EFFECTS OF IMPACTOR MASS IN CARBON/EPOXI WOVEN LAMINATES UNDER LOW-VELOCITY IMPACT LOADING

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Abstract

The use of composite laminates has become extensive in many different industries. Regarding the aeronautic and aerospace sectors, more than 50 % *of primary and secondary aircraft structures uses this type of materials resulting in: reduction of weight and therefore, less fuel consumption and gas emissions. In many of these applications composite structures could be subjected to occasional impacts, which are very dangerous due its out of plane low resistance. This type of loadings events causes internal damages such as delaminations or matrix crushing which reduce significantly its in plane strength. Impacts in composite materials have been studied in literature either at high or low velocity. Usually experimental studies use pneumatic launchers for high velocity impacts and drop-weight tower for low velocity. In particular drop-weight tower studies focus on impact damage as a functions of impact energy, impactor shape or material thickness. The present work expands the usual studies including the inertia of the impactor as a variable, and studies its effect on the laminate damage. For this purpose, an impactor with different masses has been impacted against carbon/epoxi woven laminates at different energies.*

1. Introduction

The use of composite laminates by the aeronautic industry has increased significantly in last years. One example of this increase is the use of those materials in the recent developments performed by the two largest aircraft company manufactures; in those aircraft the use of composite laminates in the structure has achieved the 50% in terms of weight. It is well known that composite laminates, in particular those made with carbon fibers and epoxy matrix, present exceptional specific mechanical properties: high strength, high elastic modulus... etc. The only drawback of those materials is the low resistance against impact, when it is produced perpendicular to the laminate plane. Impacts on composite laminates could produce internal damage (matrix cracking, delamination.. etc.), which could cause a very important diminution of the mechanical properties. When analyzing the impact on composites laminates, a differentiation between high and low velocity impact is usually done. High velocity impacts are those related to small masses [1, 2, 3, 4, 5, 6, 7, 8, 9, 10], whereas low velocity impacts are associated to larger masses (of an order of magnitude of kilograms). This work is focused in the second type; in service structures could be subjected to this kind of impacts for instance during maintenance operations.

To perform experimentally low velocity impact tests, usually a drop weight tower apparatus is used. The first works that investigate the low velocity impact on composite laminates appear in the 80's; one example is the work of Caprino et al. [11], in which the authors stated that the behavior of the composites was governed by the energy impact rather than the impact velocity or impact mass. In the following years many articles about low velocity impacts on composite laminates appear, both experimental and numerical [12, 13, 14, 15, 16, 17, 18, 19, 20, 21]. Another interesting work is the one performed by Zhou et al. [22] which studied experimentally different geometry parameters, impactor and laminate size, impactor shape and laminate boundary conditions.

In this work the analysis of low velocity impact on woven carbon/epoxy laminates is carried on. In order to analyze if the energy of the impact is governed only by the impact energy or not, experimental tests at constant impact energy were performed varying the impact velocity and the impactor mass. In addition an analysis of the influence of the thickness is carried on, to study its influence in the composite behavior.

2. Material and experimental methods

Low-velocity impact tests on carbon/epoxy woven laminates were performed by means of a INSTRON-CEAST Fractovis 6875 Drop Weight Tower to study the influence of the mass impactor. Different plates were subjected to equienergetic impacts varying the mass and impact velocity. An hemispherical nose striker of 20 *mm* of diameter, which impacted orthogonally to the specimen, was attached to the bar of the drop weight tower. Additional mass was added to the setup in order to obtain three different effective masses, 3.817, 7.817 and 15.817 *kg*, and therefore analyze its influence on the behaviour of the laminate when the impact energy is the same. The laminate specimens were 120 *mm* wide square plates made of AGP193-PW/8552 (Hexcel composites) and two different thicknesses, 4.4 and 6.6 mm, which correspond to 20 and 30 laminas. The specimens were placed on a steel support and clamped along their outer border in such a way that a squared area of 80 *x* 80 *mm* was the free laminate surface. After impact, an anti-rebound system held the striker to avoid multi hits on the specimen. The ratio between the impactor diameter and the free span assures that the damage of the composite does not reach its contour.

