EQUIPMENT AND TECHNOLOGY OF EBW IN FINISHING SMOOTHING AND REPAIR OF REVERSE BEADS OF WELDS OF TUBULAR PRODUCTS

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Given are the hardware and technological solutions for the finishing smoothing and repair of linear reverse beads of weld of up to 1200 mm long inside the position extended tubular products of a rectangular shape using a system of electron beam refraction by 90°. As applied to titanium alloy VT20, the parameters of electron beam finishing smoothing were obtained providing the formation of a smooth transition from base metal to weld, smooth surface of molten metal and prevention of undercuts of up to 0.15 mm depth.

Keywords: *electron beam welding, through penetration, reverse bead of weld, electron beam, rotating system, long tubular products, working distance, focusing, depth and width of penetration, crater*

In EBW with a through penetration of position and rotating butts of long tubular products of round, square and rectangular shape an internal surface in a number of cases is working. To perform the finishing pass or repair for eliminating of roughness on the surface of weld reverse bead, small craters and undercuts along the edges of bead by an electron beam using a conventional method is not possible due to limited internal sizes of the product and difficult access to the site of treatment.

Known is the method of flashing the internal surface of tubular products using an electron beam deflected by electric field [1]. Application of a cooper reflector, mounted on a ceramic isolator, makes it possible to accumulate a charge in entry of electron beam on it and to create the field between the tube wall and reflector, with the help of which the beam is deflected along the preset trajectory to the internal surface of the tube being flashed. During control of electron beam deflection, the angle of inclined edge surface of the reflector, distance between the reflector and tube being flashed, shape of reflector and adjustment of parameters of primary electron beam are changed. The drawback of this method of flashing is the need in maintaining of a gap between the reflector and internal surface of the tube of not less than 3 mm, as well as the location of butt or reverse bead of weld at the depth of not more than 110 mm.

Investigations on repair and finishing smoothing of reverse beads of weld were performed in installation KL-138, designed at the E.O. Paton Electric Welding Institute and having computer control of all the parameters and systems. The installation is completed with a power complex on the ELA-60/60 base and electron beam gun, which is moved inside the vacuum chamber along the linear coordinates X, Y, Z, and also rotated around the Y–Y axis along the coordinate QG by 0–90° angle. Vacuum chamber, having the 4500 × 3000 × 3000 mm internal size and 40.5 m^3 volume, is evacuated under the automatic condition of control to the operating vacuum of $2.66 \cdot 10^{-2}$ Pa ($2 \cdot 10^{-4}$ mm Hg) for less than 30 min. Application of cryogenerator of POLYCOLD type during pumping allowed decreasing significantly the time of evacuation and amount of moisture in vacuum chamber and butt of edges being welded that is particularly important in welding of titanium alloys [2]. At accelerating voltage U_{acc} = 60 kV the range of electron beam current I_b = 0–1000 mA is overlapped using two optics: 500 (I_b = 0–500 mA) and 1000 mA (I_b = 0–1000 mA). Accuracy of electron beam gun positioning along coordinates was not worse than 0.1 mm. Imaging of site of welding in secondary-emission electrons, as well as the coincidence of electron beam with a butt with an error of 0.1 mm was performed by the RASTR system.

To repair and to perform the finishing smoothing of linear and circumferential reverse beads of weld inside the tubular products of length of up to 1200 mm, and also to avoid the labor-consuming mechanical smoothing of a weld root part in welding, which is performed from the external side of the product, a system of electron beam refraction by 90° was designed, operating by the principle of effect of non-homogeneous magnetic field on electron beam in change of direct current in electric magnet coil. As is shown in Figure 1, the rotating system is mounted on the edge surface of the electron beam gun. It consists of a hollow pipe of a required diameter and length, and also water-cooled electromagnetic rotating system. Spatial position of the rotating system is selected so that after refraction by 90° the electron beam was directed strictly vertically downwards. Imaging of butt and reverse bead inside the tubular products, and also electron beam setting are made using a deflecting system, mounted in front of a rotating electric magnet, sensor of secondary-emission signal and RASTR system. The deflecting system of the main electron beam

