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# IMPACT OF HIGH-FREQUENCY PEENING AND MODERATE CLIMATE ATMOSPHERE ON CYCLIC FATIGUE LIFE OF TEE WELDED JOINTS WITH SURFACE FATIGUE CRACKS

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The paper presents the results of investigations of the effectiveness of application of the technology of high-frequency mechanical peening to improve the residual fatigue life of tee welded joints of 15KhSND steel with surface fatigue cracks and corrosion damages characteristic for structures after long-term service under the conditions of moderate climate of the central regions of Ukraine. Corrosion damages on the surface of joints were obtained by exposure in G4 hydrostat at higher temperature and relative humidity of air for 1200 h. It was experimentally established that strengthening of tee welded joints with surface fatigue cracks of up to 10 mm length and characteristic fatigue damages by the technology of high-frequency mechanical peening increases their cyclic fatigue life by up to 10 times. It is shown that application of the technology of high-frequency mechanical peening of welded joints, which contain fatigue cracks of 20 mm and greater length, does not lead to improvement of cyclic fatigue life and is not effective. 10 Ref., 2 Tables, 5 Figures.

*Keywords:* *tee welded joint, corrosive environment, fatigue, accelerated corrosion testing, high-frequency mechanical peening, improvement of cyclic fatigue life*

To improve the characteristics of welded joints of metal structures of long-term service (bridges, crossovers, off-shore platforms, etc.) to fatigue resistance both in the initial state as well as during repair and restoration works, the methods of surface plastic deformation (SPD) of metal are widely used, including the technology of high frequency mechanical peening (HMP) [1–4]. The experimental investigations established a high efficiency of applying HMP technology for welded joints not only with accumulated fatigue damages, but also with corrosion damage caused by the long-term influence of climatic factors of the environment [5]. From the analysis of the literature data [6–10] it is known that the use of SPD methods contributes to increase in the cyclic life of structural elements even with fatigue cracks. It is shown that the efficiency of SPD methods depends on type of strengthening treatment and depth of the crack. For example, after applying a pneumatic hammer treatment, the residual cyclic life of tee welded joints with surface fatigue cracks of 1.0–1.5 mm depth is increased by 10 times, with surface fatigue cracks of about 3.0 mm depth — by 1.1–1.25 times, and with surface fatigue cracks of a depth of more than 5.0 mm — the cyclic life is not increased [8]. During strengthening tee welded joints with surface fatigue cracks of up to 1.0 mm depth applying HMP, the residual life is increased by 10 times, with surface fatigue cracks of 2.0 mm depth — by 5 times, and with upper fatigue cracks of about 4.5 mm depth — the cyclic life is not increased [10]. However, at present there is no data on the effectiveness of HMP technology on welded joints of metal structures, which are operated under the influence of climatic factors of the environment and contain surface fatigue cracks of negligible depth.

The aim of this work is to investigate the residual cyclic life of tee welded joints with surface fatigue cracks and corrosion damage, which are characteristic to welded metal structures after a long-term service under the conditions of moderate climate of the central regions of Ukraine, after their strengthening applying HMP technology.

**Material and procedure of investigations.** The experimental investigations were carried out on the specimens of tee welded joints of low-alloy 15KhSND steel ($\sigma_y$ = 400 MPa, $\sigma_t$ = 565 MPa), which is widely used for manufacture of metal structural elements of a long-term service (for example, in the track structures of railway and automobile bridges), has a high strength, a good weldability, stable in atmospheric

