STRESS INTENSITY FACTOR IN V-NOTCH BY APPLYING THE IOSIPESCU SHEAR TEST FOR COMPOSITE EPOXY MATERIAL REINFORCED WITH FIBER GLASS

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Abstract. *The Iosipescu shear test of composite epoxi reinforced with fiber glass is characterized as the second failure mode of v-notches. The linear elastic fracture mechanics parameter denoted as the stress intensity factor is evaluated for some samples (plates) of the testing material. Each sample was prepared with two v-notches opposite to each other. Different geometric parameters of the v-notches were taken into consideration, such as opening angle, curvature radius and depth. The experimental tests were performed in the Strength of Materials Laboratory of authors university. Different fiber orientation were taken into account. From the analysis of the experiments, it was concluded that the maximum shear stress occurs in the sample with fiber orientation angle of 45°, with an almost symetrical distribuition for the orientation angles in the ranges from 0º to 45ºand 45° to 90º . Consequently, the corresponding stress intensity factors are greatly affected by this shear stress variation with the fiber orientation angle.*

Keywords*: Iosipescu shear test, geometric parameters of the V-notches, failure mode of V-notches.*

1. INTRODUCTION

Composites are known for their excellent combination of high stiffness and low weight. Their inherent anisotropy allows the designer to manufacture the material in order to achieve the desired performance requirements. Within these requirements it was considered, for this work, the epoxy material reinforced with fiber glass. The samples were prepared with two v-notches, opposite to each other, and from the test results it was looked for obtaining the influence of the fiber orientations.

Historically, Neuber (1958) is the benchmark for evaluating the stress distribution in the vicinities of notches. The Iosipescu (1967) shear test was originally designed for measuring the shear strength and the elasticity module of isotropic metals, Gross and Mendelson (1972) introduced some important definitions from which one may establish the expression for the stress intensity factor for plane shear stress. The Iosipescu shear test was later extended to composite materials by Walrath and Adams (1983). Ten years later, the analysis of shear properties of composite materials throng the v-notched plates was standardized by ASTM D5379 (1993). A experimental strain analysis of the Iosipescu shear test specimen was carried out by Adams and Lewis (1995) for composite material more recently, Lazzarin and Fillipi (2005) introduced the stress intensity factor for round V shaped notches.

The main geometric parameters of the slots are the radius of curvature ρ, the depth a_p and the opening angle 2α. Another significant parameter is designated as the notch severity q. This in turn is the additional angle of opening angle. The distance between the origin of the coordinate system and the tip of the notch depends on the opening angle of the notch and the radius of curvature.

$$\rho\left(\frac{q-1}{qr_0}\right)=1 \tag{1a}$$

$$q=\frac{2\pi-2\alpha}{\pi} \tag{1b}$$

When the severity assumes the values $q = 2$ represents the outline of a kind, while at $q = 1$ represents the absence of the notch. When performing a shear test these laminated composites is recommended to use the reference system radial *R* and tangential *T* as sketched in fig. 1. For example, the shear stress is designated as: $\tau_{T,\,45°}$ or $\tau_{R,\,45°}$. That is, the shear stress is accompanied by two subscripts *R* or *T*, followed by the angle of withdrawal of the sample onto a slide, marked from the orientation of the warp. The first index indicates the direction of load that causes shear in the sample.

