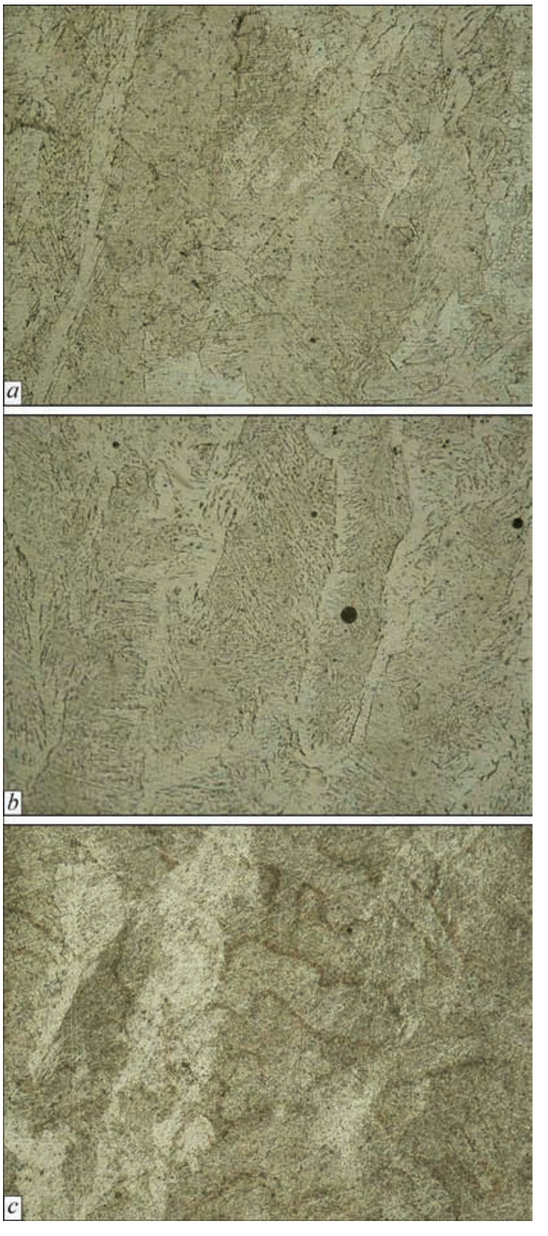

Figure 3. Microstructure of deposits produced in fresh water (*a*) and in 25 % solution of coolant FXC2 at the depth of 0.2 (*b*) and 200 m (*c*) (×250)

At the second stage, the welding technique was mastered as-applied to welding-in the bottom applying automatic machine in the hydro-pressure chamber. The specimens represented T-joint (Figure 4). A horizontal flange of 10 mm thick simulated the bottom.

Figure 4. Specimen for welding

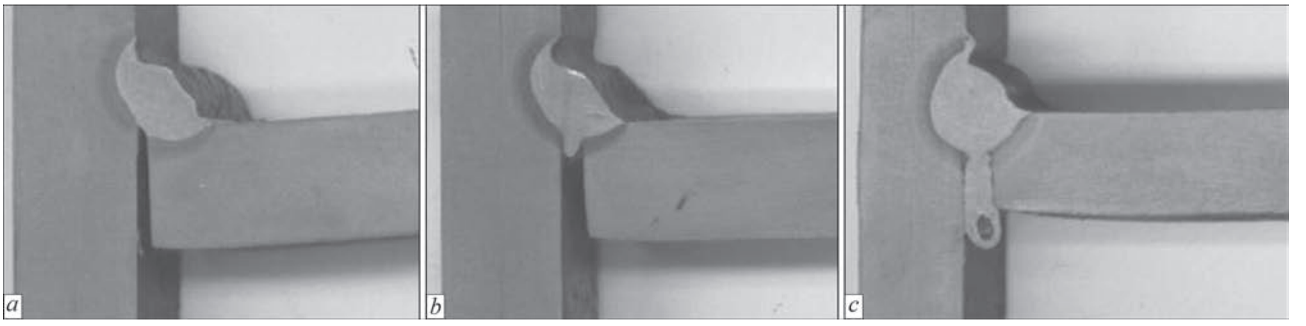

Figure 5. Examples of welded joints of specimens with different parameters of assembly and welding

Based on the design peculiarities of the automatic machine [2] and delivery terms of the bottom to welding site, it is desirable that a gap between its edges and the pipe wall was as large as possible. On the other hand, the increase in a gap can result in a loss of liquid metal. Therefore, the specimens for welding were assembled with a gap from 0 to 5 mm. Also, the inclination angle of the holder was varied in the vertical and horizontal planes and the place of ignition of the arc was varied on the wall or bottom at a different distance from the edge. The welding speed varied between 2.8–6.8 m/h, the wire feed speed was 160–260 m/h. The welding was performed by experimental flux-cored wire with diameter of 1.6 mm at the reverse polarity. The open-circuit voltage was 40–42 V.

