MODELLING OF LOW VELOCITY IMPACTS ON UNIDIRECTIONAL COMPOSITE LAMINATES USING A SEMI-CONTINUOUS STRATEGY

Bassam Mahmoud[1,2], Marcos Colungo Torrecilla[1], Pablo Navarro[1], Steven Marguet[1], Issam Tawk[2], Jean-Francois Ferrero[1]

[1] Institut Clément Ader, Université Fédérale Toulouse Midi-Pyrénées / UMR CNRS 5312 - France
[2]University Of Balamand, Kalhat - El Koura, Lebanon

Keywords: impact, explicit FEM, UniDirectional laminate

Abstract
This paper deals about the modeling of unidirectional composite laminates under low velocity impacts. The modeling of the composite laminate is based on a semi-continuous representation of the material. The structure is modeled at an intermediate scale between a microscopic and a mesoscopic scale. In each ply, the fibers are modeled with 1D rod elements stabilized by a specific resin shell element. In these elements the membrane and flexural behavior are decoupled. For the in plane loading in the fiber direction it behaves like the resin. In the other directions the stiffness is that of the homogenized ply. The laminate is then built by using specific interface elements. Delamination is modeled using bilinear cohesive laws in mode I, II and III. A low velocity impact test is finally modeled in order to validate this semi-continuous approach. The calculation results well correlate the experimental results.

1. Introduction

This paper deals about the modeling of unidirectional composite laminates under low velocity impacts. Impact loading is one of the most critical loading for composite structures. Indeed, the damage induced even by low velocity impacts can lead to the rupture of the structure. The failure scenario of composite laminates is complex, and depends on many parameters like the stacking sequence, the material parameters, the loading or the dimensions of the structure. The damage chronology can be summarized in three steps described in [1]. These steps are matrix cracking, delamination and failure of the fibers.

Numerous studies deal about the modeling of the behavior of unidirectional composite laminates under impact loading. A first approach, initially developed by [2, 3], consists in representing each ply with a damageable homogenized shell at a mesoscopic scale. Delamination is accounted for by using of damageable cohesive elements. Another approach, developed by [4], consists in using cohesive elements not only to model delamination but also to represent intralaminar matrix cracking. This strategy well represents the coupling between matrix cracking and delamination.

In this study, an intermediate modeling scale is used. The composite laminate is modeled using a semi-continuous strategy. For each ply, fibers are represented using 1D rod elements stabilized with a specific 2D "resin" element in which the membrane and flexural behavior are decoupled. Specific cohesive elements are finally used to build the laminate. Low velocity impact tests are modeled and compared to experimental tests. The calculation results well correlate the experimental results.

Excerpt from ISBN 978-3-00-053387-7

2. Low velocity impact tests

Low velocity impact tests are performed in order to observe the damage mechanisms. The results are then used to validate the modeling approach proposed in 3.

2.1. Description

Impact tests are performed, according to the Airbus Test Method (AITM 1-0010), described in [4]. A drop tower device is used. The impactor is hemispherical with a diameter of 16 mm with a mass of 2 kg. The initial velocity is set to 2 m/s, which corresponds to an impact energy of 4J. The impactor displacement and reaction force are recorded during the impact tests. The specimen is rectangular and measures 100×150 mm^2. The laminate is simply supported on a 75×125 mm^2 frame.

The specimens are made of unidirectional T700/M21 composite. Four stacking sequences are studied : $[0_2, 90_2, 0_2]$, $[90_2, 0_2, 90_2]$, $[0_2, 45_2, 0_2]$, $[90_2, 45_2, 90_2]$. The ply thickness is 0.24 mm.

2.2. Results

For each configuration, the load/time curves and the load/displacement curves are recorded. Non Destructive Controls are then performed with a tomograph to observe matrice cracking and delamination. An example is given Fig 1 for the $[90_2, 0_2, 90_2]$ specimen.

