

DISCRETE PLY MODELLING OF NOTCHED CFRP PLATES UNDER TENSION

Joël Serra¹, Christophe Bouvet¹, Bruno Castanié¹, Caroline Petiot²

¹ Institut Clément Ader (ICA) Université de Toulouse – INSA-ISAE-Mines Albi-UPS
3 rue Caroline Aigle, CNRS UMR 5312, 31400 Toulouse
<http://www.institut-clement-ader.org/>
e-mail : bruno.castanie@insa-toulouse.fr

²: AIRBUS GROUP INNOVATIONS, 12, rue Pasteur, 92152 Suresnes, France

Keywords: Composite structures, Notch, Finite Element, Discrete Ply Modeling

ABSTRACT

Numerical and experimental investigations under tensile loading of notched specimens were carried out. Three different carbon/epoxy laminates are studied. The tests were analysed with DIC and infrared thermography. A computational study of notched tensile tests using the Discrete Ply Modelling (DPM) method, which has already proven efficient on both in-plane and out-of-plane loading cases, such as pull through, low velocity impact and compression after impact is developed. The specificities of this finite element model are its discrete nature (interface elements to model delamination and matrix cracks), the small number of parameters required and its robustness. This work is in the continuity of the study of open-hole tensile tests (same three layups) by the authors [1]. Influences of layup and notch shape have been analysed. Comparisons with experiments demonstrate that tensile strengths, and failure scenarios and patterns are predicted with acceptable accuracy.

1 INTRODUCTION

The problem of large cuts in composite structures is a priority for the aeronautics industry within the framework of damage tolerance. Indeed, a composite fuselage must withstand static forces enabling a continuation of the flight, even after suffering significant damage caused for example by the breakage of rotating parts of the engines. This last accidental case may lead to a tearing of the fuselage. The design must then cover this "two-bay crack" case, which implies supporting the in-flight load even in the presence of a notch length corresponding to the distance between two bays crossing a frame. An example of a test with this type of damage is shown Figure 1.

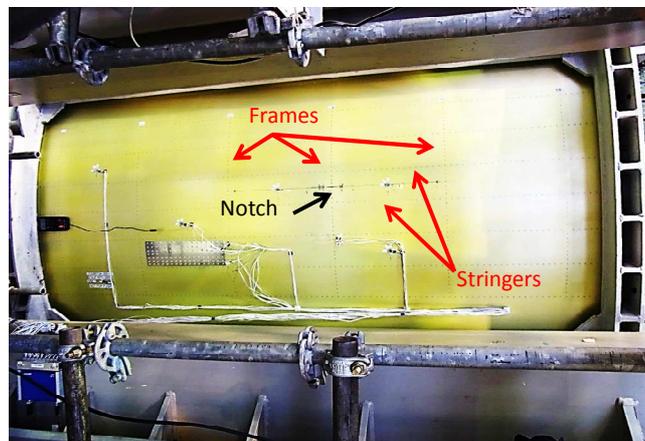


Figure 1 - Two-bay crack test on a fuselage part (courtesy of Airbus).

Due to the sharp shape of the notch, strong gradients of strains at the tip of the notch occur. Due to these particularly local effects, damages and mechanisms of failure can be different with regard to the initiation of damage, its nature and propagation. A monitoring strategy of tests coupling different techniques is therefore proposed as well as the establishment and validation of a numerical modeling of the failure of the notched laminate using the Discrete Ply Model. For this study, the curvature of the fuselage skin as well as the stiffeners is not modeled. The analysis is carried out on a flat plate provided with a cut in its center (see fig. 2). This work is an extension of the study of carbon-epoxy composite laminates subjected to simple traction by [1]. The same stacking sequences are studied.

