IMPROVEMENT OF CYCLIC FATIGUE LIFE OF WELDED JOINTS WITH ACCUMULATED FATIGUE DAMAGE BY HIGH-FREQUENCY PEENING

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The paper gives the results of investigation of the effectiveness of application of high-frequency mechanical peening (HFMP) with multistep and block loading to improve residual fatigue life of welded joints of low-alloyed steels with 50 % level of accumulated fatigue damages. It is established that application of HFMP technology allows 9–12 times improvement of cyclic fatigue life of such joints.

Keywords: *welded structures, fatigue damage accumulation, high-frequency mechanical peening, cyclic fatigue life, effectiveness*

Intensification of economic activity necessitates extension of service life of diverse engineering structures. An important role is given to organizing effective measures on restoration of load-carrying capacity of welded metal structures. In repair-reconditioning operations a lot of attention should be paid to improvement of fatigue strength characteristics of welded components and elements. The most effective extension of fatigue life of welded joints with accumulated fatigue damage can be achieved by treatment of weld zones in welded joints by high-frequency mechanical peening (HFMP). Studies [1–3] give the data of experimental studies on improvement of fatigue resistance characteristics by HFMP technology of full-scale tubular nodes and samples of welded joints after accumulation of the set level of fatigue damage right up to formation of a surface crack. Investigations in this direction were mainly conducted at regular loading. Engineering structures are exposed to complex loading modes in service, when the sequence of amplitude values and average cycle stresses varies in a random fashion, so that it is important to assess the residual fatigue life of the joints at irregular loading in the laboratory [4].

The purpose of this study was to establish the effectiveness of application of HFMP technology for improvement of cyclic fatigue life of welded joints with 50 % accumulated fatigue damage under the action of multistep and block loading with identical parameters before and after strengthening.

Experimental studies were conducted on samples of welded joints of 09G2S steel (σ_y = 370 MPa, σ_t = = 540 MPa) which consisted of a plate with transverse stiffeners welded to it from each side. Blanks for samples were cut out of rolled sheets so that the long side were oriented along the rolled stock. Transverse stiffeners were welded by fillet welds from two sides by manual electric arc welding by UONI-13/55 electrodes. Sample shape and geometrical dimensions are given in Figure 1. Sample thickness is in agreement with the wide applicability of 12 mm rolled stock in welded structures, and the width of sample working part was selected proceeding from testing equipment capacity. At joint strengthening by HFMP technology a narrow zone of weld to base metal transition was subjected to surface plastic deformation. Fatigue testing of samples was conducted in URS 20 testing machine at uniaxial alternating loading with cycle asymmetry R_σ = 0. All samples were tested to complete fracture.

Fatigue testing of welded joints of 09G2S steel strengthened at 50 % damage accumulation, was conducted on 18 samples, 9 samples in each case, respectively, under the conditions of multistep and block loading with increasing, decreasing and quasi-random order of load application. Thus, for each order of load application 3 samples were tested under the conditions of multistep and block loading.

At multistep and block loading the order of load application was assigned by the same five levels (steps) of applied maximum cycle stresses, but with different degrees of damage (number of stress reversal cycles) in each level (Figures 2 and 3).

So, increasing order of load application in the block was assigned by maximum cycle stresses equal to 180 MPa in the first loading step, with its subsequent

