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Fatigue life of S960QL steel welded joints

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Abstract. During fatigue tests connectivity, welded steel XABO960 achieved a significant reduction in the durability of welded samples compared to samples taken from the parent material. For an explanation of the reasons for this phenomenon, residual stress and fatigue tests microfractography breakthroughs were studied.
The study confirmed the occurrence of the weld area of substantial positive inclusions, residual stresses, and a high silicon content and sulphides which reduce the fatigue life of the welded joints [1, 2]. The explanation of these adverse events will be the subject of further research.
Keywords: fatigue life, welded joints
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1. Introduction

For many years, in the bridge structures, the structural steels with high strength, such as S355 (18G2A), have been used. For several years, some of the producers of this type of construction have used consistently high strength, precipitation-hardened or toughened, for example steel S960QL, better known under the name XABO 960. The problem of behaviour of welded joints made of the mentioned material was not correctly recognized. This inspired the authors to take this problem.

2. The testing fatigue life of S960QL steel and its welded joints

In order to obtain complete characteristics of the steel, fatigue tests were carried out across the number of cycles. This allowed us to obtain the Wöhler diagram (Fig. 1). Results of fatigue life tests were statistically analyzed in accordance with standard ASTM E739-91: „Standard Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (ε-N) Fatigue Data" [3, 4].

TABLE 1

The chemical composition (melting analysis) steel (by weight)

Steel	Base of data	C	Si	Mn	P	S	Cr	Mo	Ni	V	Fe
S960QL XABO 960	Own tested	0.18	0.44	1.14	0.0	0.0	0.25	0.57	1.7	0.05	95.67
	The data of producer	0.18	0.50	1.60	0.02	0.01	0.80	0.60	2.00	0.10	–

There are tested the samples produced from the flat base material having the chemical composition shown in Table 1, and the sample with the butt weld (TIG welded, beveling V, applied adhesive X96-IG) [5].

Test results for samples from the base metal and welded joint, used by the statistical method, are presented in the form of Wöhler diagram (Fig. 1).

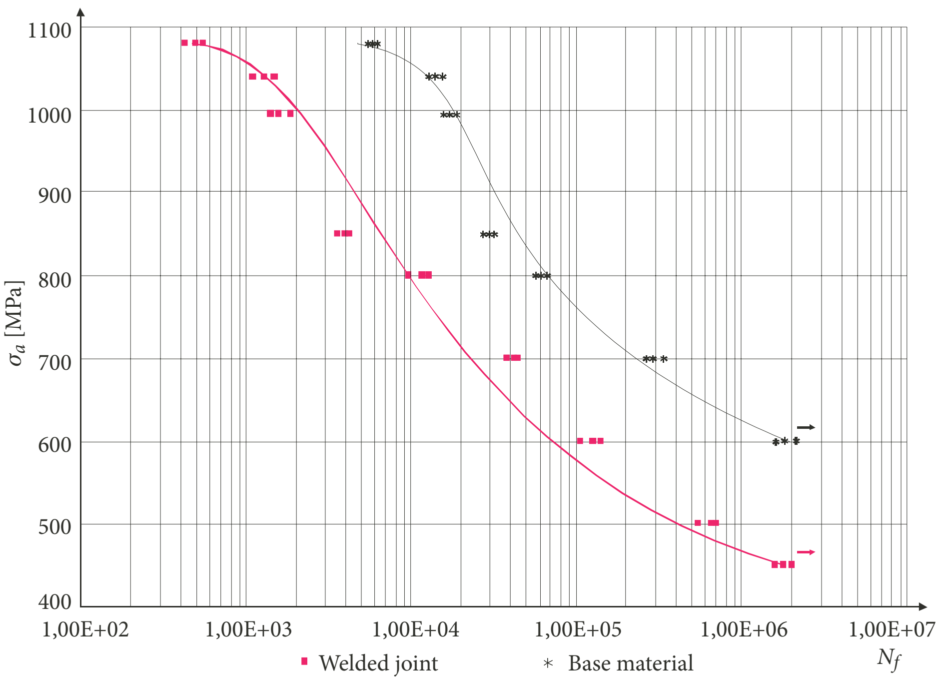

Fig. 1. Diagram fatigue life of S960QL steel and its welded joints

As the testing results show, the fatigue life of welded samples drops significantly compared to the samples taken from the base metal. It is clearly evident in the low cycles range.

