INFLUENCE OF SURFACE STRENGTHENING AND ARGON-ARC TREATMENT ON FATIGUE OF WELDED JOINTS OF STRUCTURES OF METALLURGICAL PRODUCTION

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The results of fatigue tests of the T-joints on low-alloy steels are given and methods for extending the life and increasing the strength of welded joints (surface deformation by using a ball-rod strengthening device and argon-arc treatment) are described. It is shown that the optimal method is surface strengthening of the weld and near-weld zone. Treatment of crane beams and rocker bars of well cranes «Slabbing-1150» at the «Ilyich Iron & Steel Works» by this method provided a 15 times increase in their cyclic fatigue life.

Keywords: *welded structures, crane beams, welded joints, surface strengthening, argon-arc treatment, residual stresses, stress concentration, fatigue strength, life*

The experience of service of heavy-loaded welded structures (crane beams, balance beams of well cranes, etc.) at the «Ilyich Iron & Steel Works» shows that not static but fatigue strength is of critical importance for their accident-free operation.

Damageability and fracture of crane beams and elements of load-carrying cranes depend on many factors: design, technological, service. Crane beams are subjected to different force influences, the main of which are loads from rolls of cranes in vertical and horizontal planes, transmitted to rail of a beam. It results in formation of alternate stresses, distributing very unequally in designed sections, in welded joints of beams. The characteristic damages in crane beams observed during experience of operation are the following:

- cracks formation along the line of fusion of fillet welds connecting a web with upper flange (the most typical and dangerous damage). The length of a crack in the moment of its removal is 400–500 mm and in some cases is 2–3 m;
- violation of continuity and fracture of diaphragms;
- crack in the places of fastening crane beams to the pillars;
- damage of coupling along the crane beams.

To find the most efficient method of increasing fatigue strength and life of welded joints of crane beams the cheap and simple variant of comparative fatigue tests of models of crane beams is necessary as far as full simulation of all factors causing their damage is complicated and expensive.

The fatigue tests were carried out on specimens modeling joining of a flange with a web (T-joint) at alternating flat bending with a constant amplitude of deformation (rigid loading).

During manufacture of crane beams the webs and flanges are cut of rolled flanges of a required thickness. The longitudinal axes of flanges and web during preparation coincide with direction of rolling. The next welding of a flange with a web, performed by fillet welds, has also direction along the rolling which was considered during development of scheme of cutting sheets into blanks for manufacture of welded specimens.

T-joint specimen (Figure 1, *a*) simulates the joining of a flange with a web of crane beams of storage of ore and concentrates of agglomeration factory of «Ilyich Iron & Steel Works». The width of specimen

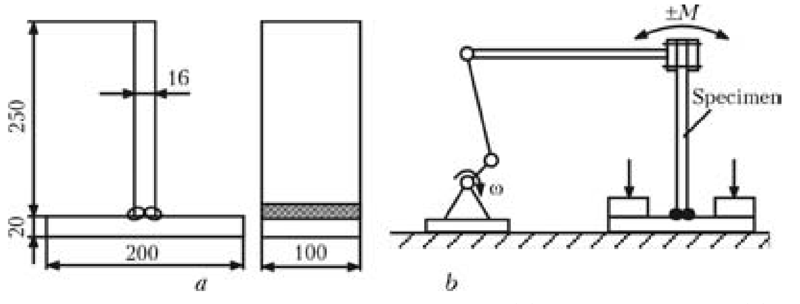

Figure 1. Scheme of the specimen for fatigue tests (*a*) and scheme of tests (*b*)

(100 mm) was selected with the purpose to obtain longitudinal residual stresses in it, approximately equal to residual stresses forming in the zones of beam welds. The surface of flanges and webs of beams and, respectively, specimens were not subjected to post-rolling treatment. The specimens were manufactured of hot-rolled steel 09G2S (σ_y = 350 MPa, σ_t = = 500 MPa).

The assembly and welding of specimens were performed in a jig allowing decrease of angular deformations of flanges using their fastening by screw clamps.

The flange welds of blanks (five specimens in the blank) of 500 mm length were performed by the automatic gravity position welding using tractor ADF-1001 with welding wire Sv-08A of 4 mm diameter under flux AN-348A in the following conditions: I_w = = 700–750 A; U_a = 36–37 V; v_w = 21 m/h; electrode stickout h = 40 mm; direct current of reversed polarity. In capacity of a power source the thyristor rectifier VDU-1201 was applied.

The beginning and end of flange welds were performed on additional tabs. The second weld was produced after cooling of a blank, heated in the process of producing the first weld.

