INFLUENCE OF TECHNOLOGICAL FACTORS ON RESISTANCE TO DELAYED FRACTURE OF BUTT JOINTS OF RAIL STEEL IN ARC WELDING

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The results of study of the effect of technological factors and groove shape on deformability and cyclic fatigue life of welded joints of rail steel are given. Dependences of variations in deformability h_{cr} of butt joints with the V- and U-shaped grooves on the welding heat input, preheating temperature and conditions of cooling of the joints after welding are presented. The technology of arc welding of longitudinal joints in rail ends of railway frogs was developed.

Keywords: *arc welding, rail steel, ends of rail frogs, welded joints, deformability, cyclic life, fracture resistance*

The frogs of railroad switches are manufactured of high-manganese steel 110G13 (Hadfield steel). In Ukraine such frogs are manufactured at railway switch factories in Dnepropetrovsk and Kerch using casting technology. As the switch frogs have complicated shape the existing technological processes of their manufacture are labor-intensive and power consuming, thus increasing their cost. Also it should be noted that evaporation of manganese in casting of products of steel 110G13 deteriorates sanitary-hygienic conditions of labor and ecology of environment. It is possible to provide significant decrease in cost of frogs and to improve ecological conditions at production sites using the rail steel for manufacture of frogs. Here, the feasibility appears in replacement of bolted joints of frogs in railways by welded rails, which decreases dynamic loads on the road bed and increases speed of movement of trains [1]. Nowadays this way of modernization of railway infrastructure is being developed throughout the world.

Production of welded structures of frogs is most widely mastered in Europe at «Voest-Alpine» company (Austria). According to the proposed technology the welding of longitudinal weld of rail end, manufactured of rail steel, is performed using automatic method by solid wire of 3 mm diameter under flux layer. Further, the ready rail end, the length of which can vary from 1.5 to 3.6 m, is welded on to a core (steel 110G13) by a flash-butt welding method using insert of steel 10Kh18N10T.

The test specimens of welded frogs with end of rail steel of domestic production (Figure 1) were manufactured at Murom Railway Switch Factory and tested at the test grounds «Koltso» (Shcherbinka, Moscow region, Russia). The tests carried out at load of 27 t per axis according to the procedure showed that only two of three frogs manufactured according to the Voest-Alpine technology of had successfully passed the test, whereas one of them fractured before the standard life (less than 80 mln t per running kilometer).

The fatigue crack in the given frog was formed in the end of a butt weld (crater zone) and propagated perpendicularly relative to the weld axis. This is probably connected with the fact that the increased heat input, characteristic for automatic submerged arc welding, caused the formation in welded joints of rail steel of a relatively wide HAZ, where structure is formed characterized by increased tendency to brittle fracture. Therefore, it was necessary to develop the new technology of welding longitudinal butt of switch frog ends, which will allow avoiding the mentioned disadvantages.

The aim of this work was evaluation of effect of technological factors (temperature of preheating and heat input of welding) and structural factors on deformability and service life of welded joints of rail steel under the conditions of static and cyclic loading.

The investigations were conducted on butt joints of high-carbon Si–Mn rail steel of M76 grade with 0.71–0.82 % C and 0.75–1.05 % Mn content.

Influence of technological factors and design shape of a groove on strength properties of joints of rail steel at static loading was studied under conditions of tests of welded specimens for three-point bending in the installation of Friedland. The specimens were loaded by the force of 3000 kg at the speed of 1 mm/min. The criterion for evaluation of these tests was the level of critical deformation of specimens h_{cr} at which the crack formation does not yet occur at the surface of welded joint. Welded specimens for tests represented the rail steel butt joints of 240 × × 85 × 18 mm size. The peculiarities of fracture of multipass joints of rail steel with V- and U-shaped grooves were investigated, the influence of value of heat input of welding (8.6 and 28.5 kJ/cm), preheat-

