Influence of speed on the crushing behavior of composite plates

Anh Vu Duong, Samuel Rivallant, Jean-Jacques Barrau, Caroline Petiot, Benoît Malherbe

Influence of speed on the crushing behavior of composite plates

Anh Vu Duong[1]*, Samuel Rivallant[1], Jean-Jacques Barrau[1], Caroline Petiot[2], and Benoît Malherbe[3]

[1] *Université de Toulouse; INSA, UPS, Mines Albi, ISAE; ICA (Institut Clément Ader); Toulouse, France*

[2] *EADS IW, Suresnes, France*

[3] *AIRBUS France, Toulouse, France*

*Corresponding author : ISAE, 10 avenue E. Belin, BP 54032, 31055 Toulouse, Fance

e-mail : anh-vu.duong@isae.fr

ABSTRACT

This paper presents a study on crushing of CFRP composite laminated plates. The objective of this study is to analyze the influence of crushing speed on the rupture behavior and the energy absorption capability of composite materials.

Two materials are tested: a carbon-epoxy unidirectional prepreg, and a carbon-epoxy fabric. For both materials, three different plate configurations are tested (three different stacking sequences).

The crushing device is an improved plate crushing setup with stabilizing guides, which can be used both on a standard static traction/compression test machine, or on a drop tower. For static tests, a 20 mm/min velocity is applied to the specimen all along the 100mm crushing stroke. For dynamic tests, only the initial velocity can be imposed. Three initial speeds were chosen: 2, 5 and 9 m/s.

A high-speed camera is used during tests to visualize the global behavior of the plate, and the rupture modes in the crushing front. The load is also recorded, which enables to calculate the load/displacement curve of plates crushing and determinate the energy absorption capability.

The analysis of these results enables to discuss on the influence of crushing speed both on the rupture modes and, as a consequence, on the energy absorption capability.

KEYWORDS: Composite, crushing, energy absorption, speed, CFRP.

1. INTRODUCTION

The use of laminated composite in vehicle structure requires a good understanding of their crash behaviour. But the range of crushing mode is very wide and strongly depends on numerous factors. Despite extensive experimental works done in the 90's [1:5], and more recently [6], it is still very hard to predict the crash response of a complex structure.

A few works were done concerning dynamic crush tests, [7], but there are very few results concerning the influence of crushing speed on crushing behavior and energy absorption capability. Moreover, conclusions seem often contradictory (problems of dispersion, to few tests…)

The aim of this study is to obtain experimental results providing a better understanding of the speed influence in progressive crushing of composite laminated plates.

The main experimental objective of this work is to perform crushing tests on two different materials, with three different stacking sequences for each material, at 4 different speeds (from quasi-static to 9 m/s). A second objective is also to compare energy absorption capability of laminates made of UD plies or fabrics, for the same equivalent modulus.

2. EXPERIMENTAL

2.1 Fixture design

The test fixture (figure 1) has been designed to improve plate crushing fixtures found in literature [8]. It is made of four vertical adjustable guides which avoid buckling of the specimen, and two horizontal adjustable guides. These ones are localised just beneath the vertical guides so that a gap exists between horizontal guides and the metallic base plate where the laminate crashes. Such a concept has been developed at the same time by Feraboli [9]. This avoid tearing of the plate observed in most of the plate crushing fixtures [10], and ensure that the boundary conditions are the same along the whole width of the plate, just above the crushing front. Two main uprights carry the guides without interference with the crush front. Visualisation holes have been made to let the crush front visible.

The thickness of the specimen can vary from 0 to 10mm. The gap (unsupported height between the base plate and the horizontal guides) can vary from 0 to 40 mm.

The laminate is fixed to a steel cylinder which is the interface with the static machine or the drop tower (dynamic tests). During crushing, plate and cylinder go down between the uprights and the vertical guides. At the bottom of the cylinder, a 120 kN Kistler piezoelectric sensor measures the crushing load. The small distance between the specimen and the sensor limits the mechanical filtering of the signal, allowing high precision in the dynamic crush load measurement. A high speed camera is used to have a real-time observation of the crushing front on the side of the plate. The filming speed is 20000 fps, with a 512x256 pixels resolution.

