HIGH VELOCITY IMPACTS OF COMPOSITE FRAGMENTS

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Abstract

In this work, the behaviour of composite fragments when impacting against a rigid plate is studied. To this end, an experimental set-up has been developed in order to launch composite/epoxy fragments perpendicularly to a steel plate, at velocities ranging from 80 to 160 m/s. The event was recorded using high-speed cameras which allows to visualize the impact process, and to follow the position of the fragment using a tracking software; performing successive derivatives, the acceleration of the fragment (and hence the force) was measured. In addition, a numerical methodology has been developed to reproduce the behaviour of the composite fragment under impact. The commercial finite element code ABAQUS/Explicit has been used to perform the simulations; the intra-laminar behaviour of the composite fragment has been modelled using the Hashin model, whereas the inter-laminar has been modelled using cohesive interactions. The numerical methodology has been validated by means of the experimental tests, including different variables such the induced force and the erosion of the fragment.

1. Introduction

The European Union (EU) aeronautic industry is a world leader in its sector, and contributes to the EU economy with more than 500000 jobs and with a turnover of close to 140 B . Regarding the production of civil aircraft, EU companies have, right now, about the 40% of the global market of short/medium range aircraft. The competition in this huge market from new countries is starting to increase and hence, in order to maintain (or if possible increase) that portion of the global sales, it is necessary to being leaders in innovation and in product performance.

Fuel consumption is probably the most important factor in the civil aircraft industry, and almost all the innovations are focused in this subject, always without compromising the security. Lower fuel consumption not only means lower operating cost of the airlines, but also lowers CO_2 emissions. One of the most promising technologies that could allow achieving the aforementioned goal is the Counter Rotatory Open Rotor engine, which could offer an improvement in fuel consumption in the range of 15% - 20% compared to the actual engines. The best position for the CROR engines is in the aircraft rear-end; this is due to the large diameter of those engines, and also to provide additional advantages such noise cabin reduction and passenger comfort.

This new unducted engines will promote new challenges in terms of safety, since due to the lack of a container, composite blades could impact the aircraft fuselage (which could be made of composite materials also). Composite materials have been studied under low and high impact conditions of both soft impactors (ice, gelatine...etc.) [1] and hard impactors (steel fragments) [2–4], but they have not

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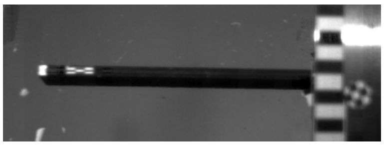
being studied when they are the impactor. The most similar tests performed on composites are the ones realized by Mamalis et al. [5, 6], which studied the compression of composite tubes under both static and dynamic conditions.

The objective of this work is to perform experimental tests of carbon/epoxy fragments when acting as impactors, launching them against a rigid plate. A numerical methodology has been also developed to predict the behaviour of those fragments.

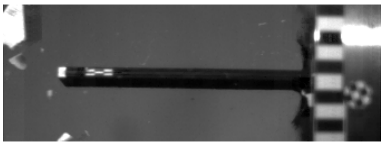
2. Materials and experimental set-up

In order to perform the experimental tests a 20 meter long, and 60 mm barrel pneumatic launcher was used to impel the composite fragment. It size was 42×100 mm^2 and hence a special sabot has been developed to assure that the fragment impacts the rigid plate perpendicularly, and get apart from the composite prior to impact in order to observe its evolution. The impact was recorded by means of two high-speed video cameras (model Photron SA-Z), which were configured at 100000 frames per second, with a resolution of 896×208 pixels and a shutter time of $8 \mu s$. The lighting system is the key to obtain clear images, which later could be used for tracking purposes; to this end two HMI Lamps of 1800 watt were used. The material selected to perform the tests was a composite laminate made using tape prepregs manufactured by Hexcel Composites (AS4 fibre and 8552 epoxy); the plates were manufactured with the aforementioned material using standard aeronautic procedures. The thickness of the studied laminate was 4 mm (with 21 layers); the ply sequence used was $(45/-45/90/0/90/-45/45/90/0/90/0)_{s'}$.