The results of fatigue tests at the constant stress σ_{max} and load zero-to-tension base material samples indicate that steel S960QL shows cyclical strengthening of the tendency for rapid stabilization. Fatigue test samples at loads significantly exceeding the yield strength $R_{0.2}$, or even approaching the tensile strength R_m (Table 2) reached up to about 7000 cycles. Plastic strain amplitude rapidly decreases, maintaining a nearly constant value until the fatigue failure of the sample.

Table 2

Average values of the results of the tests static tension

Steel	$R_{0.2}$ [MPa]	R_m [MPa]	R_u [MPa]	A [%]	Z [%]	E [GPa]
S960QL	1000	1090	2209	14	38	208

Low cycle fatigue tests of the butt weld samples showed a significant decrease in fatigue life of the test samples compared to the samples made of a base material under stress with similar values.

3. Results of measurements of residual stresses of welded butt joint

Measurement of residual stresses in welded joints performed by x-ray diffractometer STRAINFLEX PSF-2M Rigaku. A diameter of x-ray beam incident upon the surface being equal to 1.5 mm.

The measurement results showed significant gradient welding stresses (Fig. 2), which reaches a maximum value in the weld fusion line [6]. Maximally, the value of reduced stresses is about 250 MPa in a heat affected zone, which when added to the stresses derived from external forces may cause local elastic limit exceeded, which results in a clear reduction in the fatigue life of the tested joints. This was observed during durability testing.

On a plot showing the stress in the directions: x — along the longitudinal axis of the sample, y — perpendicular to the longitudinal axis of the sample and reduced stress (Fig. 2). The measuring points were placed in the centre of the welded joint (point 1), on the line of fusion (point 2), and on the border of the heat affected zone (point 3) (Fig. 3) [7].

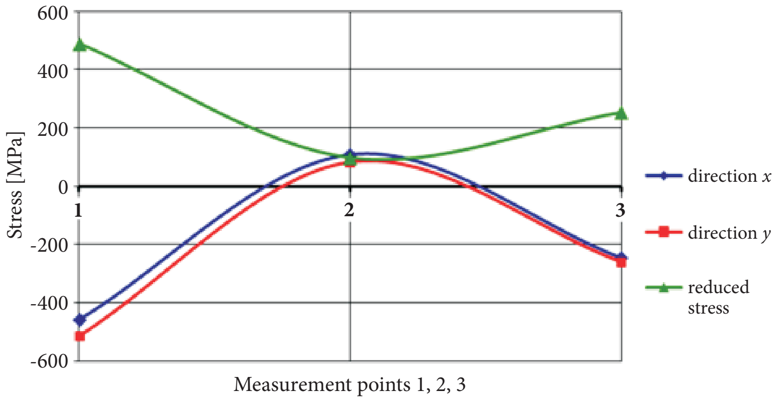

Fig. 2. The residual stresses distribution in welded butt joints (steel S960QL)

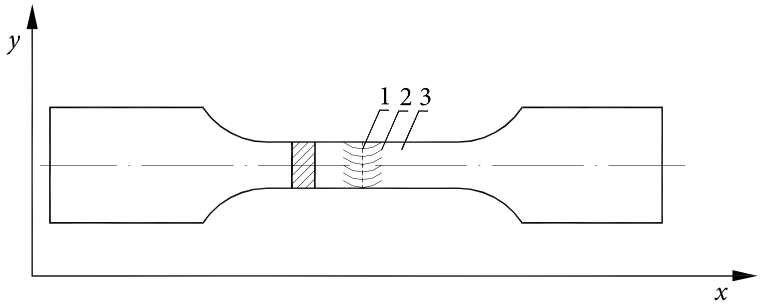

Fig. 3. Residual stresses measuring location in welded butt joint

4. The results of microfractography tests

Study of microfractography was carried out using a scanning electron microscope JEOL JSM 6610 with OXFORD detector. The subject of the study was fatigue scrap samples from the base metal and welded specimens.

The first picture shows the macro structure of fatigue crack S960QL steel samples (Fig. 4.) The initial cracking is brittle and develops in the area of the surface (Fig. 5).