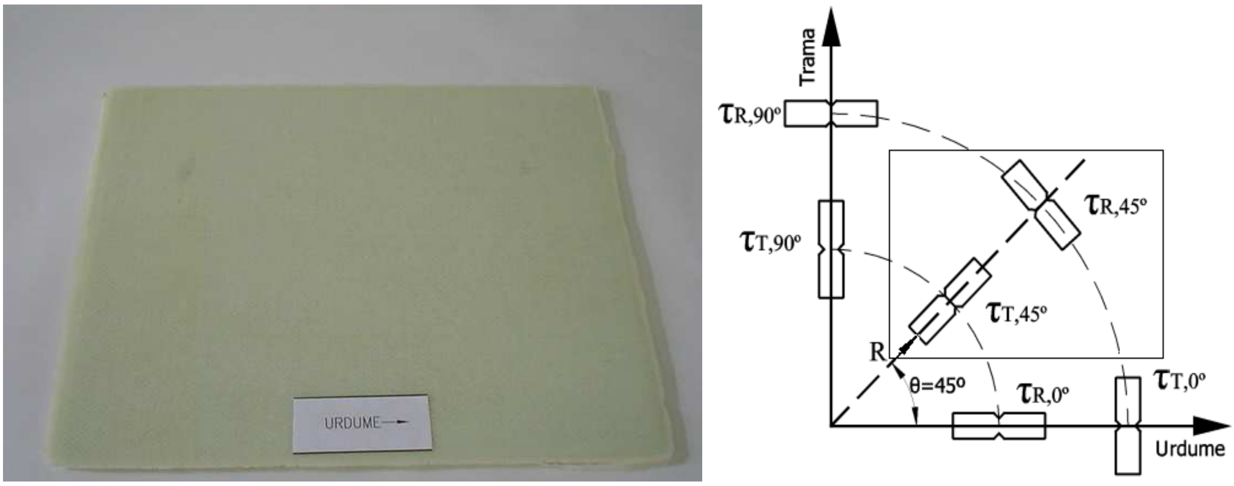

Figure 1. Composite epoxy reinforced with glass fiber.

1.1. Mechanism of Shear

In order to explain the mechanism of shear due to shearing force *Q*, as well discuss some of their peculiarities, consider the distributions of shear stress in a sample of rectangular cross section. The test procedure of Iousipescu imposes the condition of zero moment in the tough section of the sample Fig. 2a, ie, *QL = 0*. As outlined in Fig. 2b, the shear stress τ due to the remote shear stress ρ ranges from zero - *point O* the point at maximum value (τmax) - *point B*. The stress distribution on the cross section for a slot is hyperbolic parabolic - *OCB curve*. Thus, according to Mohr's circles of stress for the shear stress maximum value of the stress state can be represented by two principal stresses (a positive value $\sigma_1=\tau$ and a negative value $\sigma_2=-\tau$. Both principal stresses can be evaluated by using strain gages. The positive stress value will contribute to the appearance of small cracks, as well as for their growth. And yet, as shown in the figure, other significant values are shown by points *A*, *C* and *D*. Regardless of the relationship d/ρ, the *point* - *B* will always 1,5p as predicted by the theory of elasticity, with value p=*Q* /(2dt). The remaining points assume different values. Consider the relationship d/ρ=9.46 in this particular case, the *point A* takes the value 0,895p. While the *point D* takes the value 1.233p. As noted by the Neuber (1958) stress distribution over the cross section is given by - *ODCA curve*. The *point C* represents the situation where the shear stress predicted by Neuber (1958) is equal to the value given by the theory of elasticity, with an estimated value for point C is about 1,08p.