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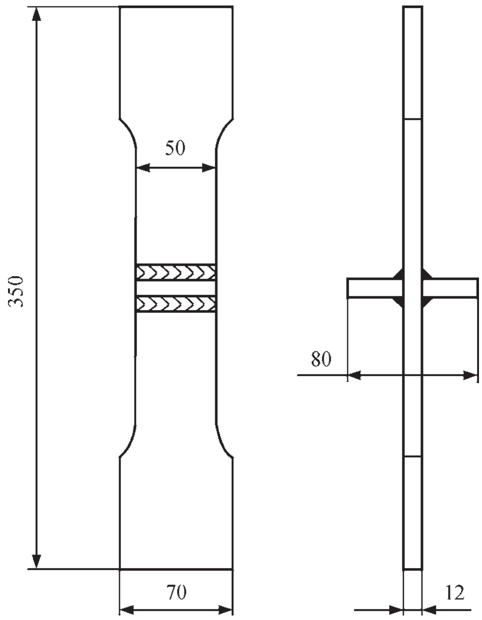


**Figure 1.** Shape and geometric dimensions of specimens of tee welded joint

conditions and is serviceable in the temperature range from —70 to 45 °C.

Workpieces for specimens of welded joints were cut out from a hot-rolled sheet metal with a thickness of 12 mm of the 12th category in the direction of rolling. Tee welded joints were produced by welding-on transverse stiffeners using manual arc welding with the electrodes of grade UONI 13/55 (also of 15KhSND steel) to the workpieces of 350×70 mm in size on both sides by fillet welds. The root (first weld) was produced by the electrodes with a diameter of 3 mm, the second weld was formed by the electrodes with a diameter of 4 mm. The shape and geometric dimensions of specimens of tee welded joints are shown in Figure 1. The thickness of the specimen is predetermined by a widespread use of rolled metal with a thickness of 12 mm in engineering welded metal structures, and the width of the working part of 50 mm was chosen based on the power of the test equipment.

All the fatigue tests were performed in the URS-20 servo-hydraulic testing machine at an alternating zero-to-tension loading with a cycle asymmetry $R_\sigma =$ $= 0$ and a frequency of 5 Hz at a regular load. At the first stage, fatigue tests were carried out at the maximum values of the applied stresses of 180 MPa cycle in order to initiate and propagate small-sized fatigue cracks on the surface of specimens. This level of applied maximum stresses is close to the boundary of the limited endurance of these joints on the basis of $2\cdot10^6$ cycles of stress changes. In order to avoid the difficulties associated with a reliable determination of depth of a fatigue crack during investigations, as a criterion for completing the fatigue tests, the achievement of a set size from 5 to 30 mm by a crack on the specimen surface was chosen. During these tests, in the weld area the specimens were lubricated with an indicator fluid consisting of kerosene and toner. After the formation of a crack of a set length (all cracks were formed along the line of transition of the weld metal to the base metal) on the surface of the specimen the remnants of the indicator fluid were removed by blowing-down with a compressed air. Indicator fluid was no longer used in the further tests of specimens, which enabled the determination of a clear front of the initial crack on the fractures of welded joints. After the propagation of a crack on the surface of the specimens to the specified size, accelerated corrosion tests were carried out under the conditions simulating the effect of the moderate climate of the central regions of Ukraine, according to the procedure [5]. Therefore, the specimens of welded joints were exposed in the G4 hydrostat at a temperature of 40 °C and at a relative humidity of 100 % for 1200 h. Thus, as a result of previous fatigue and accelerated corrosion tests, the test specimens had damages characteristic to damages of welded joints of metal structures after a long-term service at the variable loading under the conditions of a moderate climate.

During preparation of specimens with surface fatigue cracks and corrosion damages for fatigue testing, their gripping parts were cleaned again from corrosion damages. The weld zone was not cleaned from corrosion products to metallic luster. One part of the specimens was left in the nonstrengthened condition and the other was strengthened by HMP technology. Strengthening of welded joints by HMP technology was performed in the USTREAT-1.0 equipment, where a hand-held compact impact tool with a piezoceramic converter was connected to an ultrasonic generator with a output power of 500 W. In the treatment of welded joints by HMP technology, not only the fusion line containing a fatigue crack was subjected to surface plastic deformation, but all four lines of transition of the weld metal to the base metal of a tee joint. As a device for strengthening a single-row four-striker head  with a diameter of 3 mm was used. The strengthening was performed without a preliminary cleaning of surface from the corrosion products.