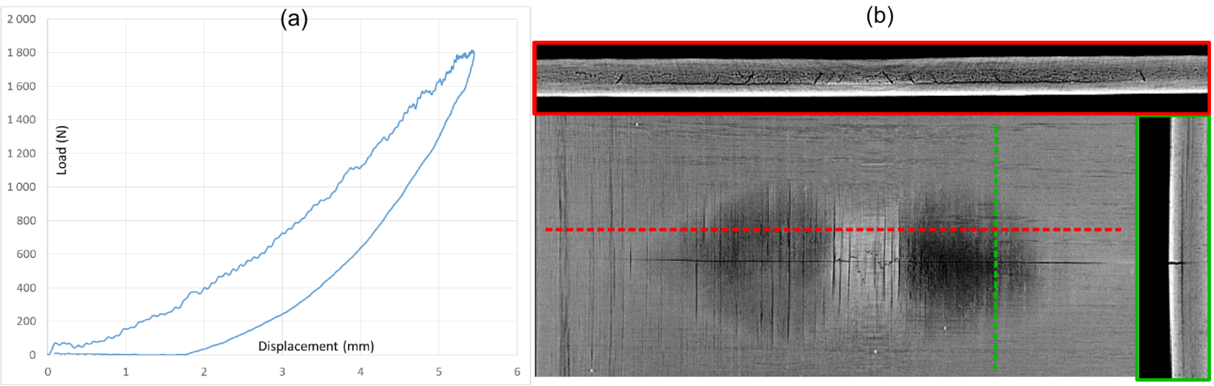

Figure 1. load/displacement curve (a) and example of tomograph images (b) for the $[90_2, 0_2, 90_2]$ specimen .

From these images, the damage scenario has been confirmed. In each ply, two main cracks parallel to the fibers and located near the impact point are observed. This intralaminar damage leads to delamination : the part of the upper ply located between the two cracks pushes the lower ply, which causes the failure in mode I of the interlaminar interface.

3. Modeling

3.1. Description

In light of previous observations, a semi-continuous modeling for the uni-directional composite laminates has been suggested. It relies on the chronology identified experimentally. For the plies behaviour, the idea is to build a modeling which can represent the behavior of the undamaged ply (a continuous panel) as well as that of the damaged ply (non-stabilized bundles of fibers). Therefore, the modeling has been

Excerpt from ISBN 978-3-00-053387-7

developed at the bundle mesh scale. The fibers are represented by the use of 1D rod elements. This truss structure is stabilized by a specific damageable orthotropic 2D element (Fig 2).

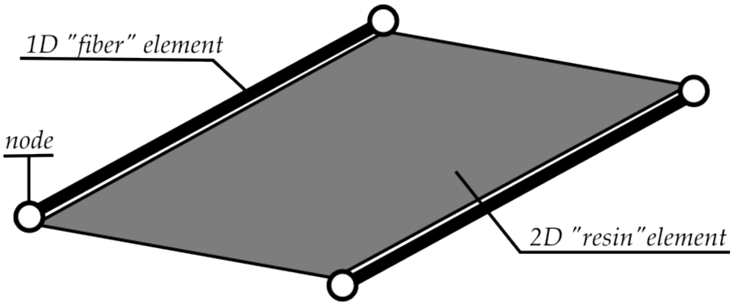

Figure 2. Semi-continuous modeling of an UD composite ply.

The micro-cracking of the resin is represented by the degradation of the 2D elements. Due to the thin nature of the skin, the damage can be assumed to be the same throughout its thickness. The evolution of the membrane, bending and transverse shear modulus due to damage is described by two parameters : (d_L) represents the damage in the fibers direction and (d_T) that represents intralaminar damage in the direction normal to the fibers.

Finally, the laminate is built by connecting the semi-continuous plies with the specific interface element described in [5]. This element is able to connect two shell elements by accounting for the rotational degrees of freedom. A bilinear cohesive law is used.

3.2. Results

The low velocity impact tests presented in section 2.1 are modeled. The explicit FEM software Radioss is used. Two consecutive plies with the same orientation are represented with one "ply" element which thickness is set to 0.48 mm. The mesh size is 0.5×0.5 mm^2. The rectangular frame and the impactor are modeled with "rigid walls" (not deformable geometries).

The applied loads are plotted against the displacement of the impactor and the delaminated areas are measured. A comparison of the experimental and numerical results for the $[90_2, 0_2, 90_2]$ specimen is given Fig 3 and 4 . A good correlation between the two curves can be observed. The modeling allows an accurate reproduction of the damage and of the delamination size experimentally obtained.

4. Conclusion

In this paper, a new strategy for the modeling of UD composite under impact is described. It relies on a semi-continuous representation where the bundle of fibres and the resin are decoupled in order to represent the damage scenario. Four impact tests have been carried out in order to validate the proposed modeling. This strategy provide interesting results and a good correlation between experimental and numerical results is found.

Acknowledgments

The authors acknowledge the supercomputing centre CALMIP for granting access to the HPC resources under the allocation 2016-P09105.