The produced blanks were divided into three series: initial position after welding; fusion of transition zone from a weld to base metal in the argon atmosphere; surface plastic deformation of transition zone of a weld to the base metal.

After welding or appropriate treatment of near-weld zone the blank was cut into specimens using mechanical method. The cutting was carried out without water cooling under a soft condition, which did not cause heating of specimens higher than 50 °C and, consequently, did not lead to relaxation of residual stresses. Then, the specimens were subjected to mechanical treatment of edges.

It is known that life of welded joints at alternate loads can be increased using different methods [1–6]:

• before welding by selection of rational welding consumables, welding conditions and other;

• during welding by regulation of thermodeformational cycle of welding and conditions of crystallization;

• after welding by improving the surface properties of metal and setting of compressive stresses in it by mechanical, heat, ultrasonic and other types of treatment.

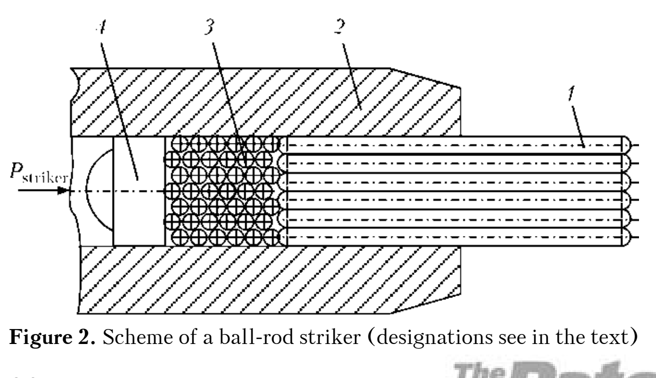

Figure 2. Scheme of a ball-rod striker (designations see in the text)

As far as methods, preceding and accompanying welding, are more perfected, the attempt has been made in the present work to evaluate the possibilities of technological methods of treatment of welded joints taking into account the results obtained earlier [3–6].

One of the most recognized methods to increase cyclic strength of welded structures is surface plastic treatment [2–6]. A ball-rod strengthener was used having a number of advantages as compared to other types [7]. The tool consists of two basic units: pneumatic hammer KMP-24 and ball-rod striker (Figure 2). Pneumatic hammer is a source of shock pulses, and design of a striker allows performing transmission of pulses through the system of bodies to freely floating rods *1* and maintaining them in working and non-working conditions in a striker body *2*. For uniform transmission of shock to all the rods, the intermediate layer of balls *3* of 2.0–2.5 mm diameter is used. The correlation of diameters of balls to diameter of rods was selected within the range of 0.6–0.8. The shock pulse is transmitted to the balls through the head *4*. A layer of balls performs function of a quasiliquid and allows conducting plastic treatment of weld surface and transition zones without missings. The speed of treatment using ball-rod strengthener was 6–8 m/h. The pressing force of working tool to strengthened surface varies in the limits of 80–120 N.

The surface plastic treatment by ball-rod strikers results in the following processes: strengthening (cold-working) of surface layers of weld metal and near-weld zone; setting of favorable compressive residual stresses in them; decrease of stress concentration in transition zone of a weld to the base metal due to increase of transition radius. The specific microrelief of a cold-worked surface is formed by multiple overlapping and intersection of single traces (dents) from rounded ends of the rods.

The depth of a cold-worked layer, intensity and character of distribution of residual stresses across the thickness of the layer *a* was determined according to the methods of the works [6, 8]. The investigations were conducted on 16 × 20 × 300 mm flat specimens of steel 09G2S under the conditions mentioned above. Figure 3 shows that the depth of a cold-worked layer and depth of spreading the compressive stresses reach 3 mm and maximal compressive stresses are close to the yield strength for the steel 09G2S.

Another method offered for testing on elements simulating the work of upper flange of crane beams was fusion of place of transition of a weld to the base metal by the arc in argon [2, 3] which finds its application in machine and ship building.