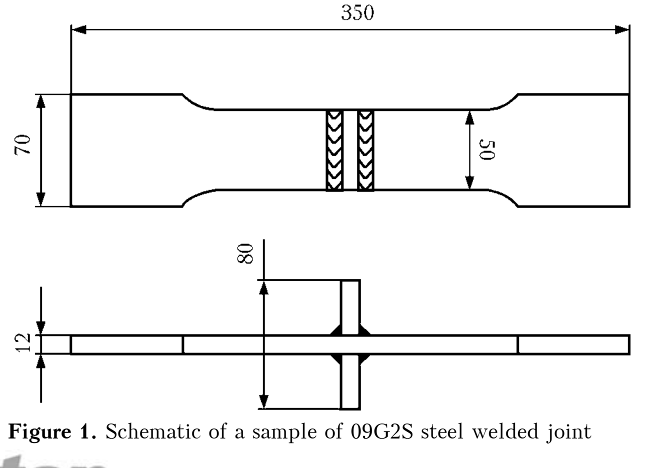

Figure 1. Schematic of a sample of 09G2S steel welded joint

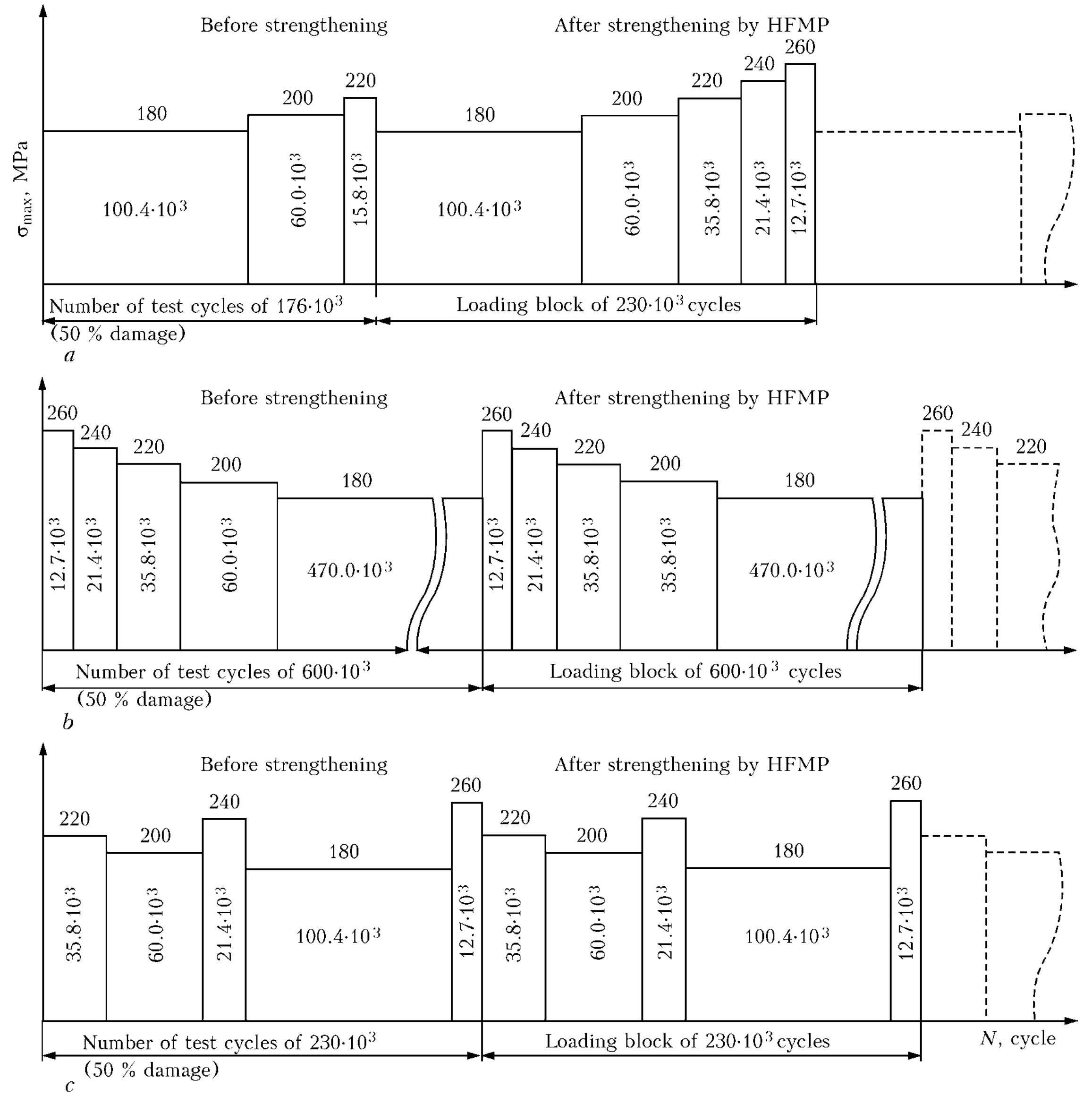

Figure 2. Schematic of multistep loading of samples of welded joint of 09G2S steel with increasing (*a*), decreasing (*b*) and quasi-random (*c*) sequence of load application in each block

increase to 260 MPa (fifth loading step) with 20 MPa step. Decreasing order of load application in the block was assigned by initial level of maximum cycle stresses of 260 MPa with subsequent decrease to 180 MPa, also with 20 MPa step. Quasi-random order of load application was assigned by the following five successive levels of maximum cycle stresses in the block: 220, 200, 240, 180, 260 MPa.

