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COMPUTATIONAL APPROACH TO DELAMINATION PROBLEMS FOR ELASTIC LAMINATES USING INTERFACIAL FRACTURE MECHANICS

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ABSTRACT

Delamination is a critical mode of failure for layered materials such as composite laminates. It usually originates from pre-existing defects and results in the progressive separation of adjacent layers (usually of different properties) when loads (mechanical or thermomechanical, static or cyclic) are applied. It eventually leads to catastrophic failure of structures made of those laminates. Hence, susceptibility of those materials to delamination prevents from their wider use in load-carrying aerospace applications. Despite a large effort from research engineers (both experimentalists and theoreticians), better understanding of delamination mechanics, and quantification of factors influencing that phenomenon is still required.

Resistance/prediction to/of delamination growth is a key issue in estimating reliability of a load-carrying laminated structure, and in improving design of advanced laminates. Classical linear elastic fracture mechanics (LEFM) is a very useful tool in inspecting that issue for macroscopically homogeneous materials such as metals. However, delamination should be interpreted as an interface mode of failure, and the classical LEFM loses its validity in that case. Instead, the non-classical elastic fracture mechanics for interface cracks is a very convenient tool in tackling that issue. In particular, it accounts for the mixed mode of stress in the vicinity of a delamination tip, caused by the mismatch in elastic properties of adjacent layers. Then, it also enables to include conveniently effects of a frictional contact between delaminated layers through a stress exponent, which is dependent on the friction coefficient. The entire concept can be implemented into a FEM-based environment, and hence it can result in a useful engineering tool for dealing with delamination problems.

Delamination problem for elastic laminates is investigated here using concepts of interfacial fracture mechanics. For that purpose a 2D computational model is proposed and implemented into the FEM-based framework. That model accounts for two scenarios that can occur during delamination growth. These are: (1) delamination growth with an opened tip, and (2) interface crack propagation with a closed tip

(subjected to unilateral contact with friction). In both cases, the energy release rate is taken as a crack driving force, but it is friction dependent in the latter case. The delamination model is combined with the modified Paris law (expressed in terms of the energy release rate), which is used to predict delamination growth under cyclic loads. The model is implemented into the commercial FEM-based environment using ANSYS to allow for a convenient and robust numerical solution of a highly nonlinear frictional contact problem. In addition, it is combined with a deterministic sensitivity analysis (based on the finite difference method) to investigate influences of composite parameters on the delamination growth, and pinpoint directions for improved laminate design against interfacial fracture.

The computational model is applied to investigate delamination growth in an elastic composite laminate, composed of two layers (Boron-Epoxy and Aluminium). Each of them is modelled as linear elastic and isotropic. The laminate is curved, defined by a constant radius of curvature, to reflect a cross-sectional shape of a fuselage. Quasi-static cyclic shear loads are applied. These specific boundary conditions enable accounting for two different scenarios, for which model was developed. As a result, computational studies show that depending on the position of load application (either to softer or harder material), different deformation behaviour should be expected near the crack tip. In particular, load application to the softer material results in the opening of the delamination tip, while delamination tip closure results from load application to the harder material. This has serious implications towards the rate of delamination growth and the number of fatigue cycles to failure. In particular, the strain energy is dissipated only due to interfacial fracture when the crack tip is opened, while the crack driving force is diminished by the energy dissipated due to frictional contact when the crack tip is closed. As a result, the rate of delamination growth is larger and the fatigue life is shorter in the former case. Hence, the near tip frictional contact retards or even arrests (for larger values of friction coefficients) the delamination process, and extends the fatigue life of the composite. Then, sensitivity studies reveal that the elastic constants (Young's modulus and the Poisson's ratio) of both layers are most crucial parameters affecting delamination growth and the fatigue life of the laminate.

The computational model is verified against analytical solutions for stresses, the Virtual Crack Closure Method for the fracture parameter, and the sensitivity gradients are compared with those obtained from the sampling-based method. Very good agreement is obtained in all those verification tests.

It is believed that the computational approach proposed here is a useful tool for engineers analysing delaminations and designing advanced layered materials. This approach can be easily implemented with post-processing routines of a commercial FEM-based package, other than ANSYS.