MODE II MACROCRACK INITIATION IN ORTHOTROPIC COMPOSITE VISCOELASTIC PLATE

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Abstract. Safe loads and initiation time for a straight macrocrack in viscoelastic orthotropic material that is intended to model a fiber composite plate under shear loads is investigated. The composite material is modeled by viscoelastic orthotropic medium. Determination of expression for crack shear displacement as function of time is based on the corresponding elastic solution and the method of operator continued fractions. Initiation time is obtained as a solution of integral equation for the incubation period. Numerical calculations are given for mode II macrocrack initiation.

Keywords: mode II crack, crack initiation, viscoelastic composite.

1. Introduction. Theoretical investigations of subcritical crack propagation in a viscoelastic material, modeling the process of long-term cracking of certain composites, are given in a number of papers (see bibliography in Schapery (1975, 1986), Kaminsky (1980, 2004)).

The experimental data of Serensen and Zaitsev (1982), Gamby and Delaumenie (1997) and Kaminsky (1998) show that the failure of polymeric composite materials due to their viscoelastic properties may occur, in some cases, at low stresses by slow subcritical crack growth. This fact does not guarantee the safe of composite-made structure elements from failure when their strength is calculated by the elastic linear fracture mechanics theories. Here, we address macrocrack initiation under mode II loading of a viscoelastic composite plate.

In linear fracture mechanics, the strength criterion for brittle elastic body with mode II crack can be written as

\[ K_{II} < K_{Ilc} \]  

(Irwin’s criterion for cracks with small process zones), where \( K_{II} \) is shear mode stress intensity factor and \( K_{Ilc} \) is its critical value. Otherwise, for cracks with considerable process zones strain criterion can be written

\[ \delta_{II} < \delta_{Ilc}, \]  

(2)
where $\delta_{\text{ILc}} = 2\mu$ and $\mu$ is elastic shear displacement at the crack tip along the $x$-axis; $\delta_{\text{ILc}}$ is the critical value of $\delta_{\text{IL}}$ (crack starts to grow when $\delta_{\text{IL}} = \delta_{\text{ILc}}$). Experimental determination of $\delta_{\text{ILc}}$ are cited in Serensen and Zaitsev (1982).

This means that if the alternating loads leading to fatigue cracks are excluded, these criteria imply that the crack does not grow. But they do not take into account viscoelastic properties (e.g. creep). As soon as the material, such as polymeric composite, is loaded for sufficiently long time, creep process leads to crack growth under loads remarkably lower than predicted by the linear fracture mechanics criteria. Therefore for viscoelastic materials these criteria (analogous to ones of Kaminsky (1980, 1998, for mode I) should be corrected to

$$K_{\text{IIc}} < K_{\text{ILs}} < K_{\text{ILc}};$$
$$\delta_{\text{ILc}} < \delta_{\text{ILs}} < \delta_{\text{ILc}},$$

where $K_{\text{ILs}}, \delta_{\text{ILs}}$ are the safe values of $K_{\text{II}}$ and $\delta_{\text{II}}$ for viscoelastic materials. These values are substantially dependent on structure and viscoelastic properties of the composite. Thus, if the condition $K_{\text{II}} < K_{\text{ILs}}$ or $\delta_{\text{II}} < \delta_{\text{ILs}}$ holds then there is no crack growth due to unbounded creep in a viscoelastic solid. If the loads are such that

$$K_{\text{ILs}} < K_{\text{II}} < K_{\text{ILc}} \text{ or } \delta_{\text{ILs}} < \delta_{\text{II}} < \delta_{\text{ILc}}$$

then the subcritical crack growth should take place. Under these conditions crack grows up to the critical length, then it becomes unstable.

Knowing $K_{\text{ILs}}$ or $\delta_{\text{ILs}}$ is vital for finding safe stresses in structures of composite materials, when subcritical crack growth should be avoided or at least minimized (e.g. in high-pressure vessels, to avoid de-pressurization or in solid propellant to avoid extra combustion surfaces formation). As the experimental determination of these characteristics for many viscoelastic composites is quite tedious, we suggest to determine them, as well as to calculate the initiation time of mode II crack, theoretically, in order to predict composites’ long-term cracking properties.

2. The long-term fracture model. A long-term fracture model of a material has to comprise a constitutive equation of the material, a model of the fracturing process zone at the macrocrack tip, and a fracture criterion. The composite material is modelled below by an anisotropic homogeneous linearly-viscoelastic medium with some average characteristics. This approach holds for the analysis of a macrocrack when its length is considerably larger than the fibre radius or the lamina thickness of the composite (see Zweben (1973), Schapery (1975)).