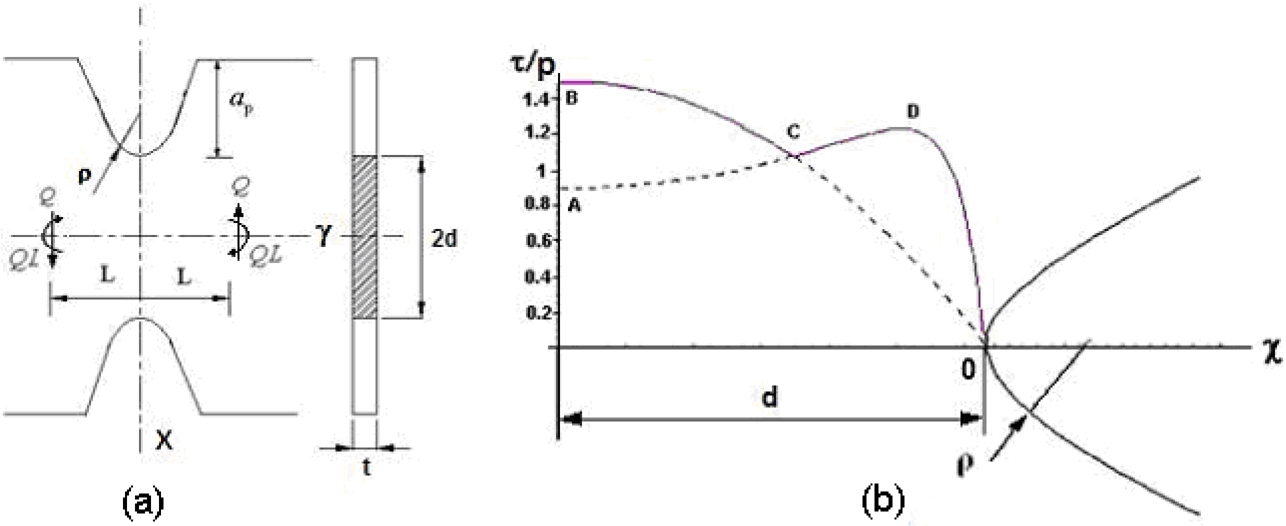

Figure 2. (a) Specimen and (b) distribution of shear stress on the cross section of the specimen.

1.2. State Stress

All parameters of the stress distribution were obtained by Lazzarin and Filippi (2005) in terms of polar coordinates r and θ, Fig. 3a, given by:

$$\begin{Bmatrix}\sigma_{\theta\theta}\\ \sigma_{rr}\\ \tau_{r\theta}\end{Bmatrix} = \lambda a r^{\lambda-1}\left[\begin{Bmatrix}(1+\lambda)\sin(1-\lambda)\theta\\ (3-\lambda)\sin(1-\lambda)\theta\\ (1-\lambda)\cos(1-\lambda)\theta\end{Bmatrix} + \chi_b(1+\lambda)\begin{Bmatrix}\sin(1+\lambda)\theta\\ -\sin(1+\lambda)\theta\\ \cos(1+\lambda)\theta\end{Bmatrix} + \frac{1}{4(\mu-1)}\left(\frac{r}{r_0}\right)^{\mu-\lambda}\left(\chi_d\begin{Bmatrix}(1+\mu)\sin(1-\mu)\theta\\ (3-\mu)\sin(1-\mu)\theta\\ (1-\mu)\cos(1-\mu)\theta\end{Bmatrix}\right) + \chi_c\begin{Bmatrix}-\sin(1+\mu)\theta\\ \sin(1+\mu)\theta\\ -\cos(1+\mu)\theta\end{Bmatrix}\right] \quad (2)$$

