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INFLUENCE OF CORROSION DAMAGE ON CYCLIC LIFE OF BUTT WELDED JOINTS STRENGTHENED BY HIGH-FREQUENCY MECHANICAL PEENING

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In the article, the results of investigation of efficiency of applying the technology of high-frequency mechanical peening for increasing the fatigue resistance characteristics of butt welded joints of steel 15KhSND with a subsequent long-term effect of the environment climatic factors, characteristic for a moderate cold marine climate are given. The effect of given climate was modeled by holding the joints in the salt fog chamber KST-1 at the temperature of (35 ± 2) °C and during spraying the sodium chloride solution for 15 minutes every 45 minutes. The duration of corrosion tests of specimens in the chamber KST-1 was 1200 h. After holding in the chamber KST-1, the metallographic examinations of the surface layer of the weld metal and the metal of heat-affected zone of welded joints in the initial (non-strengthened) state and in the state strengthened by this technology were carried out. The depth and degree of damage by corrosion spots and cavities of surface layers of weld metal and heat-affected zones of welded joints were calculated. The fatigue resistance characteristics of welded joints in the initial (non-strengthened) state and in the state strengthened by high-frequency mechanical peening were experimentally established after effect of a neutral salt fog for 1200 h. 11 Ref., 1 Table, 6 Figures.

Keywords: *butt welded joint, neutral salt fog, fatigue, high-frequency mechanical peening, increase in resistance to corrosion fatigue*

Due to a high efficiency, the technology of high-frequency mechanical peening (HMP) is widely used not only to increase the fatigue resistance characteristics of welded joints at the stage of manufacturing the metal structures, but also in repair and restoration works [1–5]. In the world literature HMP technology has also received other names: ultrasonic impact treatment, ultrasonic peening, high-frequency mechanical impact treatment [1–11]. This is connected with the fact that to perform peening of welded joints at a high frequency of the striker impact against the treated surface, the ultrasonic power is used in the HMP equipment. In the articles of recent years, the calculation of effectiveness of applying HMP technology by numerical modeling is ever often found, depending on the condition of surface layer of the material, technological parameters of treatment, induced residual compressive stresses, etc. [6–8]. These calculation models assume that the metal surface layer, plastically deformed by HMP technology, remains unchanged during the entire designed service life. However, the majority of welded metal structures (bridges, cranes, hoisting-and-transport machines, railway transport, etc.) are subjected to simultaneous action of external alternating loading and corrosive-aggressive environments in the process of long-term operation. A long-term effect of corrosive media can lead to a partial or complete corrosion-mechanical loss of the strengthened metal layer, to decrease in the designed characteristics of fatigue resistance and, accordingly, to premature fracture of the structure [9, 10]. Thus, in the work [9], the characteristics of fatigue resistance of butt welded joints of rails in the initial state, after HMP and after HMP with the subsequent holding for 450 h in the synthetic sea water (105 g/l NaCl + 12.7 g/l $MgCl_2$ + 7.7 g/l $MgSO_4 \cdot 7H_2O$ + + 12.15 g/l $CaSO_4 \cdot 2H_2O$ + + 0.5 g/l $CaCO_3$) were investigated. It was established that the value of limited endurance on the base of $2 \cdot 10^5$ cycles of welded joints in the initial state was 256 MPa, after HMP — 314 MPa, and after HMP with the subsequent holding in the corrosive medium — 290 MPa. Despite the detailed description of structure of welded joints in the initial state and after HMP in this work, the causes for decrease in the value of limited endurance by 8 % on the base of $2 \cdot 10^5$ cycles after holding in the corrosive medium are not investigated. In the work [10] it was experimentally established that holding of T-welded joints of steel 15KhSND, strengthened by HMP, in the salt fog chamber KST-1 (at a temperature of (35 ± 2) °C and spraying a sodium chloride solution for 15 min every 45 min) leads to decrease in their value of limited endurance on the base of $2 \cdot 10^6$ cycles approximately by 24.5 % (from 265 to 200 MPa). This is caused by a significant fracture of the metal layer strengthened by HMP (in some areas only traces of strengthened metal layer remained). Despite this, the value of limited endurance of joints, strengthened by HMP, based on $2\cdot10^6$ cycles is 48 % higher than that of the non-strengthened ones. The results of works [9, 10] show that investigation of regularities of fatigue resistance of welded joints, strengthened by HMP at a long-term holding in the corrosive media, and, correspondingly, at a certain damage of the plastically deformed metal layer, is an actual problem. The significant corrosion damages, characteristic to welded joints of metal structures, operated in the conditions of a moderately cold marine climate, as is shown in the work [10], can be obtained by preliminary holding of welded joints in the salt fog chamber.

