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Effect of High Humidity and Neutral Salt Mist on the Fatigue Service Life of T-Joints

Abstract: The article concerns the experimental testing of the long-lasting effect of surrounding environmental conditions (high air humidity and neutral salt mist) on the characteristics of the fatigue service life of T-joints in structures made of low-alloy steel 15HSND. The article-related research involved metallographic tests of the weld and of the heat affected zone (HAZ) of welded joints subjected to the 1200-hour long effect of humidity (in the G4 humidity chamber) and salt mist (in the KST-1 salt mist chamber). The metallographic tests made it possible to calculate the degree of corrosive effect and the entire area affected by corrosion, the depth of corrosion stain and corrosion pit penetration in the surface layer of the metal of the fillet welds and the HAZ of T-joints. The research also involved the identification of the characteristics of the fatigue service life of welded joints subjected to the long lasting effect of a corrosive environment.

Keywords: T-joint, corrosion, high air humidity and temperature, neutral salt mist, fatigue service life, cyclic loads

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Introduction

During long-lasting operation, welded metal structures (bridges, cranes etc.) can be simultaneously affected by corrosive environments and cyclic loads. Delayed technical inspections and renovation of varnish coats could result in the formation of corrosion defects and premature structural damage beyond repair (Fig. 1).

The assessment of the effect of corrosive environments on the characteristics of the fatigue service life of the base material and welded joints is usually performed directly in corrosive environments [1-9]. The authors of publications [3-7] stated that the 3% solution of NaCl decreased by 13-43% the restricted fatigue service life of T-joint (based on 10^6-10^7 cycles). As corrosion fatigue tests

Fig. 1. Corrosion damage to the main beam of the box section of a road bridge

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are performed at a load frequency of 5-50 Hz, the time during which specimens are exposed to the corrosive environment when developing fatigue curves amounts to between 10 and 200 hours. As a rule, after related tests, the surfaces of specimens do not reveal corrosion damage characteristic of welded metal structures. For this reason, it has become necessary to determine the long-lasting effect of corrosive environments on the fatigue service life characteristics.

The research work and related tests presented in the article aimed to identify the long-lasting effect of increased humidity and neutral salt mist on the characteristics of the fatigue service life of T-joints (T-shaped welded joints).

Test Conditions

The research-related tests involved welded joints (specimens) made of low-alloy steel 15HSND (chemical composition: 0.12÷0.18% C; 0.4÷0.7% Si; 0.4÷0.7% Mn; 0.3÷0.6%Ni; 0.6÷0.9% Cr and 0.2÷0.4% Cu) having yield point R_e = 400 MPa, tensile strength R_m = 565 MPa and being of category 12 according GOST 19281-89. The above-presented steel is used when making welded elements of metal structures intended for the long-term operation and exposition to variable loads within the temperature range of -70°C to +45°C. Steel 15HSND is characterised by good weldability and resistance to weather conditions. Elements (350×70 mm) used in T-joins were cut out of 12 mm thick hot-rolled sheets; the thickness of 12 mm resulted from the widespread use of 8-14 mm thick sheets in the construction of bridges. The T-joints were made by the manual welding of transverse bracings to the middle of the plate using low-hydrogen covered electrodes UONI 13/55. The root of the weld was made using electrodes having a diameter of 3 mm, whereas the subsequent runs were made using electrodes having a diameter of 4 mm. The shape and the geometrical dimensions of the T-joints are presented in Figure 2.

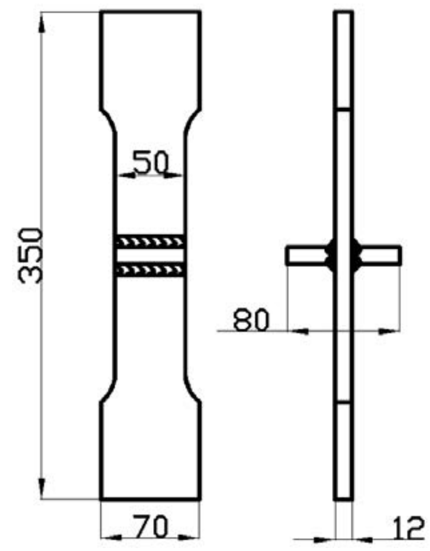

Fig. 2. Shape and dimensions of the specimens

The fatigue tests of the welded specimens were performed using a URS-20 testing machine and variable tension with stress ratio R_e=0. The load frequency amounted to 5 Hz. The criterion of test stoppage was the entire rupture of the specimen or the obtainment of the test base amounting to $2 \cdot 10^6$ cycles of load changes.

