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THE EFFECT OF NOTCH GEOMETRY UPON SHEAR STRESS STATE IN A BEAM

Florina Carmen CIORNEI, Stelian ALACI, Simion PĂTRAŞ-CICEU, Delia Aurora CERLINCĂ, Luminiţa IRIMESCU

"Stefan cel Mare" University, Suceava, ROMANIA

florina@fim.usv.ro

ABSTRACT

The precise determination of the elastic and mechanical characteristics of the materials is essential in engineering. A simple method for finding both shear the strength and the shear modulus is proposed, based on a modified Iosipescu or Hawong shear test that uses a notched beam probe loaded by forces applied on the median line via four pins. The probe presents two V notches and the effect of the geometrical parameters is studied using the finite element analysis. For the modified probe, it is found that a notch angle of 110^o is preferable in achieving an uniform shear stress state and the deeper the notch - the reduced stress concentrator effect. An advantage of the method is highlighted by the observation that the shear stress field in the studied region of the probe is symmetrical.

Keywords: Shear stress, mechanical characteristics, FEM analysis, V notch

1. INTRODUCTION

The precise comprehension of the elastic and mechanical characteristics of the materials is essential in designing and manufacturing parts and assemblies. At present time, the composite materials are widely used and their mechanical characteristics differ as the constitutive elements or loading direction vary [1, 2]. In this range of problems, one of the challenges is to find the experimental methods to perform precise, simple and low costs tests for measuring the shear properties of the materials.

In determining the shear characteristics of different materials, including composites, the following methods can be mentioned [1], [3]: torsion of bars, rings and tubes, four point bending method, Iosipescu method, two-rail shear test, double notch shear test, etc. Each of these testing methods can be applied in particular cases, but none of them fulfils all required criteria, namely: simple to perform, suitable for any material and capable of providing both the shear modulus and the shear strength.

A method responding to all above requirements was proposed by Iosipescu [4] and his method was studied at Wyoming University, the devices was realized [5] and have been used mostly in composites testing and from 2005 there are the subject of an ASTM standard [6].

2. THEORETICAL BACKGROUND

2.1. Iosipescu Shear Method

The Iosipescu method produces pure shearing in the cross section of a prismatic beam, applying an antisymmetric bending, via two couples of forces, as the scheme from figure 1 presents. The Iosipescu probe presents two central, symmetric 90° V notches and there are some dimensional configurations accepted in the literature [7].

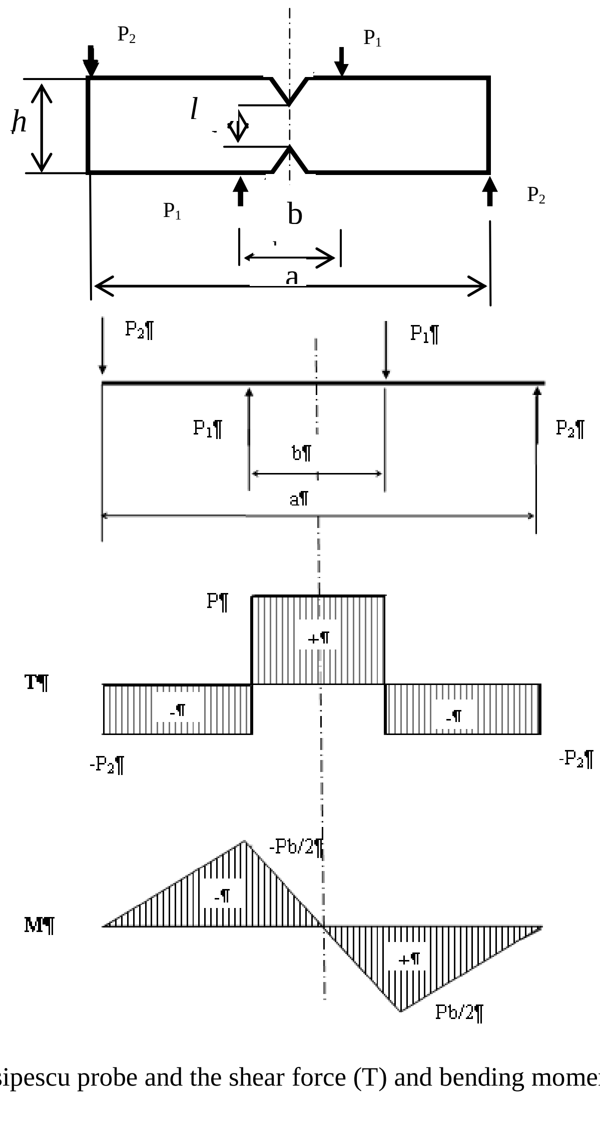

Fig. 1. The Iosipescu probe and the shear force (T) and bending moment (M) diagrams

