



DEFORMATIONS OF WELDED JOINTS IN MULTILAYER ELECTROSLAG WELDING

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The results of experimental determination of significance and character of development of deformations in multilayer electroslag welding are given. It was established that the general nature of final distribution of movements of edges being welded is similar to one-pass electroslag welding.

Keywords: multilayer electroslag welding, transverse deformations, onward movement, shrinkage of weld, angular rotation of edges

Assurance of accuracy of geometric sizes of products in manufacture or restoration of massive structures applying electroslag welding (ESW) is the important task of increasing the efficiency of welding production.

The method of proportioned counteraction [1], successfully applied in the production, provides accuracy of geometric sizes of large welded products which is approximated to that of mechanical treatment.

However, during repair of large parts of machines using multilayer ESW (MESW) it is practically impossible to apply the mentioned method, as far as specified conditions of fastening edges being welded due to presence of forming metallic crosspieces hindering free shrinkage of crystallizing weld metal and also due to not simultaneous rewelding of the whole thickness of a product cannot be reproduced [2].

As there is no methods of calculation, the expected deformations in MESW were studied experimentally. In conventional ESW the transverse deformations are of the greatest importance [3, 4], leading to the decrease of a gap between parts being joined, transverse shrinkage and angular deformations in the plane of a butt being welded. The onward movement of parts being joined occurs most intensively at the initial period of welding. For example, during the first 40–60 min the primary shrinkage is observed, which is 60–70 % of the whole onward movement of edges. With increase of thickness of metal being welded the onward movement increases [1].

Angular deformations (rotation in the plane of edges being welded) result in closing a gap between edges. These deformations as well as onward movements are most intensive at the initial period of welding. Then, with increase in resistance of a crystallized part of a weld, the rotation is decreased and in some cases can be completed even before completion of welding [5]. The angular rotation depends to a great degree on the conditions of fastening edges, and also welding conditions and can reach 0.02–0.03 rad (1–2°) and lead to dangerous probability of short-circuiting

of nozzles to the product. In welding of finally treated large-size billets the unaccounted residual angular deformations can cause considerable deviations of geometric sizes of a product from its drawing sizes.

While performing MESW the same types of deformations are formed as in one-pass ESW welding. However such factors are added to the typical conditions of formation of deformations as non-simultaneous rewelding of all thickness of a butt (constant increase of resistance to shrinkage of crystallizing metal in making each layer), succession (sequence) of layout of layers and possibility of rotation of edges in the plane perpendicular to a multilayer weld (Figure 1).

During experimental investigation of temporary and residual deformations such types of deformations as buckling of an edge and deformations caused by structural transformations were considered to be accounted in the main types of transverse deformation. In the present work the longitudinal deformation (shortening along the length of a weld) was not considered as far as it shows a great influence on accuracy of manufacture of welded structure in ESW of closed contours (for instance circumferential welds), however in ESW of rectilinear butts it is negligible [3].

Welding of full-scale specimens simulating a large defect (through crack) was performed by a consumable nozzle using machines A-645M and A1304 and power source TShS 3000/3. Specimens of steels 35L and

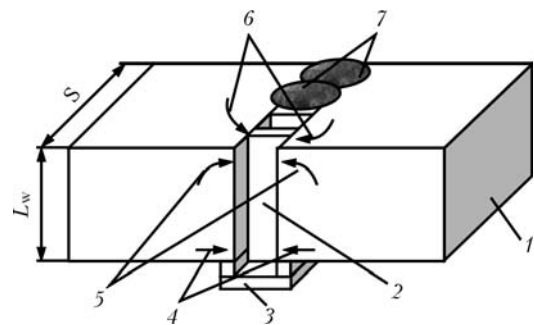


Figure 1. Scheme of expected deformations of parts in MESW: 1 – part of specimen being welded; 2 – forming bridge piece; 3 – input technological pocket; 4 – transverse shrinkage Δb ; 5 – rotation of parts being welded in the plane β of a butt; 6 – rotation of parts being welded γ in the plane perpendicular to welded multilayer weld; 7 – made layers of a weld; S , L_w – thickness and length of welded butt