The aim of the present work is to evaluate the effectiveness of applying HMP technology for increasing the fatigue resistance characteristics of welded joints of metal structures at the subsequent long-term exposure to environmental climatic factors, which are characteristic to the moderately cold marine climate.

Material and methods of investigations. The experimental investigations were carried out on specimens of butt welded joints of low-alloyed steel 15KhSND, which is widely applied for manufacture of elements of metal structures for long-term service (for example, in span structures of railway and road bridges), has an increased strength, good weldability, it is stable in the atmospheric conditions and serviceable in the temperature range from –70 to 45 °C. The chemical composition of the steel is, wt.%: 0.142 C; 0.466 Si; 0.63 Mn; 0.020 S; 0.013 P; 0.31 Ni; 0.66 Cr; 0.34 Cu. The mechanical properties are σ_y = = 400 MPa, σ_t = 565 MPa, δ_5 = 26 %.

The blanks for specimens of butt welded joints were cut from 12 mm thick hot-rolled sheet steel of 12 category in the direction of rolling. The size of blanks was 600×175 mm. The butt welded joints were produced by double-sided, single-arc automatic welding of plates without edge preparation (gap along the butt was 0–1.0 mm) under the flux of OP 192 (Oerlikon Company) using the wire Sv-08G1NMA of 4 mm diameter. The welding was carried out at reverse polarity of the electric rectifier VSZh-1600. The welding modes of the first weld were: U = 55 V, I = 650–700 A, v = 26.7 m/h; and of the second weld (on the opposite side) were: U = 57 V, I = 760–780 A, v = 26.7 m/h. The second weld was produced only after the first weld was completely cooled. After welding, from each of the produced welded plates of 600×350 mm, 8 specimens of 350×70 mm were cut. The shape and geometric sizes of specimens of butt welded joints are shown in Figure 1.

The experimental investigations were carried out in the electro-hydraulic machine URS-20 at alternating tension with an asymmetry of the cycle R_σ = 0 and frequency of 5 Hz. The criterion for test completion was the complete fracture of specimens or the excess of testing base of $2\cdot10^6$ cycles of stresses changing.

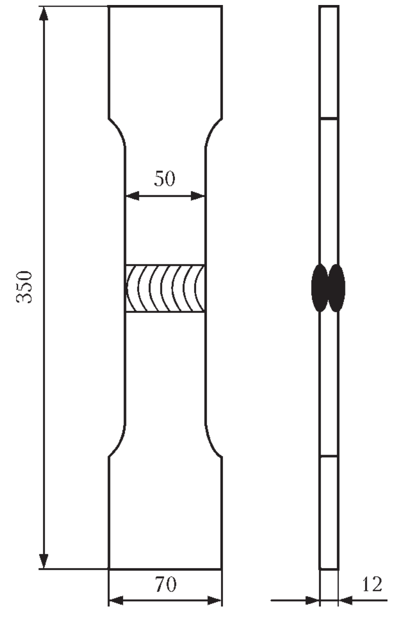

Figure 1. Shape and geometric sizes of butt welded joint specimen

The specimens were tested in the initial state and in the state strengthened by HMP after holding in a corrosive medium.

The strengthening of welded joints by HMP technology was carried out in the equipment USTREAT-1.0, in which a hand compact striking tool with a piezoceramic transducer is connected to the ultrasonic generator of an output power of 500 W. During strengthening of welded joints applying HMP technology, a narrow zone of transition of weld metal into the heat affected zone was subjected to surface plastic deformation (along the fusion line). As a strengthener, a single-row, four-needle hammer with 3 mm diameter of each hammer needle was applied. The rate of HMP during treatment of butt-welded joints was 2 mm/s, and the amplitude of oscillations of waveguide end of the hand impact tool was 25 μm.

To obtain the preliminary corrosion damages, the welded specimens were placed into the chamber KST-1. The investigations were carried out in accordance with GOST 9.401–91 «Unified system of protection against corrosion and aging. Lacquer coatings. General requirements and methods of rapid tests on resistance to climatic factors (method 1, B)» in the salt fog chamber KST-1 at a temperature of (35 ± 2) °C during spraying of sodium chloride solution for 15 min after each 45 min of investigations. The concentration of sodium chloride in the solution was (50 ± 5) g/dm^3, pH was from 6.5 to 7.2, the density was 1.03 g/cm^3. The electrical conductivity of distilled water for preparation of the sodium chloride solution was not more than 20 μOhm/cm at a tempera-