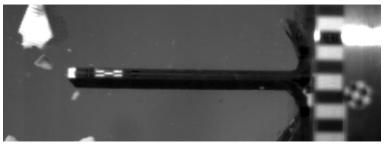
Fig. 1 shows an impact sequence for a fragment impacting at 103 m/s. The fragment open itself through the middle plane, forming a symmetric double cantilever beam opening process.



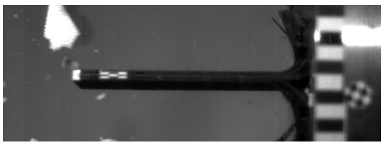
(a) $t = 0\,\mu s$



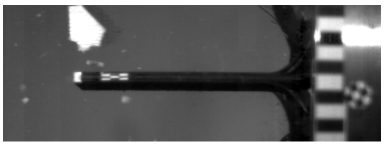
(b) $t = 10\,\mu s$



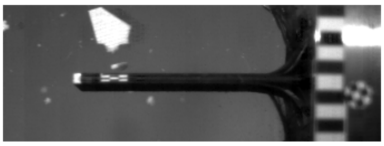
(c) $t = 20\,\mu s$



(d) $t = 30\,\mu s$



(e) $t = 40\,\mu s$



(f) $t = 50\,\mu s$

Figure 1. Sequence of the fragment impact at velocity of 103 m/s.

The marks placed in the rear side of the fragments were used to perform its tracking. The resolution of the image was high enough to provide a displacement time history; nevertheless some noise appears which has been removed using a moving average of five points. This methodology could be done because the movement of the fragment should be smooth and should not contain jumps in its curve. Once the displacement is obtained, using successive derivatives, the acceleration is calculated, and then filtered using a low pass filter of 14 kHz; the result is multiplied by the fragment mass to obtain the force time history. Fig. 2 shows the force time history for different impact velocities. As expected as the impact velocity increases, the maximum force increases also; all the curves shows the same trend with a maximum values at approximately $50\,\mu s$.

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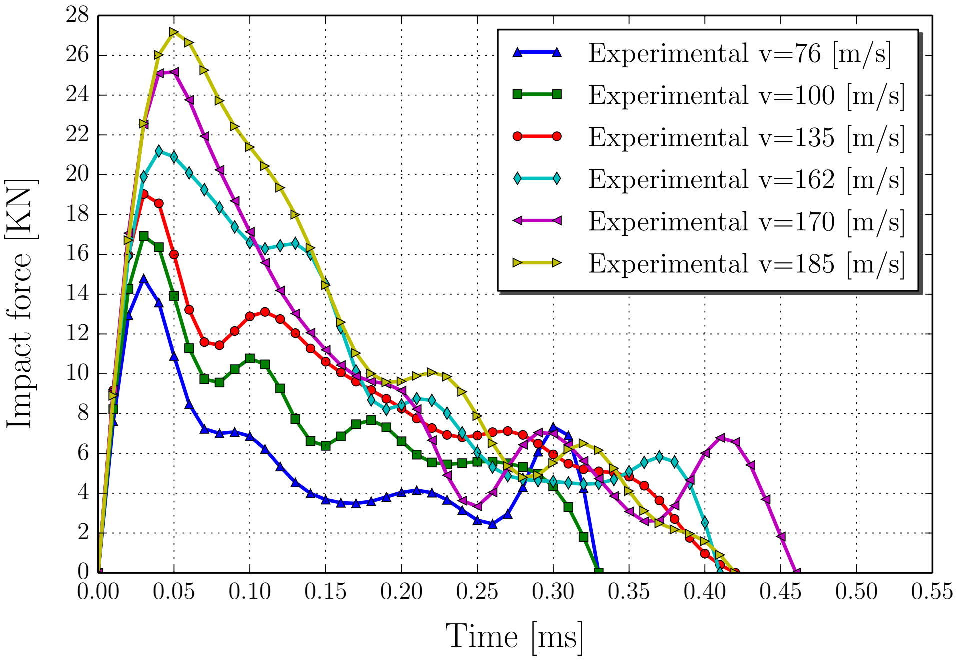

Figure 2. Write your figure caption here.