Thus, fatigue tests were performed on two series of specimens:

- specimens of tee welded joints with surface fatigue cracks of 5–30 mm length and corrosion damages (first series);
- specimens of tee welded joints with surface fatigue cracks of 5–30 mm length and corrosion damages that were strengthened by HMP technology (second series).

**Table 1.** Cyclic life of tee welded joints with corrosion damages and surface fatigue cracks

| Number of specimen | $l_{cr}$, mm | $N_{cr}$, cycles | $\sigma_{max}^{unstrength}$, MPa | $N_{cr}^{unstrength}$, cycles | Result |
|---|---|---|---|---|---|
| 2272 | 7 | 1531300 | 150 | 2000000 | Not fractured |
| 2277 | 10 | 1164000 | 180 | 1327500 | Fracture along the fusion line |
| 2279 | 10 | 826700 | 190 | 647600 | Same |
| 2278 | 12 | 811800 | 200 | 177800 | –»– |
| 2275 | 15 | 1137800 | 220 | 35900 | –»– |
| 2273 | 7 | 1735700 | 200 | 656300 | –»– |
| 2274 | 25 | 853100 | 220 | 29500 | –»– |
| 2276 | 20 | 1626800 | 200 | 48400 | –»– |

*Note*. $l_{cr}$ is the crack length before corrosion tests, established by the method of kerosene test; $N_{cr}$ is the cyclic life before initiation of a crack of a set length at the maximum applied stresses of 180 MPa; $\sigma_{max}^{unstrength}$ is the maximum cycle stresses applied to the specimen with a crack after corrosion tests in the G4 chamber for 1200 h; $N_{cr}^{unstrength}$ is the residual cyclic life of the specimen with a fatigue crack of a set length and corrosion damages.

Experimental investigations of residual life of the mentioned welded joints were carried out before a complete fracture of the specimens or exceeding the tests base of $2\cdot10^6$ cycles of stress changes.

**Test results.** The results of fatigue tests of tee welded joints of 15KhSND steel with fatigue cracks without HMP strengthening (first series) are given in Table 1 and in Figure 2. Figure 2 also shows the data of tee welded joints after $2\cdot10^6$ cycles at applied maximum stresses of 150 MPa (without fatigue cracking), corrosion tests in G4 hydrostat for 1200 h without and with subsequent strengthening by HMP technology obtained in [5].

The residual cyclic life of tee welded joints of 15KhSND steel with the surface cracks of up to 10 mm length after corrosion tests at elevated temperatures and a relative humidity stay for 1200 h at the level of residual life of welded joints, which were subjected to cyclic loading of $2\cdot10^6$ cycles at maximum stresses of 150 MPa (without cracking) and corrosion testing. As the length of the initial crack increases, the residual life of the joints decreases (see Table 1, Figure 2). As far as the specimen 2272 was not fractured before $2\cdot10^6$ cycles of stress changes, then in order to determine the dimensions (depth and length) of the initial crack of the specimen, it was destroyed at cyclic loading at the levels of the maximum applied stresses increased to 280 MPa. The fractures of specimens of tee joints with surface cracks and corrosion damages are shown in Figure 3. As is seen, the proposed method allows a clear determination of the geometric dimensions of the initial crack on the fractures after the of the specimens destruction. However, the established length of the initial fatigue cracks on the surface was found to be 2–3 mm longer than when determined directly during cyclic loading. Despite the fact that all fatigue cracks were initiated along the fusion zone in the center of the specimen, the compression ratio of the surface crack (the ratio of crack depth to half-length) in them is different. We believe that this is caused by propagation of cracks in different fields of residual welding stresses, predetermined by the order of producting fillet welds.

