An influence of notch type on material behaviour under monotonic tension

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Abstract

The paper presents results of numerical and experimental investigations conducted in order to determine an influence of notch type on material behaviour under monotonic tension. Two kinds of specimens having U and V notches were applied. Digital image correlation system was used to detect variations of strain/stress state components from beginning of the test up to fracture of the material in question. Assessments of the results enabled identification of stress concentrations in tips of notches. A comparison of tensile characteristics of unnotched and notched specimens exhibited a great reduction of the yield point independently of the geometrical discontinuities applied. In the case of V-notched specimen 50% lowering of elongation was observed.

Keywords: stress concentration, stress distribution, notches, tensile curve, digital image correlation

1. Introduction

Geometrical discontinuities in a form of notches modify magnitudes of stress state components. It is related with their geometrical sizes such as radius, angle or depth. An influence of notches on a material behaviour is usually examined either by theoretical or experimental analysis. The theory enables to assess possible fracture on the basis of the stress concentration factor and to illustrate variations of this parameter as a notch geometry function. In the case of experiment, an influence of geometrical discontinuities on fracture may be determined by the application of various specimen types. Among of them one can distinguish tubular or flat specimens with notches to be cut in the way reflecting special cases of interest. The notches may have various sizes, usually classified as: small [3, 5], medium [3] or large [3]. It has been found experimentally, that an increase of the notch radius from 0 to 6.35 mm reduces by 50% the number of cycles necessary for an initiation of the crack [1]. The same effect was noticed for an increasing stress concentration factor taking values within a range of 1÷2.833 [2, 3]. A presence of notches decreases in 60% the stress level enforcing the crack initiation during fatigue tests [5]. The results mentioned above do not sufficiently indicate geometrical discontinuities effect in a zone close to the notch. This problem may be solved using such modern techniques as Digital Image Correlation (DIC) for example. Therefore, the main aim of the paper was focused on application of DIC system for investigation of notches influence on material behaviour during tensile tests carrying out up to the fracture.

2. Experimental procedure

An influence of notch radius on the crack initiation and its subsequent propagation was analysed on the basis of results obtained using Finite Element Method (FEM) and tests performed by means of DIC technique. Flat specimens of 3 mm thickness with three U and V notches having radius equal to 0.25, 1.5 and 2.5 mm and angle 30, 60, 90° respectively were tested, Fig. 1a. A depth of the notches was equal to 1.3 mm. In FEM calculations the specimen geometry was reflected by network of 3D Solid Hex Elements of 0.3 mm high. Calculations were performed for the ideally elastic material. Before the main tests a geometry of discontinuities was checked by the profilometric measurements. Monotonic tensile tests were carried out at room temperature on the servo-hydraulic testing machine at constant displacement velocity equal to 0.5 mm/s. Distribution of the strain components was determined by means of the 4M Aramis Digital Image Correlation system.

3. Results

3.1. Numerical analysis

In order to determine a role of radius and angles of notches, the HMH effective stress distribution in 3D coordinate system was considered, Fig. 1b, c. The results presented on the 0XZ plane did not show any significant differences in the stress distribution due to application of the notches, Fig. 1b.

An opposite result was achieved for the HMH effective stress distribution presented on the 0YZ plane, Fig. 1c. In this case a notch effect is expressed by differences between zones of the maximum stress. The largest area of the stress, expressing the crack occurrence, was obtained for the smallest radius (U specimen) and biggest angle (V specimen). Moreover, one can notice that a radius increase did not cause variations of the stress level, however, it led to reduction of the maximum stress zone area along the y axis and to its expansion along the z axis. In the case of V specimen the stress reduction, was observed with lowering of a notch angle, Fig. 1c. The effect of the radius and angle of notches on the stress level was also evaluated on the basis of calculation performed using the equation recommended for notched specimens [4].

As it is presented in Fig. 2 the stress concentration factor and maximum stress increase linearly with the notch angle increase. In the case of the U notched specimen the largest values of these parameters were obtained for the smallest radius considered. These effects were consistent with the results obtained by means of FEM analysis. The representative results for this type analysis are illustrated in Fig. 1.

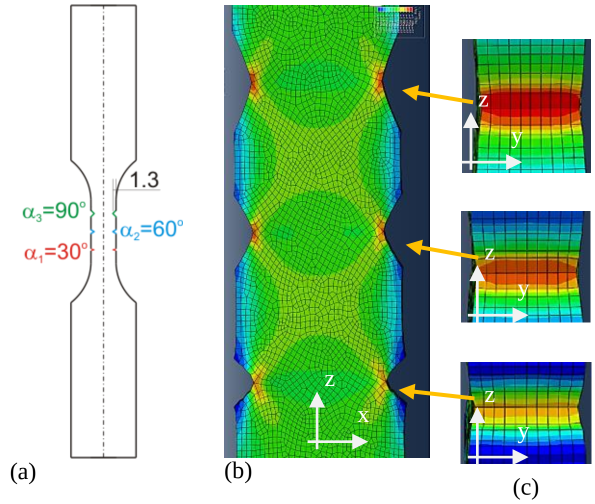

Figure 1: Multi-notched specimen: geometry (a); the HMH effective stress distribution on 0XZ and 0YZ planes (b) and (c), respectively