The fatigue tests were carried out in the machine with a crank mechanism at symmetric cycle of loading. The bending at constant deformation was carried out in the plane perpendicular to a vertical web of the

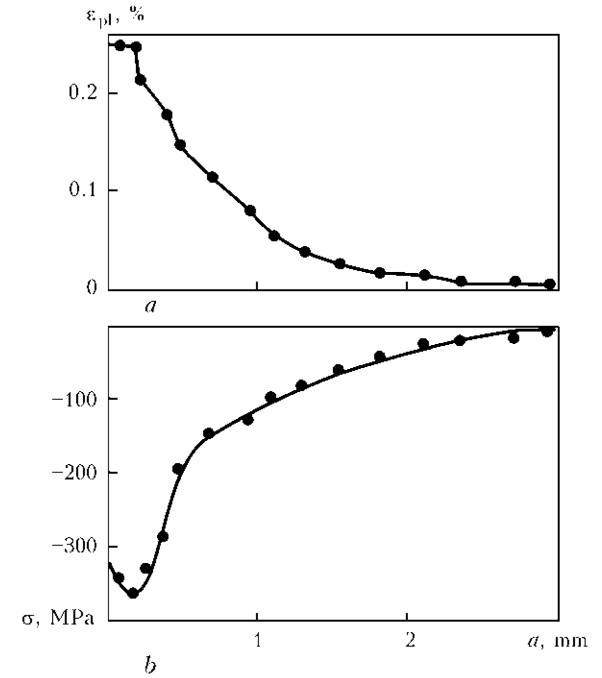

Figure 3. Distribution of plastic deformations (*a*) and residual stresses (*b*) across the section of the specimen strengthened by pneumatic hammer with a ball-rod striker

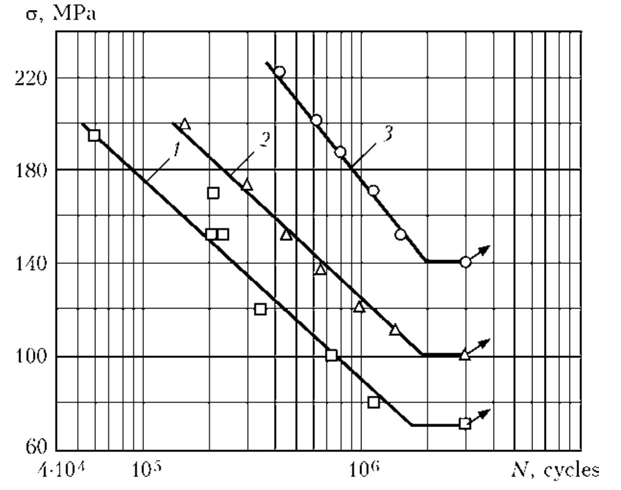

Figure 4. Results of fatigue tests of welded specimens: *1* — initial state (after welding); *2* — argon-arc treatment of transition zone of a weld to the base metal; *3* — strengthening of the same zone using pneumatic hammer with ball-rod striker

specimen (see Figure 1, *b*). The tests were carried out on the base of $3\cdot10^6$ cycles at 13 Hz loading frequency. The results of tests are given in Figure 4.

The fatigue strength of a T-joint at initial state after welding was changed from 200 MPa at $50\cdot10^3$ cycles up to 70 MPa at $3\cdot10^6$ cycles (Figure 4, curve *1*).

The argon-arc treatment of the place of transition of a weld to the base metal (Figure 4, curve *2*) increased the fatigue strength from 70 up to 100 MPa (1.4 times), the life was 2.5–3 times increased (at equal levels of loading — 140 and 200 MPa). The increase of fatigue limit and life is mainly achieved by increase of radius of transition from weld to base metal which results in decrease of stress concentration.

The surface plastic deformation using ball-rod strengthener increased fatigue strength up to 140 MPa, i.e. 2 times (Figure 4, curve *3*). The life of a T-joint after setting of compressive stresses increased 8–10 times.

The specimens in initial state after welding were fractured in the place of transition from a weld to the base metal (web) (Figure 5, *a*) which coincides with the data of works [1, 2, et al.]. After argon arc treatment a crack was formed in the place of transition of fused weld metal to the web (Figure 5, *b*). The fatigue strength and life are mainly increased due to increase of radius of transition, at least some increase of microhardness in HAZ metal (from *HV* 188–195 up to *HV* 210–214) was observed.

After treatment using ball-rod strengthener the specimens were fractured as a rule beyond the borders of the treated area (Figure 5, *c*), i.e. along the base metal.

The increase of fatigue strength of welded elements occurs as a result of setting of compressive stresses in the surface layers where grains are refined and their orientation changes, the hardness of grains practically does not change. The increase of limit of endurance 2 times and fatigue life 8–10 times and possibility to conduct this type of treatment in any spatial position under working conditions allow recommending it for treatment of critical welded structures of metallurgical enterprises.

The industrial application of technology of a ball-rod strengthening was tested at pilot batch of six crane beams (Figure 6, *a*) of storage of ore and concentrates of agglomeration factory of «Ilyich Iron & Steel Works». The formation of fatigue cracks in welded joints of beams is connected with a risk of their transition to brittle fracture, therefore the service of these structures require constant inspection and relatively costs. The pilot batch of strengthened beams has been operating without formation of fatigue cracks already more than ten years.