Strengthening of welded joints by HFMP technology was conducted after the joints have reached 50 % of their fatigue life. Number of stress reversal cycles before strengthening at each degree of loading under the conditions of multistep and block loading was assigned, proceeding from the earlier established in [5, 6] criteria of fracture of such samples of welded joints of 09G2S steel in an unstrengthened condition at similar loading. At multistep alternating loading for all the orders of load application the total damage level of the joints equal to 50 %, was assigned by reducing 2 times the values of the number of test cycles in each loading step, given in [5]. At block loading for all the orders of load application in the block 50 % damage was assigned by reducing 2 times the number of loading blocks to welded joint failure, derived earlier [6], while keeping unchanged the number of cycles in the block. After joint strengthening, the loads at multistep and block loading remained the same as before strengthening, except for multistep loading with increasing order of load application. With this type of loading, fracture of welded joint samples in an unstrengthened state occurred already in the second or third loading step [5]. As welded joint strengthening by HFMP technology greatly improves the fatigue resistance characteristics, all the five loading steps were applied to the sample after strengthening (Figure 2, *a*).

A criterion of completion of testing under the conditions of multistep and block loading was complete fracture of the samples. If under the conditions of multistep loading, the welded sample strengthened at

50 % damage accumulation did not fail after the assigned five loading stages (in one loading block), this loading block was repeated. Thus, after strengthening the welded samples instead of multistep loading, were practically brought to complete fracture under the conditions of block loading. Here the block length (number of stress reversal cycles in one block) for joints strengthened by HFMP was equal to a sum of cycles corresponding to 50 % damage of welded joints in as-welded condition (see Figure 2). An exception was multistep loading with increasing order of load application, in which after strengthening the block length was increased from 176 up to 230 thou cycles of stress reversal (see Figure 2, *a*).

At multistep loading of welded joints after 50 % damage accumulation and subsequent strengthening all the three sample series were subjected to nine loading blocks in the strengthened state. Welded joint samples which were tested in a decreasing order of load application, after nine loading blocks withstood approximately $5.5 \cdot 10^6$ cycles of stress reversal. No fatigue cracks were detected in any of the welded samples. As strengthening by HFMP technology guaranteed 9 times extension of the joint residual fatigue life, it was decided to conduct further testing of samples to fracture at higher levels of maximum cycle stresses (310 MPa) under the conditions of regular loading. Fatigue life of samples which were tested earlier at multistep loading with increasing sequence of load application, at regular loading was equal to 97.8–301.2 thou cycles, with decreasing sequence it was 109.8–276.4 thou cycles and with quasi-random sequence it was 156.1–377.8 thou cycles of stress reversal. Thus, cyclic fatigue life of all the three sample series at increased maximum cycle stress of 310 MPa was in the range of 97.8–377.8 thou cycles of stress reversal, which was equal to 21–83 % of fatigue life of welded joints strengthened by HFMP technology in as-welded condition. The difference of approximately $3.5 \cdot 10^6$ stress reversal cycles in the number of test cycles at maximum cycle stress level of 180 MPa under the conditions of multistep loading in these three sample series did not have any influence on scatter of cyclic fatigue life at increased regular loading. Thus, after HFMP of a welded joint even with 50 % damage, the levels of maximum cycle stresses (180 MPa) which are much lower than the endurance limit of a strengthened joint (260 MPa) do not have