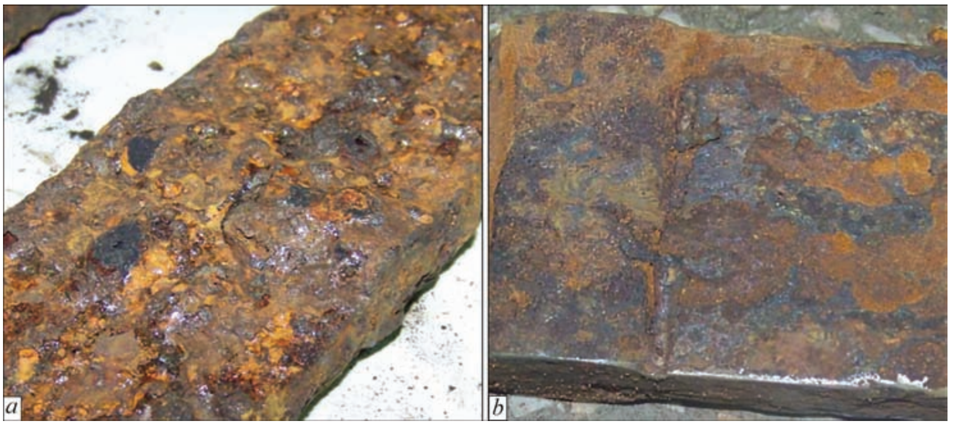

Figure 2. Appearance of weld zone of specimen of butt welded joint strengthened by HMP after holding in the KST-1 chamber for 1200 h before (*a*) and after (*b*) the partial removal of corrosion products

ture of (25 ± 2) °C. The duration of welded specimens in the conditions of effect of neutral salt fog was 1200 h.

The metallographic examinations of surface layer of weld metal and heat-affected-zone (HAZ) of butt welded joints after holding in the chamber KST-1 were performed on specimens in the initial (non-strengthened) state and in the state strengthened by HMP technology. The results of metallographic examinations of surface layer of weld metal and of HAZ metal of similar welded joints in the initial state and in the state strengthened applying HMP technology before the corrosive effect are given in the work [11].

Results of investigations. After holding in the salt fog chamber KST-1 during 1200 h, most of the specimens were covered with a continuous layer of corrosion products of 1–2 mm thickness. At the same time, on some specimens far from the weld, the areas with initial hot-rolled surface layer of light-black metal were observed, which were not subjected to corrosion. A thick layer of corrosion products prevented the visual detection of location of peening zone with a characteristic groove (Figure 2). During preparation of specimens for fatigue tests, the corrosion products were partially removed, the side edges and clamped parts of specimens were dressed to a metallic glittering. The test part of the specimens was not subjected to dressing, in the process of fatigue testing, the corrosion products were delaminated. Throughout the entire area of the specimens surface, the corrosion spots with caverns and the caverns with pitting inside were observed.

As far as fatigue cracks, as a rule, are formed along the fusion line, the corrosion damages were investigated in the transition zone of weld metal to HAZ metal.