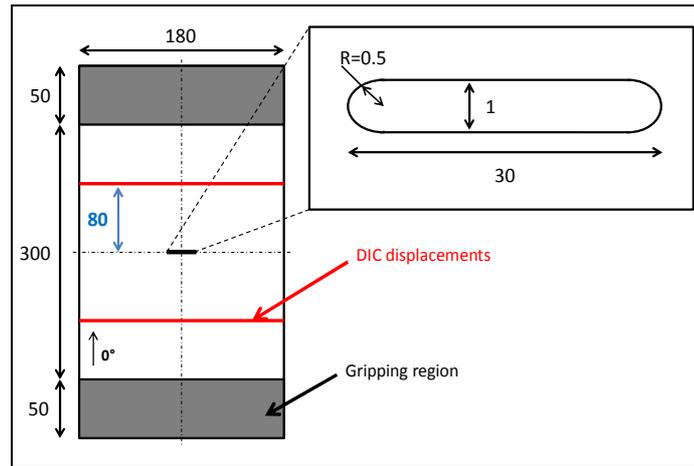


Figure 2: Notched specimen geometry (dimensions in mm).

2 MATERIALS AND METHODS

The material investigated in the present study is Hexcel's T700-M21 carbon epoxy unidirectional laminate with a nominal ply thickness of 0.125 mm. Three symmetric stacking sequences of 13 plies were studied. They present the same number of ply in each direction (0° , 90° and $\pm 45^\circ$), and only the relative position of plies changed between layups:

- C3-1 [45/-45/X/X/X/90/0/90/ X/X/X /-45/45]
- C3-2 [X/X/X/X/0/90/0/90/0/X/X/X/X]
- C3-3 [X/X/X/X/X/0/0/0/X/X/X/X/X]

Due to Privacy Policy, the stacking sequences cannot be fully disclosed in this article. The studied sample is 180 mm width and 400 mm length (not taking into account the grips) with a 30 mm central notch with a 0.5 mm end notch radius (Fig. 2). The tests are carried out on a SCHENCK electromechanical traction machine with a capacity of 250 kN at a traction speed of 0.02 mm/s. The machine provides a measure of displacement and effort. To have a more precise value of the displacement, a linear displacement sensor is placed on the upper jaw. The tests are followed by digital Image Correlation and by infrared camera (two faces of the test piece). The images are analyzed with VIC 3D and ALTAIR software respectively. The monitoring by infrared camera is carried out continuously.

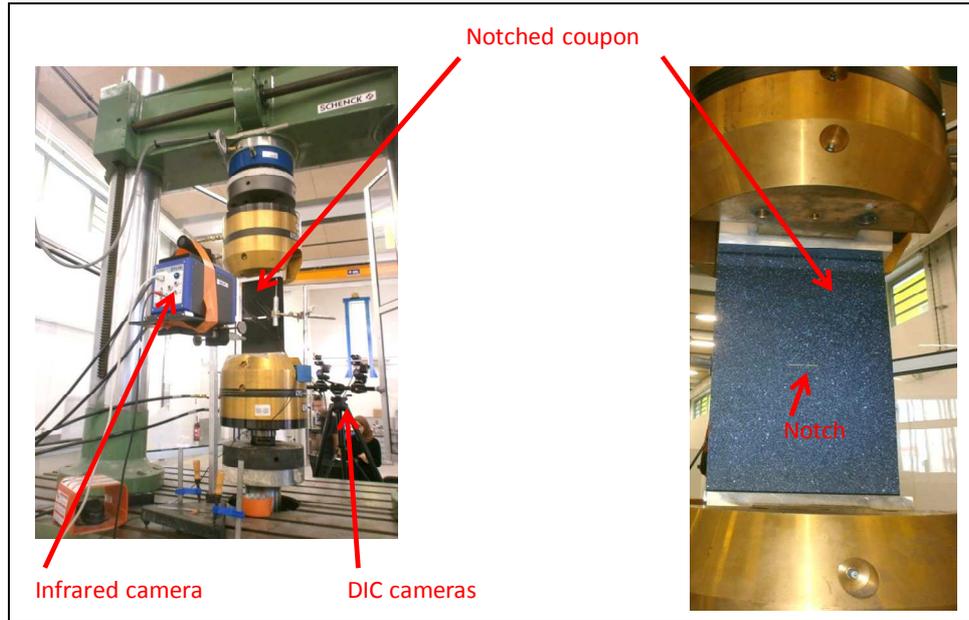


Figure 3 - Experimental setup for the notched quasi-static tension test.