Next cracks propagate into the material taking the form of brittle plastic crack with a clear presence of secondary cracks at grain boundaries deviating from the main direction of development of fatigue cracks (Fig. 6). Here, there are also observed plastic fatigue striations. (Fig. 7). Further propagation of fatigue crack had plasticity features with a lot of crease (Fig. 8).

The next photos illustrate the process of fatigue fracture samples of steel butt welded with S960QL (Fig. 9).

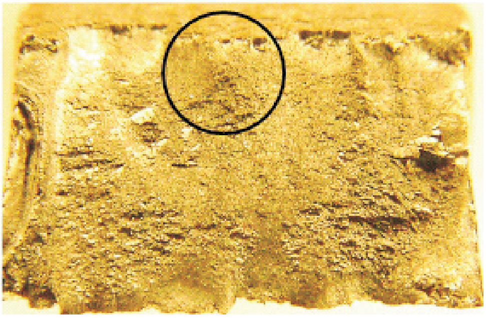

Fig. 4. View of the macrostructure of fatigue crack S960QL steel samples

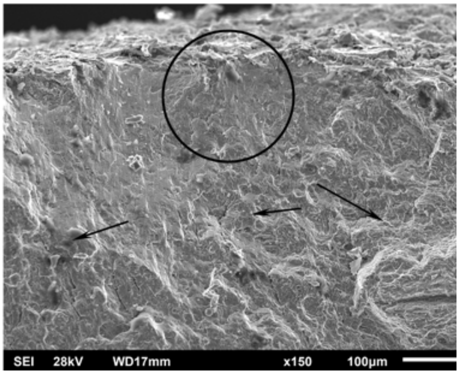

Fig. 5. View of the microstructure of fatigue crack (visible brittle cracks)

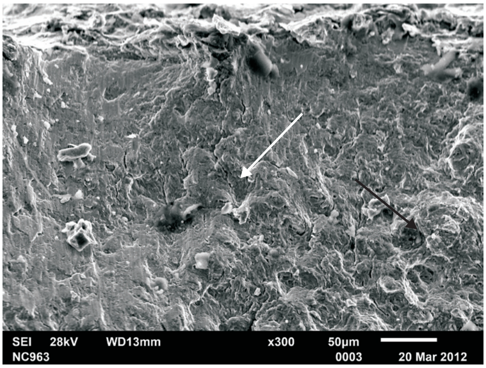

Fig. 6. View of the microstructure of fatigue crack (visible cracks on the grain boundary)

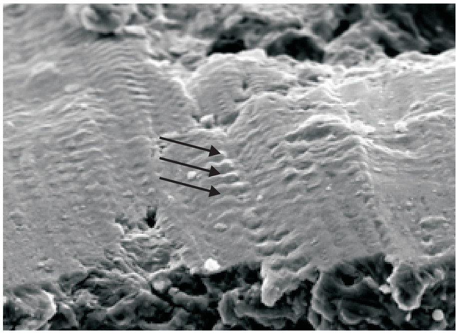

Fig. 7. View of the microstructure of fatigue crack (visible plastic fatigue striations)

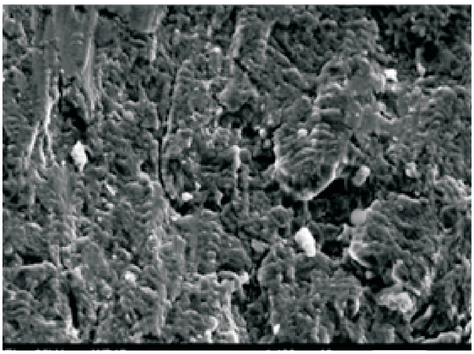

Fig. 8. View of the microstructure of fatigue crack

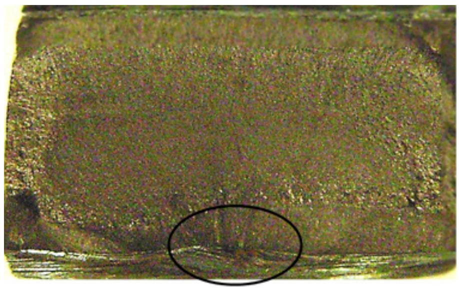

Fig. 9. View of the macrostructure of fatigue crack in a welded butt joint

As shown in figure 10, fatigue cracks were initiated in the zone as a brittle fracture surface within the fusion line. In the deep material, there are formed characteristic fatigue bands adjacent to the arrangement of pits, which were detected by the weld formed inclusion with a high silicon content (Fig. 12). These inclusions have a size of about 1 to 3 μm. When analyzing microstructure breakthroughs, there is found the presence of a lot of non-metallic inclusions of sulphides (Fig. 11) that influence the development of fatigue crack growth what is manifested by the presence of cracks from the break.