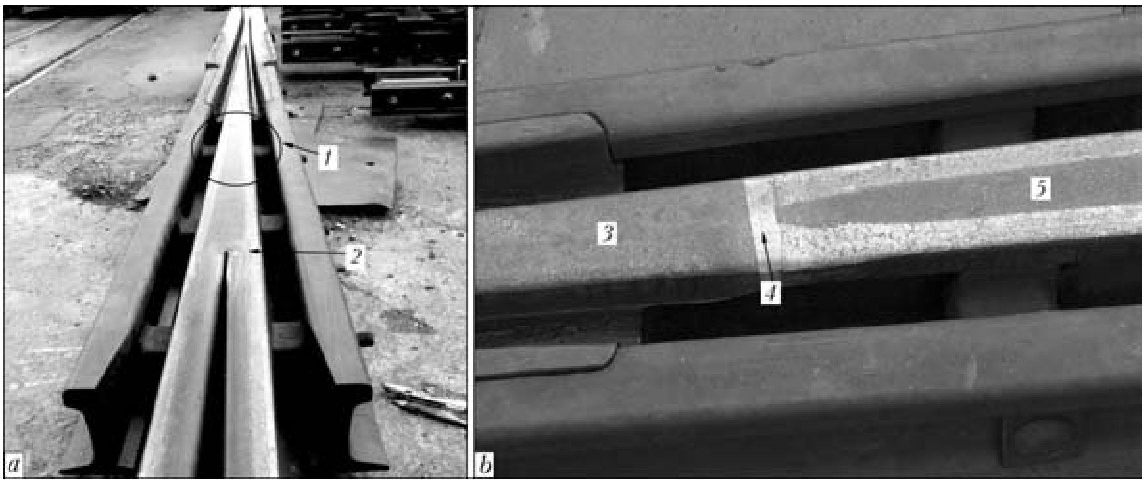

Figure 1. Welded railroad frog with rail end: *a* — general appearance; *b* — area in the site of welding of core with rail end; *1* — area of frog in the site of welding of core with rail end; *2* — place of fracture of rail end; *3* — core of steel 110G13; *4* — insert of steel 10Kh18N10T; *5* — rail end of steel M76

ing at temperatures 150 and 250 °C, and also conditions of cooling of joints after welding was evaluated. As the welding material the low-alloyed wire Sv-08G2S of 1.2 mm diameter was used. Mechanized welding of specimens was performed in mixture of shielding gases (Ar + 20 % CO_2).

In addition, the results of earlier performed works on evaluation of influence of thermodeformational cycle of welding on formation of structure, change of strength and ductile properties in HAZ metal of rail steel, as well as temperature of preheating and heat input of welding on resistance of welded joints to the formation of cold cracks [2, 3] were used.

The results of carried out investigations on evaluation of influence of technological factors and design shape of a groove on deformability of welded joints of rail steel, obtained during static bending test, are given in Figures 2–5.

As is seen from presented data, the shape of a groove considerably influences the values of critical deformation of specimens. For welded joints with U-groove h_{cr} is 1.5–2 times higher than that in welded joints with V-groove (Figure 2). The application of preheating at 250 °C in welding of joints of rail steel with U-groove contributes to increase in h_{cr} value by 1.5 times. Moreover, the character of fracture of welded joints itself changes as well. Formation of cracks and fracture of joints with V-groove occurred exclusively along the metal of fusion zone and near weld zone (area of coarse grain of HAZ). The surface of fracture of specimens was characterized by large crystal structure which was an evidence of brittle fracture (Figure 3). Fracture of welded joints with U-groove occurred in a tough way, mainly along weld metal. Surface of fracture was fine-crystalline.

The increase of heat input from 8.6 to 28.5 kJ/cm allows additional increasing of h_{cr} value of joints of rail steel practically by 1.3 times (Figure 4).

To increase the resistance of welded joints of high-carbon steels against cold crack formation, the technological process directed to delay of their cooling after welding is widely used. It favors relaxation of welding stresses in the joints and more complete proceeding of processes of hydrogen diffusion in metal. Thus, for example, wheels flanges of freight railway cars after restoration surfacing are cooled in special thermal chambers [4]. The evaluation of influence of this technological operation on resistance of welded joints of rail steel to static bending loading was the aim of further investigations carried out as-applied to butt joints of rail steel with U-groove of edges, welding of which was performed using wire Sv-08G2S of 1.2 mm diameter in mixture of gases at heat input of 28.5 kJ/cm with preheating of up to 250 °C. One part of specimens after welding was cooled in the air and another one was placed to thermal chamber. Thus, their cooling rate was delayed down to 50 °C/h. The results of carried out investigations, given in Figure 5, evidence that this technological operation allows increasing the critical deformation level of welded joints of rail steel as compared to specimens, the cooling of which was performed in the air, practically by 40 %.