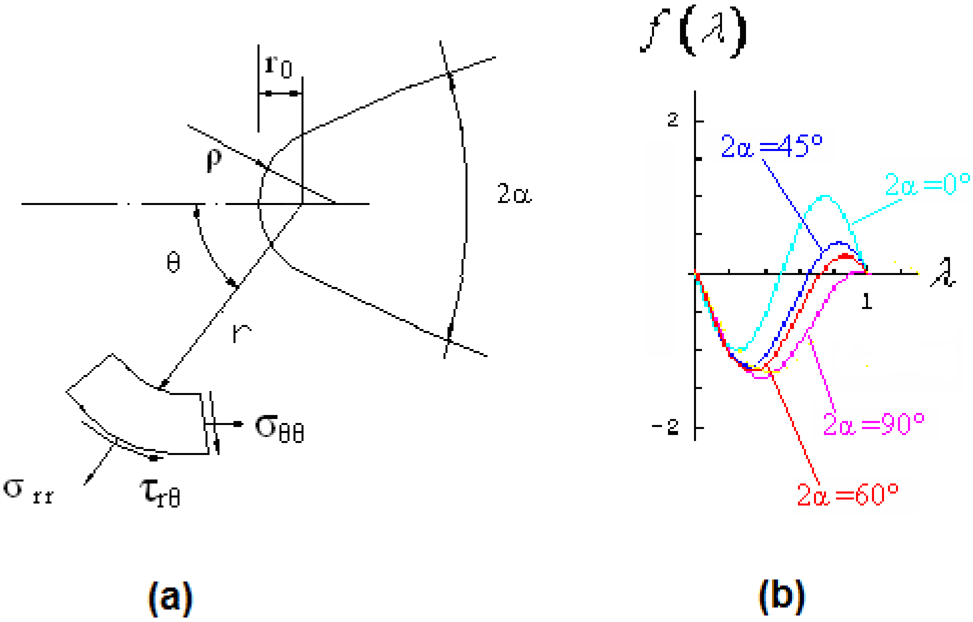

Figure 3 (a) State of stress around the notch and (b) eigenvalue anti-symmetric Williams (1957).

The so called Williams (1957) anti-symmetric eigenvalues, is sinusoidal eq.3 and enable, one to obtain the asymptotic coefficient λ.This function is specific for each opening angle of the notch and the corresponding asymptotic coefficients are the smallest positive roots of the function (Fig. 3b).

$$f(\lambda) = \sin(2\alpha\lambda) - \lambda \sin 2\alpha \quad (3)$$

So that the mentioned parameters have a relation with unbeliever the opening angle, the same relationship to the severity and the asymptotic coefficient slot. For 2α= *90º it results* λ=0.9085, for the ratio d/ρ=9.46. While for 2α = 0° one obtains λ=0.5, which is the asymptotic coefficient of a crack. As shorn I Fig.4, the parameters, λ, χ_b, χ_c, μ, and χ_d present minimum and maximum values for 2α= π and 2α=0 rd., respectively.

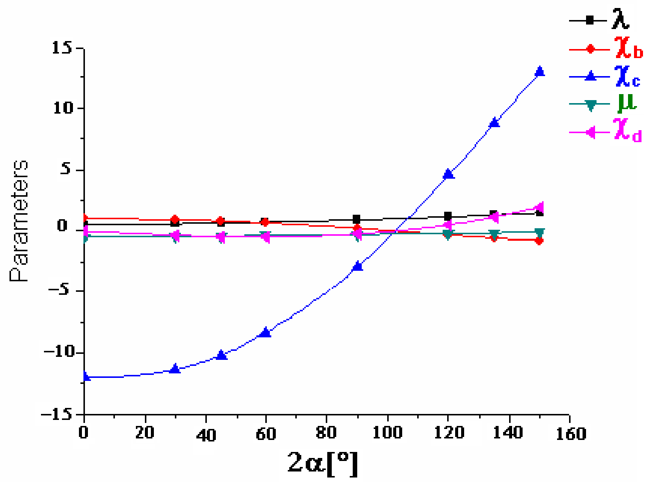

Figure 4. Parameters λ, χ_b, χ_c, μ, χ_d and 2α values.

Analysis of stress distribution along the plane bisector slot occurs when $\theta = 0°$ and implies the existence of single strain, given by:

$$(\tau_{r\theta})_{\theta=0^\circ} = \lambda r^{\lambda-1} a \left[1-\lambda+\chi_b(1+\lambda)+\frac{1}{4(\mu-1)}\left(\frac{r}{r_0}\right)^{\mu-\lambda}\left[\chi_d(1-\mu)-\chi_c\right]\right] \quad (4)$$

1.3. Factor Intensity of Stress in V-Notch

The Iosipescu test is an alternative to estimate the stress intensity factor for slots in V due to pure shear. The experimental data result or the principal stresses. The shear stress value can be obtained by the maximum principal stress on the plane bisector for a specific distance from the edge of the notch. Both principal stresses can be evaluated by using strain gages, one on each side of the sample, oriented $45°$ (Fig.5). As a result, the previous expression allows determining the constant, which is fundamental to describe the behavior of the stress σ_{rr}, $\sigma_{\theta\theta}$ and $\tau_{r\theta}$.