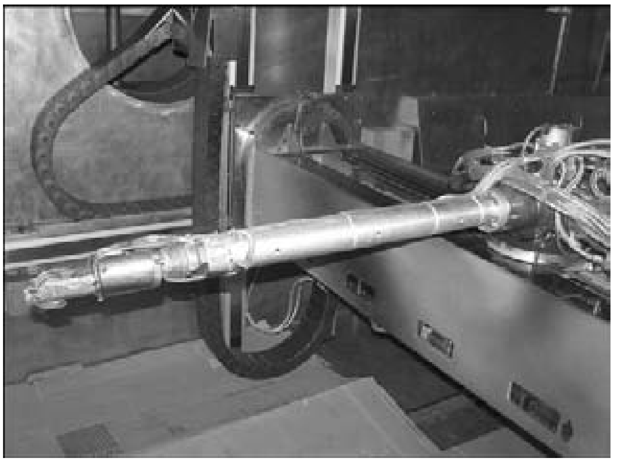

Figure 1. 90° turning system for repair and finishing smoothing of weld reverse bead

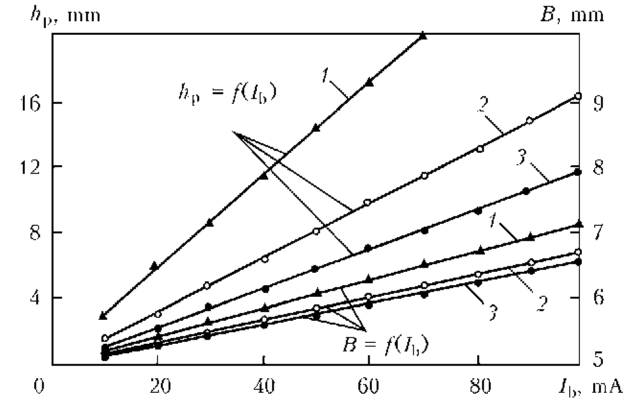

Figure 2. Dependence of depth h_p and width B of penetration of alloy VT20 on beam current at v_w = 3 (*1*), 6 (*2*) and 10 (*3*) mm/s and U_{acc} = 60 kV, l_{work} = 100 mm

gun during operation of system of electron beam refraction by 90° is disconnected from the RASTR system, it is used for adjustment of electron beam and its setting in the interval between the pole tips of the electric magnet. It was found experimentally that the design of system of electron beam refraction by 90° guarantees the reliable and long-time operation at I_b = = 0–100 mA.

The repair and finishing smoothing of linear reverse beads were made using a gun with 500 mA optics inside tubular products of a rectangular shape of up to 1200 mm length, manufactured of titanium alloy VT20, during movement of the system of electron beam refraction by 90° along the reverse bead. The selection of product material was stipulated by the non-uniform formation of reverse bead of weld with undercuts at the edges, especially typical at the through penetration by electron beam of titanium alloys of more than 6 mm thickness [3].

Selection of optimum parameters (beam current I_b, welding speed v_w, focusing current I_f and working distance l_{work} from edge of system of electron beam refraction by 90° to the product) of the process of electron beam finishing smoothing and repair was realized by making several penetrations on solid specimen of titanium alloy VT20 of 17 mm thickness.

After penetration at l_{work} = 100 mm and preparation of transverse macrosections the experimental dependence of depth $h_p = f(I_b)$ and width of penetration at the specimen surface $B = f(I_b)$ on beam current value in the range of I_b =10–100 mA at v_w = 3,6 and 10 mm/s was obtained. As is shown in Figure 2, at v_w = 6 mm/s and I_b = 20 mA, $h_p \cong 2.5$ mm and $B \cong$ $\cong 5.3$ mm. This condition is recommended for the finishing smoothing of reverse bead of weld of 1–3 mm width. In making repair for elimination or decrease of the non-uniformities of formation of the reverse bead in length, and also small craters it is enough to increase the I_b.

In case of long tubular products of a rectangular shape it is necessary to determine the value of coefficient $K = \Delta l_{work}/\Delta l_f$ in change of position of reverse bead in height, i.e. with change of cross section in length of the product. It was found that for system of electron beam turning by 90° for 1200 m length at change of l_{work} in the range of 100–200 mm the coefficient K = 20 mm/mA, i.e. the current of focusing lens of the electron beam gun with optics of 500 mA, is changed by ΔI_f = 5 mA at changing the working distance by Δl_{work} = 100 mm. This weak relation I_f = = $f(l_{work})$ proves that in this case a long focusing system is used.