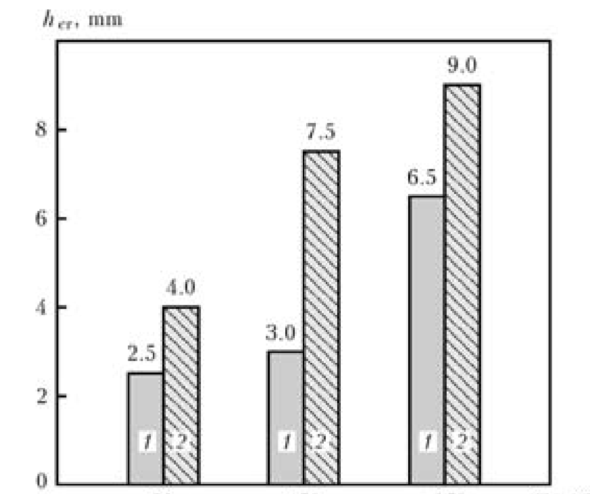

Figure 2. Influence of V- (*1*) and U- (*2*) grooves and temperature of preheating T_0 on critical deformation of welded joints h_{cr} of rail steel performed at heat input Q_w = 8.6 kJ/cm

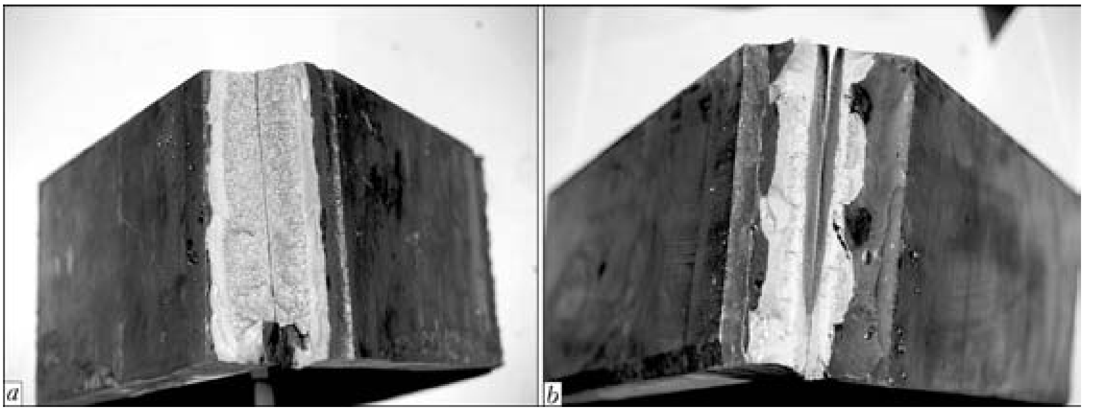

Figure 3. Characteristic fractures of welded joints of rail steel with V- (*a*) and U- (*b*) grooves performed at preheating of up to 150 °C at heat input of 8.6 kJ/cm after tests for three-point bending

The carried out investigations showed that due to transition from V- to U-groove of edges, the increase of heat input of welding from 8.6 to 28.5 kJ/cm, application of preheating of joints up to 250 °C and delay of cooling rate after welding down to 50 °C/h, the deformability of welded joints of rail steel can be more than 4 times increased.

Influence of shape of edge preparation on resistance of welded joints of rail steel to fatigue fractures was investigated according to generally-accepted methods of fatigue tests [5] in the installation UMP-1 at symmetric cycles of bend loading with 14 Hz frequency at loading cycle of 40 MPa. As specimens, the butt joints of rail steel of sizes 250 × 85 × 18 mm with V- and U-grooves without complete penetration were used, that allowed modeling the conditions for making the longitudinal weld of rail ends.

