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The Effect of Technological Treatments and Loads on the Service Life of Fillet Welds

Abstract: The paper presents test results concerning the service life of fillet welds made in steel S355. In addition, the article discusses the initiation and growth of fatigue cracks in specimens subjected to bending with torsion. The tests were performed in relation to constant stress ratio R = -1 and 0. The results presented in the article take into account the effect of the technological treatment on the service life of the specimens. The tests revealed longer service life of the specimens not subjected to the technological treatment, both when R = -1 and 0.

Keywords: welding, bending, fatigue crack growth, structure, fillet welds

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Introduction

Tests concerning the service life of welded T-joints used in the making of industrial facilities were discussed in publications [1, 2, 3]. The area of research includes, among other things, equipment and machinery operated in mines such as hoisting machines, hoisting machine vessels, cable wheels, hoist towers, shaft reinforcement structures, fans etc. The assessment of the technical condition and wear as well as the safe operation period forecast concerning individual elements and entire devices is of utmost importance. In Act [4], the lawmaker discussed in detail requirements for personnel carrying out periodic checks. In the executory order to Act [5], the lawmaker specified the scope and frequency/periodicity of performed tests. Because of this, in subsequent publications authors present results of fatigue tests of welded T-joint in relation to various factors including the manner and value of load, heat treatment or other technological treatments. This article presents results of tests concerned with the service life of fillet welds made of steel S355 as well as the initiation and grow of fatigue cracks in specimens containing the fillet welds subjected to cyclic bending with torsion.

Experimental tests

The experimental tests involved the use of specimens made of fine-grained weldable normalised structural steel S355. This unalloyed steel is characterised by the fine-grained ferritic-pearlitic structure. The primary chemical and mechanical properties of the steel are presented in Table 1. Within the scope of the tests, a 30 mm long drawn bar was sampled for specimens which, subsequently, were subjected to the argon-shielded TIG welding process.

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The shapes and dimensions of the welded specimens are presented in Figure 1. The experimental tests were performed on the welded specimens with concave weld faces (in the as-welded state) and with weld faces subjected to a technological treatment. The technological treatment involved milling off the convex welds in the specimens aimed to obtain welds with concave faces. The milling process was followed by fatigue tests aimed to determine (on the basis of related results) which specimens were characterised by longer service life.

Table 1. Primary chemical and mechanical properties of steel S355 [6]

Chemical composition of steel in [%]								
C	Mn	Si	P	S	Cr	Ni	Cu	Fe
0.2	1.49	0.33	0.023	0.024	0.01	0.01	0.035	rest

Mechanical properties					
R_e, MPa	R_m, MPa	A_{10}, %	Z, %	E, GPa	v
357	535	21	50	210	0.30

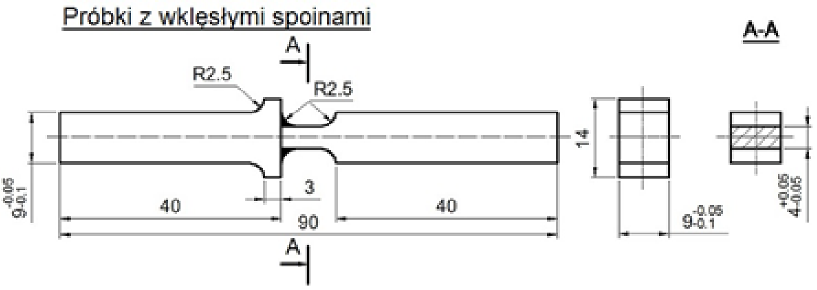

Fig. 1. Specimens containing filler welds

The experimental tests involving the proportional bending with torsion (α = 45°) were performed using an MZGS-100 fatigue testing machine [7]. The entire moment changed in time in accordance with a dependence where $M(t) = M_B(t) + M_T(t)$. Figure 2 presents the manner in which the specimen was fixed and the schematic distribution of the bending moment (M_B) and torsional moment (M_T).

The fatigue tests were performed under conditions of low and high fatigue cycles. The specimens were tested under a fatigue load characterised by the constant amplitude of the moment amounting to $M_B = 9.2$ Nm ($M_{max} = M_B + M_m = 18.4$ Nm, where M_m is the mean value of the applied moment) and stress ratio being $R = M_{min} / M_{max} = -1$ and 0. The torsional moment/bending moment ratio amounted to $M_T(t) / M_B(t) = 1$. During the tests performed using the fatigue tester, increased lengths of cracks were observed (using the optical method) on the side surfaces of the specimens. The cracks were measured using a digital micrometer placed on the table of a portable microscope (mag. 25x, accuracy of up to 0.01 mm), simultaneously recording the number of stress cycles (N).