The load cell placed on the striker provides the force time history by means of an acquisition data system. The force exerted by the striker on the specimen allows to obtain the acceleration, velocity, displacement and energy histories, assuming full contact between striker and specimen throughout the test. The mentioned data was analyzed to study the impact response of the laminates. In addition the damage induced by the impact in the laminates was also studied from different points of view. Firstly, non-destructive analysis: a visual inspection of the laminates determines the exterior damage, the shape and extension of the delaminated area were obtained using an ultrasonic inspection (C-scan technique) and the induced indentation was measured using laser extensometry. Finally, some of the laminates were subjected to destructive analysis, cutting through thickness the laminate in order to observe the different induced damages.

3. Results and discussion

Figure 1 shows the force and kinetic energy time histories for impacts with three different mass impactor for the two laminate thicknesses tested. It can be observed that, independently of the impact energy and the mass impactor, the maximum peak force reached only depends on the thickness of the laminate (around 6000 and 12000 *N* for 4.4 and 6.6 *mm* respectively). The kinetic energy histories show two different trends; in the first, one kinetic energy increase until a maximum peak (the maximum energy transferred by the impactor) and then decreases reaching a constant value. The beginning of the plateau of the curve matches with the loss of contact between the striker and the specimen, therefore this energy coincides with that absorbed by the specimen (this behaviour could be observed for example for an impact at 20 *J* in a 4.4 *mm* thickness laminate). The other energy history shape corresponds to penetration impacts, in this case it is not possible to determine the elastic recovery of the laminate (for example impact at 80 *J* for a 4.4 *mm* thickness laminate).

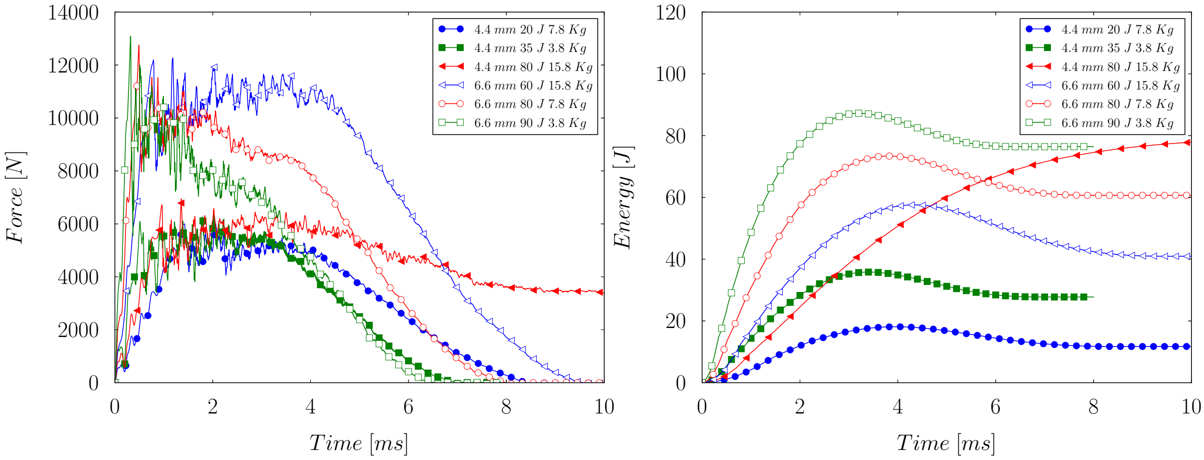

Figure 1. Force and energy time histories for different impact energies with three mass impactor and two laminate thicknesses.

