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Mejora de la respuesta estructural después de un impacto de capas delgadas mediante hibridació de las capas y laminados no simétricos

RESUMEN

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Palabras clave:
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Hibridació de capas
Compression despues el impacto

Como tal, ha habido una gran demanda por parte de la industria aeronáutica de una extensa investigación que permita mejorar la tolerancia al daño por impacto de las estructuras de material compuesto. Paralelamente, en un intento de obtener aún más ligeras aeronaves, la industria aeronáutica introdujo recientemente el uso de estructuras delgadas, aún sin tener clara la respuesta de los laminados delgados a las cargas de impacto y post-impacto. En el caso de estructuras delgadas (con un grosor inferior a 2 mm), los fabricantes de aviones carecían de información sobre cómo los distintos espesores de capa y las diferentes arquitecturas de material se diferenciaban entre sí en términos de la respuesta CAI. Este estudio se dedicó a mejorar la respuesta de la compresión después del impacto de laminados gruesos y delgados de grado aeroespacial, utilizando diseños de laminados novedoso. Asimismo, agrandando los límites del diseño de laminado, se propuso una nueva idea de hibridación de espesor de capa para mitigar la débil respuesta al impacto de las capa delgadas. Los diseños propuestos mejoraron la resistencia CAI en un 40% sobre la referencia de la capa delgada y sin olvidar la rentabilidad económica detrás de este enfoque de diseño laminado en comparación con otras técnicas de refuerzo de materiales.

Towards an improved compression after impact response of thin plies using ply grade hybridization and unsymmetrical laminate designs

ABSTRACT

Keywords:
Impact behaviour
Damage tolerance
Finite element analysis
Ply-thickness hybridization
Compression after impact

With thin structures used in the aircrafts, aeronautical manufacturers are worried about the response of these thin laminates towards impact and post impact loads. Thin laminates studied to show reduced compression after impact strengths with thin plies and hence continues to be a primary concern to the aeronautical industries. In this work, we aim to use ply grade hybridization (mixing different ply grades) and unsymmetrical laminate designs as an effort to improve the low velocity impact response and compression after impact strength of thin laminates. Using different materials, uni-directional and non-crimp fabrics, through experimental, numerical and optimization methods, we demonstrate that hybridization along with unsymmetrical designs can improve the CAI strength by upto 40% over the thin ply baseline laminates.

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1 Introduction

One of the concerns of the aeronautic industries is the impact behaviour of thin structures in the aircraft as low velocity impacts can significantly reduce the residual structural strength [1]. Thin plies (<75 gsm) in thin laminates resulted in extensive fibre damage during impact and reduced the CAI strength when compared to intermediate and thick plies [2, 3]. Studies showed that ply level hybridization, ie, mixing plies of different thicknesses in an attempt to enhance the target response, helped to improve the structural performance. In addition, impact loads are unsymmetrical in the thickness direction and hence the conventional idea of symmetric laminates need to be challenged. It is important to move away from the conventional symmetry design which will also enhance the stacking sequence design space.

In this study, we use ply grade hybridization and unsymmetrical laminate designs as an effort to improve the impact and CAI strength of thin laminates. The work was performed at AMADE research group, University of Girona in collaboration with Airbus Airnet project under Dr. Peter Linde.

2 Methodology

2.1 Material and Laminates

In this study, we used two different material systems: uni-directional prepreg tapes and non-crimp fabric (NCF), both of the same T700/M21 carbon-epoxy. We used three ply grades of the UD plies namely thick (268 gsm), intermediate (134 gsm) and thin plies (75 gsm). NCF come in bi-axial blankets of [0/45] and [0/-45]. Similarly, for the NCF: intermediate (134 gsm) and thin plies (67 gsm).