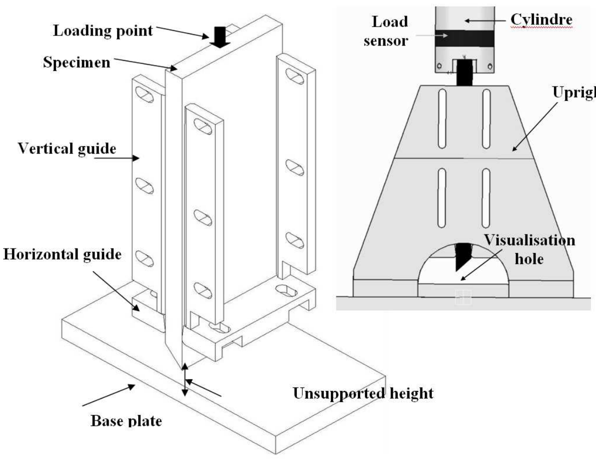


Figure 1: Design of the fixture, with (on right) and without (on left) upright

The fixture is used both for quasi-static test on a screw-driven universal testing machine and for dynamic tests on a drop tower apparatus. The load is introduced through the top of the specimen with a steel cylinder. At the bottom of this cylinder, a piezoelectric sensor measures the crushing load. The small distance between the specimen and the sensor limits the mechanical filtering of the signal.

The use of a drop tower does not enable to have a constant speed during dynamic crushing : speed decreases as energy is absorbed. Depending on the test configurations (available weight on the drop tower, energy absorption capability of specimen, initial speed), speed can just slightly decrease, or reach 0 (in that case, the specimen is not totally crushed).

2.2 Design of experiment

Specimens are 160*60 mm flat plates. White graduations are drawn on the edge of the specimen each 5 mm. The trigger mechanism is a 45° chamfer machined at the bottom end of the plate. Each test is defined by two parameters:

- Crush speed: 20 mm/min for static tests, and three different impact speeds for drop tower tests: 2 m/s, 5 m/s, and 9 m/s.
- Laminate configuration: two materials were tested:

1) Material 1: Cytec fabric prepreg 5H (6KHTA) 977-2
Ply thickness: 0.35 mm
Three stacking sequence configurations:
P1-[(0/45)3]sym
P2- [(0)6]sym
P3-[(0/45)3,0]sym.

2) Material 2: Hexply unidirectional prepreg T700/M21 (M21/35%/268/T700GC)
Ply thickness: 0.26 mm
Three stacking sequence configurations:
P4-[(0/45/90/-45)*2]sym,
P5-[(0/90)*4]sym,
P6-[(0/45/90/-45)*2,90,1/2 0°]sym

Stacking sequences were chosen so that for each kind of configuration (1 to 3), weight, global thickness and equivalent modulus of the plates are the same for both materials (Table 1). This enables to compare energy absorption efficiency for these two materials.
The unsupported height is set to 20 mm for all tests.
Each configuration and speed, two specimens are tested.

Table 1: Specimens characteristics

		Config. 1 *iso*	Config. 2 *0/90*	Config. 3 *0° oriented*
Material 1	Plate number	**P1**	**P2**	**P3**
	Number of plies	12	12	14
	Total thickness	4.2	4.2	4.9
	Equiv. Modulus	**42700**	**61000**	**45700**
Material 2	Plate number	**P4**	**P5**	**P6**
	Number of plies	16	16	19
	Total thickness	4.16	4.16	4.94
	Equiv. Modulus	**45500**	**62600**	**46100**