3. Numerical simulations

The numerical methodology developed in this work was performed using the commercial finite element code ABAQUS/Explicit. The carbon/epoxy unidirectional laminate has been modelled using the Progressive Damage Analysis (PDA) method implemented in the aforementioned software. In this method, the onset of damage is detected by the Hashin and Rotem damage initiation criteria. The damage evolution degrades the material stiffness coefficients until the energy dissipated is equal to the critical energy release; please refer to the software manual for more details.

Using the PDA method, the elements are removed from the mesh when either one of the damage variables associated with fibre failure modes reaches the unity. In this work the fragment fails in compression, and because some plies have 90^0 orientation they should fail under the matrix compression mode and since this elements are not removed by the PDA method, a user subroutine VUSDFLD has been defined to remove elements with large distortion ($\varepsilon_{eq} \geq 0.15$) and avoid errors in the simulation.

The inter-laminar failure is modelled using a cohesive interaction, based on a traction-separation law, in which is necessary to define a damage initiation criterion and a damage evolution law. The finite element mesh used to model the composite laminate uses continuum shell plane stress elements with reduced integration. The element size was constant along the geometry being its size $1 \times 1 \times 0.1905\ m^3$; a total of 4200 elements were used for each ply. The fragment uses 21 elements and 20 cohesive interactions trough the thickness (88200 elements in total). The material properties used in this simulations could be found in a previous work of the same authors [7].

4. Results and validation

In order to study if the numerical methodology predicts adequately the behaviour of the composite fragments, two variables where studied, the eroded distance and the force time history. The fragment present

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sensible erosion during the impact process, and this values is compared in Fig. 3. It appears that the model adequately predicts both the magnitude and the trend of erosion of the fragment as function of the impact velocity.

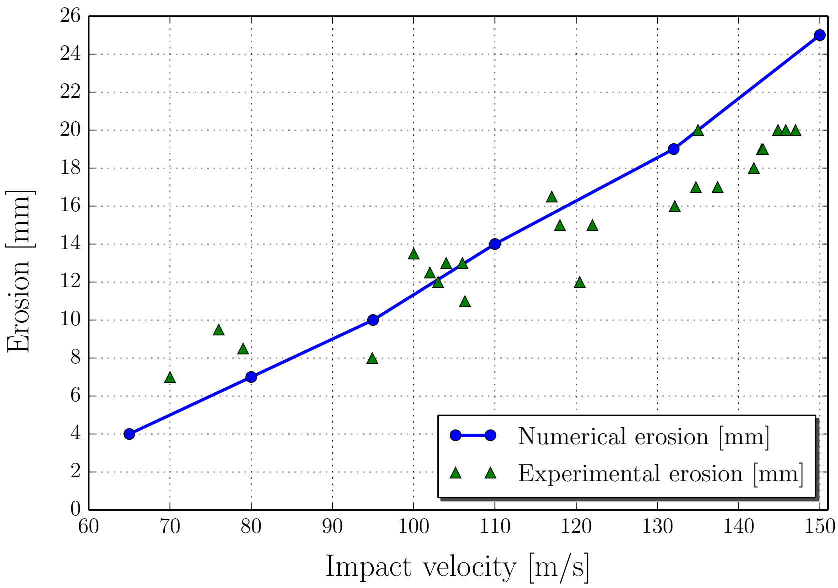

Figure 3. Fragment erosion distance vs. impact velocity, obtained from experimental results and numerical simulations

The other variable used to validate the model is the force time history. The numerical curve was obtained directly from the acceleration of the fragment multiplied by its mass; as well as the experimental curve it has filter with a low-pass filter of 14 kHz. Fig. 4 shows the comparison between the experimental tests and the numerical simulations for four different impact velocities. It is clear that the model faithfully reproduces the force performed by the fragment; both the maximum value and the duration of the pulse are well captured.

5. Conclusions

In this work the high velocity impact of composite fragments against a rigid plate has been studied. Experimental tests showed that the maximum force increases with the impact velocity, as well as the eroded distance. In addition the numerical methodology developed predicts adequately the fragment evolution.

