EFFECTIVENESS OF STRENGTHENING BUTT WELDED JOINTS AFTER LONG-TERM SERVICE BY HIGH-FREQUENCY MECHANICAL PEENING

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Cyclic fatigue life of butt welded joints of low-alloyed steel 09G2S, strengthened by the technology of high-frequency mechanical peening (HFMP) at different stages of fatigue fracture: in as-welded state, after accumulation of 70 % of fatigue damage, at formation of surface fatigue cracks, was studied. The objective of these studies is establishing the effectiveness of application of HFMP treatment of butt welded joints after long-term service at alternating loading. It is shown that strengthening of butt welded joints by HFMP right after welding increases the endurance limit (2 mln cycle base) by 50 % — from 180 up to 270 MPa, and cyclic fatigue life — by 5 to 10 times. It is experimentally confirmed that the effectiveness of strengthening welded joints with 70 % accumulated fatigue damage depends on the levels of applied maximum stresses before strengthening. So, residual cyclic fatigue life of samples, tested in the range of maximum 240–260 MPa stresses, falls within the scatter band of experimental data for welded joints in unstrengthened condition, and for those tested in the range of maximum stresses of 280–300 MPa it is within the scatter band of experimental data for welded joints strengthened by HFMP technology in as-welded condition. It is established that application of HFMP technology improves the residual cyclic fatigue life of welded joints with surface fatigue cracks (down to 2 mm deep) 2.5 times compared to fatigue life before crack formation. 11 Ref., 5 Figures.

Keyword: *high-frequency mechanical peening, increase of cyclic fatigue life, fatigue, welded joint, accumulated fatigue damage*

Application of methods of surface plastic deformation of metals allows considerable increase of characteristics of welded joint fatigue resistance. High-frequency mechanical peening (HFMP) is an effective method of strengthening welded structures operating under the conditions of alternating loading. Application of this method of welded joint treatment at the stage of structure fabrication is quite well studied: main regularities of increase of cyclic fatigue life and endurance limits of welded joints, depending on steel strength class, joint type, and alternating loading cycle characteristics are established; its advantages compared to other processes of surface plastic deformation of metal are determined [1–6]. In this research package a number of studies are devoted to evaluation of the effectiveness of strengthening welded components and elements of metal structures in service, joined by fillet welds [7–11]. It is shown that increase of residual fatigue life of welded joints with accumulated fatigue damage after strengthening by HFMP technology essentially depends on the level and duration of the applied maximum stresses before strengthening. As regards experimental data on effectiveness of application of HFMP technology to improve fatigue resistance characteristics of butt welded joints of structures in service, such data are lacking in known publications.

The objective of this work is to establish the effectiveness of strengthening by HFMP the butt welded joints after long-term operation at alternating loading.

Material and experimental procedure. Experimental studies were conducted on samples of butt joints of low-alloyed steel 09G2S (σ_y = = 373 MPa, σ_t = 510 MPa) 12 mm thick. Blanks for samples of 600 × 180 mm size were cut out of hot-rolled sheets of gauge 12. Automatic square-edge submerged-arc welding from two sides with OK Flux 10.71 was performed with 4 mm 08GA wire. Welding parameters were as follows: current of 590–620 A, voltage of 30–32 V, speed of 28.2 m/h. After welding 8 samples were cut out of each plate. Figure 1 shows sample shape and geometrical dimensions. Sample thickness is due to wide acceptance of 12 mm rolled stock in welded structures, and sample gauge width was selected proceeding from test equipment capacity. Four series of samples were prepared for fatigue testing: as-welded condition (first series); HFPM in as-welded condition (second series); HFMP after 70 % fatigue damage accumulation (third series) and HFMP after formation of surface fatigue cracks of specified length (fourth series). At joint strengthening by HFMP technology a narrow zone of weld metal transition to base metal was subjected to surface plastic deformation. Strengthening was performed with manual impact tool with piezoceramic converter connected to ultrasonic generator of output power of 500 W. Single-row four-striker attachment with 3 mm striker diameter was used as strengthening device. HFMP speed was 3 mm/s, oscillation amplitude of manual impact tool wave guide edge was 25 μm. Fatigue testing of samples was performed in URS 20 testing machine at uniaxial alternating loading with cycle asymmetry $R_\sigma = 0$. Complete fracture of the sample and exceeding test base of $2 \cdot 10^6$ stress alternation cycles were taken as the criteria of test completion.