Table 1. Different laminates studied

Laminate & Ply thickness (mm)	**Layup**	**Lam. thickness (mm)**
H-268 (0.262)	[45/-45/0/90]\$	1.83
H-134 (0.131)	[45/-45/0/45/-45/90/0]\$	1.7
H-75 (0.075)	[45/-45/0/45/-45/90/0/45/-45/90/0]\$	1.58
H-75-H1 (0.075 & 0.131)	[45/-45/45/-45/90/0_{134}/45/-45/90]\$	1.59
H-75-H2 (0.075 & 0.262)	[45/-45/45/-45/90/0_{268}/45/-45/90]\$	1.65
NCF-Int	[45/0/-45/90/22.5/-22.5]S	1.61
NCF-Thin	[(45/0)/(-45/90)/(45/0)/(-45/90)/(45/0)/(-45/0)]S	1.61
NCF-UHB	[(90/-45)/(0/45)/(90/-45)/(0/45)/(90/-45)/(0/45)/(90/45)/(0/45)/$(45/0)_{268}$/$(-45/90)_{268}$]	1.61
NCF-UHT	[$(90/45)_{268}$/$(0/-45)_{268}$/(-45/0)/(45/90)/(-45/0)/(45/90)/(-45/0)/(45/90)/(-45/0)/(45/90)]	1.61
L1 (0.131)	[45_2/-45_2/90/0_3/90/-45_2/45_2]	1.7
L8 (0.131)	[45/0_2/−45/90_2/0/90_2/−45/0_2/45]	1.7
L9 (0.131)	[45/0/−45/90_2/0_3/90_2/−45/0/45]	1.7

Table 1 presents the different laminates studied in this work, the ply grades/thicknesses used and the corresponding laminate thicknesses. H-268, H-134 and H-75 (all made of UD plies) are the baselines made of thick, intermediate and thin plies respectively. NCF-Int and NCF-Thin are the baselines (made of NCF) using intermediate and thin plies, respectively. H-75-H1 and H-75-H2 are thin ply dominant hybrid laminates, but mixing intermediate and thick 0 plies, respectively. NCF-UHB and NCF-UHT are hybrid unsymmetrical laminates made of intermediate and thin plies, where NCF-UHB has the thicker plies placed at the non-impacted side and the NCF-UHT at the impacted side. L1, L8 and L9 are laminates made of intermediate plies but with clusters (where a cluster of 2 intermediate plies refers to a thicker ply).

2.2 Experimental

We performed impact tests on specimens of dimensions 150x100 mm, in accordance with the ASTM D7136/7135-15 standard using a CEAST Fractovis Plus instrumented drop-weight tower.Total mass of the impactor was set to 3 kg and a 16mm steel hemispherical indenter was used. Impact energies were defined according to the laminate thicknesses.Post impact compressive strength was evaluated through CAI tests using an MTS INSIGHT 300 machine with a 300 KN load cell following the ASTM D7137/D7137M-15 standards. An anti-buckling device was used along with the fixture to ensure proper specimen failure.

2.3 Numerical

Laminate L1, L8 and L9 were selected through optimization followed by virtual testing through finite element simulations. We used Abaqus/Explicit conventional shell elements (S4R) to model the plies, and zero thickness cohesive elements (COH3D8) to model the interface between the plies. Progressive intraply damage was accounted using continuum damage model proposed by Maimi et al.[7]. The cohesive constitute model for the interface was proposed by Gonzalez et al. [8] and both these models are implemented in a VUMAT user-written subroutine.

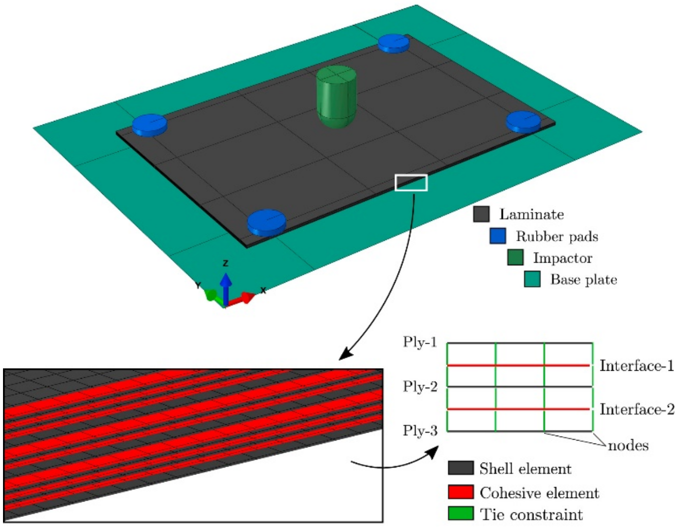


Figure 1. Virtual impact setup with the modelling strategy followed [4]

