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ASSESSMENT OF TWO FRACTURE CRITERIA FOR COMPONENTS WITH CIRCULAR HOLES

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Abstract: *A comparison between analytical and experimental results regarding the fracture strength of components with circular holes is presented. Two fracture criteria are assessed: teory of critical distance (TCD)) and a three parameters criterion. However TCD still remains a useful tool for engineering applications.*
Key words: *fracture strength, stress concentration, rigid polyurethane*

1. INTRODUCTION

Regardless of their type, the presence of stress concentrators generates difficulties in the evaluation of the components strength. Many studies were dedicated to brittle fracture of components with singular stress concentrators, like sharp V-notches (Chen & Ozaki, 2008). In exchange, the studies dedicated to fracture of components with non-singular stress concentrators are less. So, are investigated the rounded-tip V-notches (Ayatollahi & Torabu, 2010), central circular holes and U-notches (Gomez et al., 2006). The experimental verifications were made using materials with a brittle behaviour, like ceramic and polymeric materials (PMMA, PVC, acrylate).

The paper presents the experimental and analytical results obtained for *Necuron 1020*, rigid polyurethane used in engineering for aerodynamic and hydrodynamic testing models, fixtures and tooling jigs for automotive industry.

2. EXPERIMENTS

In this aim, were tested smooth specimens (type A) and specimens with stress concentrators, of different geometrical shapes (Fig. 1): central circular holes (type B), semicircular notch (type C) and U-shaped notch (type D).

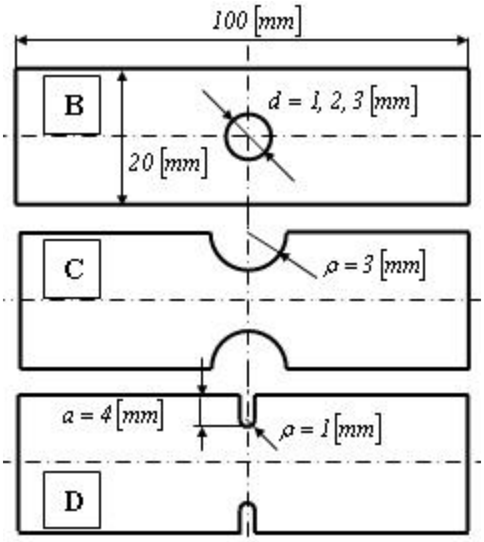

Fig. 1. Type of specimens with stress concentrators

The tension tests were performed in the Strength of Materials Laboratory from "Politehnica" University of Timisoara, at environmental temperature, with a load speed of $5\ [mm/min]$ and for a specimen thickness $t = 10\ [mm]$, which respects the plain strain condition (Negru, 2009).

For some of the tested specimens, the stress-strain $\sigma - \varepsilon$ curves are presented in Fig.2 (strain-gauge measurement base $l_0 = 25\ [mm]$). A slight non-linearity of experimental $\sigma - \varepsilon$ curves is observed for *Necuron 1020*, thereby accepting a linear elastic behaviour is justified, without the introduction of significant errors. By reaching a critical level of load, the fracture is instantaneous and indicating that the fracture of rigid polyurethane is brittle.

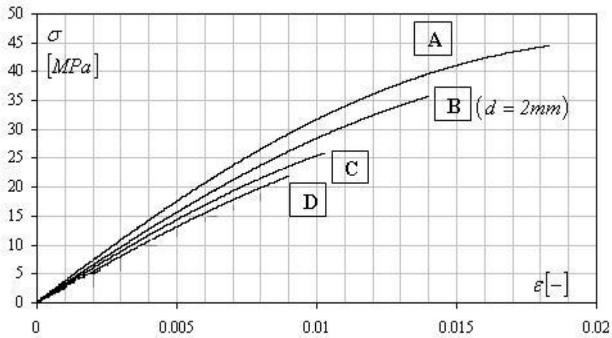

Fig. 2. Experimental $\sigma - \varepsilon$ curves from some specimens

For each type of specimen five tests were carried out and the ultimate tensile stress σ_u was determined as the ratio between the maximum recorded load F_{max} and the gross area section. In Tab.1 the average values for ultimate tensile stress σ_u are presented.

	A	B $(1\ mm)$	B $(2\ mm)$	B $(3\ mm)$	C	D
σ_u $[MPa]$	43.75	39.60	35.76	31.45	25.94	21.82

Tab. 1. The average ultimate tensile stress σ_u from experiments

Fracture mechanics tests carried out on three points bending specimens provide an average value for the critical stress intensity factor $K_{IC} = 2.72\ [MPa\sqrt{m}]$.

3. FRACTURE CRITERIA

3.1 Theory of critical distances (TCD)

The TCD represents a set of methods (point method, line method, area method, volume method), which have a common approach – they use a critical length L and a critical stress σ_0 as material parameters (Taylor, 2007). For the prediction of brittle fracture, the use of TCD requires the knowledge of elastic stress field around stress concentrators (obtained through finite element analysis - FEA) and using two material parameters (L

and σ_0). The fracture criterion used by the point method can be stated as: the failure will be produced when the stress at an $L/2$ distance measured from the maximum stress point (concentrator tip) is equal with the critical stress σ_0.

$$\sigma(r = L/2) = \sigma_0 \tag{1}$$

where *r* represents the distance from the concentrator tip.