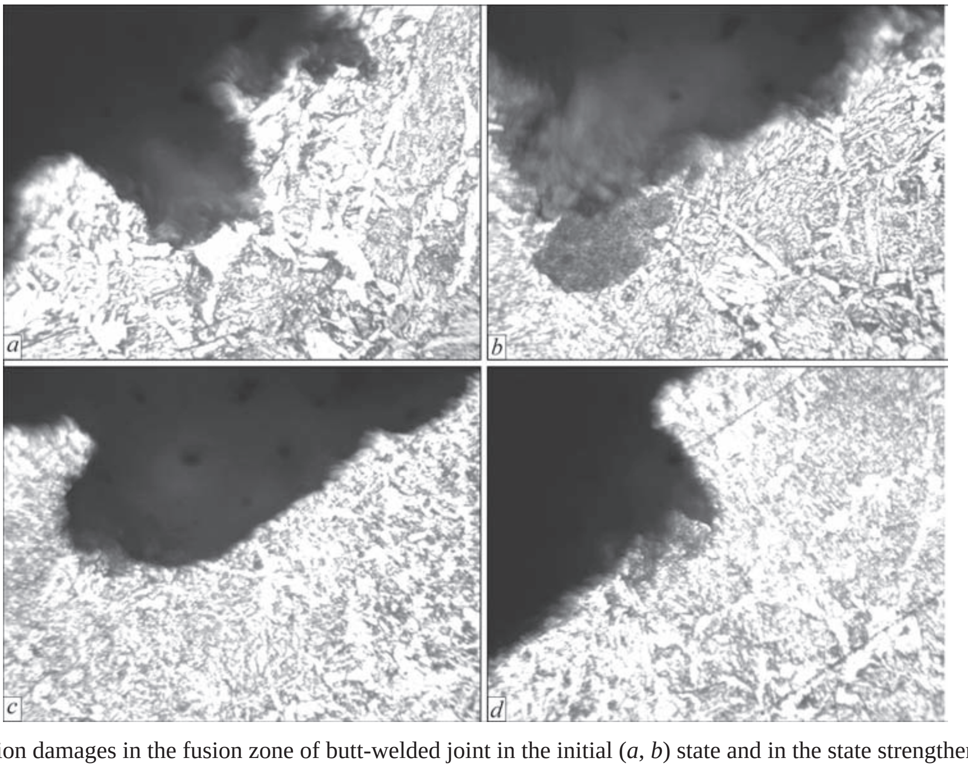

Figure 3. Corrosion damages in the fusion zone of butt-welded joint in the initial (*a*, *b*) state and in the state strengthened by HMP (*c*, *d*) after testing in the conditions of effect of a neutral salt fog for 1200 h, ×400

Dimensions of corrosion damages in the surface layers of weld and HAZ metal of butt welded joints of steel 15KhSND after holding for 1200 h in the salt fog chamber

Condition of specimens	Corrosion of surface layers of weld metal in spots			Corrosion of surface layers of HAZ metal in spots		
	Degree of damage, %	Depth of damage, mm	Sum of damaged area projection, mm	Degree of damage, %	Depth of damage, mm	Sum of damaged area projection, mm
Without strengthening	53.7	0.104–0.390	25.8	100	0.104–0.390	7.15
Strengthened by HMP	19.9	0.039–0.195	9.56	100	0.390–0.620	6.38

In the nonstrengthened welded joints, after holding in the KST-1 chamber, in the zone of transition of weld metal to HAZ metal both in weld metal and in HAZ metal (Figure 3, *a*, *b*) the corrosion damage in the form of spots and caverns of 0.104–0.390 mm diameter (Figure 1) was observed. The degree of corrosion damage of the weld and HAZ metal was 53.7 and 100 %, respectively (Table).

After strengthening by HMP the plastically deformed layers of weld metal of 1.35 mm width and of HAZ metal of 1.45 mm width were formed under the groove. In this case their depth, characterized by visible changes in the metal structure under the groove, before placing to the KST-1 chamber was 325 μm [11]. After holding of specimens of butt welded joints in the KST-1 chamber, the metal layer strengthened by HMP is not observed (Figure 3, *c*, *d*), which indicates the complete fracture (corrosion-mechanical loss) of the strengthened layer. In welded joints strengthened by HMP as compared to nonstrengthened ones after holding in KST-1, the depth of corrosion damages (spots and caverns) in the weld metal decreased to 0.039–0.195 mm, and in the HAZ metal it increased to 0.390–0.620 mm (Table). The degree of the weld and HAZ metal damage by corrosion was 19.9 and 100 %, respectively. Thus, the strengthening applying HMP technology does not lead to increase in the corrosion resistance of the metal of the zone of peening the specimens of butt welded joints in the conditions of long-term effect of the neutral salt fog.

The results of fatigue tests of specimens of butt welded joint of steel 15KhSND after holding in the salt fog chamber KST-1 are shown in Figure 4. The experimental data obtained in the work [11] on the identical welded joints without preliminary corrosion tests (obtained in the air) are also given there. The holding of specimens of butt welded joints in the salt fog chamber for 1200 h leads to decrease in the value of limited endurance of non-strengthened welded joints on the base of $2\cdot10^6$ cycles by 13 % (from 187 to 163 MPa), and the cyclic life in the range of $7\cdot10^5$–$2\cdot10^6$ cycles is reduced to 2 times (curves *1* and *3*, Figure 4). After KST-1, the characteristics of fatigue resistance of welded joints, strengthened by HMP technology, also decreased significantly: the value of limited endurance on the base of $2\cdot10^6$ cycles decreased by 35 % (from 273 to 178 MPa), and the cyclic life decreased to 30 times (curves *2* and *4*, Figure 4). Thus, applying the HMP technology allowed increasing the value of limited endurance of butt welded joints with the subsequent effect of the neutral salt fog only by 9 % (from 163 to 178 MPa), whereas their cyclic life is at the level of cyclic life of welded joints in the initial state (in air).