2.3 Detailed analysis of progressive crushing mechanisms

Figure 3. shows some examples of load-stroke curves obtained from the tests. Each curve may be divided in three phases: the initiation phase, the transition phase and the stable crushing phase on which the specific energy absorption (SEA) is calculated as :

$$SEA = F_{mean} / \rho . A$$

F_{mean}: mean load during the stable crushing phase
ρ specimen density
A surface of the cross-section

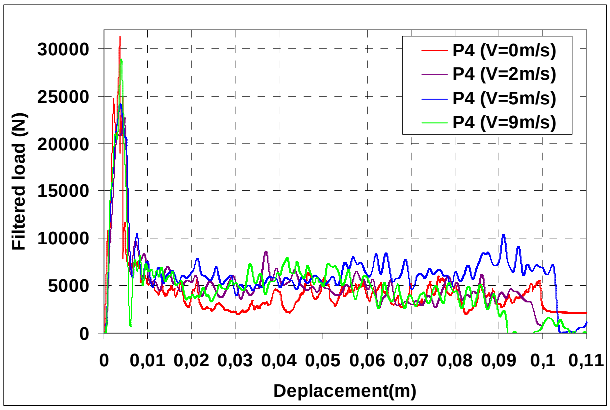
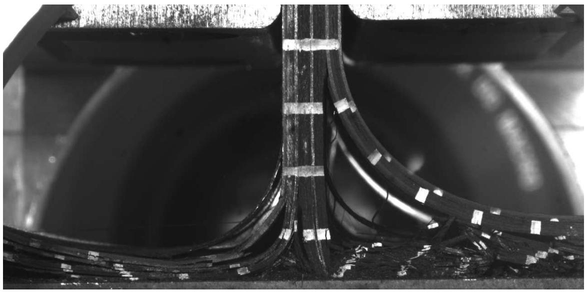


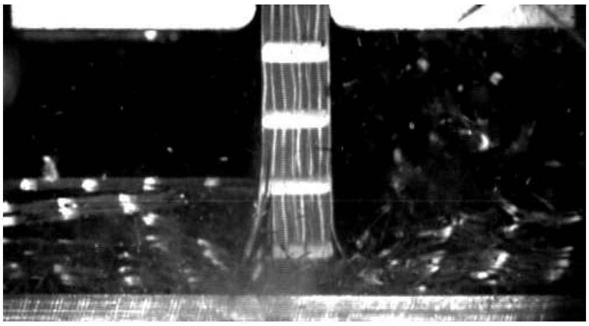
Figure 3: some examples of load-stroke behaviour

3. RESULTS and DISCUSSION

The numerous experiments made enabled to observe the different crush modes of composite laminated plates with different configurations and different speeds. Crush mechanisms are homogeneous through the width of the plate, thus the real-time pictures of the side of the crushed laminate (figure 4 and 5) allow observation and understanding of crush modes. Following is shortly described some of the main modes observed.



(a) Mixed mode: laminate of T700/M21 - chamfer trigger



(b) Fragmentation: laminate of Cytec- chamfer trigger

Figure 4: Examples of crush modes observed

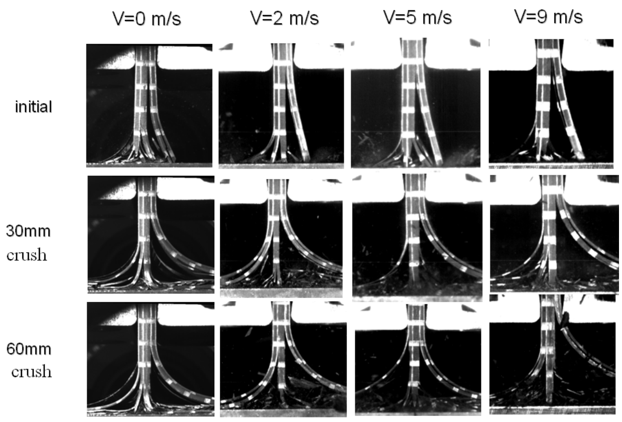
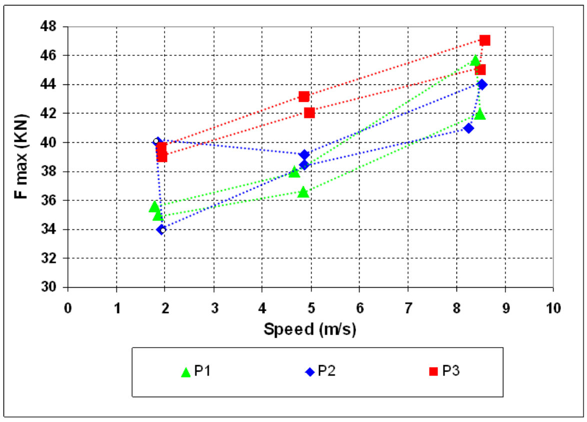