Excerpt from ISBN 978-3-00-053387-7

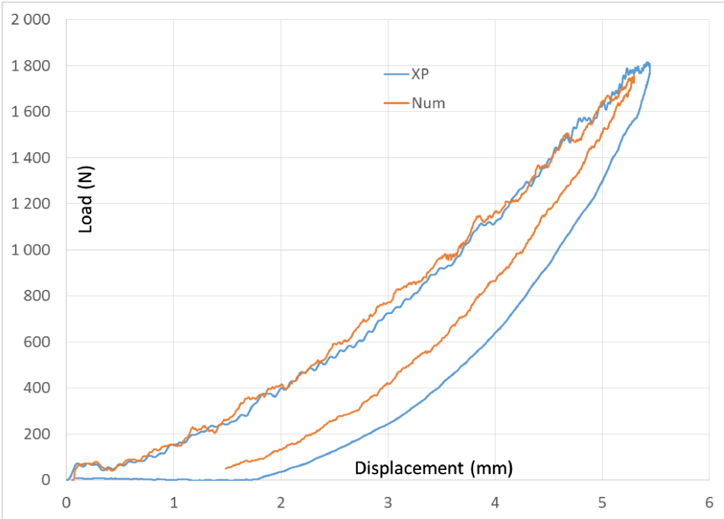

Figure 3. Experimental and numerical load/displacement curve for the $[90_2, 0_2, 90_2]$ specimen .

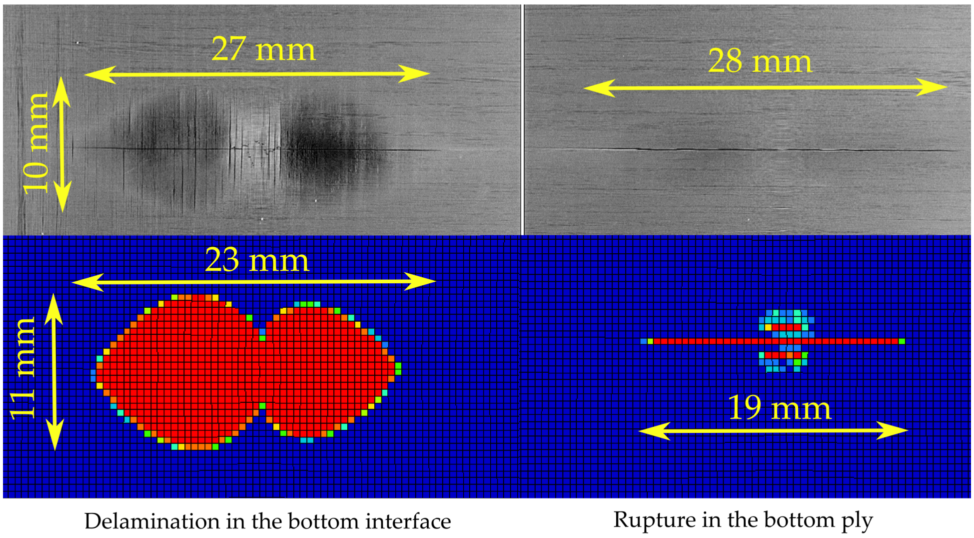

Figure 4. Experimental and numerical damages for the $[90_2, 0_2, 90_2]$ specimen .

Excerpt from ISBN 978-3-00-053387-7

References

[1] Serge Abrate. *Impact on composite structures*. Cambridge University Press, 1998.

[2] P. Ladevze. A damage computational method for composite structures. *Computers & Structures*, 44(1):79–87, July 1992.

[3] P. Ladeveze and E. LeDantec. Damage modelling of the elementary ply for laminated composites. *Composites Science and Technology*, 43(3):257–267, 1992.

[4] Christophe Bouvet, Bruno Castani, Matthieu Bizeul, and Jean-Jacques Barrau. Low velocity impact modelling in laminate composite panels with discrete interface elements. *International Journal of Solids and Structures*, 46(1415):2809–2821, July 2009.

[5] P. Navarro, F. Pascal, J. Aubry, S. Marguet, J. F. Ferrero, S. Lemaire, and P. Rauch. Semi-continuous

approach for the study of impacts on woven composite laminates: Modeling interlaminar behavior with a specific interface element. *International Journal of Impact Engineering*, 75:184–193, January 2015.

Excerpt from ISBN 978-3-00-053387-7