Starting from the hypothesis that the theory of critical distances is useful for the prediction of fracture for the problems where the nominal stress field is linear-elastic (high cycle fatigue, ceramic materials fracture), respectively the strains are elastic, excepting of a small area at the concentrator tip, the possibility of applying thid theory for the fracture of polymetric materials was studied (Taylor et al., 2004). In this modified approach, the two material parameters (L and σ_0) are determined on the basis of recorded experimental results for specimens with two different stress concentrators, by plotting the distributions of stress versus the distance from the tip concentrators, for maximum load corresponding to fracture. For specimens type D and C, the maximum forces recorded at fracture in uniaxial tension were $F_{max} = 4364\,[N]$ and respectively $F_{max} = 3187\,[N]$, which correspond to the ultimate tensile stresses $\sigma_u = 21.28\,[MPa]$ and $\sigma_u = 25.94\,[MPa]$. Following this approach, a plane strain finite element analysis was performed using *PLANE2D* elements with 8 nodes, available in the *CosmosM 2.9* software library. In the Fig. 3 are plotted the stress distributions versus the distance *r* from the concentrator tip, resulting the critical distance $L = 1.180\,[mm]$ and the critical stress $\sigma_0 = 55.10\,[MPa]$.

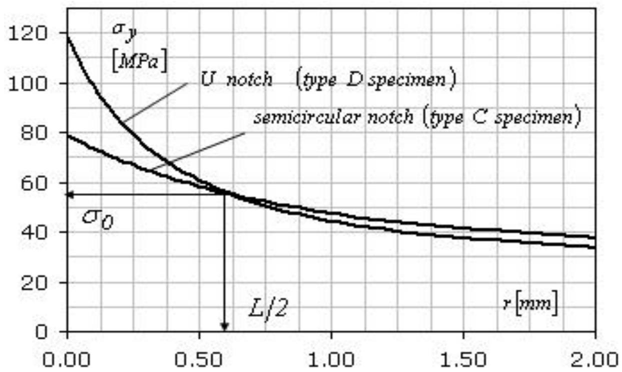

Fig. 3. Determination of the value L and σ_0 from FEA

Further the application of point method is using only a linear elastic analysis of the components with notches and requires the plotting of the stress-distance curves.

3.2 Fracture criterion proposed by Zhang & Li

Taking into account the different stress concentration levels the criterion uses three material parameters: the ultimate stress σ_r, the critical energy release rate for crack growth G_c and the energy release rate for fracture under uniaxial tension G_c^u. The crack initiation occurs if the following two conditions are simultaneously satisfied (Zhang & Li, 2008):

- in the non-cracked component the maximum principal stress reaches at a point the material strength $\sigma(l_c) = \sigma_r$;
- in the cracked component the energy release rate at the virtual crack tip, located at the same point, reaches the critical toughness $G(l_c) = G_c^s(\alpha)$, where l_c is a characteristic length.

The critical energy release rate $G_c^s(\alpha)$ for any stress concentration level is estimated by interpolation:

$$G_c^s(\alpha) = \alpha G_c + (1-\alpha) G_c^u \tag{2}$$

where $\alpha\ (0 \le \alpha \le 1)$ is a parameter depending on the stress concentration level. In equation (2) the critical energy release rate for crack growth G_c was determined for the plain strain conditions:

$$G_c = K_{IC}^2(1-\nu^2)/E = 1.9\,[kJ/m^2] \tag{3}$$

with elastic modulus $E = 3300\,[MPa]$, Poisson ratio $\nu = 0.38$ and $K_{IC} = 2.72\,[MPa\sqrt{m}]$. The third parameter G_c^u was determined, admitting that the creation of the new surface is the only source of energy dissipation:

$$G_c^u = -\Pi/S \tag{4}$$

where Π is the total potential energy and S is the fracture surface; for *Necuron 1020* was found that $G_c^u = 5.5\,G_c$.

Using the well known solutions (Barber, 2002), the two imposed conditions lead to the following system of equations:

$$\frac{\sigma_u}{2}\left(2 + \left(\frac{a}{a+l_c}\right)^2 + 3\left(\frac{a}{a+l_c}\right)^4\right) = \sigma_r$$

$$\frac{\left[\sigma_u\sqrt{\pi(a+l_c)}\sqrt{sec\,(a+l_c/H)}\right]^2(1-\nu^2)}{E} = \alpha G_c + (1-\alpha)G_c^u \tag{5}$$

whose numerical solution represent σ_u and l_c.

4. RESULTS AND CONCLUSIONS

A comparison of the obtained results is presented in Tab.2.

σ_u $[MPa]$	B $(1\,mm)$	B $(2\,mm)$	B $(3\,mm)$
Tests	39.60	35.76	31.45
PM	46.69	38.00	32.51
Zhang	40.58	35.42	31.54

Tab. 2. The average ultimate tensile stress σ_u from tests, point method (PM) and Zhang & Li criterion

At diameter value $d = 1\,[mm]$ the error between experimental and point method results is maximal 17.9 % (2.5 % for Zhang & Li criterion) which indicated that this method could not be applied for stress concentrators with the absolute dimension comparable with critical distance *L*.

By increasing the number of parameters the accuracy increases from 3.1 ÷ 6.2 % for point method, to −0.9 ÷ 0.3 % for Zhang & Li criterion, with the disadvantage of a more complicated methodology.

For applications TCD is more appropriate due to possibility of integrations in the engineering codes.

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