EFFECT OF ANISOTROPY ON CRACK RESISTANCE OF POLYMER COMPOSITES FOR AIRCRAFT BUILDING

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ABSTRACT

The analytical dependencies are presented for the experimental determination of stress intensity factor, taking into account the effect of anisotropy of the elastic properties. Test results on crack resistance of the specimens under tension are given. The analysis of the function effect, taking into consideration the anisotropy of elastic properties and the point of applying the tensile load on the crack resistance values is presented.

KEYWORDS

Reliability, specimen, critical stress intensity factor, anisotropy function, plane stress state, carbon fiber reinforced plastics (CFRP), crack.

The critical normal stress intensity factor K_{1c} can be determined by the linear fracture mechanics methods by the experimentally measured load value, corresponding to the moment of crack opening P_c under the specimen monotonic static tension. It is expedient to take into account the effect of anisotropy on the material elastic properties while determining K_{1c}, as the field of stresses near the crack tip, entirely described by the stress intensity factor depends on the anisotropy of elastic coefficients.

A quantitative analysis of elastic properties anisotropy effect on crack resistance under tension of the structural polymer specimens was carried out by the authors.

The analytical dependencies have been used for the determination of the normal stresses intensity factor $K_{1c,o}$ in infinitely orthotropic body with the central crack.

Taking into consideration the function of elastic properties anisotropy φ and the effect of the function of the ratio of notch length to the specimen width

$Y(\lambda)$, the expression for $K_{1c,o}$ in the case of plane stress state has the following form:

$$K_{1c,o} = (P_c / t\sqrt{\pi a}) \cdot \varphi \cdot Y(\lambda) \qquad (1)$$

where P_c - critical tensile load, corresponding to the moment of crack opening;
t - specimen width;
a - half of the central notch length.

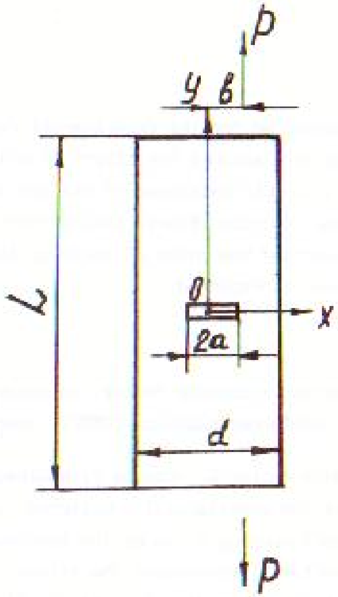

Fig.1. Diagram of the cracked specimen.

The function, describing the anisotropy of the specimen elastic properties, the calculated diagram, given in fig.1 is determined by the expression:

$$\varphi = \frac{1 + a_{66}/a_{11}(q_2^2 - q_1^2)}{\sqrt{2[1+(1+B)^2/q_1^2 H^2][B^2+q_1^2 H^2-1+\sqrt{(B^2+q_1^2 H^2+1)^2-4B^2}]}} + \frac{1 - a_{66}/a_{11}(q_2^2 - q_1^2)}{\sqrt{2[1+(1+B)^2/q_2^2 H^2][B^2+q_2^2 H^2-1+\sqrt{(B^2+q_2^2 H^2+1)^2-4B^2}]}} \qquad (2)$$

where H - the ratio of the specimen length to the notch length 2a;
$q_{1,2}$ - the roots of the characteristic equation, having the form:

$$a_{11} q^4 - (2a_{12} + a_{66}) q^2 + a_{22} = 0$$

$$a_{11} = 1/E_y, \quad a_{22} = 1/E_x, \quad a_{12} = -\mu_{yx} \cdot a_{11}, \quad a_{66} = 1/G_{xy},$$

where E_y, E_x - tensile elasticity modulus respectively, in the orientations Q_y and Q_x;
G_{xy} - shear modulus in X_{oy} plane;
μ_{yx} - Poisson's ratio;
$Y(\lambda)$ - the function, taking into account the ratio of the notch length 2a to the specimen width is defined by the expression:

$$Y(\lambda) = 1,770 + 0,227\lambda - 0,510\lambda^2 + 2700\lambda^3$$

The critical normal stresses intensity factor $K_{1c,m}$ without the account of the elastic properties anisotropy is determined by the formulas:

$$K_{1c,m} = \frac{P_c}{td}\sqrt{\pi a} \qquad \text{at } \lambda = \frac{2a}{d} \leq 0,25$$

$$K_{1c} = \frac{P_c}{td}\sqrt{a} \cdot Y(\lambda) \qquad \text{at } \lambda = \frac{2a}{d} > 0,25 \qquad (3)$$

The normal stresses intensity factors ratio, determined by the formulas (1) and (3) are as follows:

$$K_{1c,o}/K_{1c,m} = (2\varphi/\lambda\pi) \cdot Y(\lambda) \qquad \text{at } \lambda \leq 0,25$$

$$K_{1c,o}/K_{1c,m} = 2\varphi/(\lambda\sqrt{\pi}) \qquad \text{at } \lambda > 0,25 \qquad (4)$$

The study of elastic properties anisotropy effect on the cracking resistance parameter K_{1c} under tension was conducted for four types of structural CFRP, based on the tape and tow fillers.

