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Evaluation d'une méthode de modélisation des assemblages collés composites par la technique des éléments cohésifs.

par

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Résumé traduit :

Les travaux ont été réalisés dans le cadre du projet MAAXIMUS FP7 qui visait à développer des fuselages d'avions composites hautement optimisés. Parmi les objectifs à atteindre, les questions de vulnérabilité étaient notamment abordées, avec un intérêt particulier pour la tenue aux chargements d'impact des jonctions collées, aujourd'hui largement répandues dans les structures aéronautiques composites. Le présent article concerne ainsi l'évaluation des capacités du code EUROPLEXUS à modéliser des jonctions composites représentatives d'assemblages fuselage/raidisseur par co-bonding. Dans ce but, un programme d'essai a d'abord été réalisé, incluant d'une part des essais sur éprouvettes Double Cantilever Beam (DCB) et End Notch Flexure (ENF), et, d'autre part, des essais sur éprouvettes peau/renfort. Dans un deuxième temps, l'étude a porté sur l'évaluation d'une méthodologie de modélisation reposant sur la méthode des éléments cohésifs, au travers de la simulation des essais DCB et ENF afin de valider l'approche en mode de sollicitation pure, puis de la simulation des essais sur éprouvettes peau/renfort pour l'évaluation finale en mode de sollicitation combinée.

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ASSESSMENT OF A MODELLING METHOD FOR COMPOSITE BONDED JOINTS USING COHESIVE ELEMENTS METHOD

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Introduction

Works have been performed within the EU FP7 MAAXIMUS project that aimed at achieving fast development and right-first time validation of a highly-optimised composite fuselage. Among the targeted objectives, vulnerability issues were notably addressed, with a specific emphasis for the resistance to impact threats of bonded joints, today widely applied in aeronautical composite structures. The present paper thus concerns the evaluation of the EUROPLEXUS code to model composite joints representative of co-bonded stringer-skin junctions. In that goal, a test programme was first performed, including, on one hand, tests on Double Cantilever Beam (DCB) and End Notch Flexure (ENF) specimens, and, on the other hand, on Skin-Doubler specimens. In a second step, the study then aimed at assessing a modelling method involving cohesive elements techniques, by first simulating the DCB and ENF specimens in order to evaluate the model in pure mode loading, and then the Skin-Doubler specimens for final assessment in mixed mode loading.

Tests data

DCB and ENF tests - Mode I and mode II fracture toughness energies

The experimental campaign on DCB and ENF specimens has been presented in [1]. Specimens were extracted from assemblies made of 2 co-bonded $[0_{15}]$ carbon fabrics laminates, with a PTFE foil insert to generate an initial pre-crack.

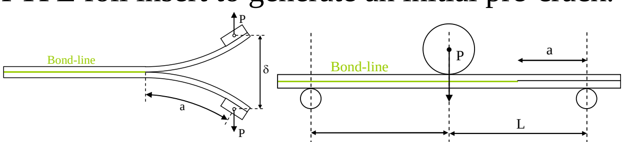

Figure 1: DCB and ENF tests specimens

Tests were exploited respectively according to the AITM 1.0053 [2] and the IGC 04.26.382 test standards [3], and led to the following fracture toughness energies.

Table 1 : DCB and ENF tests results

G_{IC} (N/mm)	G_{IIC} (N/mm)
0,648	1,638

Skin-Doubler tests – Mixed mode loading

Skin-Doubler specimens aim to introduce a combination of peel and shear forces into the bond-line. The specimen specifications are summarized in the following table.

Table 2 : Skin-Doubler specimens specifications

Skin lay-up	[45/135/0/90/135/45/0/45/135/ 90/0/135/45]
Doubler lay-up	[45/0/135/0/90/0/135/0/45]
Skin length	180mm
Doubler length	40mm
Width	20mm

The specimens are tested in static with the recording of the load (P) and opening (δ) data, using a four-point bending test device with the span lengths set to 120mm and 70mm. Results are presented in the following figure in terms of force/displacement curves for the 5 statically tested specimens.