Test results and analysis

Test results concerning the specimens containing the concave welds ("raw" face in the as-welded state) and the specimens subjected to the technological treatment (the face of the weld was also concave but the specimens were subjected to the technological treatment) are presented in Figures 3 and 4. Figure 3 presents the comparison of the results concerning the fatigue service life during the development of fatigue cracks in relation to the tests where the stress ratio was R = -1. In turn, Figure 4 contains the comparison of the results in relation to R = 0 and the specimens subjected to bending and torsion.

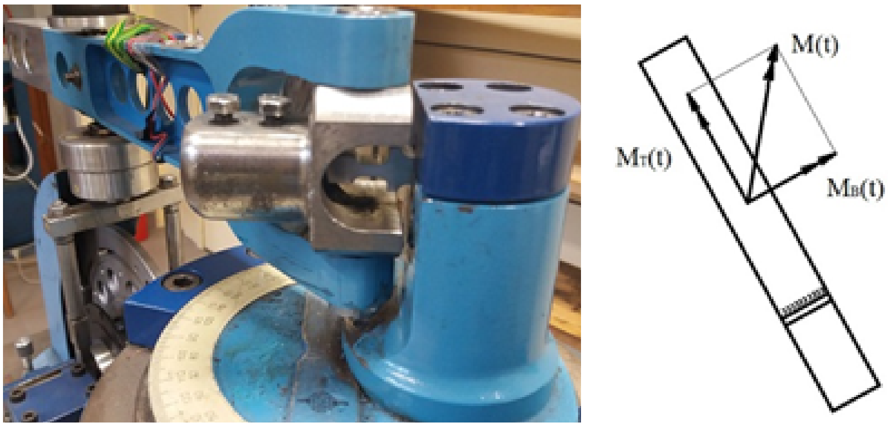

Fig. 2. Fatigue tests involving bending and torsion: a) specimens in the clamps of the testing machine and b) distribution of loads

Figure 3 reveals that the fatigue service life of the specimens subjected to the technological treatment was shorter than that of the specimens not subjected to the technological treatment. In the specimen subjected to the technological treatment, the cracks (0.10 mm) were initiated after the performance of 40000 cycles. The growth of the cracks was fast and the specimen was destroyed after 44300 cycles had been performed. The specimens not subjected to the technological treatment (the specimens containing the concave welds) were characterised by longer fatigue service life. The cracks (0.10 mm) were initiated after 53200 cycles had been performed, where the specimen was destroyed after 57800 cycles had been carried out. The decrease in the fatigue service life of the specimens subjected to the technological treatment amounted to 13500 cycles (i.e. by 23.36 %) in comparison with the specimens containing welds in the as-made state.

Figure 4 reveals that the change in the stress ratio from R = -1 to R = 0 was followed by a decrease in the fatigue service life of the test specimens. In relation to R = 0, the specimens with the welds subjected to the technological treatment obtained shorter fatigue service life than those not subjected to the technological procedure. In the specimen subjected to the technological treatment, the cracks (0.10 mm) were initiated after 4500 cycles had been performed. The specimen was destroyed after 8200 cycles had been performed. In turn, the specimens not subjected to the technological treatment were characterised by longer fatigue service life. The cracks (0.10 mm) were initiated after 5000 cycles had been performed and the specimen was destroyed after 9000 cycles had been performed. The decrease in the fatigue service life of the specimens subjected to the technological treatment amounted to 800 cycles, (i.e. by 8.89 %) in comparison with the specimens containing welds in the as-made state.

In relation to both load-related cases the analysis of the experimental test results revealed that the specimens subjected to the technological treatment were characterised by shorter fatigue service life. The decrease in the fatigue service life of the test specimens could result from the fact that the mechanical treatment (milling and grinding) of the convex welds resulted in an increase in stresses (affecting fatigue service life). Another reason could be an increase in the temperature of the welded joint area during the treatment, possibly affecting the joint structure. The decrease in fatigue service life could also be triggered by the reduction of the weld cross-section through the removal of the entire excess weld metal from the welded joint.