An appropriate fixture transforms the central force P into pure shear at the probe cross section. The shear strains are usually measured using strain rosettes with two elements at $\pm 45^{\circ}$ with respect to the longitudinal probe axis. The principal shear strains are:

$$\gamma = \varepsilon_{45} - \varepsilon_{-45} \tag{1}$$

and the mean shear stress in the cross section is

$$\tau = \frac{P}{A}, \tag{2}$$

where A is the area of the cross section between notches and P is the global force applied and measured by the force transducer of the testing machine. An apparent shear modulus can be calculated:

$$G = \frac{\tau}{\gamma} \tag{3}$$

and this is as close as to the actual modulus as the probe geometry and the loading scheme ensure uniform strains and stresses along the cross section of the probe.

The fixtures proposed using this principle, found some inconvenient like being parasitic in plane and out of plane movements or twisting [7].

2.2. Modified Iosipescu Shear Test

Hawong [8] proposed a simplified shear method, based on the Iosipescu test. The scheme of the modified method is presented in figure 2 and it may be noticed that the loading of the probe is made in the neutral plane. The forces are applied on four pins and transferred to the probe by holes made on the longitudinal axis. The traction force *P*, applied by the testing machine, is divided into components on the pins, specifically:

$$P_1 = \frac{Pb}{a+b}; \quad P_2 = \frac{Pa}{a+b}; \quad P = P_1 + P_2 \tag{4}$$

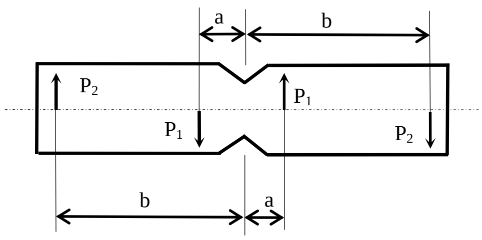

Fig. 2. Hawong shear test loading scheme [8]

In the central weakened cross section, the bending moment is zero and the shear force has the expression:

$$T = \frac{b-a}{a+b} P . \tag{5}$$

Based on the above loading model, numerical models will be made for sheared probes considering variable geometrical parameters such as notch angle, notch radius or notch depth.

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3. FEA ANALYSIS OF SHEAR STRESS

3.1. Iosipescu V Notched Shear Probe

A Iosipescu probe was modelled with two symmetric 90° V notches and a FEA analysis was made. In Figure 3, the shear stresses from the entire probe are shown and it is evident a region between the notches, where the shear stresses are almost constant but a slight asymmetry is also observed.

Details of the region under pure shear are presented in Figs. 4-5 and the effect of the notches as a concentrator is seen along with the zone of pure shear.