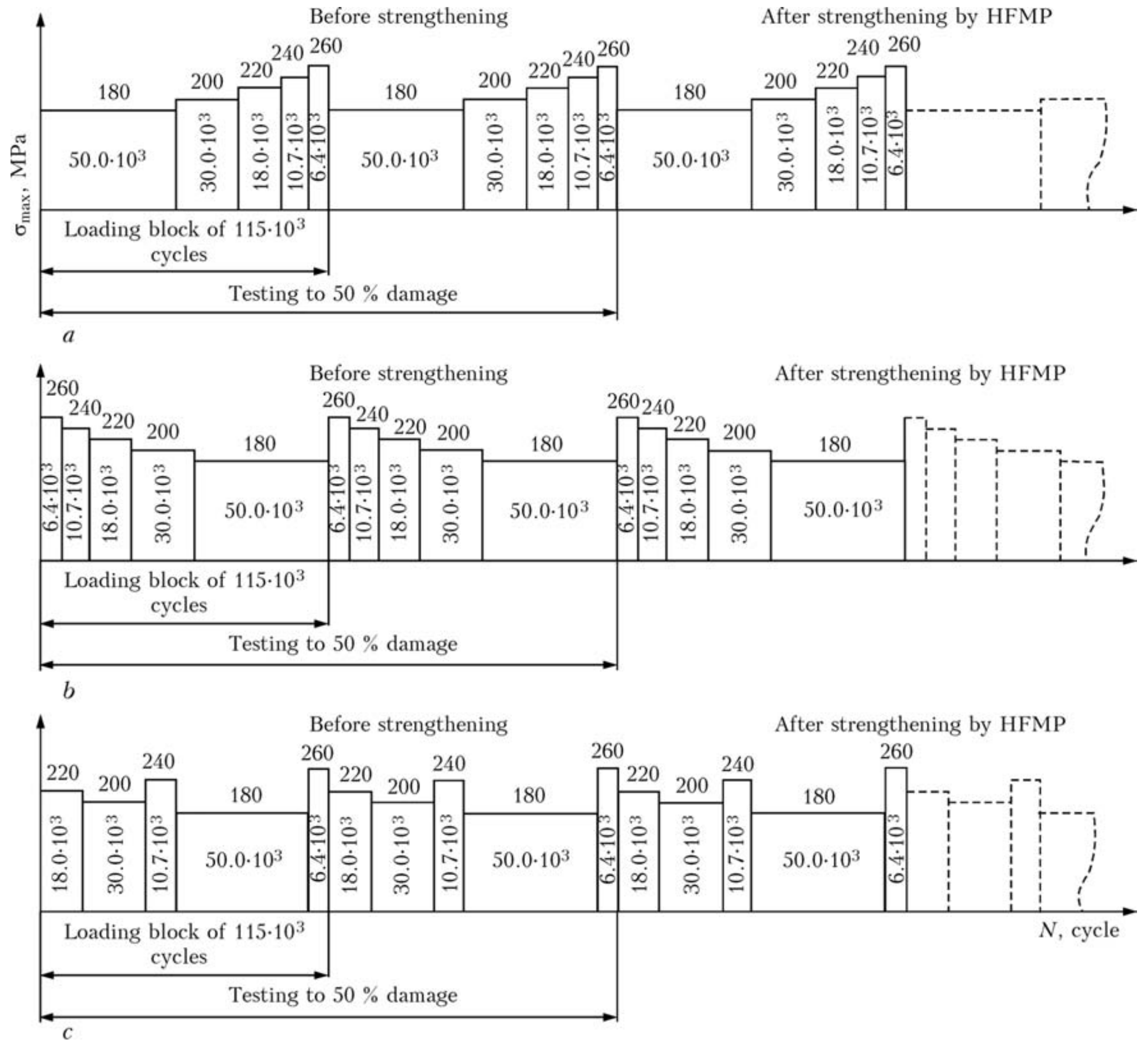

Figure 3. Schematic of block loading of samples of welded joint of 09G2S steel with increasing (*a*), decreasing (*b*) and quasi-random (*c*) sequence of load application in each block

any damaging effect. This is also confirmed by experimental data obtained in [2].

At block loading, after 2 loading blocks in unstrengthened condition (accumulation of 50 % damage) and subsequent strengthening all three sample series were subjected to 25 loading blocks in the strengthened state. No fatigue cracks were found in any of the welded samples. Considering that HFMP strengthening of welded joints with 50 % damage guarantees extension of their residual fatigue life by more than 12 times at unchanged parameters of block loading, it was decided to conduct further fatigue testing of samples to fracture at the level of maximum cycle stresses increased up to 310 MPa under the conditions of regular loading. Scatter of fatigue life values for nine samples tested at increased load was in the range of 115–284 thou cycles, which was equal to 25–62 % of fatigue life of welded joints, strengthened by HFMP technology in as-welded condition.

CONCLUSIONS

1. It is established that strengthening by HFMP technology of welded joints after accumulation of 50 % damage guarantees extension (without crack formation) of their residual fatigue life by 9–12 times under the conditions of application of multistep and block loading before and after strengthening. Fatigue life of tested samples of welded joints was equal from $2\cdot10^6$ up to $5\cdot10^6$ stress reversal cycles.

2. After HFMP of welded joints with 50 % fatigue damage accumulation the levels of applied maximum cycle stresses in the loading block that are much lower than the endurance limit of a strengthened welded joint, do not have any damaging effect.

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