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A NUMERICAL FRAMEWORK FOR SIMULATING PROGRESSIVE FATIGUE FAILURE IN COMPOSITE LAMINATES

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ABSTRACT

Fatigue is one of the main long-term failure mechanisms in composite structures. In order to speed up the design process and to reduce the number of tests to be carried out for ensuring safety of new composite designs, virtual testing tools need to be developed that accurately simulate the various failure processes and their interactions under fatigue loading conditions.

In this work we present a numerical framework for simulating high-cycle fatigue failure in composite laminates. For modeling initiation and propagation of matrix cracks and delamination, the state-of-the-art cyclic cohesive zone model (CZM) by Dávila [1] is used. The model only requires a few fatigue parameters based on S-N curves and simple engineering assumptions for including the effect of the mode-mixity and stress-ratio, thereby keeping characterization efforts limited.

As a part of our work, we have improved the existing formulation of the fatigue CZM as presented in Ref. [1], by using an implicit time integration scheme for updating the fatigue scalar damage variable. The damage variable is updated by performing Newton iterations at local integration point level. In combination with an adaptive time stepping scheme based on the convergence behavior of the previous global iteration, much larger cycle jumps can be used in comparison to the damage update procedure presented in Ref. [1], which is crucial in full laminate analyses. Furthermore, in the previous implementations of the formulation in Ref. [1], a numerical tangent stiffness matrix is used, based on finite differences. However, the choice of the magnitude of the difference perturbation can influence the robustness and efficiency of the simulation. Therefore, the traction update algorithm is consistently linearized to obtain the consistent tangent stiffness matrix. In order to simulate the initiation and propagation of mesh-independent matrix cracks, the fatigue CZM has been combined with XFEM [2] (see Figure 1).

The cyclic cohesive zone model is used to simulate fatigue crack growth in a double cantilever beam specimen. It is demonstrated that the implicit time integration scheme of the damage variable improves the robustness and allows for more efficient analyses in combination with an adaptive time stepping scheme and the consistent tangent stiffness matrix. Furthermore, the model is applied to the simulation of an open-hole [±45]-laminate under fatigue loading. It is shown that the numerical model can accurately simulate the interaction of matrix cracking and delamination.

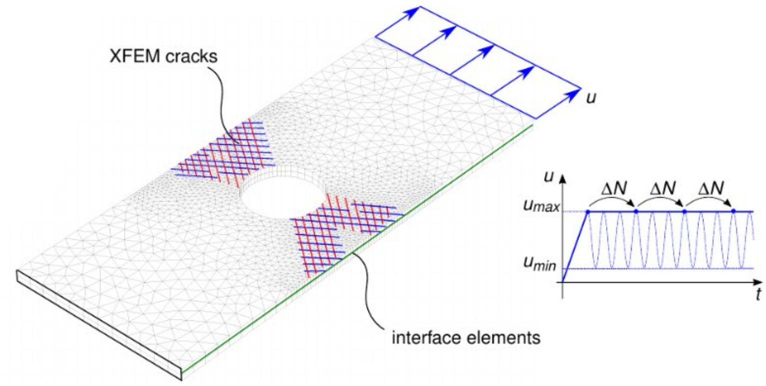

Figure 1: Numerical model of an open-hole [±45]-laminate under high-cycle fatigue loading.

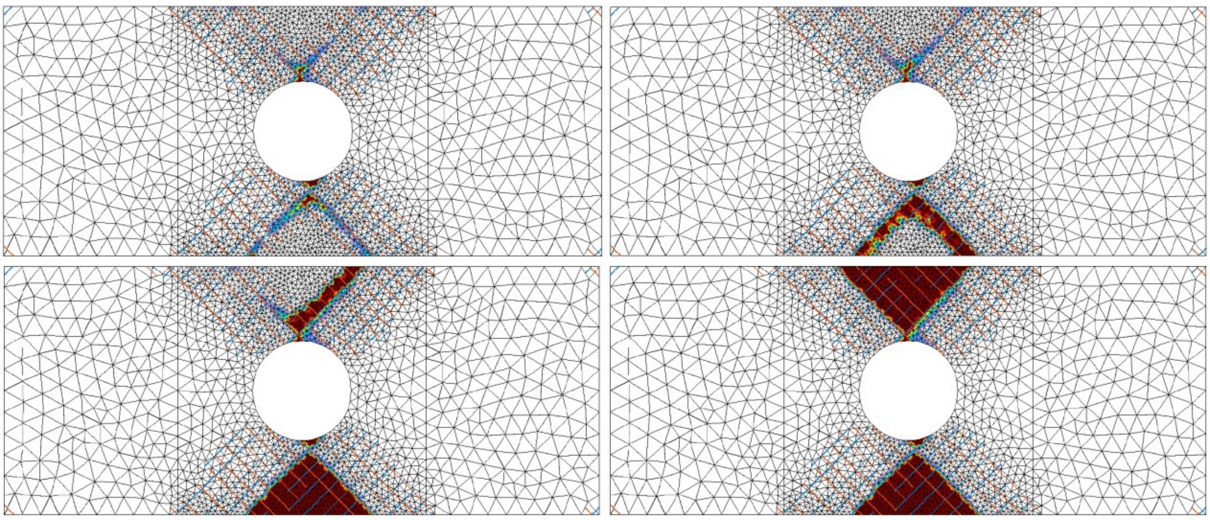

Figure 2: Evolution of delamination damage in an open-hole [±45]-laminate due to cyclic loading. The dark red color indicates fully damaged material. XFEM cracks are indicated with red (bottom ply) and blue (top ply) lines.

REFERENCES

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