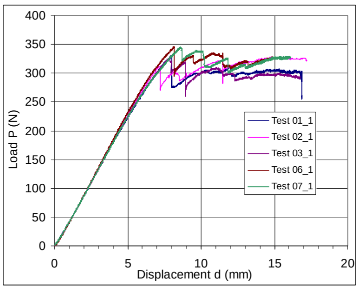

Figure 2: Four-Point Bending test on Skin-Doubler specimens

Numerical modelling

Bonded joint modelling method

The bonded joint is modelled with cohesive elements associated with a traction-separation law defined by the following parameters:

- Stiffness :
  - Transverse stiffness: k_3^0
  - Shear stiffness : k_1^0 and k_2^0
- Energy release rates G_I, G_{II}, G_{III}
- Damage law (3 options)
  - Exponential law
  - Bi-triangular law
  - "Cachan" law

Evaluation of the method in mode I and II

The evaluation of the modelling method, presented in [1], was performed using as starting point the parameters identified from the experimental campaign on DCB and ENF specimens. In mode I, the analysis referred to the Turon works [4] which aim at defining a calibration criterion for delamination in composites. Results, shown in the following figure, proved to lead to a convenient correlation, whatever the traction-separation law. For mode II, results showed that the onset of debonding was predicted significantly sooner than in the tests, whatever the law, thus requiring calibration.

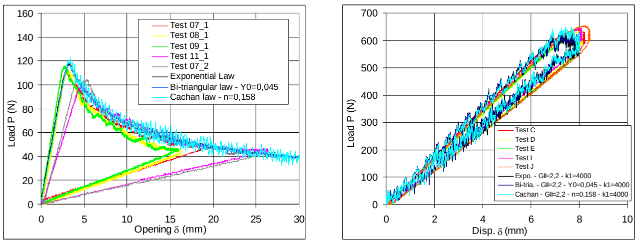

Figure 3: Num./Exp. comparison for the DCB and ENF specimens

Evaluation in mixed mode I/II – Simulation of the Skin/Doubler specimens

The bonded joint of the Skin-Doubler specimens is modelled with 2mm mesh size cohesive elements, with the mode I and II traction-separation law parameters as defined from the DCB and ENF simulations.

Table 3 : Traction-separation law parameters

k_3^0 (MPa)	G_I *(N/mm)*	$k_1^0 = k_2^0$ (MPa)	G_{II}=G_{III} *(N/mm)*
2500	0,648	4000	2,2

The loading is applied through a progressive imposed velocity on the upper and lower fixtures. Simulations are run with the exponential law only. As set-up, numerical results compared with the tests data show that the onset of debonding initiates with a significant delay compared to the experiments, resulting in an overestimation of the force levels in the debonding phase. Such results confirm the conclusions drawn in [5], by the fact that the Skin/Doubler specimens present no initial pre-crack, by contrast to the DCB and ENF specimens. This implies, all the more for mode I loading (which is here predominant), that the Turon criteria cannot be directly applied, which consequently requires further calibration of G_{IC} (to G_{IC}=0,3N/mm) so that debonding initiates conveniently, as illustrated in the following figure which shows a correct estimation of the force at debonding onset and during the debonding development.

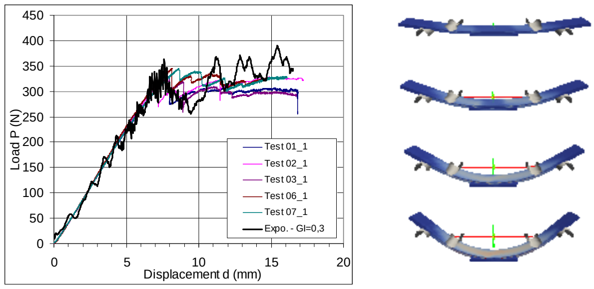

Figure 4: Num./Exp. comparison for the Skin/Doubler specimens

Conclusions

Works targeted at evaluating a numerical method to model composite bonded joints with cohesive elements, using the EUROPLEXUS code. In a first step, DCB and ENF specimens have been tested and simulated to assess mode I and mode II properties. Following, the numerical method has been applied to the simulation of Skin-Doubler specimens for mixed-mode validation. Works thus permitted to identify a convenient set of parameters applicable for modelling stringer-skin junctions.

Acknowledgments

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