The mechanical properties of these materials necessary for the calculation are listed in table 1.

Table 1. CFRP Elastic Properties.

Material	$E_{y} \cdot 10^{-5}$ MPa	$E_{x} \cdot 10^{-3}$ MPa	$G_{xy} \cdot 10^{-3}$ MPa	μ_{yx}
1	2	3	4	5
Material 1 (KMU-4e)	1,20	9,35	6,50	0,265
Material 2 (KMU-9TB)	1,25	7,72	5,20	0,330
Material 3 (KMU-6-36)	1,25	5,90	5,10	0,450
Material 4 (KMU-9)	1,40	7,00	5,20	0,420

The effect of elastic properties anisotropy on K_{1c} value can be estimated by using the relationship:

$$\gamma = (1 - K_{1c,o} / K_{1c,m}) \cdot 100 \qquad (5)$$

The specimens with the sizes: L = 240 mm, d = 40 mm and the thickness of about 2 mm were studied. The effect of elastic properties anisotropy on K_{1c} value is shown in table 2.

Table 2. Values of φ function and γ value for the studied materials.

Material	$\lambda = 2a/d$	φ	γ, %
1	2	3	4
1	0,24	0,172	16,4
	0,25	0,179	16,3
	0,26	0,185	19,7
	0,30	0,213	19,9
2	0,24	0,194	5,7
	0,25	0,202	5,5
	0,26	0,210	8,9
	0,30	0,240	9,7

1	2	3	4
3	0,24	0,196	4,7
	0,25	0,204	4,6
	0,26	0,212	8,0
	0,30	0,243	8,6
4	0,24	0,204	0,9
	0,25	0,213	0,4
	0,26	0,221	4,1
	0,30	0,254	4,5

The highest value γ is obtained for material 1 and it is about 20%. For all considered materials value γ is minimum at λ = 0,25, i.e. in case when the notch length is 25% of the specimen width.

The lowest value of γ = (0,4 ÷ 4,5) % was obtained for material 4. In this case the ratio of the elasticity moduli in the orientation of the major ordinate axes E_y/E_x is equal to 20.

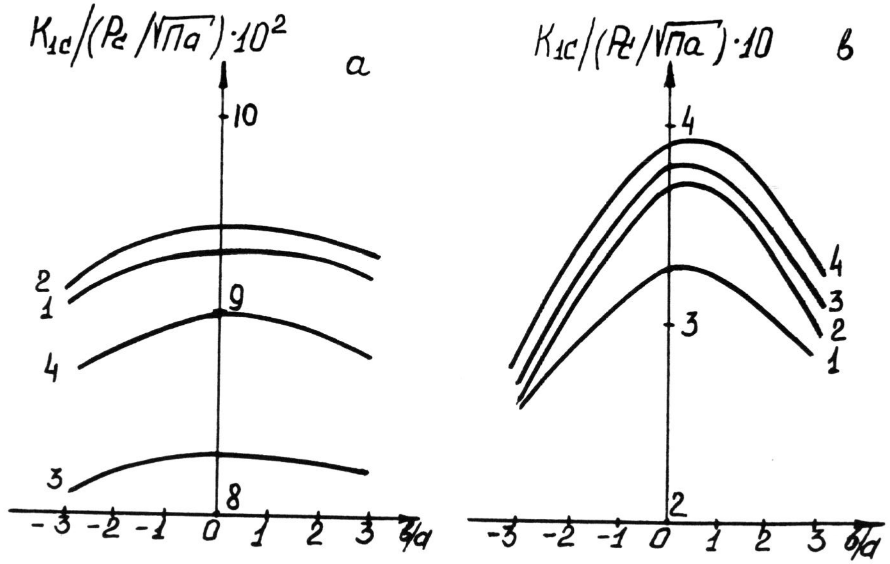

Fig. 2. The results of calculations, depending on load application point for the right crack tip.

Fig. 2 a,b shows the plots of $K_{1c,0}/(P_c/\sqrt{\pi a})$ variation, depending on the tensile load application relative to the cracked specimen longitudinal axis (fig.1).

The following specimens sizes have been chosen: ℓ = 240 mm, d = 40 mm, λ = 0,25. Fig.2 a corresponds to the case of the crack position parallel to the y axis, and fig. 2 b - parallel to the x axis.

The use of φ function, taking into account the elastic properties anisotropy of polymeric composites, results in a decrease of cracking resistance K_{1c} parameter. Hence, the reliability of the results for calculating the structures of anisotropic materials basing on the linear fracture mechanics is increased. The results of the work can be also considered as an improvement of the existing approaches to the engineering estimation of the materials cracking resistance.

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