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COHESIVE ZONE MODELLING OF WRINKLE DEFECTS IN GLASS-EPOXY LAMINATES USING USER FINITE ELEMENT FEATURE

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In recent years cohesive zone modelling approaches are becoming more and more popular for the prediction of onset and growth of cracks in laminated composite structures. Despite that cohesive zone modelling is becoming available in commercial finite element software, there are still many challenges to be addressed in order to improve the reliability, numerical robustness and spread the applicability of the method.

This work considers strength analysis of wrinkle defects in glass-epoxy laminates and is a continuation of the work presented in [1-4]. The work is conducted in collaboration with Siemens Wind Power A/S which is one of the leading manufacturers in the wind turbine industry. The wind turbine blades manufactured by Siemens Wind Power A/S are made of glass-epoxy laminated sandwich materials using balsa wood as core material. In the infusion process of such large scale laminated composite structures several types of manufacturing defects may arise. One of these defects is an out-of-plane fiber misalignment, also known as a "wrinkle" defect. Such a defect is critical to the structural performance, since it may initiate delaminations, which eventually may lead to structural collapse of the blade during operation. In previous work [4] the stress based NU criterion has been applied to predict the occurrence of delaminations in wrinkle defects. However, the NU criterion only provided information regarding delamination initiation which was found through experimental testing of a wrinkle test specimen to be significantly lower than the load carrying capacity. In this work, cohesive zone modelling is applied in the framework of the finite element method to better predict the static strength of a wrinkle defect.

A user programmed element is developed and implemented in the commercial finite element program ANSYS Mechanical 14.5 for the purpose of conducting strength analysis of wrinkle defects, since all options in the element affecting results and convergence rates would be accessible to the user. Among these options are: integration rule, order of integration, mode interaction criterion, numerical damping, computation of tangent stiffness matrix and internal force vector as well as non-standard result output such as element damage, energy dissipation, and average mode mixity. All these options are very important and essential in the establishment of a robust and reliable numerical finite element model using cohesive zone elements.

The cohesive zone element is implemented in ANSYS Mechanical as a user programmed feature (UPF) [5] and is based on the formulation in [6]. The developed UPF is a zero thickness bilinear eight-noded isoparametric element, uses a bilinear traction-separation law, and is capable of simulating mixed mode crack development in 3D. The Benzeggagh-Kenane criterion [7] is used to determine equivalent properties for a given mode mixity and the damage evolution law is based on a single scalar damage parameter.

The implemented cohesive finite element is benchmarked against the ANSYS Mechanical available cohesive zone element, INTER205 [8], and significantly better convergence rates of 15% to 100% percent are obtained on standard test cases of DCB, ENF, and MMB test specimen using the standard arc-length solver in ANSYS Mechanical.

It is well-known that convergence problems may appear when cohesive zone models are used to predict crack initiation in relatively coarse meshed models. The typical remedy to this problem is to either refine the mesh if possible or lower the onset traction in the constitutive law for the cohesive interface. In this work we clearly demonstrate by parametric studies on DCB specimens that the latter approach may lead to underestimated load carrying capacity.

In the strength analysis of the wrinkle defect major convergence issues are encountered. These issues are especially related to the high onset traction needed in order to properly predict crack initiation without introducing non-physical compliant behaviour of the cohesive interfaces. Actions and solutions to overcome these convergence problems will be presented together with numerical simulations of the failure delamination process of the wrinkle defect.

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