The specimens were welded without preliminary heating in mixture of shielding gases using wire Sv-08G2S of 1.2 mm diameter under the conditions providing heat input of 9.2 kJ/cm in making of weld root bead and 28.5 kJ/cm in filling of remaining part of the groove. This, on the one hand, allowed decreasing of volume of base metal in weld metal and, on the other hand, preventing of hot cracks formation in the joint.

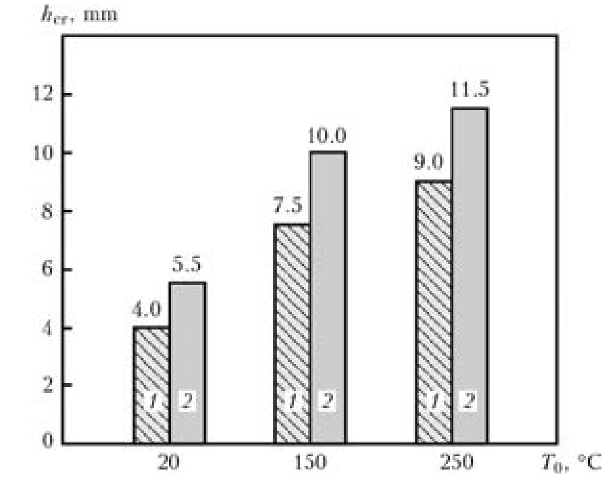

Figure 4. Influence of heat input and preheating temperature on critical deformation of welded joints of rail steel with U-groove: *1* — Q = 8.6; *2* — 28.5 kJ/cm

It was established as a result of carried out investigations (Figure 6) that resistance to fracture at cyclic loading of welded joints with V-groove is twice lower than that of joints with U-groove (formation of fatigue crack of 3 mm length was observed, respectively, after 190,000 and 430,000 loading cycles).

Fracture of welded joints with V-groove occurred along the fusion line and HAZ metal. Fatigue crack in the joints with U-groove was also formed along the fusion line in the lack of penetration zone. Their further fracture occurred along the weld metal. Thus, from the position of static and cyclic life during producing of welded joints of rail steel the joints with U-groove should be preferred. As applied to these joints the investigations were carried out at their final stage.

As in previous case, welding of specimens was performed in mixture of gases using wire Sv-08G2S. Welding conditions remained unchanged. The difference was in fact that specimens were welded with complete penetration, before welding they were preheated up to 250 °C and placed after welding into the

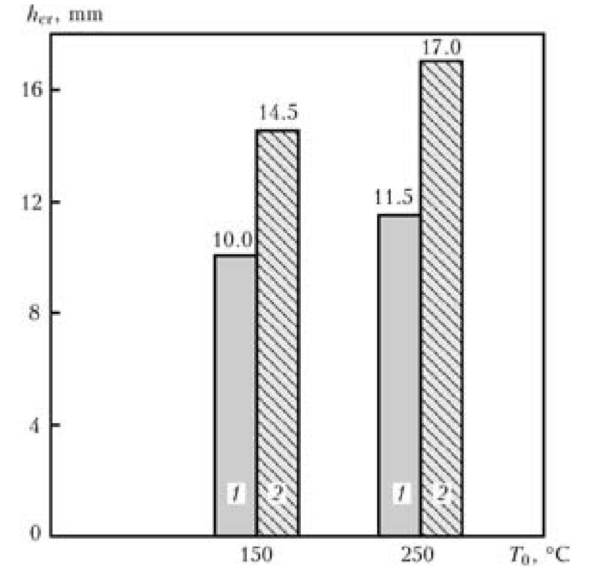

Figure 5. Influence of conditions of postweld cooling on critical deformation of welded joints of rail steel with U-groove, performed at heat input of 28.5 kJ/cm: *1* — cooling in the air at 20 °C; *2* — cooling in thermal chamber at 50 °C/h