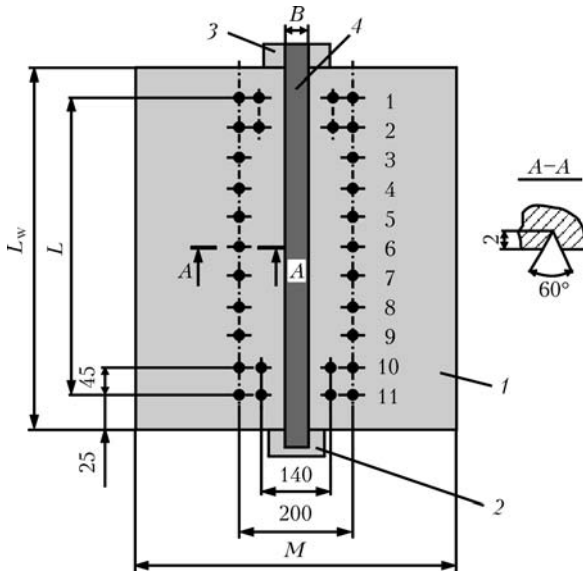


Figure 2. Scheme of reference marks arrangement (1–11) for measurement of onward movements of edges being welded: 1 – parts being welded; 2 – input pocket; 3 – run-out tab; 4 – forming bridge piece; $L_w = 500\text{--}650$ mm; $M = 1200\text{--}1400$ mm, $L = 450\text{--}600$ mm; B – welded gap

34L-ESH were of the following sizes, mm: thickness – 300 and 600, height of a butt – 500–650, width – 1200–1400. Depending on the thickness the butts were rewelded, respectively, for four and seven passes with a different sequence of layout of layers at specific heat input of MESW $E_w = 110\text{--}170$ kJ/cm². Welding condition parameters were controlled using an information-measuring system SU-150 [6].

The movement of edges was measured on the reference marks (indentations) using a caliper having an accuracy of 0.01 mm. Reference marks were made on both sides of edges being welded on the base of 140 and 200 mm (Figure 2). The measurements were performed every 20 min in the process of making a layer (weld) and also before beginning of making each next

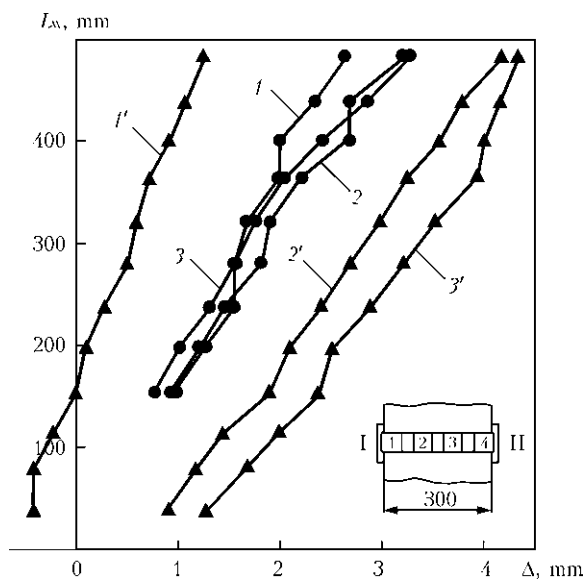


Figure 3. Distribution of movements of edges being welded Δ in performing MESW with layout of layers from one edge of a butt to another one: 1–3 – movement of edges on the side I after making the first, second and fourth layers; 1'–3' – the same on the side II

layer. The actual onward movement (transverse shrinkage of a weld) Δb was defined as difference in measurements of distances between reference points of the lower parts of edges on both sides of a butt. The actual rotation angle β of parts being welded was determined after layout of each layer according to the known expression of the work [7]:

$$\beta = \frac{\Delta b_{a,t} - \Delta b_{a,b}}{L} [\text{rad}], \quad (1)$$

where $\Delta b_{a,t}$, $\Delta b_{a,b}$ is the actual value of onward movement of edges, respectively, at the top and bottom of the butt, mm; L is the distance between points of measurements, mm.

It was established that the onward movement and rotation of parts in ESW are not related. Therefore, onward movements and rotation angles of parts in MESW performance were measured on the same specimens according to the methods given in the work [7].

General character of deformations of edges being welded is similar to one-pass ESW [5]. However, the presence of forming metallic bridge pieces in a gap, hindering the free shrinkage of a weld, and also method of filling a groove by filler metal cause the definite changes in the character of deformation of products.

