DUCTILE FRACTURE ELEMENTS WITH NOTCHES UNDER COMPLEX LOADING

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1. Introduction

This paper presents the results of the experimental studies and numerical modelling on ductile fracture of axisymmetric specimens with various round notch radii (five radii) at the notch's root. The specimens underwent proportional biaxial loading (tensile–torsion) until failure. The load was forced onto the specimens by elongation as well as angular movement and was controlled by a device for the non-contact measurement. Stress and strain fields in whole specimens with notches were calculated using finite element analysis (FEM). The EN-AW 2024 T351 aluminum alloy was used in this research. Special attention was paid to the change in shape of the fracture surface, changing the force-elongation curve and torsional moment–torsional angle curve, which are dependent on loading. Based on numerical results it was paid to changing distributions of stresses and plastic strains induced biaxial loading and notch radius. By taking advantage of numerical calculations, new ductile fracture criterion for notched specimens under biaxial loading was proposed.

2. Experiments and numerical calculation

The tests were conducted for seven load cases (table 1). It was assumed that the time of each test until reaching a failure point should be constants (*1*). This means that the equivalent plastic strain rate remains constant. The study began by determining the value of velocity displacement (case 7), assuming that the angular velocity equal zero. Next, the value of the angular velocity was set (case 1) at displacement velocity equal zero. The obtained parameter values $\dot{u}_0$ and $\dot{\varphi}_0$ were used to determine the initial velocity of a kinematic forcing value for the given cases.

Kinematic forcing	Load cases						
	1	2	3	4	5	6	7
$\dot{u}$	0	$0.2\dot{u}_0$	$0.4\dot{u}_0$	$0.5\dot{u}_0$	$0.6\dot{u}_0$	$0.8\dot{u}_0$	$1.0\dot{u}_0$
$\dot{\varphi}$	$1.0\dot{\varphi}_0$	$0.8\dot{\varphi}_0$	$0.6\dot{\varphi}_0$	$0.5\dot{\varphi}_0$	$0.4\dot{\varphi}_0$	$0.2\dot{\varphi}_0$	0

Table 1. Calculation scheme in experimental studies

As a result of the study (*2*) the authors recorded the relationship between the tensile force and elongation, as well as the torsional moment and the torsional angle of the measurement base (L_0 = 25 mm) for each of the notches (Fig. 1), and in particular, the maximal (critical) displacement u_c, torsional angle φ_c, critical force F_c and critical torsional moment M_c, causing the fracture initiation in the specimens.

In numerical calculations (3), authors assumed the elastic-plastic model of the material with isotropic hardening and the Huber-von Mises condition of plasticity. Full three-dimensional finite element mesh was used in the calculations. Moreover, isoparametric elements consisting of eight nodes with linear shape functions were also used in the calculations.

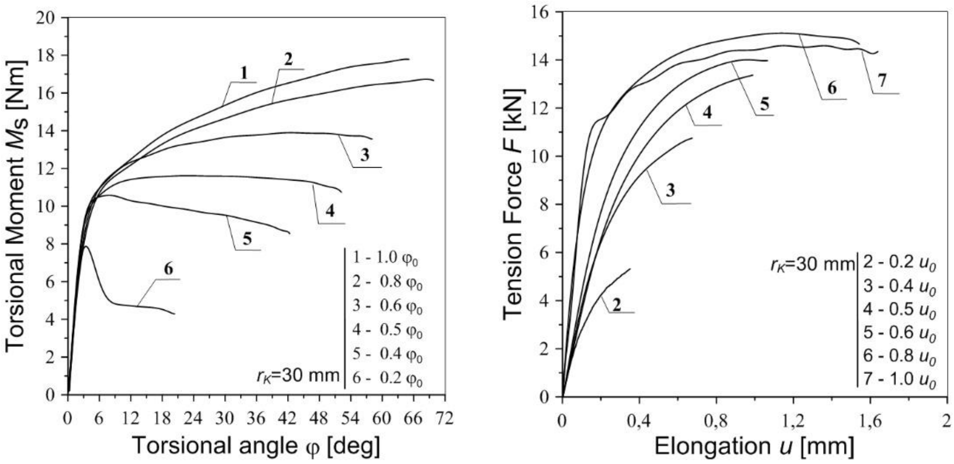

Fig. 1. M_s - φ and F - u dependency graph in specimens with notch for various load cases

Based on calculation results, it was found that the place of the maximum stress depends on the size of the notch radius r_K as well as the load case. It can be concluded that the point of fracture initiation may take place either at the notch root, near the notch root or on the symmetry axis of the specimen. Thus, fracture initiation in the notch root occurs when the dominant load is torsion (the maximum stress and plastic strain are just in the notch root). In the case where the dominant load is tensile and radius of the notch is equal to or greater than 4 mm, fracture initiation starts at the axis of symmetry of the specimen, where the stresses and plastic strain are greatest (triaxial stress state). In the case where the dominant load is tensile and the radius of the notch is equal to or less than 2 mm, the fracture initiation can occur either at the notch root (the highest value of plastic strain) or in the vicinity of the notch root (the highest value of stress).

3. Ductile fracture criterion

It also proposed the stress-strain ductile fracture criterion of specimens under biaxial load condition. It was assumed that the normal and shear stresses on the physical plane are responsible for the decohesion process. For aluminum alloy the criterion was proposed as the elliptical form condition for tensile stress and in Coulomb form condition for compressive stresses. On the basis of experimental tests for aluminum alloy EN AW 2024-T351 and numerical calculations it was assumed that the critical value of the normal stress depends on the linear plastic strain, while the critical value of the shear stress is constant.

6. References

[1] L. Derpenski, A. Seweryn (2011), Experimental research into fracture of EN AW 2024 and EN AW 2007 aluminum alloy specimens witch notches subjected to tension, *Exp. Mech.*, **51**, 1075-1094.

[2] L. Derpenski, A. Seweryn (2016), Ductile fracture of EN-AW 2024 aluminum alloy specimens with notches under biaxial loading. Part 1 - Experimental research, *Theor. Appl. Fract. Mech.*, DOI: 10.1016/j.tafmec.2016.06.007

[3] L. Derpenski, A. Seweryn (2016), Ductile fracture of EN-AW 2024 aluminum alloy specimens with notches under biaxial loading. Part 2 - Numerical research and ductile fracture criterion, *Theor. Appl. Fract. Mech.*, DOI: 10.1016/j.tafmec.2016.06.008

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