Figure 5: Images from high-speed camera P4

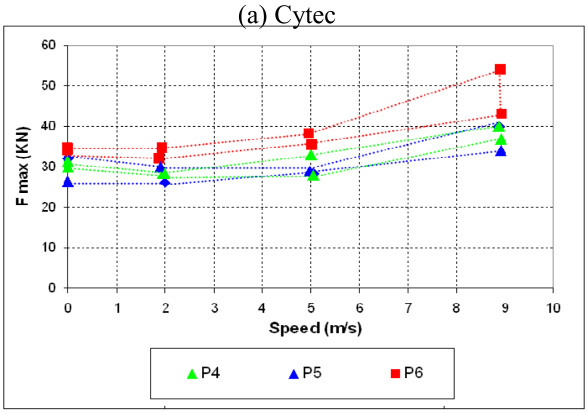
With all specimens tested, there isn't undamaged splaying mode. The crushing mode observed is mixed mode and fragmentation mode. In mixed crush mode, exterior plies on both sides bend and evacuate in splaying crush mode. The proportion of plies that bend on each side is variable. An obstacle, like a debris wedge, in the front separating two splaying arms is the reason why this mode appears. Fragmentation occurs when plies reach the metallic base at right angle and can not slip on the base. Failure appears continuously at macroscopic scale. Energy absorbed can be very high: up to 50 kJ/kg, depending on the number of fragmented plies. But fragmentation is not a stable crush mode, plies crush evolving from fragmentation to bending, leading to undamaged or fractured splaying crush mode.

3.1 Influence of speed

The results of these tests for different stacking sequences of composites plates Cytec and T700/M21 with different initial speeds are shown in figure 6 and figure 7. The dataset of the maximum loads Fmax during the tests for each sample is created. Fmax is the initial peak load (figure 3). Globally, this peak load increases with the speed of the initial velocity before impact.