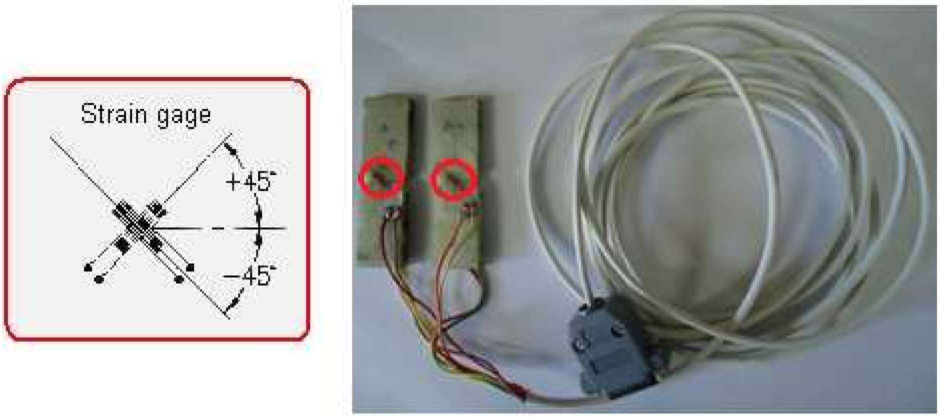

Figure 5. Full Wheatstone bridge.

The generalized form of the stress intensity factor is extended to V-notches from the definitions of Gross and Mendelson (1972) and the resulting stress intensity factor due to the shear plane. Is called and the stress intensity factor in the second mode due to the absence of geometric radius of curvature ρ and the presence of the same, respectively.

$$K_{II}^{\ V} = \sqrt{2\pi}\lim_{r\to 0} r^{1-\lambda}\left[(\tau_{r\theta})_{\theta=0^\circ}\right] \quad (5a)$$

$$K_{II,\rho}^{\ \ V} = \sqrt{2\pi}\lim_{r\to r_0} r^{1-\lambda}\left[(\tau_{r\theta})_{\theta=0^\circ}\right] \quad (5b)$$

The generalization of the ratio of the stress intensity factors is expressed in terms of the parameters of stress distribution. Since, the shear stress is the tension in the bisector plane.

$$\frac{K_{II,\rho}^{V}}{K_{II}^{V}}=\frac{1}{1+\frac{1}{4(\mu-1)}\left(\frac{qd}{(q-1)\rho}\right)^{\mu-\lambda}\left[\frac{\chi_d(1-\mu)-\chi_c}{1-\lambda+\chi_b(1+\lambda)}\right]} \tag{6}$$

Therefore,

$$K_{II,\rho}^{V}=\tau_{\max}\sqrt{\pi}d^{1-\lambda}\left\{\frac{\sqrt{2}}{1+\frac{1}{4(\mu-1)}\left(\frac{qd}{(q-1)\rho}\right)^{\mu-\lambda}\left[\frac{\chi_d(1-\mu)-\chi_c}{1-\lambda+\chi_b(1+\lambda)}\right]}\right\} \tag{7}$$

2. MATERIALS AND EXPERIMENTAL PROCEDURE

ASTM D-5379 [2] describes the Iosipescu test to determine the properties of composite laminates. The samples in double V-notch opening angle of *90°* showed average values for the radius of curvature *of 0.65 mm* nominal thickness of 5 mm, length *76.2 mm* and width of *19.9 mm*. The samples were cured in an autoclave at *121°C* and pressure *0.71 MPa*. The values of the applied loads and deformations for the calculations of shear stress to the blade on the analyzed region are shown in Fig. 6 (a and b) and Tab. 1. Here *r* is defined as the distance between the notch tip to the reference *d*, specifies how and deformation ε_m.

