Prediction of random transverse cracking in laminates using deterministic and probabilistic fracture criteria

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Abstract

When a laminate coupon is subjected to a tensile static or cyclic load, multiple matrix cracks form in the off-axis plies. The crack density increases with the applied load or the number of cycles, which gradually reduces the effective stiffness of the laminate.

The problem of accumulation of transverse matrix cracks in cross-ply laminates under monotonously increasing load is addressed, while two energy based fracture criteria are used to determine the location a new crack appearance and the corresponding applied stress.

Using a deterministic fracture criteria, when the critical energy release rate of the cracking ply is assumed to be constant, it is shown that formation of new cracks can still be a random process during the stage of initial cracking, when the inter-crack spacing are large and existing cracks do not interact. The probability density function for the inter-crack spacing distribution at the end of this stage can be determined analytically. This distribution controls further fragmentation of the transverse ply, leading to a relationship between the applied stress and the corresponding crack density. This approach though leads to some conclusions that are inconsistent with experimental observations.

In order to overcome these disagreements a probabilistic fracture criterion is used, which assumes the critical energy release rate to be a random function of location. The previous approach is modified to take this randomness into consideration, which leads to the so-called fragmentation equation coupling the rate of change of the inter-crack spacing distribution with the applied stress and the probability distribution of the critical energy release rate. However, it will be shown that the typical assumption that at each step of the fragmentation process the probability of cracking depends only on the cracking state attained in the previous step (Markov process), is accurate only for low crack densities.

A simple approximation is derived on the basis of the fragmentation equation, which attempts to extend viability of the analytical approach to the range of higher (moderate) crack densities. Parameters of the critical energy release rate distribution can be obtained by fitting the crack density growth with applied stress to experimental measurements for any laminate. The cracking process for any other laminate made of the same material may be predicted. The model demonstrates good agreement with published experimental data. The potential of using the probabilistic approach to predict cracking under cyclic loading is discussed as well.