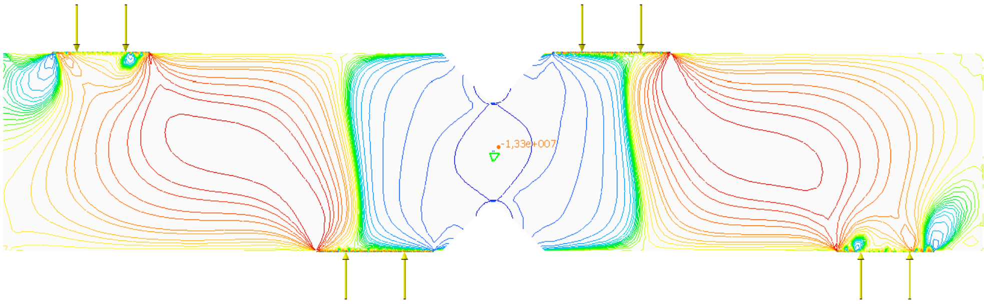


Fig. 3. FEA analysis of Iosipescu probe

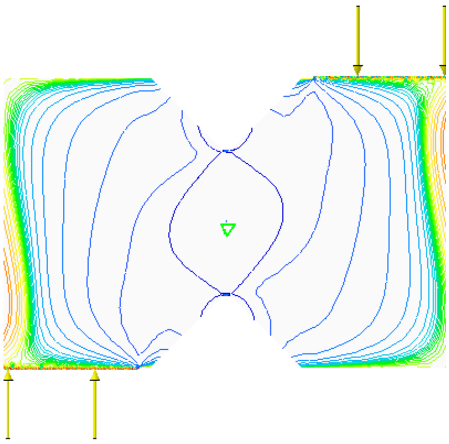


Fig. 4. Shear stresses contours between notches

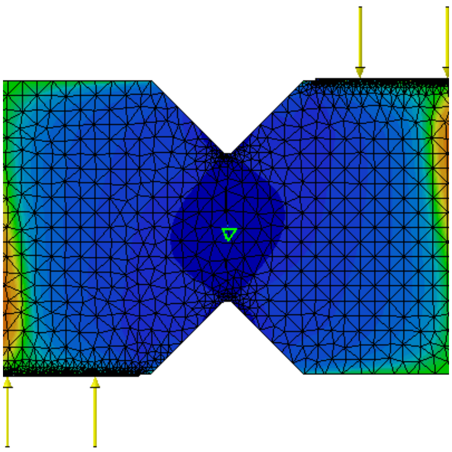


Fig. 5. Refined meshing for accurate FEA analysis

3.2. Modified Iosipescu Shear Probe

For the modified Iosipescu probe, as proposed by Hawong [8], the forces are applied on the longitudinal axis and the effect of the notch angle is first studied. Some aspects of the analysis are given in Figs 6-10.

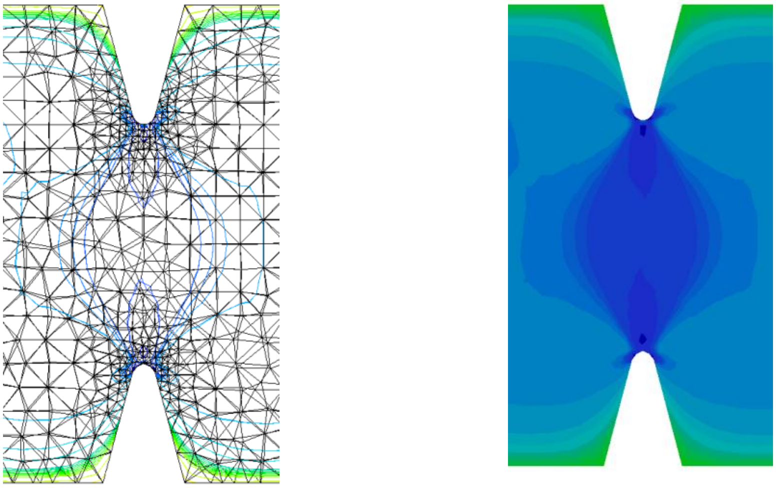


Fig. 6. Modified Iosipescu shear probe, $\alpha = 30^{\circ}$

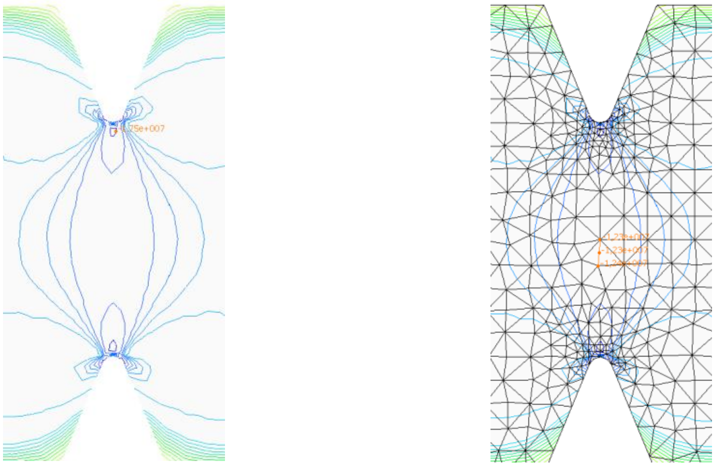
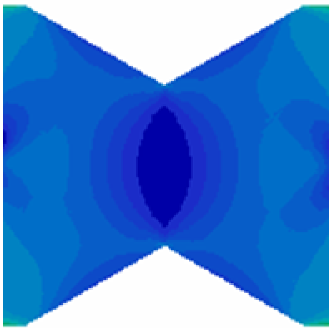
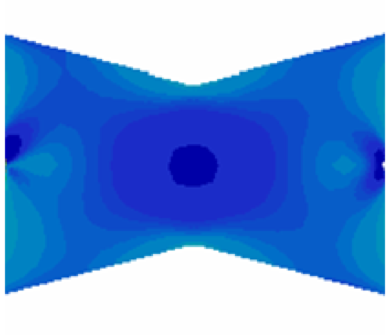