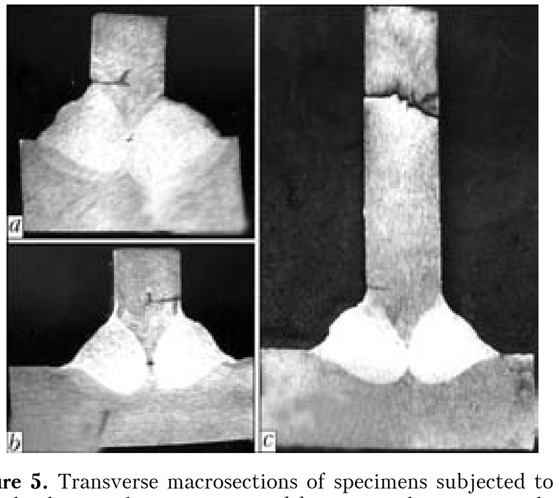

Figure 5. Transverse macrosections of specimens subjected to fatigue loading: *a*, *b* — initiation of fatigue cracks, respectively, in initial specimens (non-treated) and treated using remelting of transition zone by arc in argon; *c* — fracture of specimen along the base metal after strengthening of transition zone using pneumatic hammer with a ball-rod striker

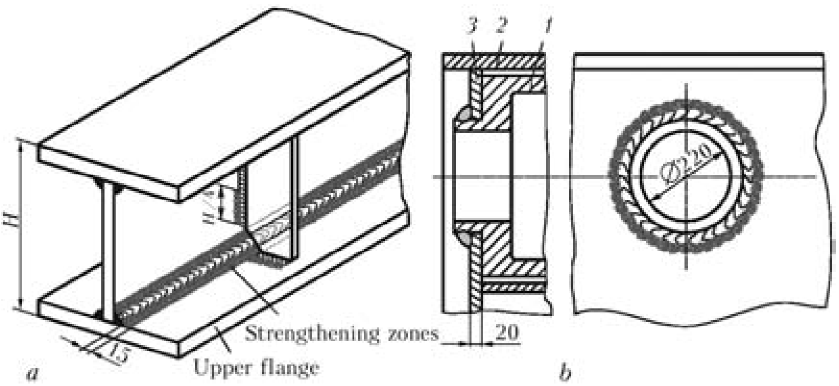

Figure 6. Strengthening zones of welded joints (darkened) of crane beams (*a*) and balance beam of well cranes (*b*): *1* — bushing; *2* — upper flange; *3* — web

Another critical welded structure subjected to cyclic loading and formation of fatigue fractures is a balance beam of well crane «Slabing-1150». It was found by the service of master mechanic together with authors that effect of alternating loads caused service life of a balance beam to be not more than three months before initiation of crack along the weld or HAZ metal at the distance of 5–10 mm from the fusion line in the zone of welding-on of a bushing to the body of a balance beam (Figure 6, *b*).

At the beginning of 2007, basing on the results represented in this article, two balance beams of well cranes were treated using a ball-rod strengthener. Nowadays the life of balance beams after such strengthening treatment reached 15-times increase. The operation of balance beams is continuing, thus proving high technical and economic efficiency of strengthening treatment using the ball-rod strengthener.

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LASER WELDING OF THIN-SHEET STAINLESS STEEL

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Peculiarities of laser welding of the 0.15 and 0.20 mm thick austenitic stainless steel sheets were studied. It was shown that at a certain power of the laser beam the experimentally measured width of the weld could be satisfactorily described by the model of a linearly moving source in a homogeneous approximation. Increase in power of the laser beam results in formation of a hole on the surface being welded, through which part of the beam power goes away, thus leading to violation of correlations with the model. Based on the peculiarities revealed, a procedure is proposed for determination of optimal welding parameters to provide the maximal effective efficiency of the process.

Keywords: *laser welding, stainless steel, thin sheet, effective efficiency, quality criteria, weld width and shape, weld metal structure, strength*

Butt laser welding of thin (δ = 0.1–0.2 mm) stainless steel sheets is applied for manufacture of tubular billets to produce bellows. A prompt selection of optimal welding parameters is required under the small-scale production conditions because of a large number of different types of the billets.

Domestic and foreign literature comprises an insignificant amount of publications dedicated to estimation and effect of the laser welding parameters on properties of the butt joints on thin stainless steels, and disclosing methods for selection of optimal technological modes [1–6].