3 EXPERIMENTAL RESULTS AND ANALYSIS

The stress and strain values presented in Figure 4 are normalized using the maximum values obtained during tensile tests on pristine specimen (C3-3, [1]) as references. On average, stacking C3-2 and C3-3 show a slightly higher failure stress than stacking C3-1. The differences between the laminates are strongly attenuated in comparison with the plain and open hole tests [1]. Since the failure stresses are smaller than for the holes, the edge effects become insignificant.

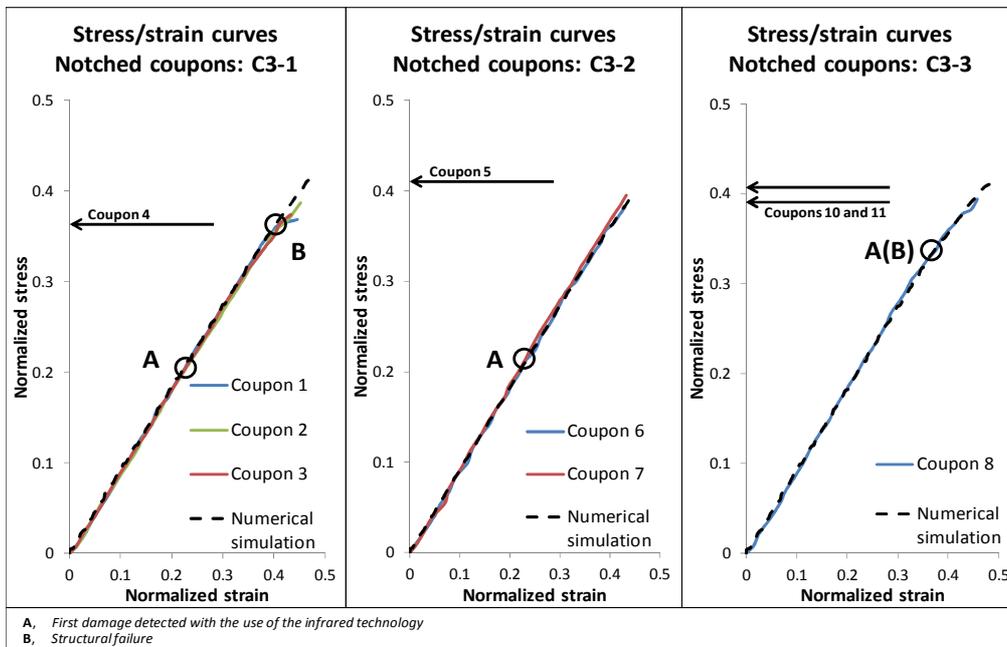


Figure 4 – Stress/strain curves of the three notched layouts (C3-1, C3-2 and C3-3) - comparison between numerical and experimental data.

The first damages observed on the C3-1 laminate are seen from from point A (Fig. 4). It may be

fiber/matrix decohesion, matrix cracking, delamination or fiber breakage. The failure mode releasing the most energy is obviously the rupture of fibers. A local increase in temperature of about one degree was observed in figure 5, seems to indicate such a mode of damage. The other modes of rupture, less energetic, increase the temperature locally by a few tenths of a degree [3]. Once the propagation has begun, there are local heat increases on the right side of the notch, point B, Fig 5. The latter appear to be relatively symmetrical on either side of the notch Fig. 5). The damage thus continues to progress and a sudden final failure occurs. The failure propagates explosively, slightly oriented by a few degrees with respect to the horizontal. After failure of the laminate, a symmetrical pull-out pattern is obtained. The C3-2 and C3-3 laminate failure scenarios are very similar to that observed for C3-1 draping. From point A (Fig. 4), the damage progresses on each side of the notch and causes the specimens to break completely. In the same way as for C3-1, the fracture pattern of C3-2 and C3-3 appear to reveal a failure of the fibers at 0° with an orientation in a direction approximately orthogonal to the direction of traction. .