Testing the conditions of finishing smoothing of reverse beads of welds using a system of electron beam refraction by 90° was performed on flat specimens of titanium alloys VT20 of 17 mm thickness. Welds and reverse beads were produced after making through penetration at a gravity position without backing of titanium specimens by a horizontal electron beam at v_w = 30 mm/s using a main electron gun of installation KL-138 without a system of electron beam refraction by 90° during a gun movement in horizontal plane [4]. By changing the amplitude of transverse oscillations of electron beam by a sawtooth law it was managed to form the defect-free face beads of weld and reverse beads with small undercuts of 1.2–2.0 mm width and height of 0.5–0.8 mm and without undercuts. As is shown in Figure 3, the finishing pass along the reverse beads of width of 1.2 (Figure 3, *a*, *c*) and 1.8 mm (Figure 3, *b*, *d*) at the selected condition (U_{acc} = 60 kV, I_b = 20 mA, v_w = 6 = mm/s, l_{work} = = 100 mm) made it possible to form a weld root part with smooth transitions from base metal to the weld, to produce a smooth surface without drops of molten metal and to eliminate small undercuts of depth down to 0.15 mm. Height of both reverse beads decreased and was not more than 0.4 mm, and the depth of penetration on the weld root side was 2.5 mm, that is correlated with results given in Figure 2.

The obtained results were realized in finishing smoothing of reverse bead of weld on the long tubular product of a rectangular shape of an intricate configuration with a reverse bead location on the lower surface. During movement of system of electron beam by 90° along the reverse bead, l_{work} = 100–250 mm. In

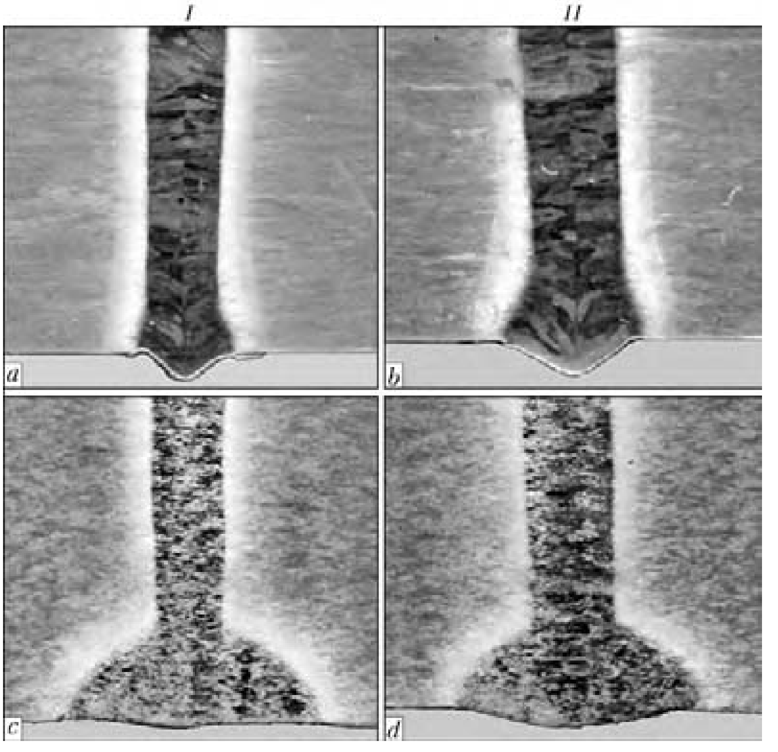

Figure 3. Macrostructure (×27.5) of welded joints of alloy VT20 and formation of weld reverse beads of 1.2 (*I*) and 1.8 (*II*) mm before (*a*, *b*) and after (*c*, *d*) their finishing smoothing

compiling the computer program of control of finishing smoothing all the parameters of electron beam are preserved constant, except the focusing current. This procedure allowed obtaining almost the constant width of penetration along the entire length of the product, which was $B \cong 5.3$ mm.

The investigations of finishing smoothing of linear reverse beads of weld can be fully applied in EBW with through penetration of position butts of long tubular products of a round shape. In this case the task of smoothing is simplified, as the working distance is preserved constant. In making EBW of long products of refractory materials with a depth of penetration $h_p \leq 6$ mm, for example such as waveguides and resonators [5], the application of system of electron beam refraction by 90° is the only possible variant of finishing smoothing of weld reverse bead with a formation of a smooth surface without undercuts.

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