Figure 3 shows results of movements of reference points depending on their coordinates at the edge and coordinates of a length of produced layers in layout of the latter from one edge of a butt to another one. The vertical axis is a starting position of an edge before making the first layer. The movement of one edge is plotted along the horizontal axis, e.g. a half of a measured value. In contrast to one-pass ESW [5] the noticeable opening of lower edges (see Figure 3, curve 1') is observed in the mentioned case after making the first layer. It can be explained by the following reasons. As far as the thickness of a layer being produced is much smaller (by 4–15 times) than the thickness of the whole butt, the forces arising in shrinkage of metal of the first layer of a weld in the upper part of a butt overcome the resistance of initial area of a layer and bring apart the lower edges. In layout of next layers the resistance grows and lower edges are first returned to initial position and then continued to bring together. Besides, the bends of a moving curve in MESW are practically absent at the beginning and end of a weld (see Figure 3), characteristic of the conventional ESW [4, 5], e.g. the uniform (linear) increase of angular deformation takes place along the length of a butt in layout of each next layer.

It is seen from Figure 4 that the final movement of edges (after rewelding of the whole butt) on the opposite sides of a butt is different.

For a possibility of accounting for the expected shrinkage and rotation of edges the onward movement of lower parts (reference marks 11, Figure 2) of edges being joined Δb and their rotation β depending on



sequence of making layers and their quantity were studied.

In successive layout of layers from one edge of a butt to another one the onward movement of edges (transverse shrinkage) of the opposite edges of a butt occurs not in the same way (Figure 5, *a*). The shrinkage of edges, located on the side where the first layer was made, is almost completely finished after layout of this layer and in layout of next layers it does not change its value (Figure 5, *a*, curve 1). In this connection the final shrinkage of mentioned edges is not large and does not exceed 1.5 mm. The onward movement of edges, located on the side of the last laid layer of the multilayer weld, is increased gradually with increase of a number of layers (Figure 5, *a*, curve 2). It is necessary to note that after making the first layer some opening of edges is observed caused by their rotation as a result of shrinkage relative to a longitudinal axis passed through the center of the first layer. After layout of the third layer the further increase in onward movement does not occur that is due to the increased resistance to shrinkage of metal of formerly laid layers. The onward movement of mentioned edges in layout of the next layers does not exceed 2.4–2.5 mm.

In MESW with layout of layers from the center of a butt to its edges the movement of edges, located on the opposite edges of a butt, has the more complex character. After welding of a central hole the shrinkage is negligible and sufficiently uniform on the both sides of a butt, however after making the second (adjacent) layer the edges being welded, on the side of which this layer was laid, are brought together, while the opposite ones are brought apart (Figure 5, *b*). After layout of the third layer (on the opposite side from the central one) the contrary situation is observed. However, the edges, located on side I (Figure 5, *b*, curve 1) are brought apart to a less degree than the opposite ones after layout of the second layer. The absolute value of the onward movement of mentioned edges after layout of the third layer is several times lower here than that of the movement of the opposite edges. It is connected with non-simultaneous making of the second and third layers. After layout of the fifth and next layers the edges, on the side of which the second layer was laid, are returned to the initial position and remained in that way until completion of rewelding of the whole butt (Figure 5, *b*, curve 1). The onward movement of edges, opposite to those mentioned above, remains almost unchanged after layout of the fifth layer until completion of rewelding of the whole butt is finished (Figure 5, *b*, curve 2). After complete cooling of welded specimen the shrinkage of edges, on the side of which the second layer was made, was 0.5 mm, and the shrinkage of the opposite ones was 1.15 mm. After high tempering and complete cooling of the specimen the shrinkage of edges on the side of the second layer was 1 mm, and that on the other side was

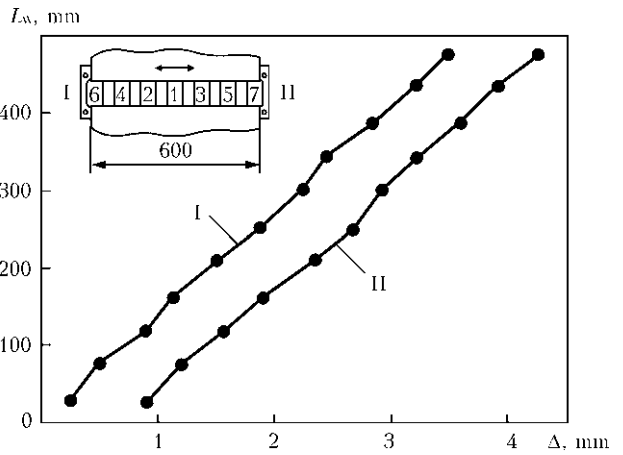


Figure 4. Final distribution of movements of edges being welded in MESW with layout of layers from the center of a butt to the edges: I, II – numbers of sides of a butt being welded

2.5 mm. It is possible to remove difference in shrinkage of the opposite sides of the welded joint and to reduce its absolute value by making simultaneous layout of each pair of layers on the opposite sides of the first layer, e.g. symmetrically to vertical axis passed through the center of a butt.