Fig. 7. Modified Iosipescu shear probe, $\alpha = 45^{\circ}$

$\alpha = 90^{\circ}$ $\alpha = 100^{\circ}$

Fig. 8. Stress field variation with notch angle





$\alpha = 120^{\circ}$ $\alpha = 150^{\circ}$

Fig. 9. Stress field variation with notch angle

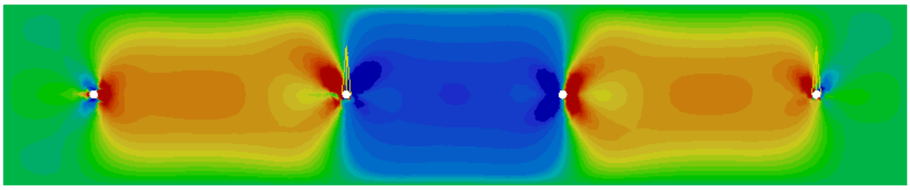


Fig. 10. Shear stress field variation, $\alpha = 180^{\circ}$

The effect of the concentrator is evidenced (figs 6-7) and the region of pure shear between the notches is shown by stress contour lines. There is a strong variation of the stress field with the notch angle, revealed for examples in Figures 8-9. For the extreme case of $\alpha = 180^{\circ}$, the Juravski probe (prismatic probe) is obtained (Fig. 10) and the stress shape with a central nucleus, where the stress reaches maximum value, is validated by theoretical calculus.

The maximum values of the shear stresses from the centre of the cross section were identified from FEA analysis and represented on the same graph, together with the maximum shear stresses obtained near the concentrator (Fig. 11), depending on the notch angle.

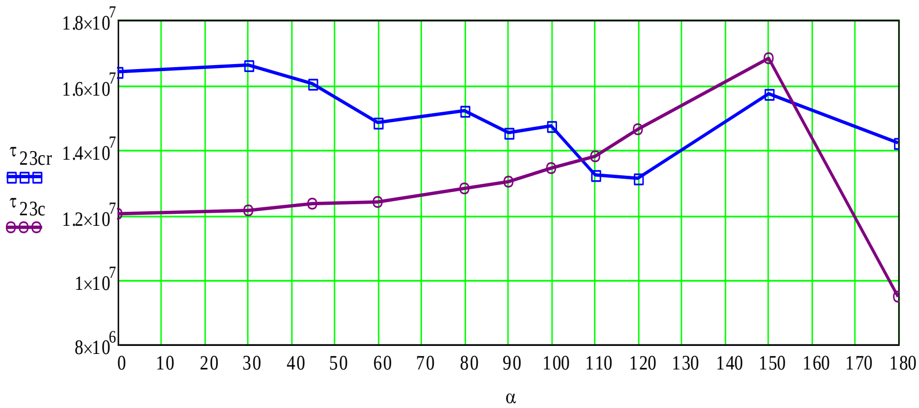


Fig. 11. Variation of maximum central shear stresses τ_c and the stresses near the concentrator, τ_{cr} with notch angle

From the graph, it is clearly observed that the most favorable situation is reached for an angle around $\alpha = 100^{\circ}...110^{\circ}$. The ratio between the maximum central stress and the mean stress $\tau_{med} = T / A$ is a dimensionless central stress and by plotting it, as seen in Fig. 12, the same conclusion is found because the maximum central shear equals the medium shear. The same favorable angle was found by Hawong [8], by a photoelastic analysis.