The tests concerning fatigue service life characteristics involved three series of specimens:

- specimens in the initial state after welding without initial corrosion damage (first series);
- specimens subjected to accelerated corrosion tests in a humidity chamber (second series);
- specimens subjected to accelerated corrosion tests in a salt mist chamber (third series).

The obtainment of characteristic damage to the specimens of the second series required the performance of accelerated corrosion tests in humidity chamber G4 by exposing the specimens to a higher air humidity of 98% and a higher temperature of 40°C for 1200 hours. The specimens of the third series were held in salt mist chamber KST-1, where they were subjected to a temperature of 35±2°C as well as affected by NaCl solution sprayed for 15 minutes every 45 minutes; the NaCl concentration in the solution amounted to 50 ± 5 g/dm³, pH was between 6.5 and 7.2, whereas the density amounted to 1.03 g/cm³. The accelerated corrosion test performed using salt mist chamber KST-1 was also 1200 hours in duration.

Test Results

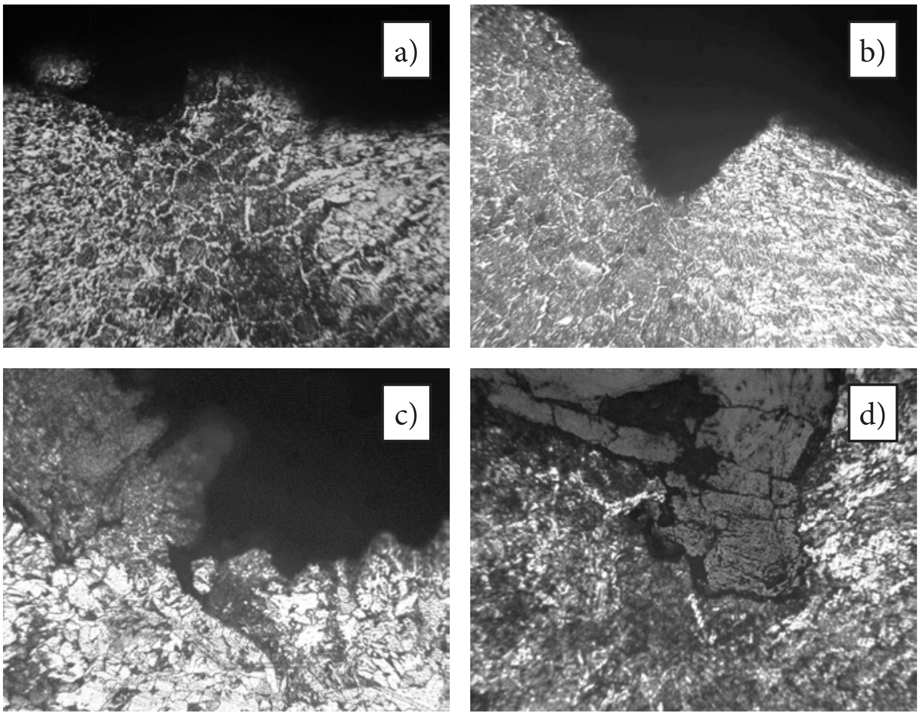

Fig. 3. Corrosion damage to the HAZ metal of the T-joint after 1200 hour-long hold in humidity chamber G4 (a and c) and salt mist chamber KST-1 (b and d) at 100x (a and b) and 250x (c and d) magnification

The surface layers of the weld metal and of the HAZ of the T-joint subjected to elevated humidity and temperature in humidity chamber G4 contained deep and extensive corrosion defects having the form of stains (2.8×0.26 mm) or caverns (1.56×1.17 mm) (Fig. 3a and c).

