UDC 539.422.24

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Prediction of the fatigue cracks propagation in elements of structural elements made of composite materials

The method , using experimental data on the rate of crack growth at an early stage of its development, to predict the process of crack growth in a structural element from a composite material up to the moment of its destruction (fracture) is proposed. The study of durability was carried out using two types of carbon fiber (CFRP) plates with a hole and two radial cracks.

The widespread use of composite materials in aviation is due to high strength and low weight compared to metallic materials. Analysis of the fatigue fracture of structures from composite materials shows that the fracture mainly begins at the junction of the elements (holes, places of application of concentrated loads, etc.). For aviation constructions, the most important characteristic is fatigue durability. Increasing the efficiency of structures, improving their characteristics, resource extension, is impossible without solving the problems associated with assessing the fatigue durability of structural elements.

The study of fatigue cracks growth process was carried out using two types of CFRP plates, which have a hole and two radial cracks. In the first case, the cracks spread perpendicularly to the direction of the load, in the second - at an angle. The cyclic load was uniformly applied to the ends of the plate.

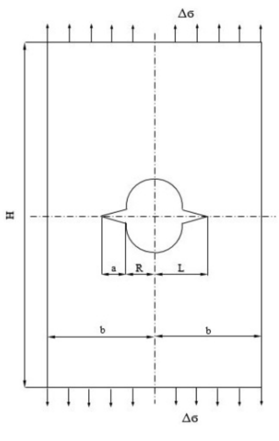

Fig.1. Shape and size of the structural element with radial cracks

The differential equation transformed from the Forman`s formula for crack propagation in the given case were used

$$dN = \frac{dL[(1-R)Kc - \Delta\sigma L^{0.5}\alpha] \ )}{C5*\Delta\sigma^n*(\sqrt{L})^n*\propto^n} \quad (1),$$

where: N - the number of stress cycles,

C_5 and n - experimentally determined constants,

$\Delta K = (K_{max} - K_{min})$ - range of stress intensity factor (SIF),

K_c – critical SIF,

$L = a + R$

$\Delta\sigma^n = (\sigma_{max} - \sigma_{min})$ - range of stress intensity.

The initial conditions in this case have the form:

$N = N_{0,} L = L_0$

(L_0 - corresponds to the number of cycles). When the critical crack length is reached $L = L_k$, the value of L_k is determined from the condition that K reaches the critical value Kc

Integrating equation (1) with allowance for the initial conditions and replacing the variable $\lambda = L/b$, we can determine the number of cycles up to fracture (fatigue durability).

$$N_k - N_0 = \frac{(1-R)*Kc}{C5*\Delta\sigma n*b^{0.5n-1}} * \int_{\lambda 0}^{\lambda k} \frac{d\lambda}{\propto^n\lambda^{0.5n}} - \frac{1}{C5*\Delta\sigma n*b^{0.5n-1}} * \int_{\lambda 0}^{\lambda k} \frac{d\lambda}{\propto^{n-1}\lambda^{0.5(n-1)}} \quad (2)$$

The integrals entering into formula (2) are computed numerically (in the present paper by the Simpson formula). The value of the critical SIF, the correction function α, and the constants C_5 and **n** are determined by the results of the experiment.

Representing the results of the experiment in the form of the function L = f(N), we determine the growth rate of the crack V = dL/dN. Further, using formula (1) and the crack growth rate V, we can determine the constant C_5

$$C_5 = \frac{V[(1-R)Kc - \alpha\Delta\sigma(\lambda b)0.5}{\Delta\sigma^{0.5}\alpha b^{0.5}\lambda^{0.5n}} \quad (3)$$

The value of the critical SIF (K_c) is determined by the method given below. We denote by σ_c and K_c the stress and SIF at the moment of the plate fracture with the crack length L. The stress σ_c is determined at the moment of fracture along the gross cross section.

$$K_c = \alpha*\sigma_c*L^{0.5} \quad (4)$$

The various experimental studies carried out during which the different lengths of cracks were determined the value of SIF K_c showed that the value of the critical SIF does not depend on the length of the crack. Thus, if the value of $\boldsymbol{\sigma}_c$ is found for the material, then for any crack length, according to the dependence (4), it is possible to obtain the value of the critical CIF.

Experimental research was carried out on samples of carbon fiber with an arrangement of layers ($0^o{}_3/90^o{}_2$) with geometric dimensions H = 200mm, 2b = 100mm, R = 5mm, t =2mm. The tests were carried out by dynamic loading frequency of 10.75 Hz with a σ_{max} = 70MPa, σ_{min} = 30MPa. Good agreement between the theoretical and experimental results was found.

The values of the stress intensity factors obtained for the various types of structural elements allow using the material characteristics, determined at an early stage of the development of the crack, to predict the process of a crack propagation until fracture.

Conclusions

To predict the growth of a radial crack in various elements of composite materials it is enough to determine the value of $\boldsymbol{\sigma_c}$ for a particular material. Using which one, according to the proposed method, it is possible to define the value of the critical CIF. The value of the critical CIF makes it possible to predict the process of crack growth until element`s fracture.

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