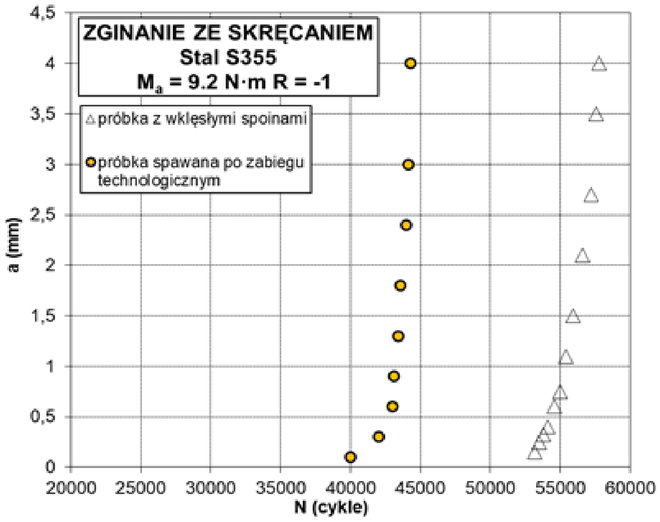

Fig. 3. Length of fatigue cracks in the function of the number of cycles related to bending with torsion for R = -1

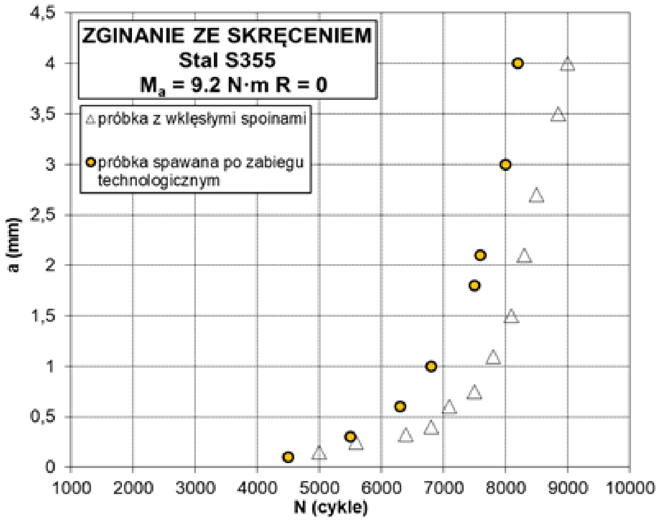

Fig. 4. Length of fatigue cracks in the function of the number of cycles related to bending with torsion for R = 0

It cannot be excluded either that the technological treatment "uncovered" microcracks, inclusions or other imperfections "hidden" in the excess weld metal of the initially convex weld. Figure 5 and 6 presents exemplary paths the fatigue cracks in the specimens containing concave welds not subjected and subjected to the technological treatment in relation to R = -1 and R = 0. In all of the specimens subjected to proportional bending with torsion, the location of the crack path was displaced in the cross-sectional direction. The cracks were initiated on one side of the specimens, i.e. in the heat affected zone.

The primary cracks were located mainly outside the weld, i.e. in the heat affected zone, and propagated towards the zone of recrystallization and the base material, in the area characterised by the thinnest cross-section.

As regards the specimens subjected to loads applied in the manner presented in the article and in view of the obtained test results it can be stated that the technological treatment adversely affected the fatigue service life of the welded T-joint. The reduction of the geometrical notch present in the convex weld did not result in the obtainment of longer fatigue service life.

Concluding remarks

The results of the experimental tests involving the specimens subjected to cyclic bending with torsion justified the formulation of the conclusions presented below.

1. The longest fatigue service life was that of the specimens not subjected to the technological treatment.
2. The cracks present in the test specimens were initiated on one side, i.e. in the HAZ.