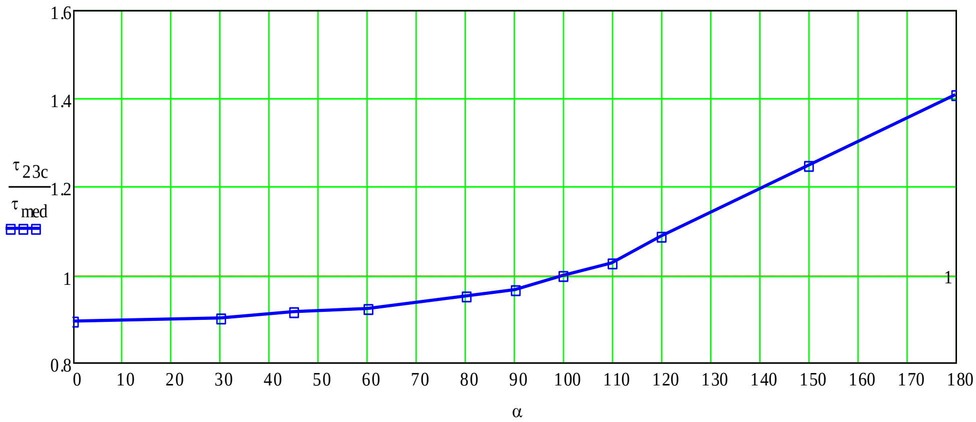


Fig. 12. Variation of dimensionless central shear stress with concentrator angle

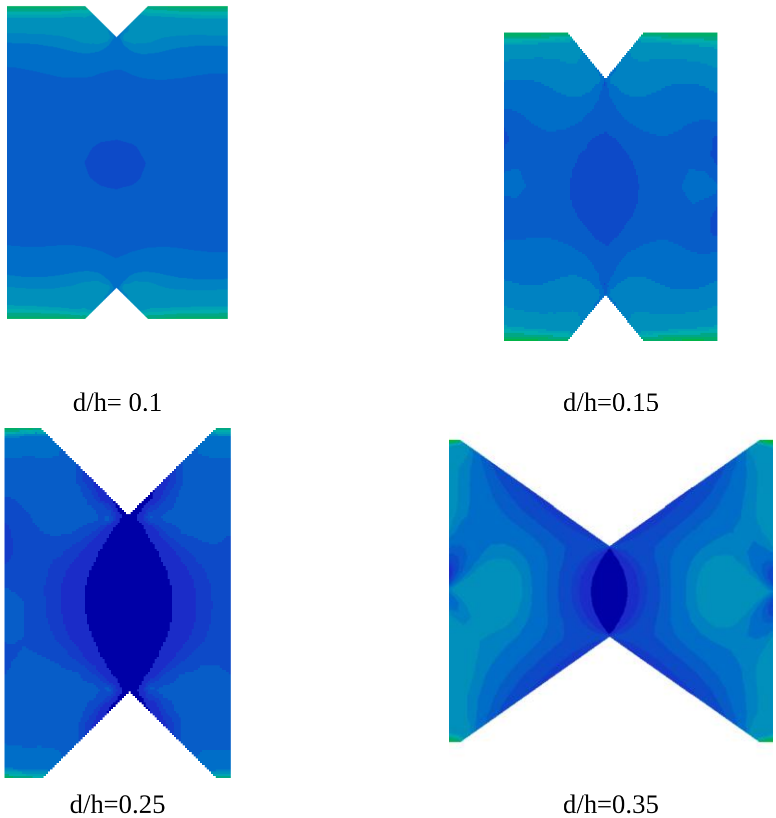


Fig.13. Shear stress field for different notch depths, $\alpha = 90^{\circ}$

The second considered parameter was the depth of the notch, defined as $a_{.c} = d/h$ (where $d = h - l/2$ form Fig. 1). For a notch of $\alpha = 90^\circ$, as for the Iosipescu probe, the analysis was made for different depths and some stress plots are presented in Fig. 13 and it is observed that the shear stresses depend on this geometrical parameter. Both the central stress and the stress from the concentrator vary and the conclusion can be only drawn after representing the variation of the dimensionless stresses, both central and near the notch (Fig. 14). There is an optimum notch depth, around 0.19, for which the stresses are almost uniform.