The experimental investigation of dependence of the angular rotation of edges β (see Figure 1) on the time of welding and quantity of made layers of a multilayer weld showed that during layout of layers from the one edge of a butt to another one the rotation of edges is more intensive in making the first two layers (Figure 6). During layout of further layers the rotation of edges is practically interrupted and remains unchanged up to the completion of the whole welding cycle which is due to the increased resistance of metal

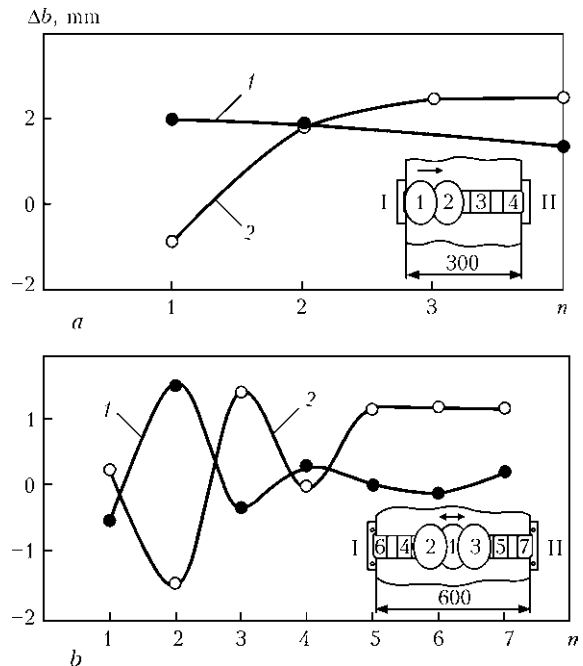


Figure 5. Dependence of transverse shrinkage Δb of edges being welded on the number n of produced layers of MESW: *a* – layout of layers from one edge of a butt to another one; *b* – layout of layers from the center of a butt to the edges (at random); 1 – movement of lower parts of edges on the side I; 2 – the same on the side II

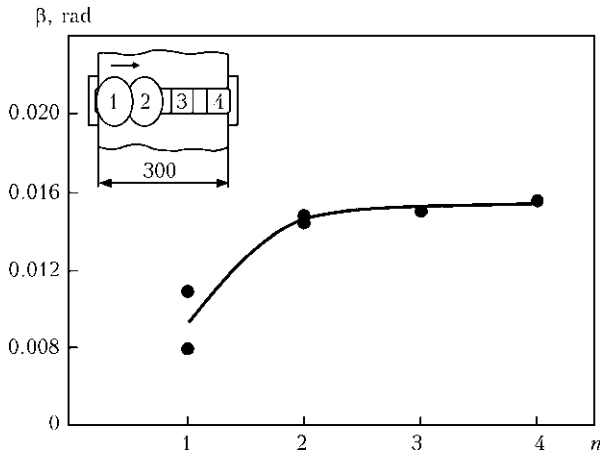


Figure 6. Dependence of rotation angle β of edges being welded on the number n of laid layers of a multilayer electroslag weld performed by layout of layers successively from one edge of a butt to another one

of made layers. Thus, after rewelding of the whole butt the total angular rotation of edges at thickness of billets of 300 mm and more is 0.0156 rad that is in compliance with the angular rotation of edges in one-pass ESW at the value of a specific counteraction moment of 40 kg/cm [1]. It was established that during MESW performance from the center of a butt to its edges the intensive angular rotation of edges occurs in making the first four layers (Figure 7). In that period the increase of rotation angle of edges β is almost in a linear dependence on the number of laid layers (thickness of rewelded part of a butt). The layout of next layers does not almost change the rotation angle attained at the moment of completion of the fourth layer (see Figure 7). Only after the last (external) layers the negligible increase in β is observed. However, considering the fact that before the moment of completion of the last layers 80 % of the whole section has been already rewelded (e.g. 480 mm of butt thickness) it should be noted that the mentioned-above β increase can hardly characterize the actual value of mutual rotation of billets being welded after layout of the external layers. Most probably, the local bending of external areas of edges is observed in this case as a result of a lower rigidity of fastening