Experimental results. First fatigue curves of butt welded joints of 09G2S steel in as-welded condition and in the condition after HFMP strengthening of as-welded samples, respectively, were established from the results of testing samples of the first and second series. HFMP strengthening increases the endurance limit (base of 2 mln cycles) of butt welded joints by 50 % from 180 up to 270 MPa, and cyclic fatigue life by 5–10 times. Experimental data scatter decreases essentially.

Third series samples were subjected to preliminary cyclic loading up to achievement of 70 % fatigue life by the established fatigue curve of welded joints in unstrengthened condition, and then were treated by HFMP technology. After strengthening by HFMP technology fatigue testing was carried on at the same loading levels as before strengthening. Figure 2 gives fatigue testing results. HFMP strengthening of butt welded joints with 70 % accumulated fatigue damage increases endurance limit (2 mln cycle base) by 22 % – from 180 up to 220 MPa. Here residual cyclic fatigue life of samples, tested in the range of maximum stresses of 240–260 MPa, is within the scatter band of experimental data for welded joints in unstrengthened condition, that of samples tested in maximum stress range of 280 to 300 MPa is within the scatter band of experimental data for welded joints strengthened by HFMP technology in as-welded condition. Note that the majority of third series samples failed through base metal at a distance from fusion line (Figure 3).

Similar improvement of fatigue resistance characteristics of welded joints was obtained when studying the influence of preliminary cyclic loading on effectiveness of strengthening tee welded joints by HFMP technology [8, 10].

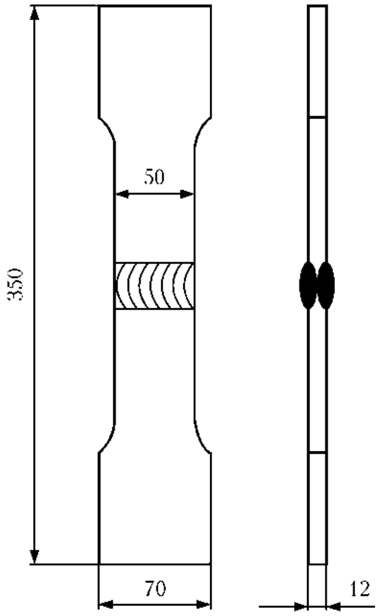

Figure 1. Shape and dimensions of sample of 09G2S steel butt welded joint

Obtained experimental data for butt welded joints confirm that at cyclic preloading of welded joints with maximum cycle stresses corresponding to ratio $\sigma_y > \sigma_y/\alpha_\sigma$ (where σ_y is the material yield point, α_σ is the coefficient of stress concentration), subsequent strengthening by HFMP technology leads to greater increase of fatigue resistance characteristics compared to strengthening in as-welded condition.

This is due to the fact that at maximum stress levels corresponding to the above-given inequality, complete relaxation of residual tensile welding stresses takes place in concentrator zones of welded joints. Method of increasing fatigue resistance characteristics of welded joints by preloading by higher stress levels was called «overloading» in scientific publications. Obtained re-