Acknowledgments

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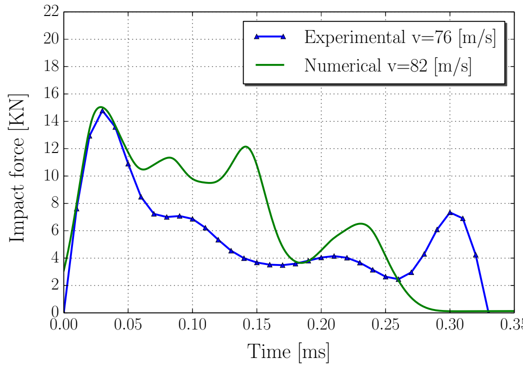
References

[1] H. Kim and K.T. Kedward. Modeling hail ice impacts and predicting impact damage initiation in composite structures. *AIAA Journal*, 38:1278–1288, 2000.

[2] J. López-Puente, R. Zaera, and C. Navarro. The effect of low temperatures on the intermediate and

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



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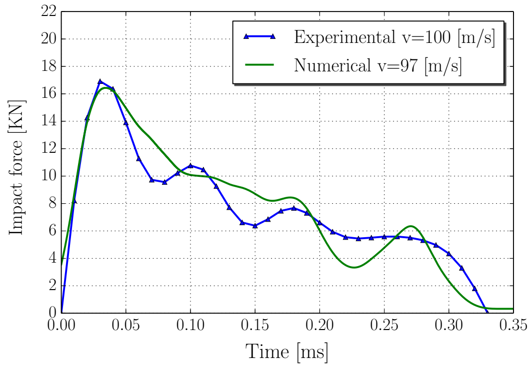

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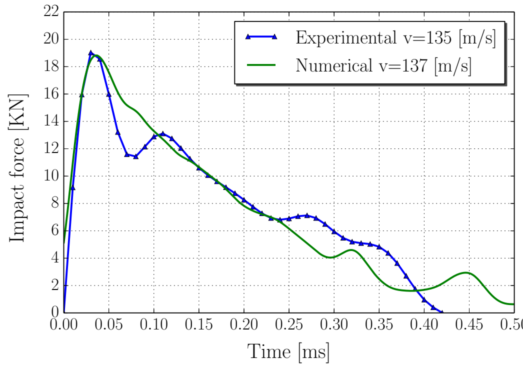

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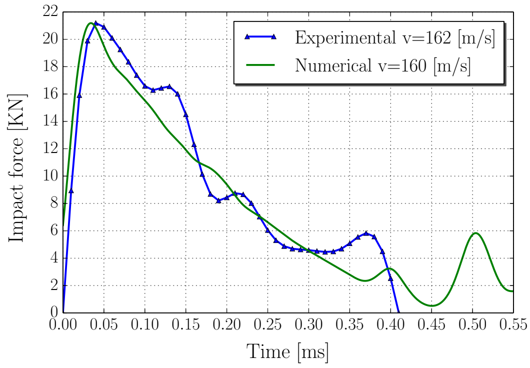

(d)

Figure 4. Force time history comparison between numerical and experimental results for different impact velocities

high velocity impact response of cfrps. *Composites Part B: Engineering*, 33:559–566, 2002.

[3] J. López-Puente, R. Zaera, and C. Navarro. Experimental and numerical analysis of normal and oblique ballistic impacts on thin carbon/epoxy woven laminates. *Composites part A: applied science and manufacturing*, 39:374–387, 2008.

[4] D. Varas, J.A. Artero-Guerrero, J. Pernas-Sánchez, and J. López-Puente. Analysis of high velocity impacts of steel cylinders on thin carbon/epoxy woven laminates. *Composites Structures*, 95:923–929, 2013.

[5] A.G. Mamalis, D.E. Manolakos, M.B. Ioannidis, and D.P. Papapostolou. On the response of thin-walled cfrp composite tubular components subjected to static and dynamic axial compressive loading: Experimenta. *Composite Structures*, 69:407–420, 2005.

[6] A.G. Mamalis, D.E. Manolakos, M.B. Ioannidis, and D.P. Papapostolou. The static and dynamic axial collapse of cfrp square tubes: Finite element modelling. *Composite Structures*, 74:213–225, 2006.

[7] J. Pernas-Sánchez, J.A. Artero-Guerrero, J. Zahr, D. Varas, and J. López-Puente. Numerical analysis of high velocity impacts on unidirectional laminates. *Composites Structures*, 107:629–634, 2014.

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