The CAI simulation was performed using a RESTART option in Abaqus/Explicit, where apart from the standard, a non-standard anti-buckling fixture was accounted in the model. Reader is referred to [4] for more details on the numerical model.

3 Results & Discussion

Figure 2 presents the impact curves of the baseline laminate H-134 from both experimental and numerical results of 8.9 and 10.5 J. The force-deflection and energy curves show that the numerical model I in very good agreement with the experimental curves. The load drops seen in the force-deflection curves are attributed to the fibre damage at the non-impacted side of the laminate.

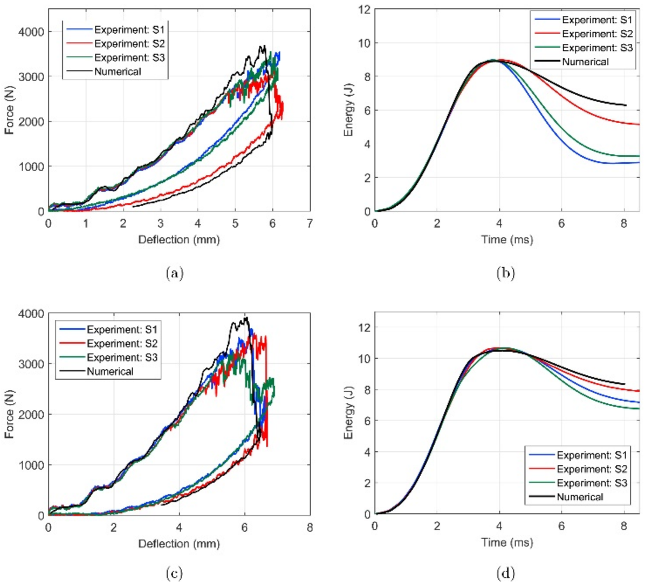
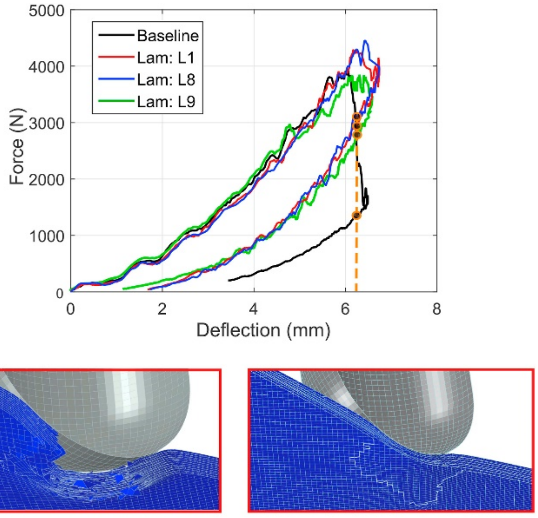
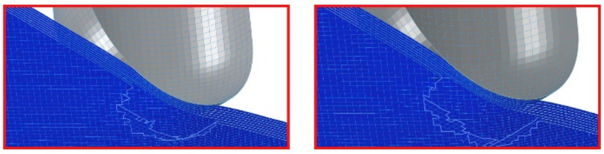


Figure 2. Validation of the numerical model by comparing baseline H-134 experimental impact curves with the simulation results for 8.9 J (a, b) and 10.5 J (c, d).