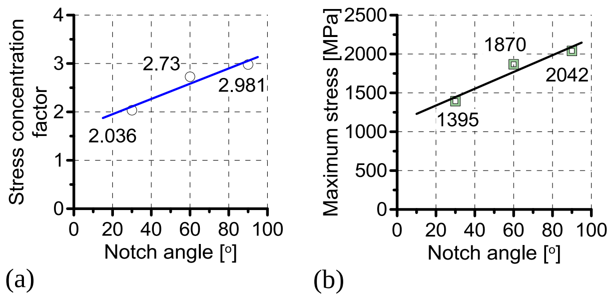

Figure 2: Diagrams representing variation of: (a) stress concentration factor; (b) maximum stress, versus notch angle for V-notched specimen

3.2. Experimental results

The strain distribution obtained under monotonic tension on the multi-notched specimens is shown in Fig. 3a, b.

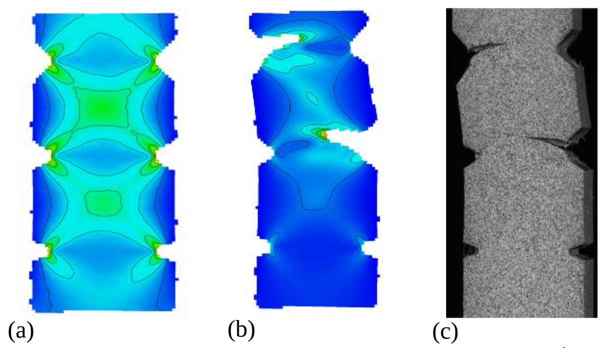

Figure 3: Results of DIC analysis: the HMH strain at 500th and 750th stages (a) and (b), respectively; view of the specimen fracture at 750th stage (c)

An effect of the notches is reflected by variations of the HMH effective strain isolines. At the beginning of tension represented by 500th stage, two biggest notches are appeared as significant stress/strain concentrators. Further tension led to the stress/strain components increase in the middle notch, and subsequently, in the largest notch. Finally the specimen fracture appeared (Fig. 3b, c). Comparison of the tensile curves determined for specimens without and with notches enables identification of their essential differences. It is expressed by a clear drop of the yield point observed for test performed on the notched specimen, Fig. 4. Additionally, the material hardening and its instability are clearly manifested. As it is shown in Fig.4, both curves differ significantly for deformation range higher than 5%.

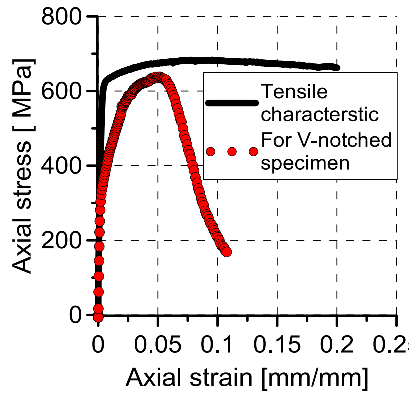

Figure 4: Comparison of tensile characteristics of the 41Cr4 steel for unnotched and notched specimens, respectively

4. Remarks

The reduction of radius for U-notched specimen leads to the linear increase of the stress concentration factor and maximum stress. The same effect can be observed for the V-notched specimen when the angle takes higher values. The main difference in the shape of the tensile curves for the unnotched and notched specimens takes place in the range of stresses higher than the yield point.

References

[1] Bennett, J.A., Weinberg, J.G., Fatigue Notch Sensitivity Of Some Aluminium Alloys, *Journal of Research of the National Bureau of Standards*, 52, 5, pp. 235-245, 1954.

[2] Fatemi, A., Fang, D., Zeng, Z., Notched Fatigue Behaviour Under Axial And Torsion Loads: Experiment And Predictions, *8th International Fatigue Congress*, Stockholm, Sweden, 3, pp. 1905-1914, 2002.

[3] Fatemi, A., Zeng, Z., Plaseied, A., Fatigue behavior and life predictions of notched specimens made of QT and forged microalloyed steels, *International Journal of Fatigue*, 26, pp. 663-672, 2004.

[4] Pilkey W.D., Peterson's *Stress Concentration Factors*, Wiley, New York, 1997.

[5] Qian, G., Hong, Y., Zhou, Ch., Investigation of high cycle and very-high-cycle fatigue behaviors for a structural steel with smooth and notched specimens, *Engineering Failure*, Analysis, 17, 7-8, pp. 1517-1525, 2010.