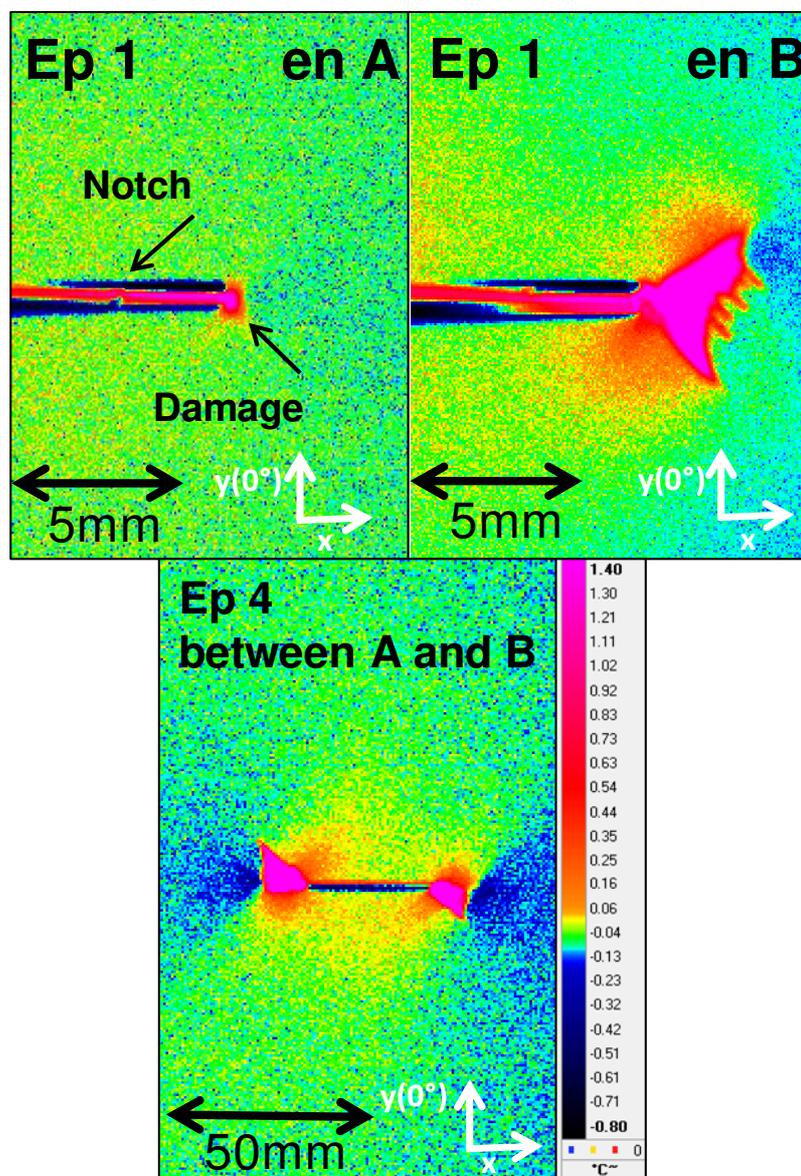


Figure 5 – Damage progression in coupon n°1 (wide shot) and n°4 (close-up) observed by IRT camera.

4 DISCRETE PLY MODELING

The behavior of the tensile test specimens subjected to tension is simulated using the Discrete Ply Model, whose characteristics are detailed in [4-6] and the architecture shown in Figure 6.