After the exposure to salt mist in the salt mist chamber, the specimens were covered with the 1-2 mm thick layer of corrosion products. The surface layers of the weld metal were affected by extensive corrosion defects in the form of surface stains and caverns (e.g. 1.95×0.65 mm and 4.16×0.26 mm). In the HAZ metal, the defects were less extensive but deeper (Fig. 3b), e.g. (1.3×0.65 mm), and, in some cases, filled with corrosion products (Fig. 3d). The long term effect of neutral salt mist led to the corrosion-mechanical depletion of metal resulting in the reduction of the specimen thickness and of the geometric leg dimensions of the welds. The results of the metallographic tests with calculated values concerning the degree of corrosion effect, the entire area affected by corrosion as well as the depth of corrosion stain and cavern penetration in the surface layer of the metal of the fillet welds and the HAZ of the T-joints are presented in the table below.

The fatigue test results concerning all three series of the specimens (T-joints) made in steel 15HSND are presented in Figure 4.

The experimentally identified limit of the restricted fatigue service life of the T-joints in the initial state (without the effect of corrosive environment) amounted to 179 MPa. The specimens ruptured along the fusion line.

The initial hold of the welded joints in humidity chamber G4 for 1200 hours led to the decrease in the characteristics of fatigue service life; the limit of restricted fatigue service life based on $2 \cdot 10^6$ cycles decreased by 13% (from 179 MPa to 156 MPa), whereas fatigue service life within the range of $4 \cdot 10^5$ to $2 \cdot 10^6$ decreased 2 times (Fig. 4). The above-presented slight

Table 1. Sizes of corrosion damage in the surface layers of the weld metal and the HAZ of the T-joints made in steel 15HSND after accelerated corrosion tests

Specimen condition	Stain corrosion of weld metal surface layers		Stain corrosion of HAZ metal surface layers	
	Degree of damage,%	Depth of damage, mm	Degree of damage,%	Depth of damage, mm
After hold in chamber G4	31.2	0.091-1.17	38.5	0.13-0.39
After hold in chamber KST-1	50.4	0.039-0.65	64.0	0.065-0.65

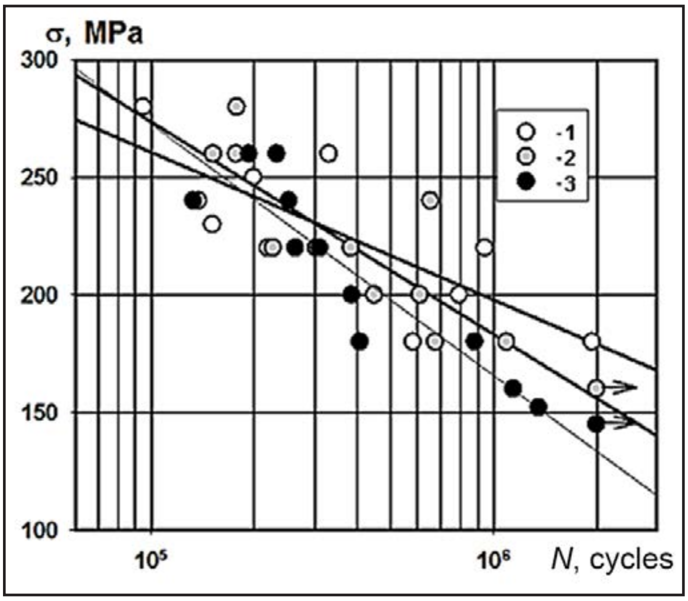

Fig. 4. Fatigue curves of the T-joints made in steel 15HSND: 1 – in the initial state after welding, 2 – after the initial hold in humidity chamber G4 for 1200 hours, 3 – after the initial hold in salt mist chamber KST-1 for 1200 hours

reduction of the characteristics of the fatigue service life of the welded joints confirmed that welded structure elements made of steel 15HSND were resistant to weather conditions. All of the specimens ruptured along the fusion line (Fig. 5a).