The results of fatigue tests of tee welded joints of 15KhSND steel after the formation of surface fatigue cracks, corrosion tests in the G4 hydrostat for 1200 h and with a subsequent strengthening by HMP technology (second series) are given in Table 2 and Figure 2. The obtained experimental data indicate that the effectiveness of applying HMP technology for the specimens of the second series is actually determined by geometric dimensions of the fatigue crack formed before treatment. Thus, strengthening of tee welded joints with surface fatigue cracks of up to 10 mm length by using HMP technology increases their cyclic life by up to 10 times. Scattering in the experi-

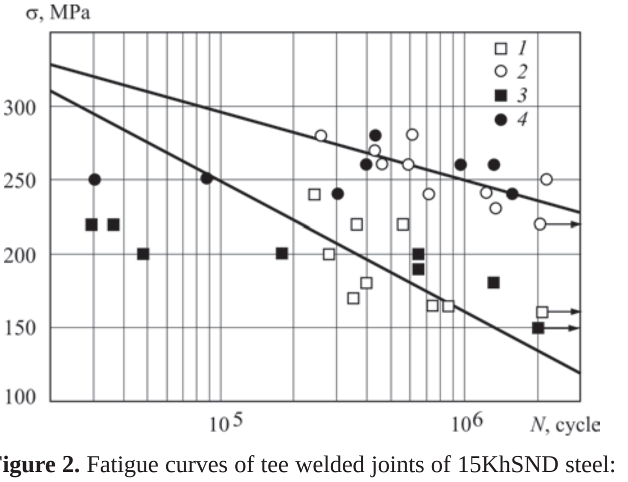


**Figure 2.** Fatigue curves of tee welded joints of 15KhSND steel: *1* — after 2 mln cycles and exposure in the G4 chamber for 1200 h [5]; *2* — after 2 mln cycles, exposure in the G4 chamber for 1200 h and a subsequent strengthening by HMP technology [5]; *3* — after testing before the formation of surface fatigue cracks and exposure in the G4 chamber for 1200 hours; *4* — after testing before the formation of fatigue surface cracks, exposure in the G4 chamber for 1200 h and a subsequent strengthening by HMP technology

