23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

ANALYSIS OF SIZE EFFECT FOR NOTCHED MINI SPECIMENS MADE OF STAINLESS STEEL

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Abstract: *The use of test results obtained on mini specimens requires that the size effect is taken into consideration. The impact of object size on strength properties is interpreted depending on the test conditions. In this paper, a geometrical size effect resulting from the non-linear distribution of stress occurring in the notched specimen was analysed. Two specimens of different sizes were prepared of 1.4301 stainless steel. The finite elements method was used for calculating theoretical stress concentration factor. The impact of size effect was evaluated based on the test results obtained for high-cycle fatigue strength.*

Keywords: High-cycle Fatigue, Steel, Notch, Size effect, Mini specimen.

1. Introduction

There is an existing need for identifying strength properties based on mini specimens (Sokolov et al., 2009). This applies to situations where it is impossible to collect a standard specimen (Tomaszewski et al., 2017), as well as situations of limited test material (Zastempowski et al., 2015) or higher speed of performing fatigue examinations required (Strzelecki et al., 2016). Due to the impact of the tested object size on strength properties (size effect), it is necessary that such results are referred to tests performed on standard specimens. Such tests were performed on smooth specimens made of several construction materials (Tomaszewski et al., 2016). The obtained divergences of results resulted from the statistical or technological size effect (Kloos et al., 1981). Moreover, the analysis of the size effect is relevant in the case of a large-size object (Richard et al., 2013 and Holka et al., 2016). In this situation, the strength decrease significantly affect the fatigue life of element.

In the tests reported an attempt was made to verify the size effect in reference to notched specimens, in which non-linear distribution at high value of stress concentration (Fig. 1) (geometrical size effect) occurs. At specified length (a0), stress concentration in the mini specimen (σ_1) is smaller compared to the standard specimen (σ_2). The relation is true provided that identical distribution of stress is assumed, i.e. fixed value of nominal stress (σ_n), shape coefficient ($\alpha_k = \sigma_{max} / \sigma_n$) (Makkonen et al., 2003 and Schumacher et al., 2009).

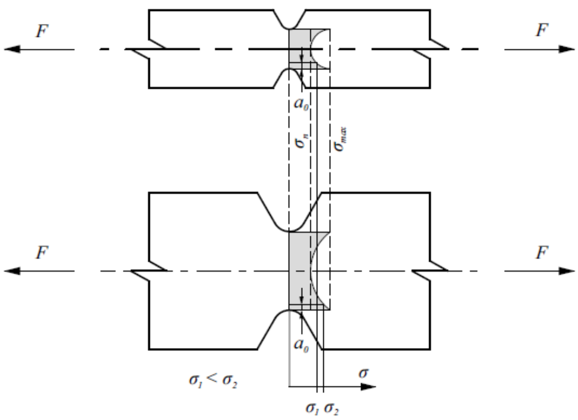

Fig. 1: Stress distribution in the notch tip for various specimen size.

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The purpose of the paper is to determine fatigue properties for material sensitive to the size effect. 1.4301 stainless steel was used for the tests, featuring relatively high sensitivity to minor changes to the smooth specimen cross-sectional area (Tomaszewski et al., 2016). The test conditions proposed (tension, compression; notched specimens) allow to verify this material in terms of the occurrence of geometrical size effect.

2. Experimental tests

The test specimens were collected from 1.4301 steel in the form of cold-rolled steel sheet of 4 mm thickness (R_m = 710 MPa, R_e = 319 MPa). This stainless steel is commonly applied in some of the machinery used in the food industry. The tests were performed for two different specimen shapes and sizes (Fig. 2, Tab. 1).

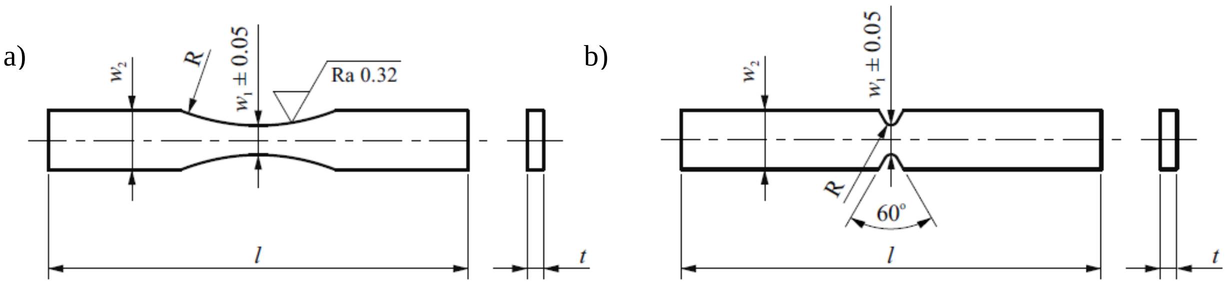

Fig. 2: Geometry of the flat specimen for fatigue testing made of 1.4301 steel: a) smooth, b) notched.

Tab. 1: Specimen dimensions.