The initial subjecting of the T-joints to neutral salt mist (in a neutral salt mist chamber) for 1200 hours decreased their characteristics of fatigue service life; the limit of restricted fatigue service life based on $2 \cdot 10^6$ cycles decreased by 25% (from 179 MPa to 134 MPa), whereas fatigue service life within the range of $2 \cdot 10^5$ to $2 \cdot 10^6$ cycles decreased 2.5 times (Fig. 4). The limit of the restricted fatigue service life of the T-joints held in the chamber KST-1 (with more significant corrosion damage to the surface) was by 14% lower than that of the T-joints held in humidity chamber G4. Apart from one specimen, where a corrosion-triggered crack occurred at the interface between the working part and the fixing element of the specimen (Fig. 5b), the fatigue failure of the specimens occurred along the interface between the weld metal and the baser material.

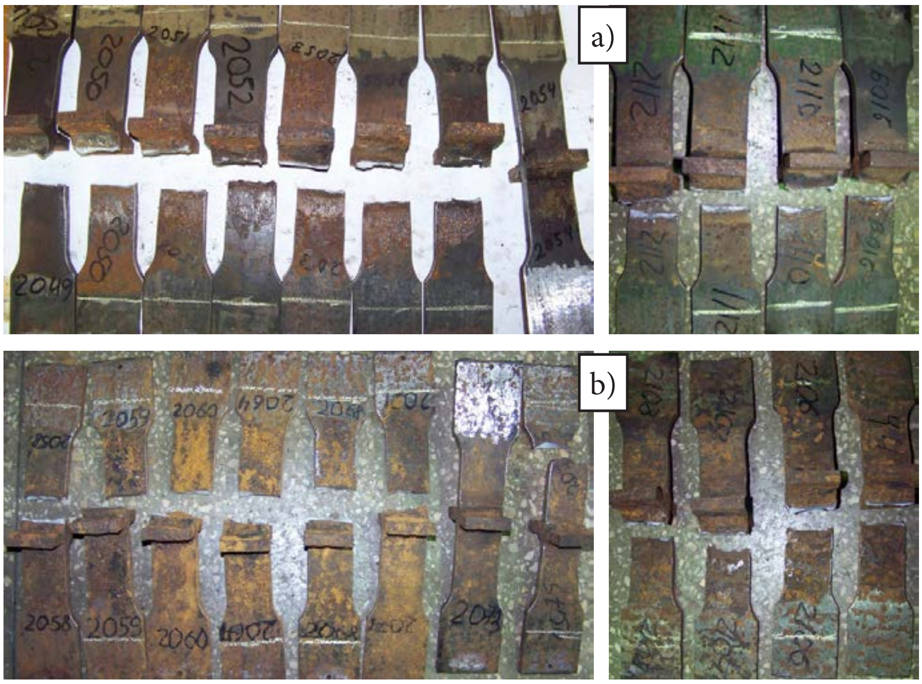

Fig. 5. Ruptured (after fatigue tests) specimens of the T-joints, initially held (for 1200 hours) in humidity chamber G4 (a) and salt mist chamber KST-1 (b)

Conclusions

1. The research-related metallographic tests were focused on the surface layers of the weld metal and the HAZ of the T-joints made in steel 15HSND subjected to increased humidity and neutral salt mist for 1200 hours. Based on the calculations concerning the degree, depth and the total size of the area affected by corrosion stains and caverns of the surface layers the weld metal and HAZ of the T-joints revealed that neutral salt mist led to more significant corrosion damage.

2. Related experiments revealed that the subjecting of the T-joints made of steel 15HSND to humidity (in a humidity chamber) for 1200 hours decreased the limit of restricted fatigue service life based on $2 \cdot 10^6$ cycles by 13% (from 179 MPa to 156 MPa) and decreased by twice the cyclic fatigue service life within the range of $4 \cdot 10^5$ to $2 \cdot 10^6$ cycles.

3. It was demonstrated that the subjecting of the T-joints to neutral salt mist (in a neutral salt mist chamber) for 1200 hours decreased the limit of restricted fatigue service life based on

$2 \cdot 10^6$ cycles by 25% (from 179 MPa to 134 MPa) and decreased by 2.5 the cyclic fatigue service life within the range of $2 \cdot 10^5$ to $2 \cdot 10^6$ cycles.

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