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PROPOSITION DE SUJET DE THESE

Intitulé: Prediction of delamination propagation during complex fatigue loading of laminated composite structures using incremental damage cohesive zone models

Référence : **MAS-DMAS-2025-22**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2024	**Date limite de candidature :** 01/04/2024

Mots clés

Fatigue, incremental damage model, cohesive zone element, laminated composite

Profil et compétences recherchées

Master's degree or engineering school, specialising in simulating and testing on composite structures.
Good knowledge of damage mechanics, the finite element method and an interest in carrying out fatigue tests.

Présentation du projet doctoral, contexte et objectif

Laminated composite materials with high specific properties are being used extensively in the manufacturing of the latest generation of civil aircrafts to meet the demands of the aerospace industry for lighter, safer and less polluting civil aircrafts.

As composite laminates have higher fatigue resistance than metallic materials, composite components are subjected to increasingly severe loading conditions and for longer lifetimes. The estimation of the fatigue lifetime or the residual properties after fatigue loading will become an industrial issue in the next few years. Strength and fatigue lifetime are strongly related to the damage state within the composite, and in particular to the presence and propagation of delamination cracks. The prediction of delamination evolution during complex fatigue loading and its influence on the residual strength of the material are still scientific challenges.

Therefore, the proposed thesis deals with the experimental and numerical study of the delamination evolution during fatigue tests applied to laminated composite structures subjected to complex industrial spectral loads.

In order to establish the damage and failure scenario of a new generation of carbon/epoxy laminates, some multi-instrumented fatigue tests will be carried out. Particular attention will be paid to the accurate determination of the position and shape of the delamination crack front during the fatigue tests, using various measurement techniques such as digital images correlation, infrared thermography or X-ray tomography for interrupted tests. Some fatigue tests are stopped and then re-subjected to static loading in order to provide an experimental estimate of the residual properties of the material. In addition, some delamination propagation tests already carried out in the AMADE laboratory and at ONERA could also be considered.

A unified damage model for delamination during both static and fatigue loading for laminated composite materials manufactured with unidirectional plies is proposed in this thesis. Existing cohesive damage models [1,2] have already been developed at the AMADE laboratory for many years to simulate delamination propagation during fatigue loading. The proposed damage laws depend on the number of cycles, and other parameters describing the fatigue loads, which is well adapted and efficient for cyclic loading, but remains difficult to use for complex spectral industrial loading. The main objective of this thesis is to develop a cohesive zone damage law based on an incremental damage formalism, as it has recently been performed to predict the evolution of transverse crack density [3,4] in different laminates subjected to static and fatigue loading. Such a methodology is an alternative to the Rainflow method, associated with the classical cumulative damage approach, and allows the consideration of real spectral fatigue loading without additional assumptions.

The present approach will be identified and validated using the experimental data generated in this thesis and also found in the literature. A clear identification procedure will be developed, taking into account the information provided by the different measurement techniques. Then, the fatigue lifetime predictions will be compared with experimental data to determine the predictive capabilities of the model on some test cases defined during the thesis with increasing complexity.

Finally, the present incremental damage approach will be implemented in a commercial finite element code in order to predict the fatigue lifetime of laminated composite structures. In order to limit the computational time of such a simulation for a large number of cycles (about 10^6 cycles), an efficient computational strategy, based on a cycle jump method [5] developed at ONERA, adapted to the incremental damage formalism, will be proposed and adapted to the specificities of cohesive zone elements.

This doctorate thesis will be co-financed by ONERA and the University of Gerona (UdG). It will be carried out in the AMADE laboratory in Gerona (Spain) and also in the Materials and Structures Department of ONERA in Châtillon (France).

[1] Turon A., Simulation of delamination in composites under quasi-static and fatigue loading using cohesive zone models, doctorate thesis of University of Gerona, 2006.

[2] Carreras L., Development of efficient testing methods and cohesive zone models for analysing fatigue-driven delamination, doctorate thesis of University of Gerona, 2018.

[3] Patti S., From an experimental study of static and fatigue transverse matrix cracking in laminated composites towards damage prediction using an incremental model with an observable variable, doctorate thesis of Paris-Saclay University, 2023.

[4] Llobet, J., A constitutive model for fatigue and residual strength predictions of composite laminates, doctorate thesis of University of Gerona, 2019.

[5] Sally O., Julien C., Laurin F., Desmorat R., Bouillon F., Fatigue lifetime modeling of oxide/oxide composites, Procedia Engineering, 213 (1), 2018, pp. 797-803.

Collaborations envisagées

University of Gerona (UdG), AMADE Laboratory, Spain

Laboratoire d'accueil à l'ONERA	**Directeur de thèse envisagé**
Département : Matériaux et Structures Lieu (centre ONERA) : Châtillon **Contacts** : Frédéric Laurin Tél. : +33 1.46.73.46.92 Email : frederic.laurin@onera.fr	Nom : Turon Albert Laboratoire : University of Gerone, AMADE, POLITÈCNICAII Campus Montilivi 17003 - GIRONA Tél. : (+34) 972 41 8492 Email : albert.turon@udg.edu

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