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GEOMETRIC SIZE EFFECT IN RELATION TO THE FATIGUE LIFE OF S355J2+C STEEL UNDER VARIABLE BENDING CONDITIONS

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Abstract: *The fatigue tests are mainly carried out on the specimens with dimensions, which differ from actual tested items. Failure to allow for the item size in engineering practice can lead to significant errors in the assumed fatigue life of structural materials. The size effect is a complex phenomenon and no universal analytical or numerical models are currently available. The material strength decreases with the increase in size of the tested item subject to monotonic or fatigue loads. The reduction in strength is affected by the factors related to a random distribution of defects in the material, shape and type of load and the effects of technological processes during production. The study analyses the size effect in a geometrical approach. The test conditions (rotary bending) allow to estimate the stress gradient effect on the fatigue life. The tests were carried out on specimens to PN-H-04326 and specimens with reduced cross-sectional area (minispecimens).*

Keywords: Steel, High-cycle fatigue, Size effect, Minispecimen.

1. Introduction

Data about materials used for engineering computations should address the size effect or, otherwise, assumptions about various magnitudes can go astray. It is particularly true of heterogeneous materials (Carpinteri et al., 2009).

The size effect is a complex phenomenon depending on material structure, specimen size, load type and component manufacturing process (Kuguel, 1961), which means there are no universally applicable analytical or numerical models. How the size effect affects fatigue properties depends on material type and local structural features (such as grain size, microcracks, inclusions, discontinuities, dislocations and other flaws) (Bažant, 1984).

In general, fatigue is assumed to be reversely proportional to the structure size. This change is typically non-linear and valid up to a certain structure size limit (Sonsino et al., 2005).

This paper aims to determine the size effect for steel S355J2+C. Related monotonic and fatigue tests used specimens smaller than the standard ones. The size effect is described using some generic equations (coefficient of size of cross-section K (Tomaszewski et al., 2014a). The tests on the minispecimens described in the works of authors (Tomaszewski et al., 2012, 2014b).

2. Experimental tests

Experimental tests were done for steel S355J2+C. The specimens were cut out from a 10 mm diameter drawn bar. This material is generally used for the manufacture of machine components. See Fig. 1 and Tab. 1 for geometries of the fatigue test specimens. Each specimen for the static elongation test had a fixed-diameter bore for extensometer: 25 mm long for standard specimen or 12.5 mm long for minispecimen.

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The effect of geometry was checked by determination of the aspect ratio α_k for the both specimen types, using the finite element method. The values of α_k were similar in the both cases, so the shape of the specimens should not produce any discrepancies in test results.

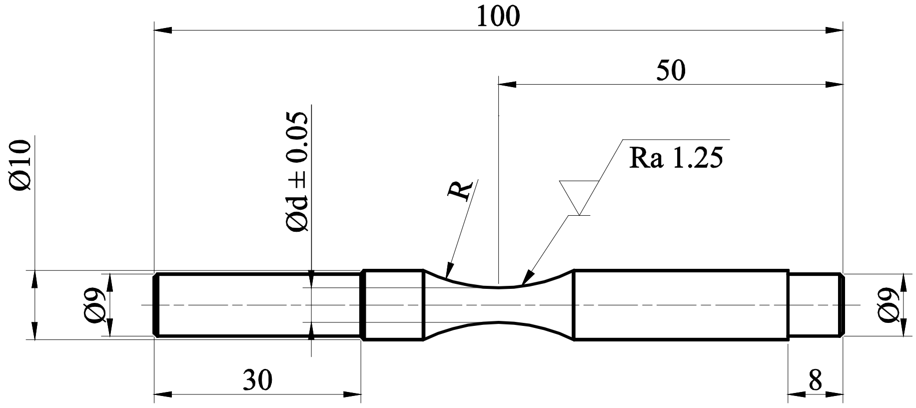

Fig. 1: Specimen geometry used in fatigue test (PN-74/H-04327).

Tab. 1: Specimen dimensions.

Type of geometry	*d* [mm]	*R* [mm]	S_o [mm^2]
Standard specimen	5	25	19.6
Minispecimen	2	12.5	3.1

The physical properties of steel S355J2+C were determined experimentally, by a static elongation test (acc. to PN-EN ISO 6892-1:2010). See Fig. 2 and Tab. 2 for the mean values.