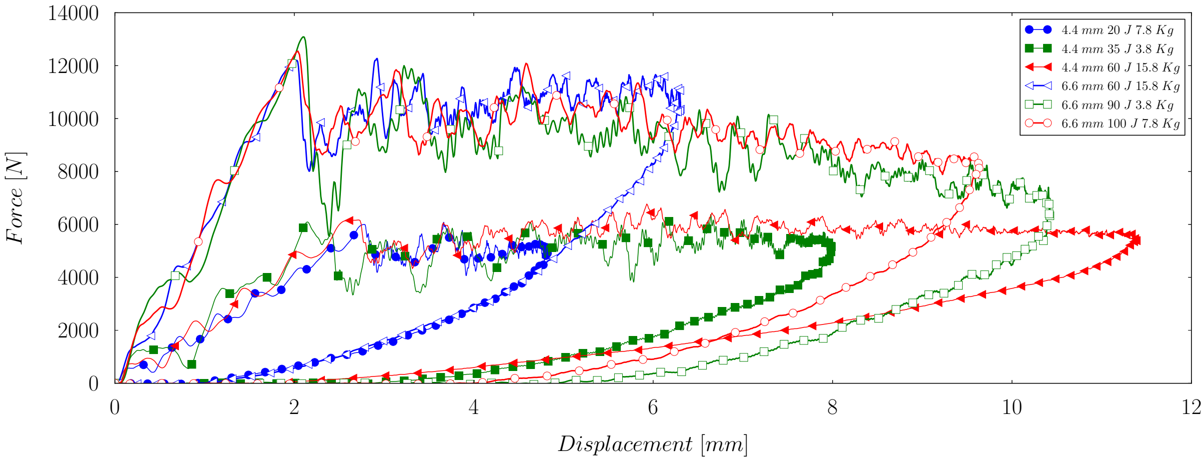

Figure 2. Force evolution as a function of impactor displacement for different impact energies with three mass impactor and two laminate thicknesses.

Figure 2 shows the force-displacement curves for different impact energies with three impactor mass and two laminate thicknesses. The force peak is the same for any impact energy, only depends on the laminate thickness, as it was already observed in Figure 1. At the beginning of the impact, the laminate behaves as an elastic plate until that maximum, independently of the energy, the only dependence is with the stiffness of the plate, that is the reason why the maximum force only depends on the thickness. Once the maximum is reached the force drops suddenly, this moment correspond with the onset of damage; this threshold energy could be deduced by measuring the energy below the force-time curve portion up to that first peak. Then the force remains constant up to the recovery zone (elastic recovering in the energy evolution). The area inside the curve is the energy absorbed by the laminate.

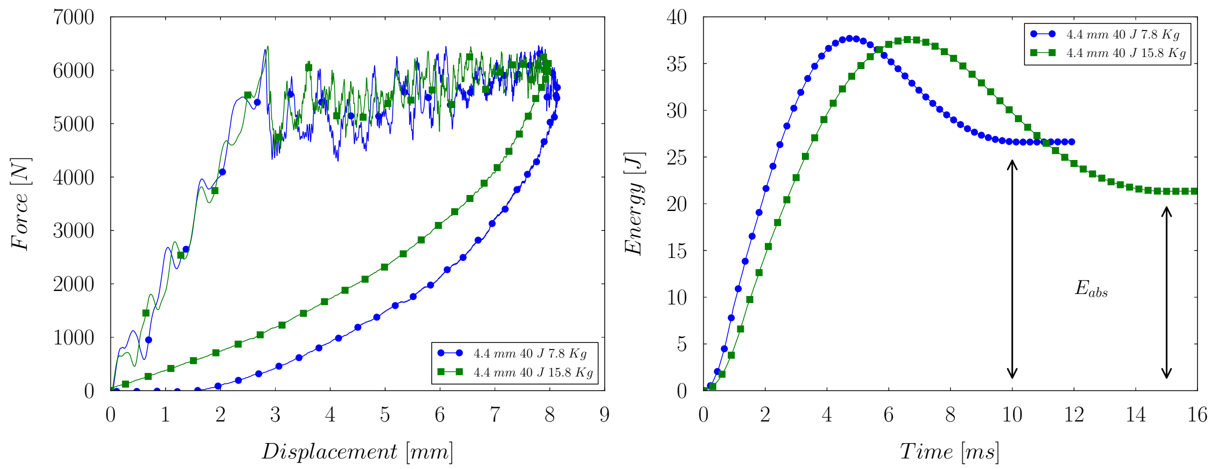

Figure 3. Force and energy time histories for different mass impactor impacting at 40 J of kinetic energy against a 4.4 mm thickness laminate.