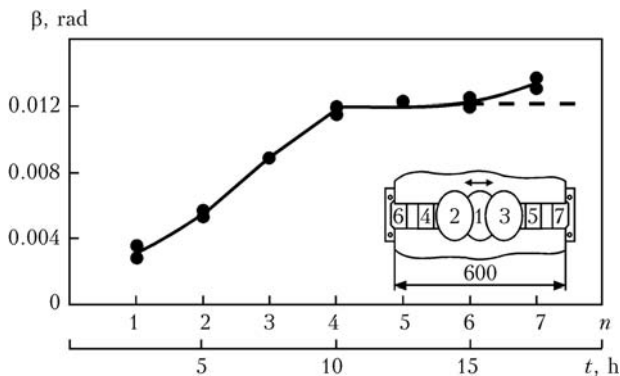


Figure 7. Dependence of rotation angle β of edges being welded on the time of welding t and number n of layers of multilayer weld in MESW with a random layout of layers from the center of a butt to its edges

of the external surfaces of edges. Besides, it is necessary to consider that during measurements of the onward movements of edges during making the external layers an error in measurements can appear as a result of influence of edges heating in the region of location of reference points.

Thus, the total angular rotation of billets after MESW performed in the direction from the middle of a butt to edges for the parts of thickness of 400 mm and more will amount to about 0.0134–0.0137 rad that is in compliance with the angular rotation in one-pass ESW at the value of counteraction moment, equal to 70–87 kg/cm [7].

The investigation of dependence of rotation angle of edges β on the length of welded area of a layer and time of welding showed that in making the first layer the intensive mutual rotation of billets takes place causing edges bringing together at the top of a butt (Figure 8). In the period of a slag pool passing through the middle of the butt length (groove depth) the reverse process is observed (bringing apart of edges). After the slag pool passing from the middle of groove depth, the change in sign of rotation takes place again and by the moment of completion of the first layer the edges of parts being welded are returned to the initial position (see Figure 8, curves 1 and 2). With fulfillment of next layers the sufficiently uniform increase in β takes place achieving 0.013 rad by the moment of layout of the fifth layer. In making the fifth layer the rotation angle of edges is firstly a bit increased, then after rewelding of half of height of a butt β begins to decrease and it is stabilized by the end of welding (Figure 8, curves 3 and 4). In making

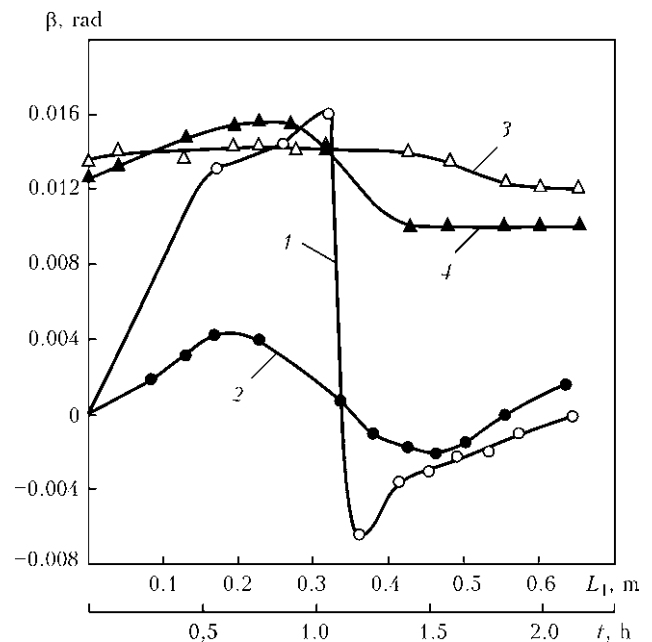


Figure 8. Dependence of rotation angle β of edges being welded on the length of a layer L_1 and time of layout t of the latter in MESW with a random layout of layers from the center of a butt to its edges: 1, 2 – rotation angle of the opposite edges in making the first layer; 3, 4 – the same in making the fifth layer



the last layers the rotation angle of edges does not almost change the achieved value.

As was stated earlier, in MESW the appearance of angular rotation of edges γ in the plane perpendicular to welded multilayer joint is possible (see Figure 1), which is due to a non-simultaneous filling of a butt with filler metal across the thickness. The appearance of this kind of deformation can inadmissibly change geometric sizes of large-sized product, cause, for example, the increased fracture of a band and obliquity along the generatrix which will increase later the wear of rolling surface and decrease its service reliability. Therefore, it is necessary to know the level of residual angular deformation to determine the optimal shape of edge groove for MESW.