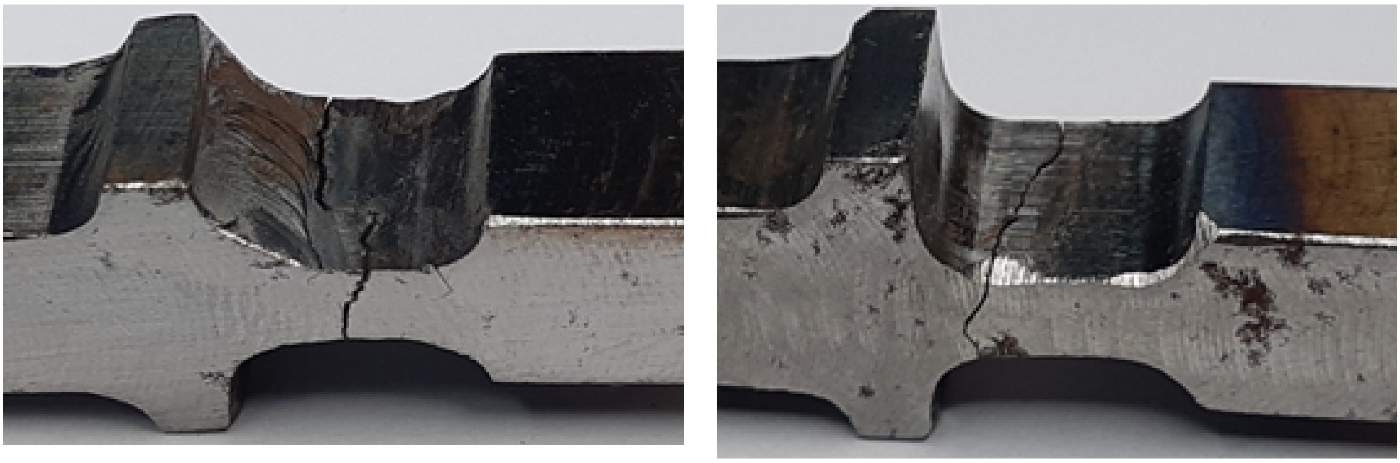

Fig. 5. Paths of fatigue cracks in the specimens subjected to bending and torsion in relation to R = -1: a) welds not subjected to the technological treatment, b) welds subjected to the technological treatment

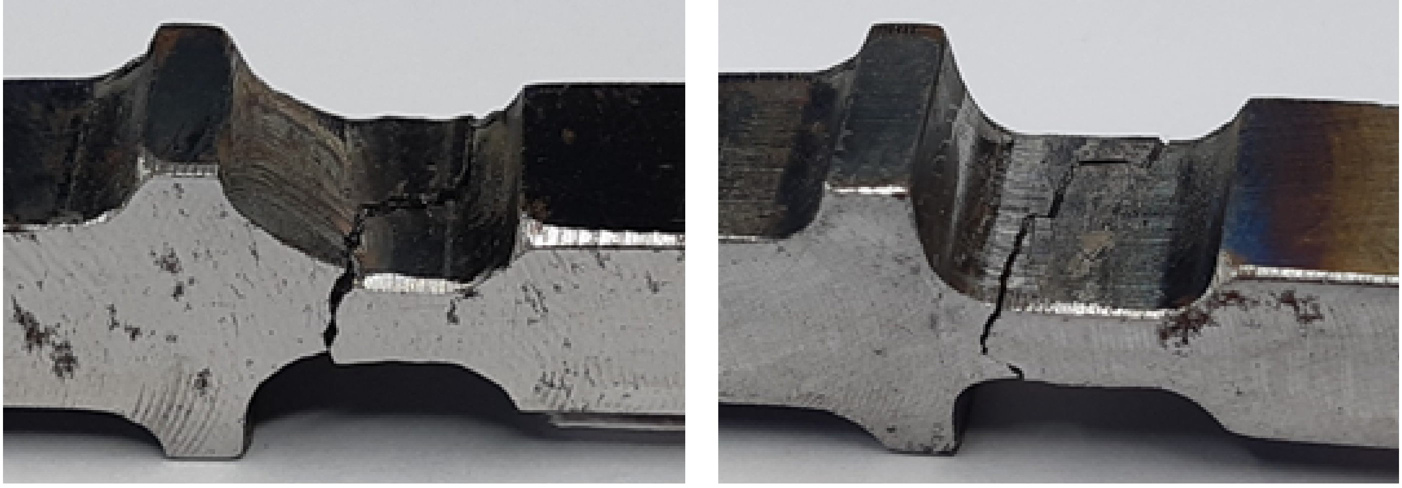

Fig. 6. Paths of fatigue cracks in the specimens subjected to bending and torsion in relation to R = 0: a) welds not subjected to the technological treatment, b) welds subjected to the technological treatment

3. The location of the crack paths was displaced in the cross-sectional direction.
4. The primary cracks were located mainly outside the weld, i.e. in the heat affected zone, and propagated in the direction of the base material.
5. Both in relation to R = -1 and R = 0, the technological treatment adversely affected the fatigue service life of the test specimens.

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