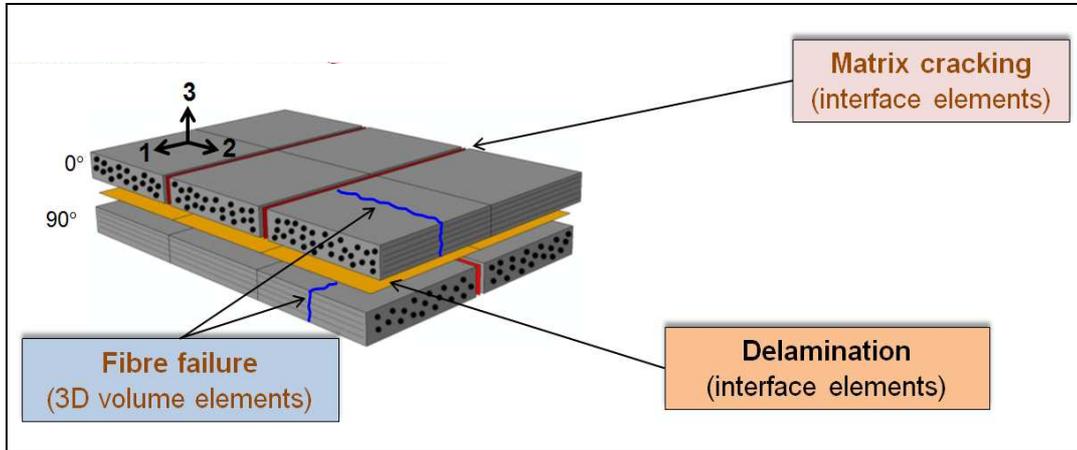


Figure 6 – Discrete Ply Modeling principle.

Since specimens are large ($180 \times 300 \text{ mm}^2$), meshing all the laminate with the same mesh density would have led to prohibitive calculation costs. To overcome this difficulty, two types of elements are used: damaging elements: C3D8 and COH3D8, and non-damaging elements: C3D8R - respectively blue and gray in Fig. 6). For these two types of elements, one element per ply is used. A third type has been added: C3D8 elements away from the cut (blank in Fig. 7) with a single element in the thickness and the homogenized behavior of the laminate.