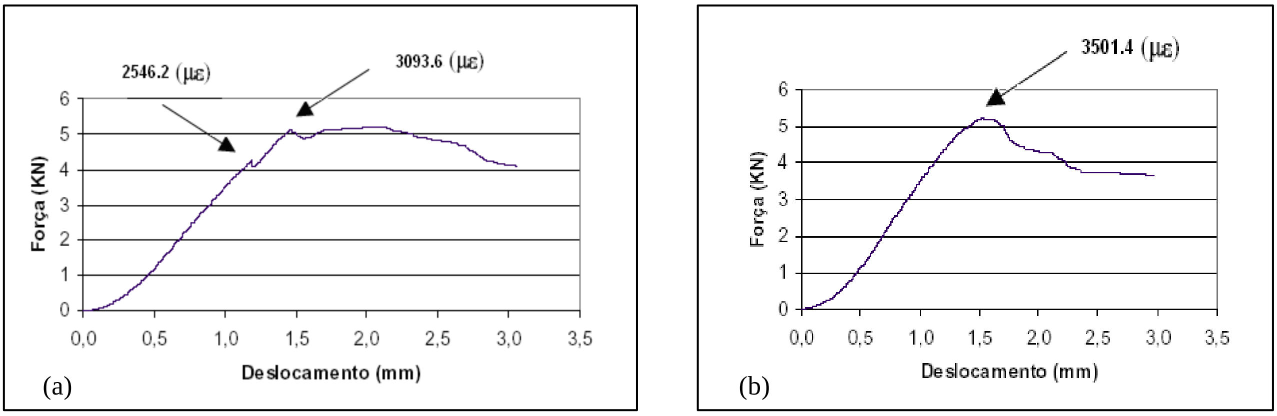

Figure 6. Loads vs. deformations.

The dashed line shows the trend curve of the shear stress response of the composite, Fig. 7. From the analysis of the experiments, it was concluded that the maximum shear stress occurs in the sample with fiber orientation angle of 45°. The trend curve was obtained from the experimental data for orientation fiber angles of 0° and 90°, with almost identical shear stress values. It was assumed a symmetrical shape about the angle of 45°.

Table 1. Estimated values for the shear stress.

specimens	[1] Load, N	[2] ε_m, $\mu\varepsilon$	[3] τ, MPa
radial	5030	3093.6	83.65
tangential	5070	3501.4	84.56

Note;[1]Force obtained the graph of force vs. displacement - Iosipescu Test,[2] Strain specific - on the instrument reading (Wheatstone bridge) and [3] Shear stress obtained from the equations:

$$\tau_{R,45°} = \frac{\varepsilon_m - 2.3795}{36.952} \quad \text{and} \quad \tau_{T,45°} = \frac{\varepsilon_m - 1.5843}{41.56}$$