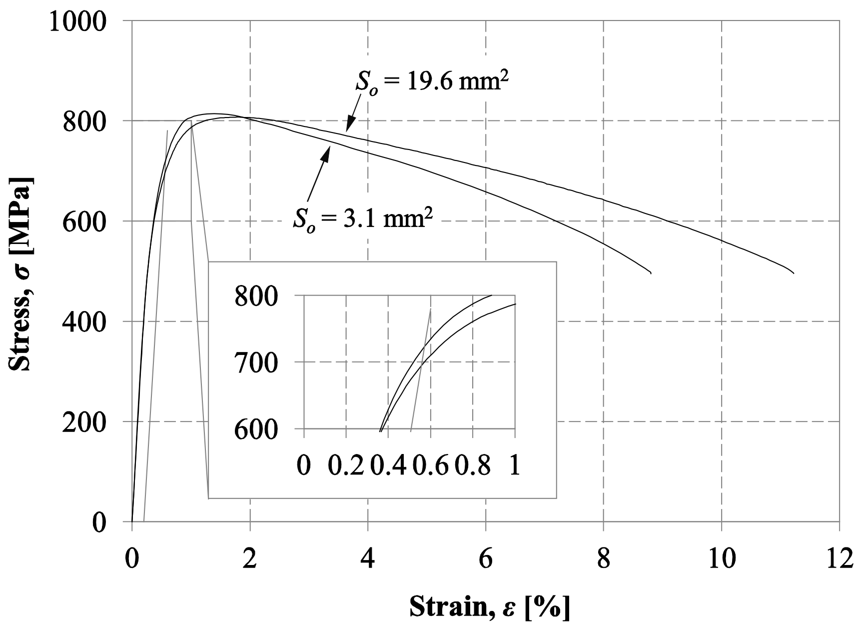

Fig. 2: Static tensile plot.

Tab. 2: Mechanical properties.

Minispecimen			
R_m, MPa	R_e, MPa	*A*, %	*Z*, %
820	713	10.8	65.5
Standard specimen			
809	684	12.2	63.8

3. Test result review

Ten experimental points provided input to the bilogarithmic linear regression and the Basquin's equation (Tab. 3). At least 7 such points are required for initial testing (Strzelecki et al., 2015). Fig. 3 shows a graphic representation of the resulting fatigue characteristics *σ-N* within the high-cycle loading range.

Tab. 3: σ-N characteristic parameters for various specimen sizes.

Type of geometry	Linear regression line $\log\sigma_a = a \log N + b$		Basquin relation $C = N(\sigma_a)^{\beta}$		Correlation coefficient, R^2
	a	b	C	β	
Standard specimen	-0.1008	3.1601	$2.26 \cdot 10^{31}$	9.92	0.901
Minispecimen	-0.1276	3.2761	$5.56 \cdot 10^{25}$	7.86	0.956

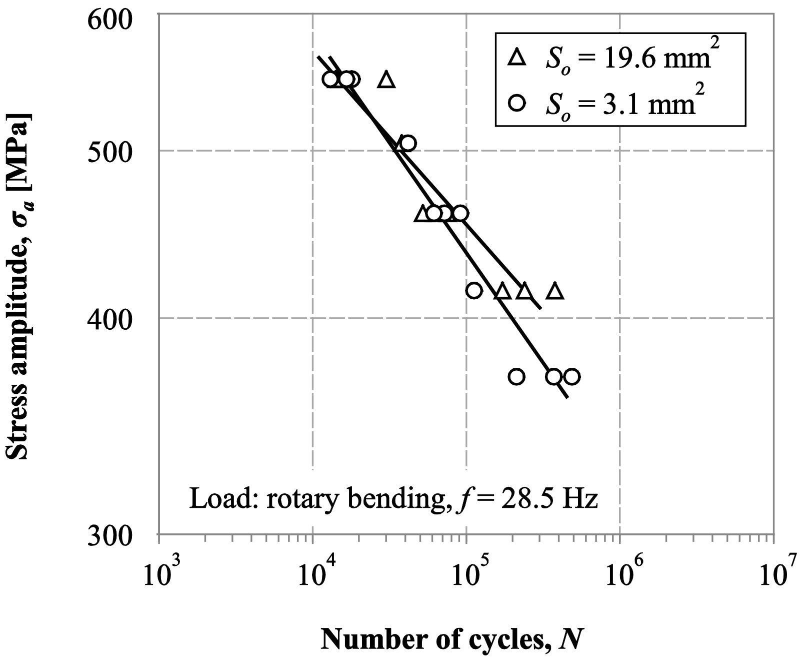

Fig. 3: σ-N characteristics compared for the specimens of different sizes.

The mutual relation of placement of the individual regression lines was evaluated statistically the line slope (*a*) parallelism test. The test was done for characteristics *σ-N*, for a standard specimen (S_o = 19.6 mm^2). The lines were parallel.

The coefficient of size of cross-section *K* (K_S = Minispecimen ultimate tensile strength / Standard specimen ultimate tensile strength, K_{HC} = Minispecimen fatigue strength / Standard specimen fatigue strength (Tomaszewski et al., 2014a)) was determined for examination of the size effect. See Tab. 4 for the results.

Tab. 4: Cross-section area ratios (K).

S_o [mm^2]	K_S	K_{HC}
3.1	1.014	0.974
19.6	1	1

4. Summary

The size effect did not apply to the tested material. Both fatigue and monotonic tests reported similar material properties. The values of coefficient *K* close to 1 confirm this claim. The tests were applied to a narrow range of specimen sizes. Typically, material property change depending on cross-section area is non-linear, so it would be reasonable to complement the tests by testing specimens with larger cross-section areas than those of the tested standard specimens.

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