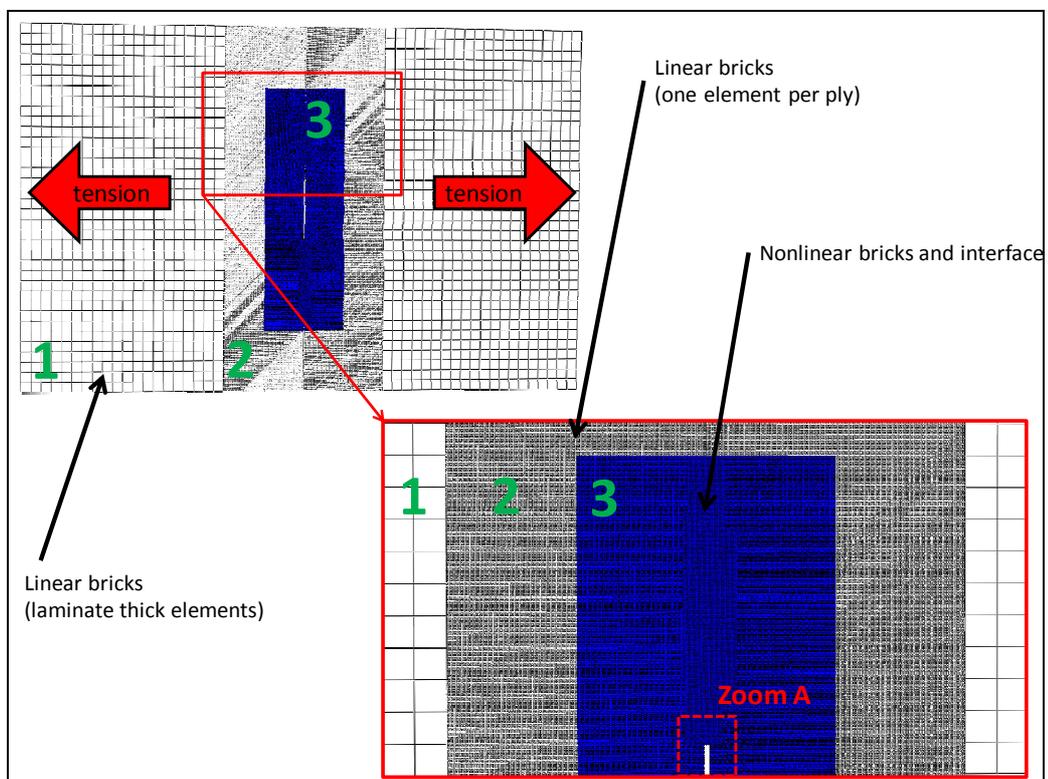


Figure 7: Numerical model of a notch specimen under tensile stress.

Since damage progression is substantial before total failure, a customized management of the distorted elements had to be implemented. First, the calculation was divided into two parts: one step including very little damage (corresponding to the stress/strain curve part before A in Figure 4) and the second step from the initiation of the damage propagation until total failure of the laminate. For the second part, step time is set to one third of the first one's. Moreover, Abaqus "Distortion control" function has been exploited to restrain damaged elements distortion through the use of an artificial energy. It is a posteriori verified that this energy lies under 1% of internal energy.

The overall behavior of the laminates represented by the stress/strain curves seems to be correctly modeled (Figure 4). The evolution of the crack length determined by numerical simulation, obtained by taking the number of volumetric elements (representing the rupture of fibers of the central fold at 0°) completely damaged, is in complete conformity with that detected by infrared analysis for the C3-1 specimens. In particular, the initiation of the crack propagation and its maximum amplitude before total rupture (8% of the ligament) are simulated with good precision [2].

9 CONCLUSIONS

Tests on specimens have confirmed the tendency observed on specimens with holes [1]: in spite of cut sensitivity (hole and notch) greater than the other two other laminate (C3-1 and C3-2), the C3- 3 has the highest failure stress. Differences between the failure stresses of the holes and notches are related to the type of geometry. After using various monitoring techniques to decipher the behavior of the notched specimens, the method of determining the change in the cut length using infrared tracking was more accurate than that using the Digital Image Correlation. As a result of the various numerical model changes required to simulate the behavior of notched specimens with reasonable computational times, the numerical results were validated by the experiments. The "Discrete Ply Model" has thus proved its effectiveness in modeling the behavior of "coupon" specimens with a stress concentration of cut type (holes of different diameters [4] and notch) and subjected to tension.

ACKNOWLEDGEMENTS

The research and results presented in this paper were granted by the National Research Agency, VERTEX project, MATETPRO (ANR - 12 - RMNP-0001).

REFERENCES

- [1] J. Serra, C. Bouvet, B. Castanié, C. Petiot. Scaling effect in notched composites: The Discrete Ply Model approach, *Composite Structures*, 148, 127-143, 2016.
- [2] J. Serra, C. Bouvet, B. Castanié and C. Petiot. Experimental and numerical analysis of CFRP notched coupons under tensile loading. Submitted to *Composite Structures*.
- [3] Lisle T., Bouvet C., Pastor M.L., Margueres P., Prieto Corral R., 2013. Damage analysis and fracture toughness evaluation in a thin woven composite laminate under static tension using infrared thermography. *Composites Part A*, 53, 75-87. doi: 10.1016/j.compositesa.2013.06.004
- [4] Achard V., Bouvet C., Castanié B., Chirol C. Discrete ply modelling of open hole tensile tests. *Composite Structures*. Vol. 113, p. 369-381, 2014.
- [5] C. Bouvet, B. Castanié, M. Bizeul, and J.-J. Barrau, Low velocity impact modelling in laminate composite panels with discrete interface elements, *Int. J. Solids Struct.*, vol. 46, no. 14–15, pp. 2809–2821, Jul. 2009
- [6] S. Rivallant, C. Bouvet, and N. Hongkarnjanakul, Failure analysis of CFRP laminates subjected to compression after impact: FE simulation using discrete interface elements, *Compos. Part Appl. Sci. Manuf.*, vol. 55, pp. 83–93, 2013.