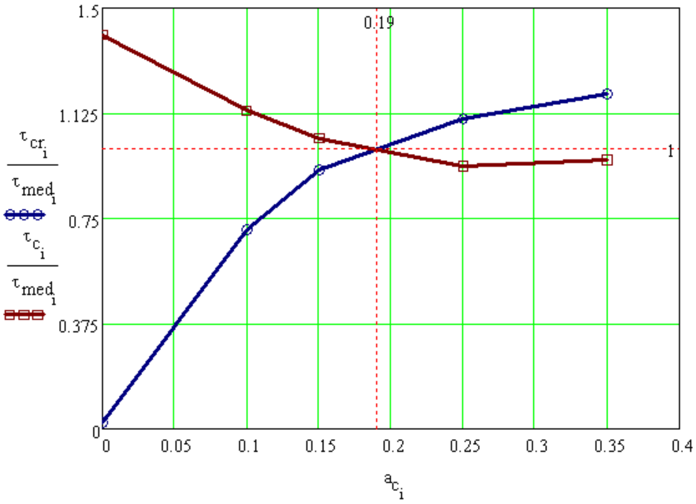


Fig. 14. Dimensionless stresses (τ_{cr} -notch stress, τ_c -central stress), versus notch depth, a_c for a notch $\alpha = 90^\circ$

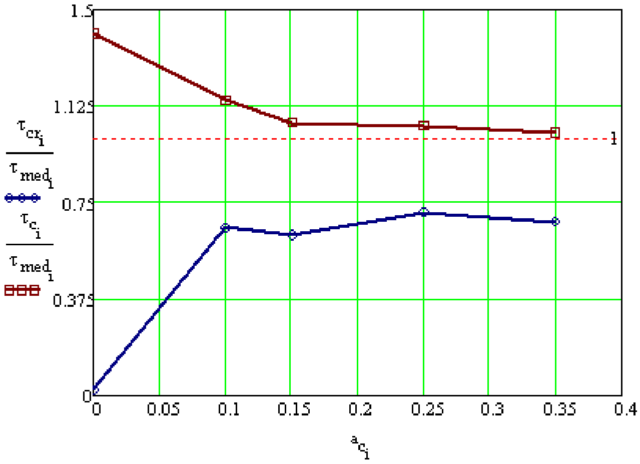


Fig. 15. Dimensionless stresses (τ_{cr} - notch stress, τ_c - central stress) versus notch depth, a_c for a notch $\alpha = 110^\circ$

For a notch of angle $\alpha = 110^\circ$, the same shear stresses are represented in Fig. 15 and it can be seen a better influence, the central dimensionless stresses tend to the unity and, therefore, the maximum stresses tend to the medium value, for notch depths greater than 0.15. A precision calculus proves that the errors lie under 3% for $d/h > 0.35$. The reason is that, for small depths of the notches, the probe is closed to Juravski shape and there is a maximum stress, 1.5 times greater than the medium value, in the centre of the cross-section. From these aspects, it results the conclusion that, in order to obtain a uniform shear stress distribution in the cross-section, the investigated section should have 0.3 from the total height. A similar analysis was made to investigate the influence of the notch radius upon the shear stress variation in the cross-section, but it was found insignificant as compared to the influence of the notch angle and the notch depth.

4. CONCLUSIONS

Finding experimental methods to perform precise simple and low costs tests for measuring shear properties of materials is a permanent challenge for engineers. FEA analysis proves to be a powerful instrument in designing the optimum shape of probes to be tested. This paper presents an anlysis concerning the optimum geometrical parameters required for obtaining a uniform shear stress state in a probe.

The Iosipescu shear test uses a double V notched probe with an angle of $\alpha = 90^\circ$. The FEA analysis reveals a slight stress asymmetry in the central region due to the loading and clamping system.

A modified loading scheme was proposed by Hawong [8] and, for this case, the influence of notch parameters was studied. The notch radius was analysed, but it was found to have a little influence and, therefore, it was not presented here.

The notch angle determines central nuclei of maximum stresses together with important stresses around the concentrators. The variations of the dimensionless stresses showed that an angle of $\alpha = 110^\circ$ is preferable in achieving an uniform shear stress state as compared to the standard Iosipescu probe, having the notch angle $\alpha = 90^\circ$.

The effect of the notch depth on the shear stress field in the cross section was also analyzed by finite element analysis. The effect of this geometrical parameter was studied for two notch angles, $\alpha = 90^\circ$ and $\alpha = 110^\circ$, respectively. For the first angle, the optimum situation, when the stresses are nearly uniform across the section, is met for a ratio $d/h = 0.19$ and for a deeper notch, a slight increased stress near the concentrator was found. For the case of the notch with an angle $\alpha = 110^\circ$, the plots traced following the finite element analysis led to the conclusion that the deeper the notch, the reduced concentrator effect. A supplementary advantage of the method consisting in loading on the longitudinal axis of the probe is highlighted by the observation that the shear stress field in the region of the probe between notches is symmetrical.

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