Regarding the influence of the impactor mass (or the impact velocity) in the laminates behavior, the force-displacement data and the energy time history have been analyzed. As an example, Figure 3 shows the mentioned results for a 40 *J* impact energy with two different masses. It is observed that the maximum force is the same for both impacts, but the impact with the lower mass impactor absorbs more energy (area inside force-displacement curve ,figure 3 left, and plateau value in figure 3 right). The same behaviour was observed for the different test cases, therefore it can be said that the laminate absorb different values of energy depending on the impactor mass, and hence the velocity impact, for the same impact energy. In order to check if that different energy absorbtion turned into a different shape or extension of the delaminated area, specimens were inspected using a C-scan technique, Figure 4. It is observed that although the delaminated area may slightly differs, the shape of the delamination is similar for the same impact energy. This can lead to the conclusion that, for the cases analyzed, impacts at higher velocities may activate different energy absorbtion mechanisms from those that appear at lower velocities for the same impact energy.

Figure 5, left depicts the values of delaminated area at different impact energy for the two laminate thicknesses studied. It seems that two different trends appear. The delaminated area is similar for both thicknesses until reaching approximately 40 *J*, whereas above that energy the delaminated results seems to be dispersed without following a clear trend. However when the indentation depth is analyzed, different trends are clearly shown, Figure 5, right. It is observed that at certain impact energy, the indentation depth trend depends on the laminate thickness. This threshold energy is approximately 50 *J* in the 4.4 *mm* laminates whereas it is bigger

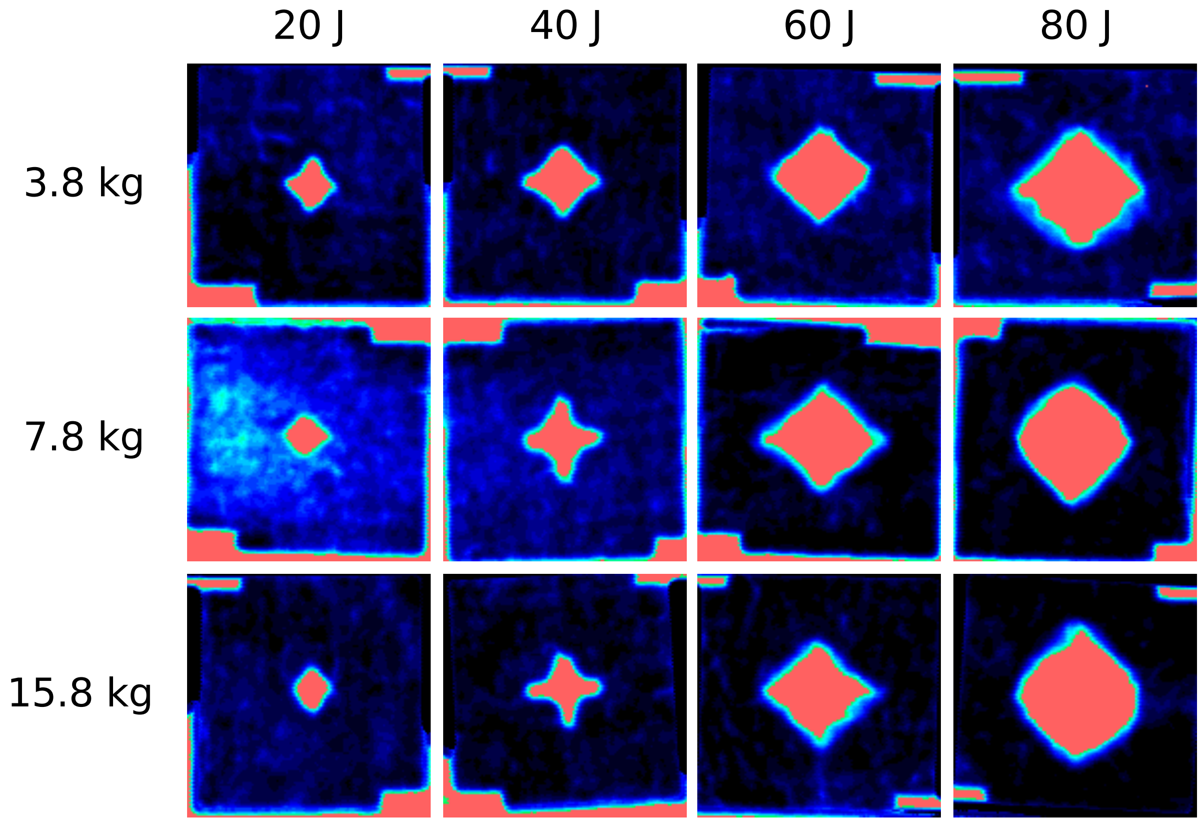

Figure 4. Comparison of the C-Scan results for a 4.4 mm thickness laminate impacted at different energies with different masses.