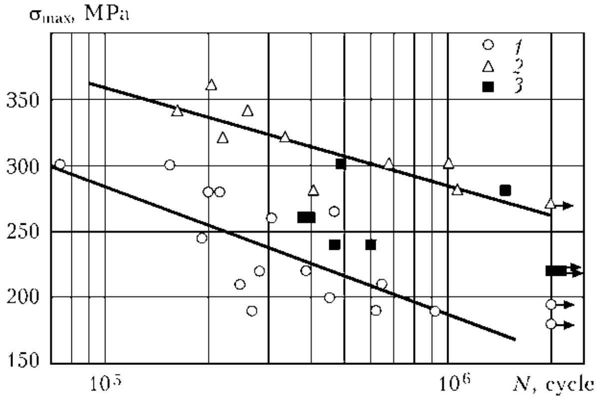

Figure 2. Results of fatigue testing of butt welded joints of 09G2S steel in as-welded condition (*1*), condition of HFMP strengthening after welding (*2*) and HFMP strengthening after accumulation of 70 % fatigue damage (*3*)

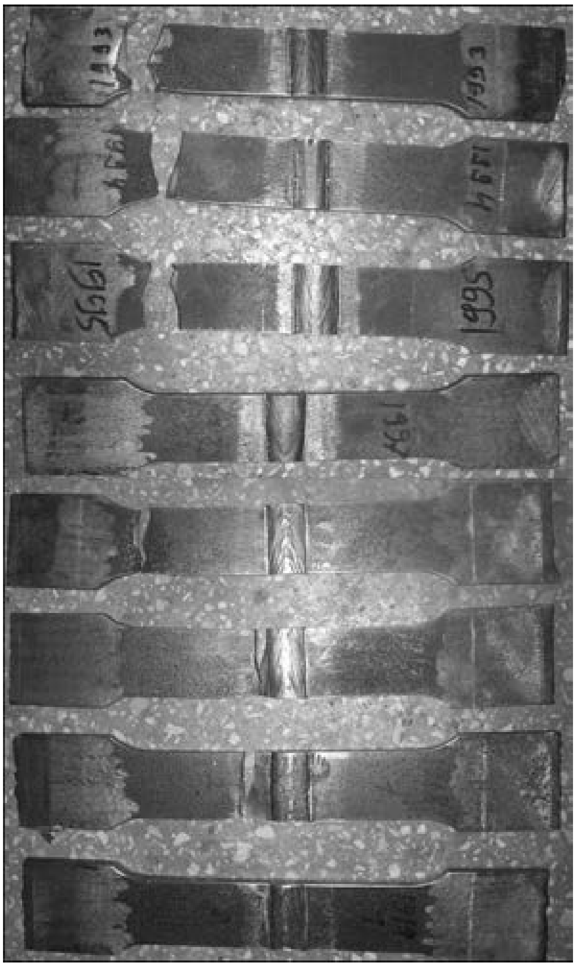

Figure 3. Appearance of 09G2S steel samples, strengthened at accumulation of 70 % fatigue damage, after fatigue testing

sults show the high effectiveness of application of HFMP technology to increase cyclic fatigue life of butt welded joints after long-term service.

The fourth series of samples were strengthened by HFMP technology after formation of surface fatigue cracks of 5 (2 samples), 20 (2 samples) and 50 mm (2 samples) length. To reveal the crack front the welded joint in as-welded condition was lubricated by indicator liquid consisting of kerosene and toner. After formation of a crack of specified length (all cracks formed on the line of weld to base metal transition) remains of indicator liquid were removed by blowing with compressed air. HFMP strengthening was applied not only to the fusion line, containing a crack, but also to all the four lines of weld to base metal transition. No indicator liquid was used after HFMP strengthening. Thus, on sample fractures after fatigue testing the crack front is clearly visible, which was treated by HFMP technology. Figure 4 gives the results of fatigue testing, and Figure 5 shows photographs of broken samples.

HFMP treatment of welded joint samples with cracks of 50 mm length (up to 5 mm depth) did not result in higher cyclic fatigue life. Samples failed within the scatter band of experimental data for unstrengthened welded joints. Strengthening of welded joints with fatigue cracks of 5 mm length (up to 0.5 mm depth) and 20 mm length (up to 2 mm depth) increased their residual fatigue life 2.5 times compared to fatigue life before crack formation. Here, one of the samples with 5 mm long crack after strengthening by HFMP technology did not fail within the range of test base of $2\cdot10^6$ cycles of stress alternation (increase of residual cyclic life by more than 10 times compared to fatigue life before crack formation).