Type of geometry		t [mm]	w_1 [mm]	R [mm]	l [mm]	S_o [mm^2]
Smooth	Standard specimen	4	7	25	100	28
	Mini specimen	1.4	2.5	18	35	3.5
Notched	Standard specimen	4	7	1.5	100	28
	Mini specimen	1.4	2.5	0.5	35	3.5

Theoretical stress concentration factor (α_k) was evaluated with the use of software basing on the finite elements method (Zienkiewicz et al., 1972) and on the diagrams presented in (Peterson et al., 1953). Calculations were performed based on a two-dimension numerical analysis for isotropic elastic modulus of steel (E = 210000 MPa, ν = 0.33). Due to the symmetry of specimens in x and y axes, a simplified flat model was employed, as shown in Fig. 3. A grid was built of four-node quadrangular elements, the dimensions of which were chosen experimentally (depending on the accuracy of result). The adopted geometric values corresponded to actual dimensions of the test specimens (Tab. 1). Even stress was applied on the extreme nodes in the form of a force applied along the x axis. Ansys software environment (Ansys) was used for modelling the finite elements grid and for numerical calculations. The results of analyses are presented in Tab. 2. α_k factor values were the same for the standard specimen and the mini specimen.

Fig. 3: Stress distribution map for the notched specimen.

Tab. 2: Theoretical stress concentration factor.

Type of geometry	α_k	
	numerical	according to (Peterson et al., 1953)
Notched specimen	2.28	2.1
Smooth specimen	1.05	-

3. Test result review

The stressing procedure included stress-controlled fatigue tests for high-cycle fatigue life (PN-74/H-04327). Micro-cracks were assumed as the end of test criterion. The tests were performed for symmetrical load (R = -1) at frequency 7 Hz. The results of fatigue tests were described through linear regression and Basquin's equation (Tab. 3). Fig. 4 presents graphically the obtained σ – N fatigue characteristics for smooth specimen and notched specimen.

Tab. 3: σ-N characteristic parameters for various specimen size and shape.

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	
Smooth	Standard specimen	-0.0399	2.578	$2.78 \cdot 10^{64}$	25.00	0.983
	Mini specimen	-0.0558	2.695	$1.87 \cdot 10^{48}$	17.91	0.933
Notched	Standard specimen	-0.0706	2.719	$3.15 \cdot 10^{38}$	14.16	0.966
	Mini specimen	-0.0794	2.756	$5.35 \cdot 10^{34}$	12.60	0.898

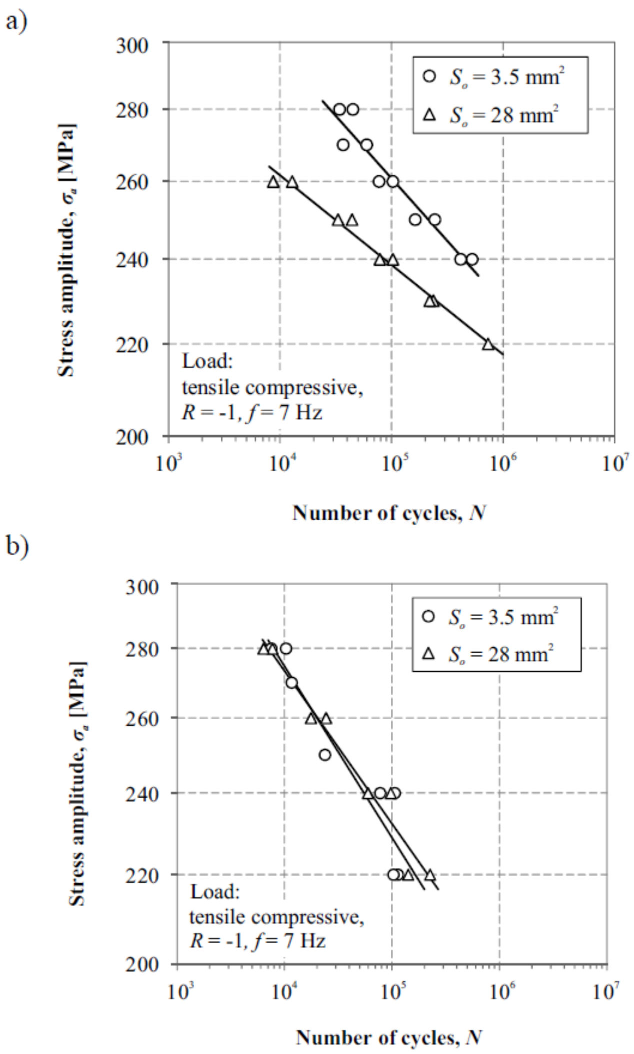

Fig. 4: σ-N characteristics compared for the different sizes of: a) smooth specimen, b) notched specimen.

Cross-sectional area coefficient (K_{HC}) (Tomaszewski et al., 2016) was assumed as the measure of material sensitivity to changes in cross-sectional area. Diversification in the fatigue test results was noted for smooth specimens (K_{HC} = 1.089). No differences in test results were observed for the notched specimens (K_{HC} = 1).

4. Summary

A relationship between fatigue strength and cross-sectional area value was demonstrated in the smooth specimens tests. An increase in fatigue strength compared to the standard specimen can be noted. No size effect was observed for the notched specimen shape tested.

The data obtained deviate from the assumed geometrical size effect theory. This may result from an inappropriate approach to analysing the size effect, or different interpretation of the size effect in terms of crack development mechanism for small specimen geometries. This would result in application of the geometrical size effect assumptions, as presented in the introduction, to a different range of variability of the object's cross-sectional area. Proper explanation of this phenomenon will require further research.

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