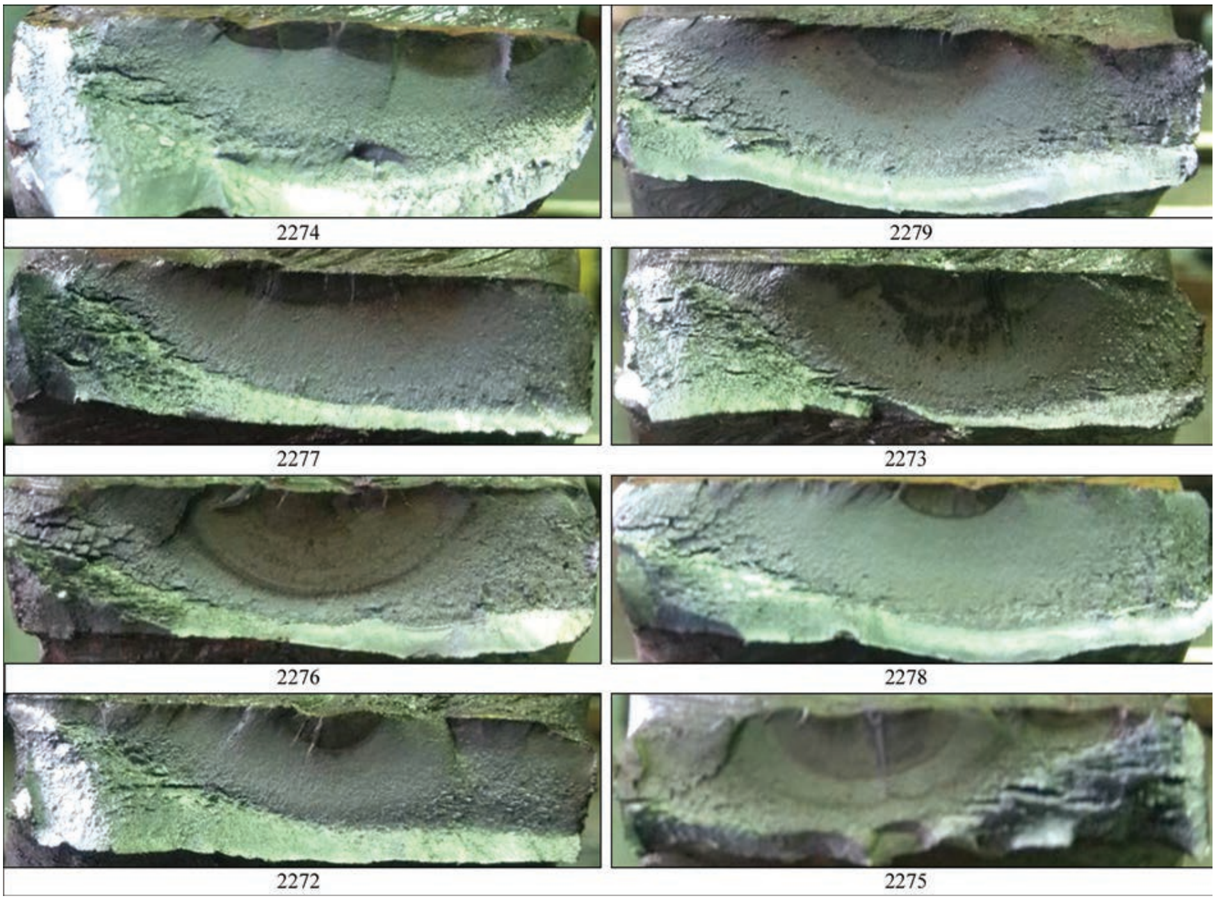


**Figure 3.** Fatigue fractures of specimens of tee welded joints of 15KhSND steel with fatigue surface cracks which were not strengthened by HMP after exposure in the G4 chamber for 1200 h (see Table 1)

mental data of such joints is within the range of the fatigue-free cracks strengthened by HMP at a set level of fatigue-corrosion damages (life of $2\cdot10^6$ cycles of stress changes + G4 chamber for 1200 h). The use of HMP technology for welded joints containing fatigue cracks of 20 mm length or more does not lead to increase in the cyclic life and is ineffective (Table 2). Three specimens (2155, 2156, and 2178), which contained fatigue cracks of 5 mm length, fractured far from the weld along the base metal (Figure 4) after strengthening by HMP. The cracks in the specimens 2155 and 2156 initiated from caverns in the surface hot-rolled metal layer, and in the specimen 2178 from a notch on the gripping part of the specimen, formed during its clamping in the test machine (Figure 5). Other specimens were fractured from fatigue cracks

**Table 2.** Cyclic life of tee welded joints with corrosion damages and surface fatigue cracks after their strengthening by HMP technology

| Number of specimen | $l_{cr}$, mm | $N_{cr}$, cycles | $\sigma_{max}^{strength}$, MPa | $N_{cr}^{strength}$, cycles | Result |
|---|---|---|---|---|---|
| 2155 | 5 | 432200 | 260 | 1335200 | Fracture of base metal at a distance of 25 mm from the weld |
| 2156 | 5 | 292900 | 260 | 972700 | Fracture of base metal at a distance of 40 mm from the weld |
| 2175 | 10 +10* | 960700 | 280 | 434200 | Fracture along the fusion line |
| 2180 | 10+8+6* | 401800 | 260 | 396000 | Same |
| 2177 | 20 | 1138000 | 250 | 30700 | –»– |
| 2178 | 5 | 261100 | 240 | 1588100 | Fracture of base metal in the gripping part of the specimen |
| 2179 | 10 | 643500 | 240 | 306400 | Fracture along the fusion line |
| 2176 | 30 | 463900 | 250 | 88000 | –»– |

*Note*. $l_{cr}$ is the crack length before corrosion testing, established by the kerosene test method; $N_{cr}$ is the cyclic life before the origin of a crack of a set length; $\sigma_{max}^{strength}$ is the maximum cycle stresses applied to the specimen with a crack after corrosion testing in G4 chamber for 1200 h and strengthening by HMP technology; $N_{cr}^{strength}$ is the residual cyclic life of the specimen at a specified length crack and corrosion damages after strengthening with HMP technology; * are the specimens that had several separate surface cracks along one fusion line.