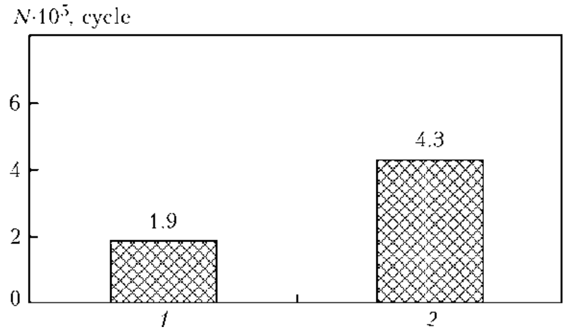

Figure 6. Influence of V- (*1*) and U- (*2*) groove on cyclic life of welded joints of rail steel

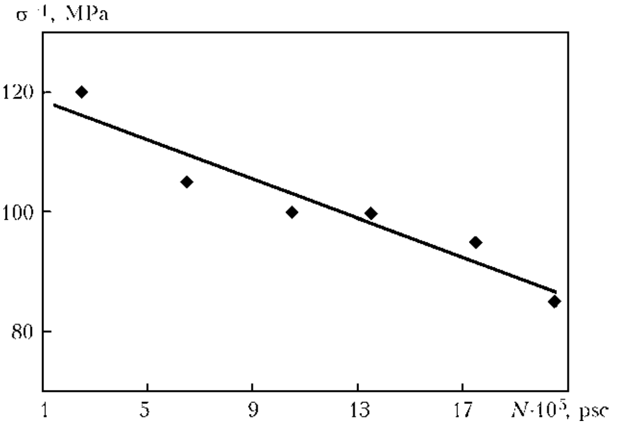

Figure 7. Influence of cycle stresses on cyclic life of welded joints of rail steel with U-groove, made with preheating of up to 250 °C at the heat input of 28.5 kJ/cm

thermal chamber to delay their cooling rate. Thus, technological process was reproduced when welded joints of rail steel acquired the highest ability to deformation.

The results of tests carried out at cycle stresses of 120, 105, 95 and 85 MPa are given in Figure 7. They showed that at the cycle stress of 120 MPa the fatigue cracks of 3 mm length were formed after approximately 220,000 loading cycles, after another 50,000 loading cycles the specimens were fractured completely. Initiation and primary development of crack occurred along the fusion line and then along the near weld HAZ metal. It was noted that after crack formation at 10 % of general area of section of specimen, its further development occurred in a brittle way (Figure 8).

At decrease of cycle stress down to 105 MPa the fatigue crack of 3 mm length formed after 643,000 cycles, and at 95 MPa — after 1,760,000 loading cycles.

In two of three specimens, the test of which was carried out at cycle stress of 85 MPa, after 2,000,000 cycles the cracks were not detected, therefore, the tests were interrupted. In one of the specimens the fatigue crack of less than 1 mm length was formed along the fusion line of a joint after 1,901,000 loading cycles, but as far as during further loading it did not propagate, the tests were interrupted. It gave grounds for us to consider the loading of 85 MPa as a conditional limit of endurance of rail steel welded butt joints, made using the offered technology.

Figure 8. Surface of fracture of welded joint of rail steel with U-groove, made with preheating of up to 250 °C at the heat input of 28.5 kJ/cm after cyclic loading by bending

The additional investigations on mastering of proposed technology of welding of joints of rail end were carried out during manufacture of a pilot batch of railway switches at the «Dnepropetrovsky Strelochny Zavod». The service tests of switches with rail ends, the electric arc welding of which was performed according to developed technology proved the high reliability and quality of products. Basing on these tests the technology of electric arc welding of rail ends was implemented in serial production, and a patent of Ukraine was granted for developed method of arc welding of longitudinal weld of a rail end [6].

CONCLUSIONS

1. It was established that the longitudinal weld of rail end should be performed by the design with U-shaped groove preparation.

2. It was shown that mechanized welding of rail ends should be performed at increased values of heat input in mixture of shielding gases under the conditions providing the process of spray transfer of the electrode metal.

3. It was determined that to provide high deformability and increase of life of welded joints of rail steel, they should be preheated before welding up to 250 °C and provide delayed cooling at the rate about 50 °C/h after welding.

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