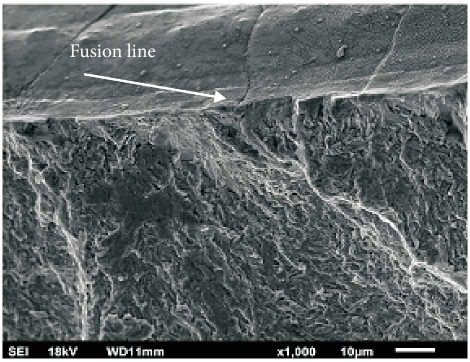

Fig. 10. View of the microstructure of fatigue crack in a welded butt joint (visible fusion line)

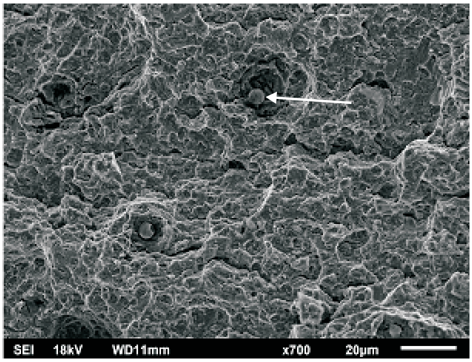

Fig. 11. View of the microstructure of fatigue crack in a welded butt joint (visible non-metallic inclusions of sulphides)

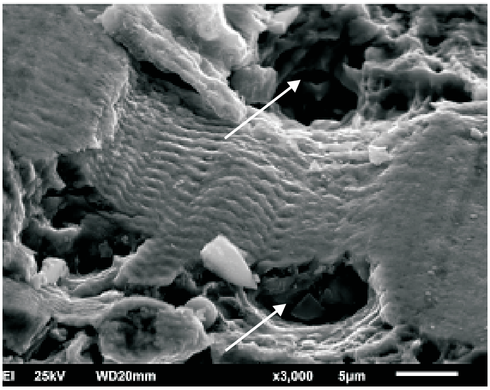

Fig. 12. View of the microstructure of fatigue crack in a welded butt joint (visible inclusions with high silicon content)

Microfractography tests have shown that the process of fatigue crack growth in the samples of both welded and made of the base material is a very rapid process. This can be seen by numerous secondary cracks causing sudden local changes in the direction of cracking.

5. Summary

During the study, the properties of steel fatigue S960QL and its welded joints was found cyclical strengthening of the material at loads zero-to-tension with constant maximum stress. Fatigue life test samples with the butt weld is reduced from 40% to 60%, and in some cases by about 90%, especially in the range of low cycles, as compared to the samples made of the base metal. Measurement of residual stresses in welded joints showed positive values, combined with the stress coming from external forces can result in the lowering of the fatigue life of welded joint tested, which were observed during the tested durability. In the welding process, heating of the material results in the formation of various types of precipitates, around which there is a stress concentration. The fatigue cracking examined steels and their welded joints proceeds very rapidly and to a large extent is a brittle fracture.

It is possible to increase the fatigue life of the weld joint by introducing compressive stresses in the joint region, for example by shot peening.

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Trwałość zmęczeniowa połączeń spawanych ze stali S960QL

Streszczenie. Przedstawiono rezultaty badań zmęczeniowych stali S960QL i jej połączeń spawanych. Badano próbki płaskie z materiału rodzimego i spawane czołowo. Wyznaczono wykres trwałości zmęczeniowej. Przedstawiono rezultaty pomiaru naprężeń własnych i badania makro- i mikrostrukturalne przełomów zmęczeniowych.

Słowa kluczowe: trwałość zmęczeniowa, połączenia spawane