The actual angular rotation γ of billets being welded in the plane, perpendicular to welded multilayer joint, was determined after completing each layer according to the formula

$$\gamma = \frac{\Delta b_1 - \Delta b_2}{S} \text{ [rad]}, \quad (2)$$

where Δb_1 , Δb_2 are the actual onward movements of upper parts of edges on the opposite sides of a butt, mm (see reference marks 1 in Figure 2); S is the thickness of a product being welded, mm.

The results of carried out measurements showed that at successive layout of welds from one edge of a butt to another one the angular rotation of edges takes place with change of the rotation direction (Figure 9). After making the first layer the opening of a gap occurred (rotation of billets being welded relative to longitudinal axis of the first layer) and edges bringing together occurred after layout of the second and next layers. The total value of angular rotation after MESW of the specimen of 300 mm thickness was 0.008 rad (Figure 9, curve 1). To compensate the considered type of deformation it is necessary to account for the expected difference of shrinkage in the process of assembly of billets for welding, having formed, for example, a wedge-shaped gap between edges being welded in a horizontal plane or to perform preheating of that side of a butt where the last layer will be performed. The results of measurements of rotation angle γ of edges in layout of layers into the groove from the center of a butt to its edges (at random) showed that while making the first four layers the change of direction of rotation of billets was observed twice (Figure 9, curve 2). After making the fifth layer the rotation angle γ reached its limiting value and did not increase later. This was due to the increased resistance of rotation of a metal of formerly laid layers, and also due to the selected most favorable sequence of layers layout (at random from the center of a butt).

CONCLUSIONS

1. It was established that common character of final distribution of movements of edges being welded is similar to one-pass ESW. However, in MESW after making the first layer the noticeable bringing apart of the lower edges is observed and after layout of the second and next layers their bringing together is ob-

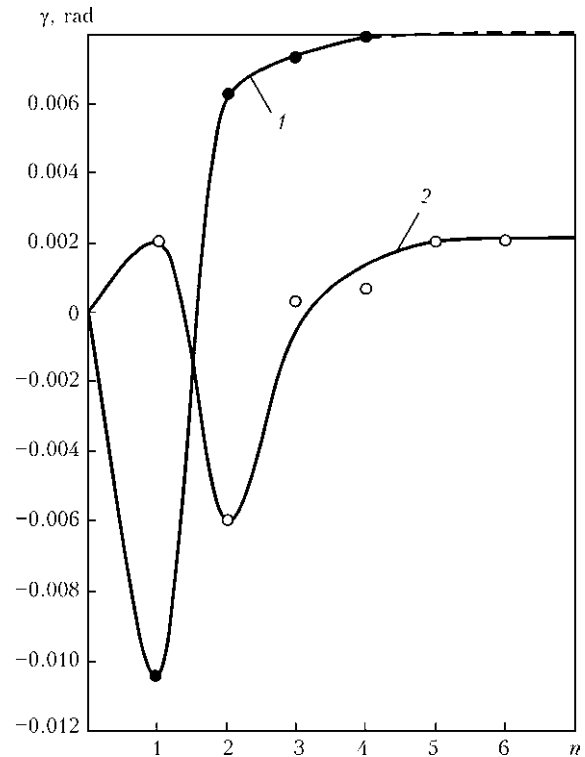


Figure 9. Dependence of rotation angle γ of edges being welded in the plane perpendicular to welded multilayer weld on sequence of layout of layers of a multilayer electroslag weld from one edge to another one (1) and from the center of a butt to its edges (at random) (2)

served, which was gradually increased up to the completion of cycle of the whole specimen welding.

2. In MESW the bends of curve of final distribution of movements at the beginning and end of a weld, characteristic for conventional ESW, are almost absent, i.e. along the length of a butt in layout of each layer the uniform increase of angular deformation is occurred.

3. While performing multilayer ESW from the center of a butt to its edges the intensive angular rotation of edges β takes place during making the first four layers, and after layout of the fifth layer the β value is stabilized and does not change its value up to the completion of welding of the whole butt.

4. The lowest values of deformations (onward movement Δb , angular rotation of edges β and γ) can be obtained at simultaneous layout of pairs of layers of multilayer electroslag weld symmetrically from the center of a butt to its edges.

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