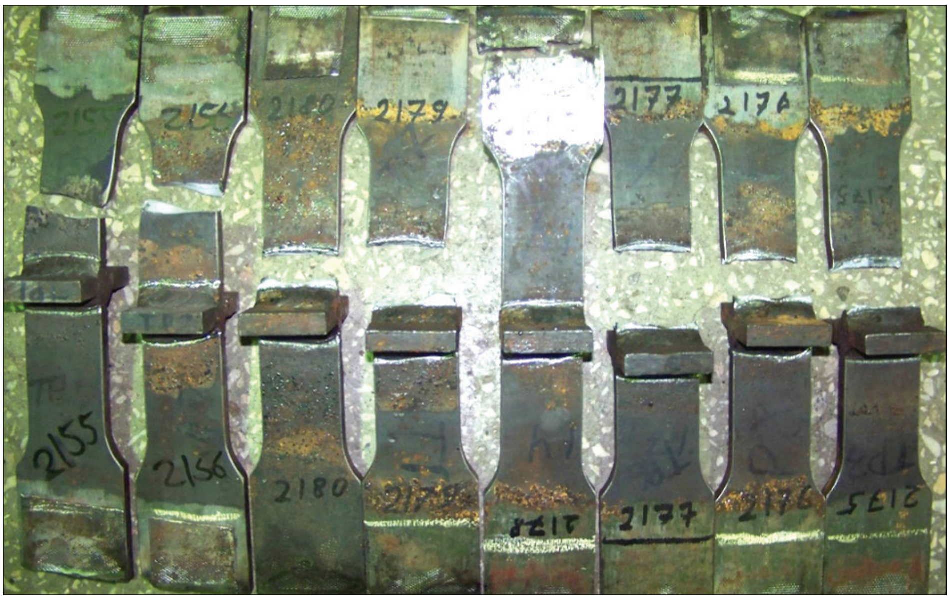

**Figure 4.** Specimens of tee welded joints of 15KhSND steel after fatigue tests with surface fatigue cracks, strengthened by HMP after exposure in the G4 chamber for 1200 h