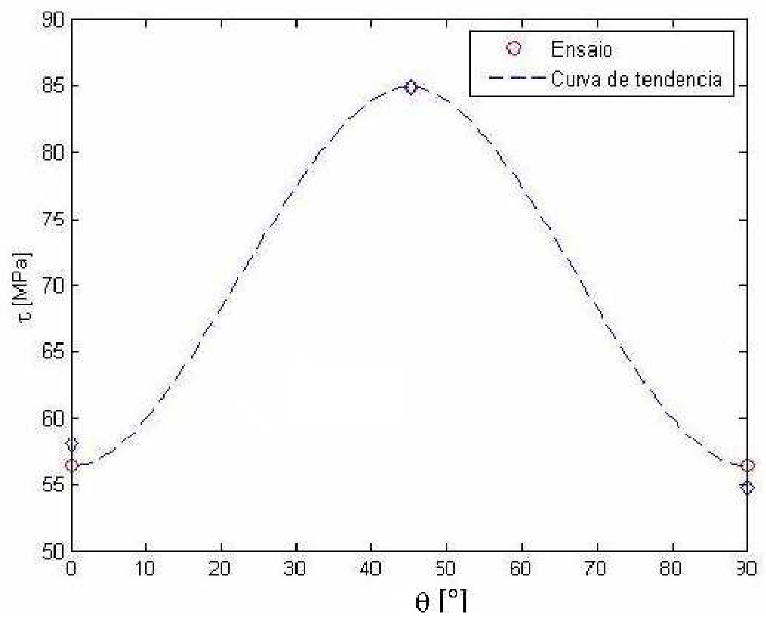

Figure 7. The shear stress vs. orientation angle.

3. RESULTS AND CONCLUSIONS

From the analysis of the experiments, it was concluded that the maximum shear stress occurs in the sample with fiber orientation angle of 45°. However the shear stress was slightly higher for the samples with fiber orientation angle of 0°, in comparison with the samples with 90°orientation angle, due to residual stresses in the samples.

The Iosipescu test is an alternative to estimate the stress intensity factor for slots in *V* due to pure shear. Thus, samples of laminated composite reinforced with fiber glass fabric with different orientations in relation to the fibers are evaluated. Consequently, the resulting principal stresses on the plane bisector to a specific distance from the edge of the notch. Table 2 shows the values for the shear stresses (values of the trend of test data) and stress intensity factors for the epoxy composite reinforced with glass fiber.

Table 2 Estimated values for the stress intensity factors.

θ	$\tau_{\max}\ MPa$	$K^V_{II,\rho} = 1.6\tau_{\max}\ MPa(m)^{0.0915}$
0º	58.05	92.88
30º	77.27	123.63
45º	84.10	134.56
60º	78.89	126.22
90º	54.70	87.52

As may be seen from Table 2 the maximum shear stress occurs in the sample with fiber orientation angle of 45°, with an almost symetrical distribuition for the orientation angles in the ranges from 0º to 45ºand 45° to 90º . Consequently, the corresponding stress intensity factors are greatly affected by this shear stress variation with the fiber orientation angle, due to the anisotropy in the composite laminates.

4. NOMENCLATURE

ap: Notch depth
2d: Width of the sample resistance
K^{v}_{II} : Stress intensity factor for samples with V-shaped notch in mode II

$K^{v}_{\Pi,\rho}$: Stress intensity factor for samples with V-shaped notch in Mode II whose radius of curvature is relevant
p: Shear stress
Q: Shearing force
q: Notch severity
QL: Moment
*r: P*olar coordinate
r_0: Distance from the origin of the polar coordinate system to the tip of notch
a: Notch depth
t: Thickness of the sample
2α: Opening angle of the notch
ε: Deformation
ε_m: Measurable deformation
ρ: Radius of curvature
σ_1, σ_2: Principal stresses
σ_{rr}, $\sigma_{\theta\theta}$: Tangengial radial and normal stresses in polar coordinates
τ: Shear stress on the cross section of the specimen
$\tau_{T,0°}$: Shear sense of tangential load with 0 ° angle
$\tau_{R,0°}$: Shear direction of radial load with 0 ° angle
$\tau_{T,45}$: Shear sense of tangential load with 45 ° angle
$\tau_{R,45°}$: Shear direction of radial load with 45 ° angle
$\tau_{T,90°}$: Shear sense of tangential load with 90 ° angle
$\tau_{R,90°}$: Shear direction of radial load with 90 ° angle
τmax: Maximum shear stress
$\tau_{r\theta}$: Shear stress in polar coordinates
θ: Polar coordinate
λ, χ_b, χ_c, μ, χ_d: Coefficients of the stress distribution in the vicinity notch

5. ACKNOWLEDGEMENTS

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