(a) Baseline (b) Laminate: L1

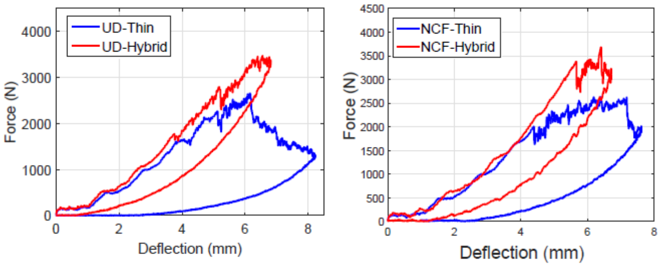


(c) Laminate: L8 (d) Laminate: L9

Figure 3. Comparison of force-deflection curve between baseline and proposed laminates. Figure shows the fibre damage status at the non-impacted side of different laminates from 10.5 J impact.

Using the virtual testing framework, out of 30 proposed laminates, L1, L8 and L9 performed better over the baseline H-134, in terms of the CAI strength. L1, L8 and L9 improved the CAI strength by 29%, 31% and 29% respectively over the baseline. Figure 3 shows the comparison of the force-displacement curves of these three laminates against the baseline for the 10.5 J impact. The sudden load drop is mitigated in the proposed laminates which have thicker plies. These plies help to mitigate fiber damage at the non-impacted side through more energy dissipation through delaminations. The same figure shows in detail the difference in the fiber damage for the baseline under the impactor compared with the proposed laminates. Baseline exhibited fiber damage locally under the impactor in all the plies, whereas the hybrid laminates mitigated the load drop and constrained the fiber damage only to the last ply [4].

Figure 4 compares the baseline laminates and the proposed hybrid laminates with UD plies (a) and NCF(b). Both the proposed hybrid laminates (H-75-H2 and NCF-UHB) mitigated the fiber failure compared to the thin ply counterparts as seen in the curves. Addition of thicker plies to thin plies helped to dissipate energy through matrix cracks and delaminations and thereby reducing the fiber damage.



(a) (b)

Figure 4. Comparing force-deflection impact curves of hybrid laminates with their thin ply counterpart laminates

Figure 5 presents the different impact damage resistance parameters and the CAI strength from the 10.5 J impact. Thin ply laminates exhibit low resistance to impact and a low CAI strength when compared to the proposed hybrid laminates.

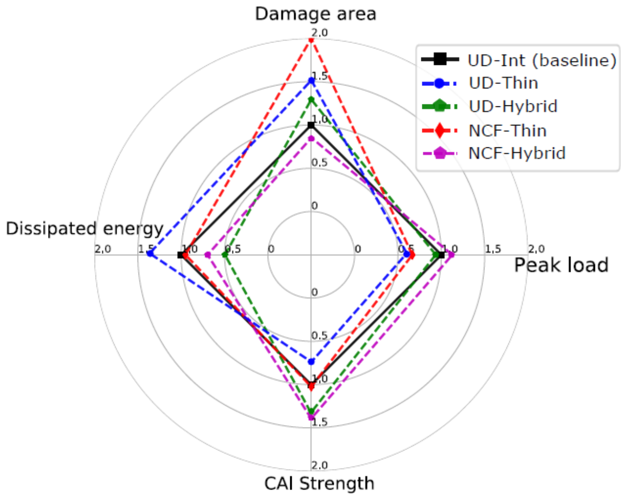


Figure 5. Comparison of impact damage resistance parameters and CAI strength of proposed hybrid laminates and their corresponding thin-ply counterparts

Compared to the UD hybrid laminates, the NCF proposed hybrid laminates possessed better CAI strength.

4 Conclusions

In the quest to improve the impact damage tolerance of thin ply thin laminates, in this study we have aimed to incorporate ply grade hybridization and unsymmetrical designs. This strategy is economically feasible as no external reinforcement is added, whereas only different ply grades have to be added at the optimum through-the-thickness locations of the laminate. The addition of thicker plies has helped to mitigate extensive fiber damage through matrix cracks and delaminations. This change in damage morphology dramatically improves the CAI strength (up to 40%) over the aerospace baseline laminate made of intermediate grade plies. We have pushed the boundaries of damage tolerant designs through novel stacking sequences and proved that through judicious tailored laminate designs, it is feasible to substantially improve the impact and post-impact response without added costs.

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