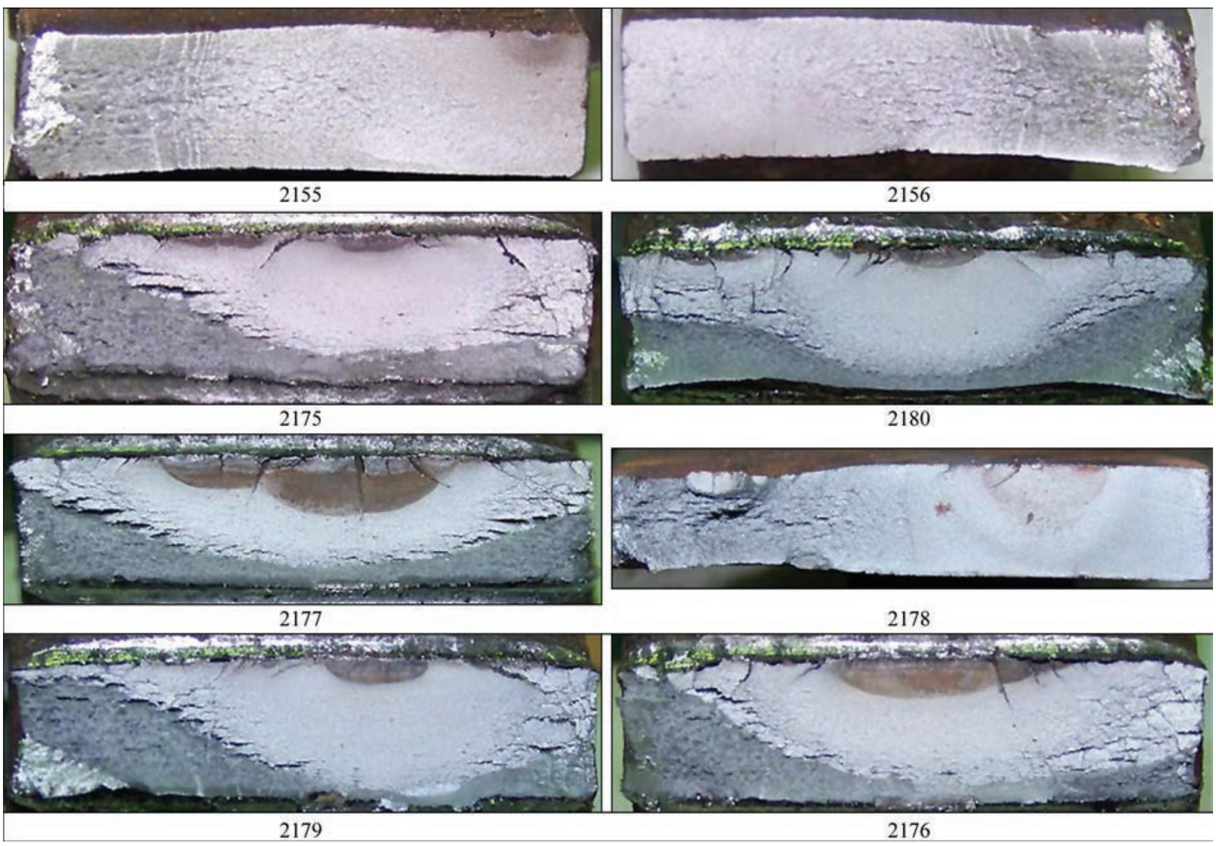


**Figure 5.** Fatigue fractures of specimens of tee welded joints of 15KhSND steel with surface fatigue cracks, strengthened by HMP after exposure in the G4 chamber for 1200 h (see Table 2)

subjected to strengthening along the fusion line (see Figures 4 and 5).

Thus, a high efficiency of applying HMP technology was established to increase the cyclic life of tee welded joints of metal structures, which, as a result of a long service under the conditions of moderate climate of the central regions of Ukraine, contain fatigue surface cracks of up to 10 mm length and characteristic corrosion damages.

## Conclusions

1. The residual life of tee welded joints of 15KhSND steel with surface fatigue cracks and corrosion damages characteristic to metal structures after a long-

term service under the conditions of moderate climate of the central regions of Ukraine was experimentally investigated. The long-term effect of the moderate climate was modeled by exposing the joints in the G4 hydrostat at a temperature of 40 °C and at a relative air humidity of 100 % for 1200 h. It was confirmed that the residual life of the joints decreases with increasing the length of initial crack.

2. It was established that applying strengthening by HMP technology for tee welded joints with the surface fatigue cracks of up to 10 mm and corrosion damages characteristic to metal structures after a long-term service under the conditions of moderate climate of the central regions of Ukraine, increases their residual cyclic life up to 10 times. The values of residual life are within the range of experimental values scattering of joints without fatigue cracks, strengthened by HMP technology at a set level of accumulated fatigue and corrosion damages (life of $2\cdot10^6$ cycles of stress changes at maximum stresses of 150 MPa and exposure in G4 hydrostat for 1200 h). It was shown that application of HMP technology to welded joints containing fatigue cracks of 20 mm length or more does not lead to increase in cyclic life and is ineffective.

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