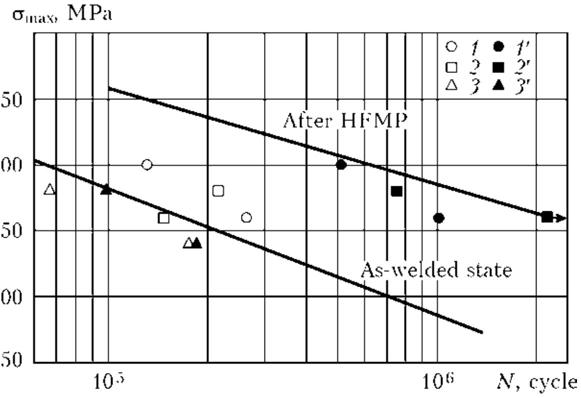

Figure 4. Fatigue curves of butt joints of 09G2S steel in as-welded and HFMP strengthened conditions, as well as results of fatigue testing of samples: *1–3* — up to formation of 5, 20 and 50 mm long crack, respectively; *1'–3'* — after HFMP strengthening of 5, 20 and 50 mm long cracks, respectively

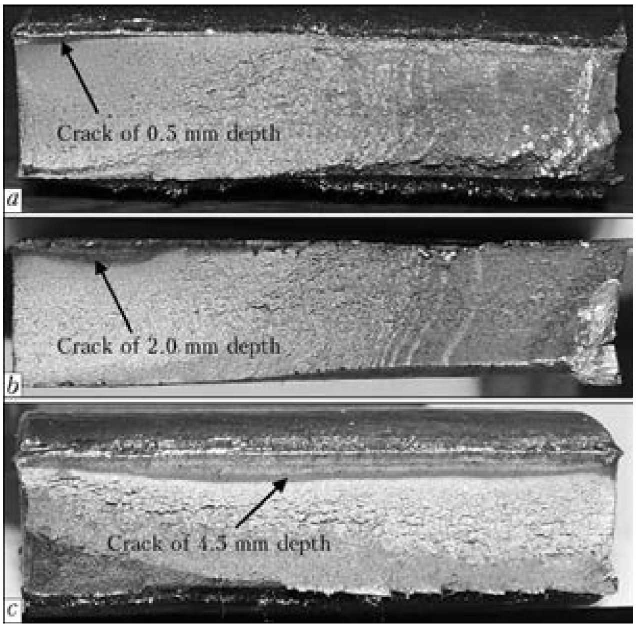

Figure 5. Fatigue fractures of samples of 09G2S steel butt joint strengthened at formation of fatigue cracks of 5 (*a*), 20 (*b*) and 50 (*c*) mm length

Similar improvement of residual fatigue life of welded joints with shallow surface fatigue cracks by HFMP treatment was obtained on tee welded joints [11]. Thus, a high effectiveness of HFMP technology application for increasing cyclic fatigue life of welded joints with up to 2 mm fatigue cracks was confirmed.

Conclusions

1. It is established that HFMP strengthening of butt welded joints of 09G2S steel with 70 % accumulated fatigue damage (fatigue cracks were absent) increases the endurance limit (2 mln cycle base) by 22 % from 180 to 220 MPa. Cyclic fatigue life of samples tested in maximum stress range of 240 to 260 MPa is within the scatter band of experimental data for welded joints in unstrengthened condition, and that of samples tested in maximum stress range of 280 to 300 MPa is within the scatter band of experimental data for welded joints strengthened by HFMP in as-welded condition.

2. It is shown that HFMP strengthening of all the four near-weld zones of butt welded joints with surface fatigue cracks of 5–20 mm length (depth from 0.5 to 2.0 mm) increases their residual fatigue life 2.5 times compared to fatigue life before crack formation.

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