(60 *J*)in the 6.6 *mm* thick laminates. It is reasonable to think that the observed threshold impact energy is related to the different absorbtion mechanisms (and hence damage mechanisms) that appear when certain energy is reached. Figure 6 shows the different damage appearance

between two laminates impacted below and above the threshold impact energy observed in the tests.

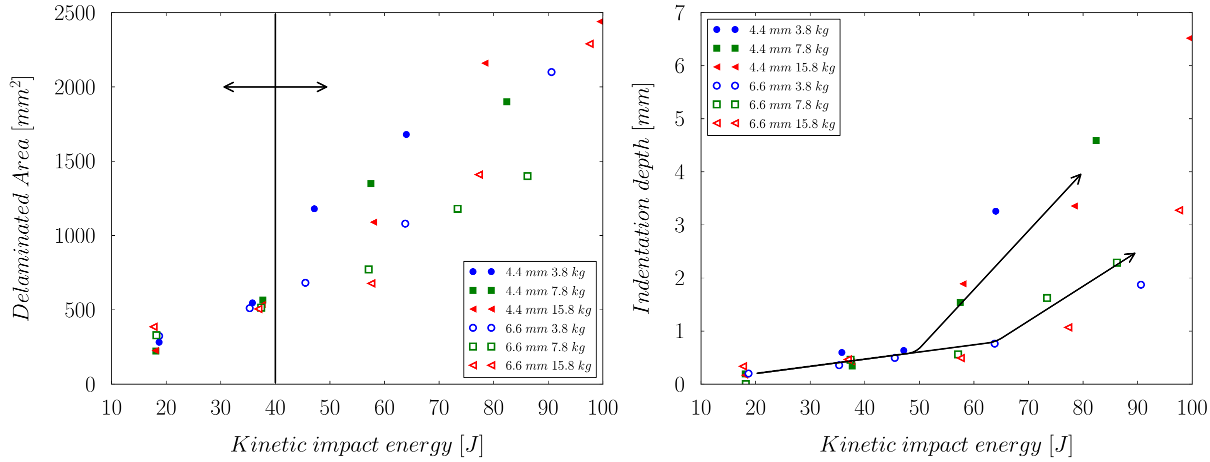

Figure 5. Delaminated area and indentation depth against kinetic energy of the impactor.

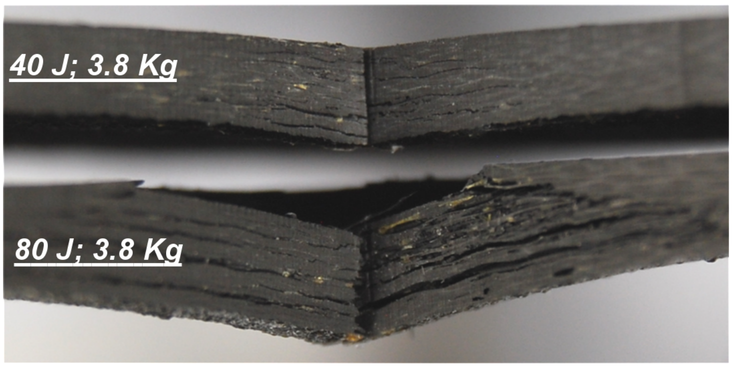

Figure 6. Through thickness cut of two laminates, 4.4 mm thick, impacted at 40 and 80 J.

4. Conclusions

The low-velocity impact tests performed in this work have helped to analyze the influence of the mass of the impactor on the behavior of carbon/epoxy woven laminates.

It has been seen that the mass of the impactor influences the energy absorbed by the laminate, so that for the same impact energy, a laminate impacted by a lighter impactor (with higher velocity) absorbs more energy than the same laminate impacted by a heavier impactor.

The ultrasonic inspection of the specimen has shown that the delaminated area and shape is very similar in the cases in which the laminate absorbs more energy due to the mass of the impactor. So it is reasonable to think that the higher velocity activates certain energy absorbtion mechanisms that cannot be identified by this non-destructive technique.

A change in the indentation depth trend has been identified at a certain impact energy. This threshold energy depends on the laminate thickness and could be related to different energy absorbtion mechanisms.

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