The obtained values of fatigue resistance characteristics of the joints strengthened by HMP technology confirm that preliminary holding of joints for 1200 h under the conditions of a neutral salt fog (imitation of influence of environmental climatic factors characteristic for the moderately cold marine climate) resulted in the complete corrosion-mechanical loss of the plastically deformed metal layer in the peening zone. The fracture of both non-strengthened welded joints as well as those strengthened by HMP after holding in the KST-1 chamber occurred along the line of weld metal transition into HAZ metal (Figure 5). The fractographic analysis of fractures revealed the significant corrosion damages of HAZ metal in the peening zone

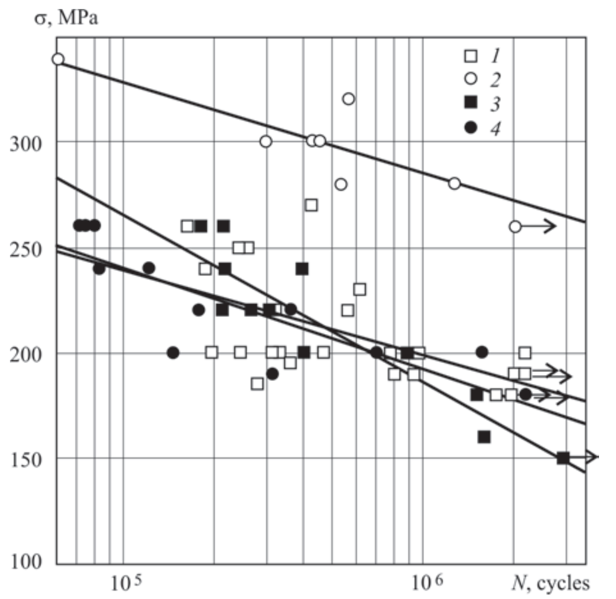

Figure 4. Fatigue curves of butt welded joints of steel 15KhSND: *1*, *2* — in the initial state and in the state strengthened by HMP technology in air [11], respectively; *3*, *4* — in the initial state and in the state strengthened by HMP technology after holding in the KST-1 chamber for 1200 h, respectively

Figure 5. General view of butt welded joint specimens strengthened by HMP technology after holding in the KST-1 chamber for 1200 h and fatigue tests

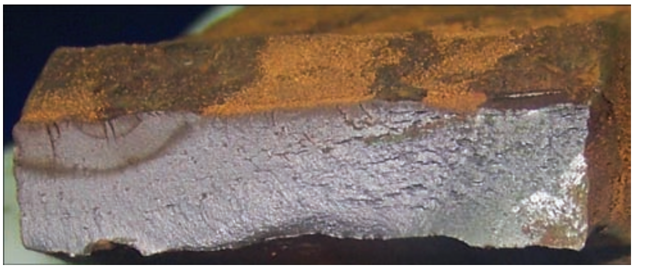

Figure 6. General view of fracture surface of the butt welded joint specimen strengthened by HMP technology after holding in the KST-1 chamber for 1200 h and fatigue tests

in the form of caverns and caverns with pittings inside (Figure 6). The initiation and propagation of cracks in the HAZ metal confirms the data of metallographic examinations (Table) of the fact, that the HAZ metal of strengthened welded joints has a lower corrosion resistance as compared to the base and weld metal.

Therefore, the experimentally obtained results indicate that in case of the long-term effect of the environmental climatic factors, characteristic for a moderately cold marine climate, a complete fracture of the surface of metal layer, plastically deformed by HMP, occurs. And, accordingly, the decrease in values of fatigue strength characteristics of welded joints occurs, strengthened to the values typical for non-strengthened joints. This can be caused by inopportune works on maintenance and restoration of protective coatings (for example, lacquer ones) of metal structure welded joints, strengthened by HMP technology.

Conclusions

1. The metallographic examinations of surface layers of the weld and HAZ metal of butt welded joints of steel 15KhSND in the initial (non-strengthened) state and in the state strengthened by HMP after corrosion tests in the salt fog chamber KST-1 for 1200 h were carried out. Based on the calculations of degree and depth, as well as the total size of projection of the area of damages by corrosion spots and caverns of surface layers of weld and HAZ metal of joints, it was established that strengthening applying HMP technology does not lead to increase in the resistance of joints against the effect of the neutral salt fog.

2. It was experimentally established that strengthening of butt welded joints of steel 15KhSND by HMP technology before holding in the neutral salt fog chamber for 1200 h does not contribute to improvement in their fatigue resistance characteristics. This is caused by the fact that preliminary holding of the joints for 1200 h in the conditions of a neutral salt fog (modeling the influence of environmental climatic factors characteristic for the moderately cold marine climate) leads to a complete corrosion-mechanical loss of the metal layer plastically deformed by HMP in the peening zone.

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