Figure 5 shows macrosections of typical welded joints. The most acceptable results were obtained at the value of gap of 4 mm between the horizontal and vertical flanges of T-joint. The ignition was carried out in the horizontal flange at distance of 1–2 mm from the edge. The inclination angle of the electrode

Figure 6. Specimen for rupture tests: before welding (*a*), after welding at the depth of 200 m (*b*) and after test (*c*)

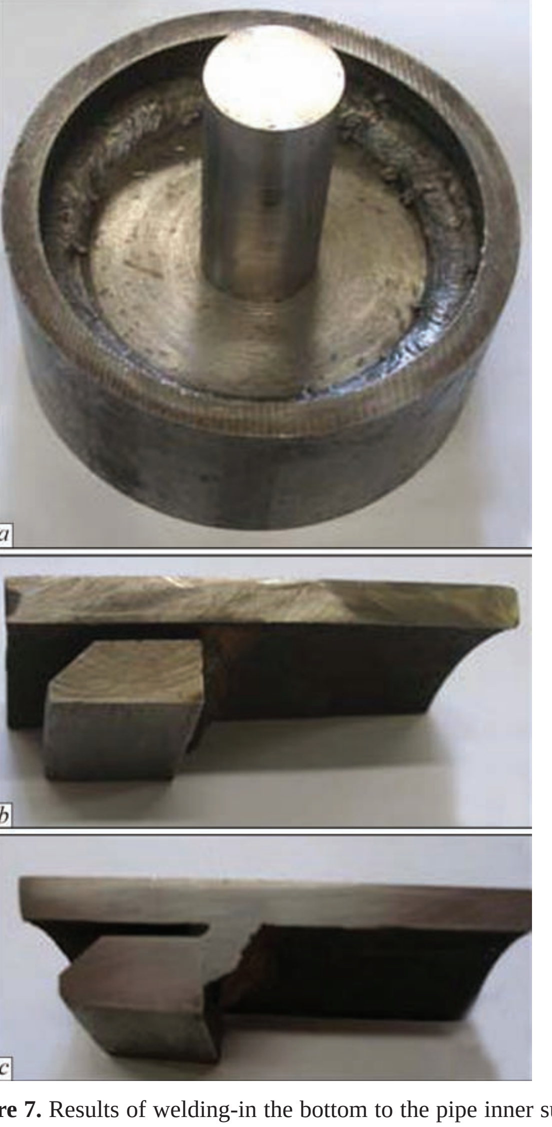

Figure 7. Results of welding-in the bottom to the pipe inner surface: *a* — circumferential weld with overlapping; *b* — real gap between bottom and pipe; *c* — shape of welded joint

in the vertical plane was 40–50° and in the horizontal it was about 20°. The welding speed was about 5 m/h, the wire feed speed was 220–240 m/h.

To determine the shear strength of weld metal, the specimens were welded simulating a fillet joint (Figure 6) and tested for tension. The welding speed was 5.1 m/h, the wire feed speed was 240 m/h, $U_{o\text{-}c} = 41$ V. The failure force was 9150 kg or 438 MPa in terms of failure section. Taking into account that the bottom undergoes the pressure of a water column of 200 MPa, it can be concluded that the formed welded joint has a significant margin of safety.

At the final stage the developed technology was tested in automatic mode in the special testing stand, designed at the EDTB of the PWI. The welding was performed in two stages. With the help of a tack the bottom was fixed relative to the pipe wall to prevent rotation of the bottom together with the automatic machine inside the pipe. Then the machine moved to the opposite side of the bottom and the welding of circumferential weld was performed. The welding time was selected taking into account the overlapping in 2–3 cm of weld beginning. The appearance of welded-in bottom and macrosections are shown in Figure 7.

In industrial conditions the welding was carried out in Crayford, Great Britain, in the pipe of 119 mm diameter. The object consisted of 15 wells with the depth from 180 to 210 m, the angle of well location relative to the vertical was from 0 to 15°. Before the start of welding operations, the wells were checked by a special set of models with the diameters of 118, 117 and 116 mm for passing ability of welding machine and for determination of the bottom diameter. The welding speed was 6.3 m/h; the welding time was 3 min 18 s; the welding current was 200–220 A; the voltage was 50 V. After welding, the weld quality was evaluated visually with the help of a special video camera (Figure 8) and with an excessive pressure of 1 MPa for 30 min.

Figure 8. Appearance of welded-in bottom

The obtained results showed that the developed technology of welding-in the bottom inside the pipe provides its sealing, preventing the loss of expensive coolant and reducing the efficiency factor of the heat pump.

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