Simulation of Delamination Migration in Laminated Composite Structures

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How can the failure of a fiber reinforced composite structure be predicted? This is one of the key issues that any engineer must deal with when designing lightweight components in such materials. Yet, it is not fully understood how the different failure mechanisms interact with each other, and the complex material modeling offers several challenges. In this master thesis[1]*, a modeling approach is developed that is able to predict the interaction between interface cracks and ply cracks, which causes delamination to migrate.*

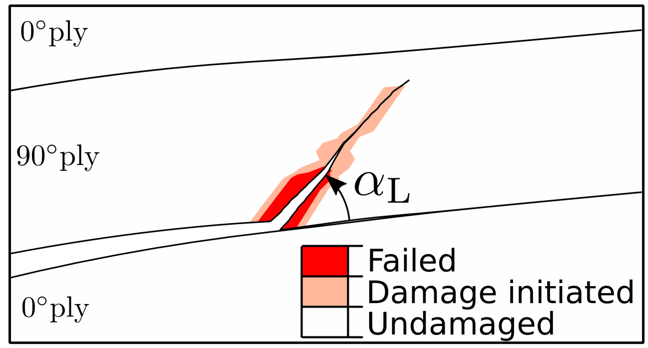

Figure 1. Predicted crack path for the delamination migration in a cross-ply laminate. The failed region corresponds to the physical crack face and the damaged region is the cohesive zone in front of the crack tip.

Fiber reinforced polymers (FRP) provide unique material properties for the design of lightweight components, primarily used in the wind energy- and aerospace industry. It is thereby essential to develop modeling techniques and methods that enable predictions of how and when a component is going to fail.

The FRP structure is built up by plies in each of which the fibers are aligned in the same direction. By stacking the plies in a certain sequence, the appropriate structural behaviour is obtained. When delamination takes place, a crack is formed between the plies and propagates in the ply interface. Eventually, this can lead to that the crack kinks out of the interface and into one of the adjacent plies and thereby causing the delamination to migrate from one ply interface to another (Fig. 1).

Due to the complex micro structure and anisotropic material response, numerical modeling can be done in several different ways, depending on if the material is modeled on a micro- meso- or macroscopic scale. By assuming homogeneous material properties in the individual plies, a continuum model of the structure is created within the finite element method. With the "smeared-out" material properties, stresses and strains can be calculated in the material without modeling of the actual fibers. Thus, the simplified model is less computationally expensive than if the complete micro structure would be modeled.

Two experimental tests are simulated to evaluate the accuracy of the modeling approach. The prediction of the crack path during failure of the structure and the location of the different fracture events (Fig. 2) are in good agreement with the experiments. By utilising the extended finite element method, arbitrary crack paths can be predicted in the plies, almost independent from the mesh topology. Additionally, a progressive damage model is employed to account for damage ahead of the crack tip. This is an efficient way of modeling propagating cracks, as the mesh does not have to be redefined as the crack propagates and the same mesh can be used throughout the simulation.

The location where delamination migration takes place is found to be dependent on the fracture toughness of the interface. Small variations of the ply interface properties can thereby have an impact on the failure of the structure, but are on the other hand difficult to accurately measure in practice.

The results from the simulations show that the extended finite element method can be combined with a cohesive zone model to simulate delamination migration. However, improvements can be made by introducing more sophisticated fracture criteria with a stronger coupling between inter- and intralaminar cracks. In the ultimate application, such numerical models can be used to predict the failure of arbitrary laminated structures. Thus, the development of strong and durable FRP components is enabled in a time and cost efficient way.

[1] V. Björklund. *Simulation of Delamination Migration in Laminated Composite Structures – An Approach Combining Extended Finite Elements and a Cohesive Zone Model*. Master's Dissertation, Lund University, 2018

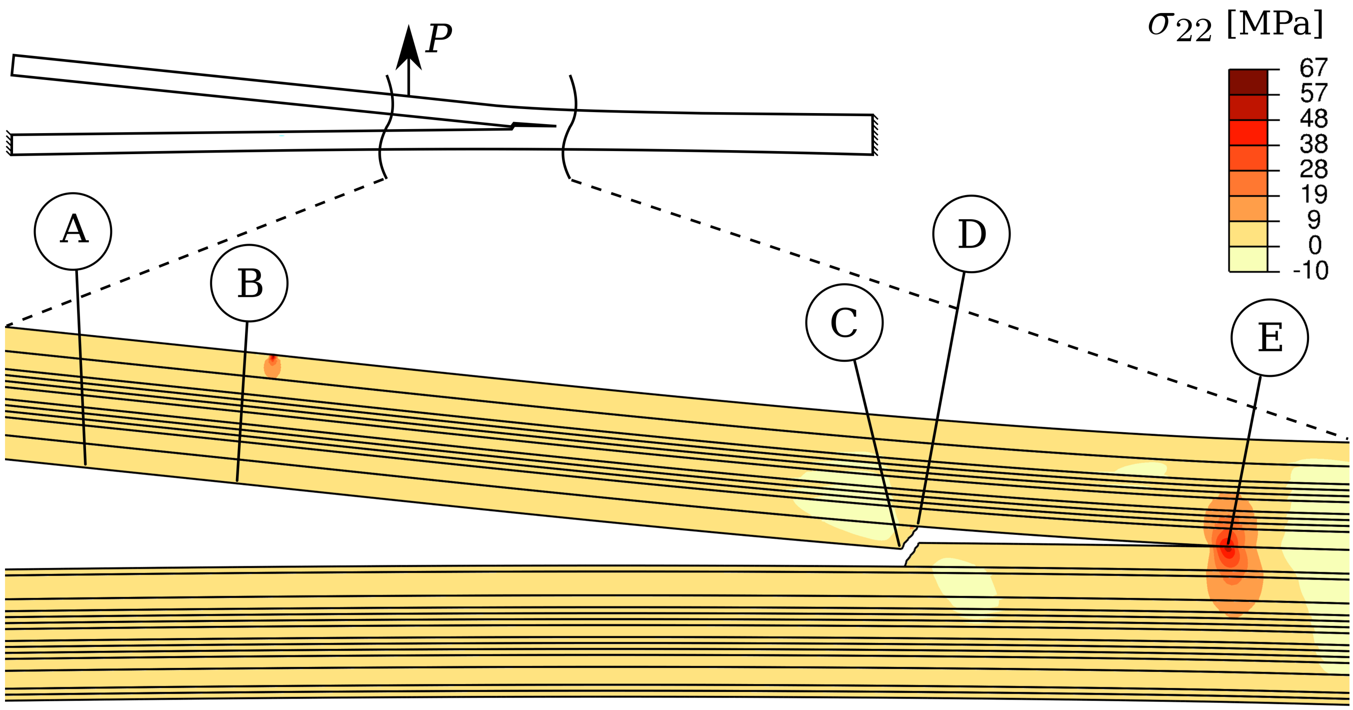

Figure 2. The predicted failure of a cross-ply laminate. An initial delamination front is located at (A) and delamination migration takes place between (C) and (D). The crack propagation is unstable between (B) and (E).