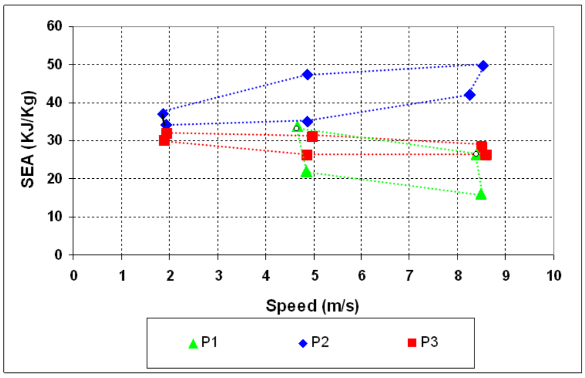
(a) Cytec



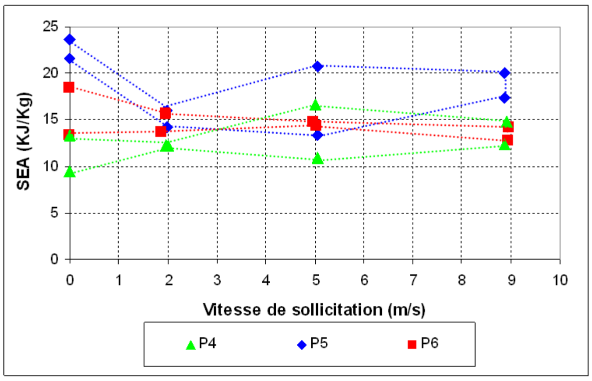
(b) T700/M21

Figure 6: Fmax with different initial speeds

However, the results of energy absorption with different speed are difficult to analyze: no clear tendency is observed. The dispersion of the results can be explained by the different observed crush modes which depends on the debris wedge created in the test. A debris wedge made of debris issued from the initiation process or from fracture of central plies can appear at different time and create different crushing modes in which the number of plies in fragmentation is not stable during the test (and not the same from one test to the other). In figure 7, the dataset of each stacking sequence of both materials with different initial velocity of the test is shown. It can be concluded that there is no visible influence of speed on the energy absorption on the two materials tested with the three stacking sequences.



(a) Cytec



(b) T700/M21

Figure 7: SEA with different initial speeds

3.2. Comparison unidirectional (UD)/fabrics

The Cytec samples and T700/M21 samples have the same equivalent Young modulus for each stacking configuration (iso-rigidity). To compare UD to fabrics, as no visible influence of speed on the results of SEA was found, an average value of SEA was calculated for each material and stacking configuration taking into account the SEA of tests at all speed for a given stacking configuration. Comparison is shown on Figure 8.

The results show that the energy absorption capability of Cytec fabric is much higher (approximately twice) than T700/M21, for the three tested configuration. This can be explained by the fact that in Cytec samples, plies damage happens earlier than in T700/M21, leading to fragmentation whereas in T700/M21, delamination appears between plies, before fiber rupture, developing splaying mode in the external plies, and reducing the number of fragmented plies.

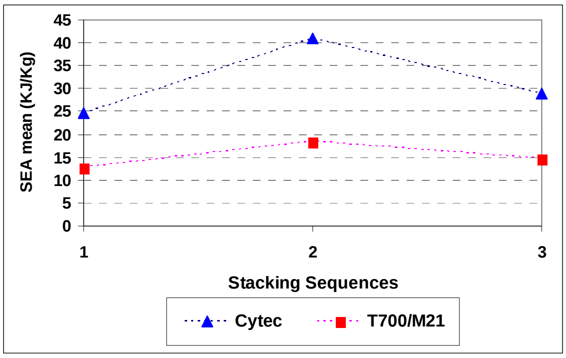


Figure 8: Comparison of SEA for the two materials

4. CONCLUSIONS

The influence of initial velocity on the crushing behavior of composite plates is studied. With two materials tested, the influence of speed to the maximum load is easily observed. However, its influence on the energy absorption is not visible.

The results show clearly that Cytec specimen can absorbed more energy than T700/M21 specimen in crush test.

References

1- Hull D. “A unified approach to progressive crushing of fibre-reinforced composite tubes”, *Composites science and technology* 1991;40:377-421.
2- Farley G.L., Jones M.R. “Crushing characteristics of continuous fibber-reinforced composites tubes”, *Journal of composites materials* 1992;26:37-50.
3- Mamalis A.G., Robinson M., Manolakos D.E., Demosthenous G.A., Ioannidis M.B., Carruthers J. “Crashworthy capability of composite material structures”, *Composite structures* 1997; 37:109-134.
4- Ramakrishna S. “Microstructural design of composite materials for crashworthy structural applications”, *Materials & Design* 1997;18:167-173.
5- Karbhari V.M., Haller J. “Effect of preform structure on progressive crush characteristics of flange-stiffened tubular elements”, *Composite Structure* 1997; 37:81-96.
6- Ueda M., Hiraga A., Nishimura T. “Energy absorption of unidirectionam CFRP plate unde compression”. *14th European Conference on Composite Materials*, Budapest, Hungary, June 2010.
7- Lavoie J.A., Kellas S. “Dynamic crush tests of energy absorbing laminated composites plates”, *Composites: Part A* 1996;27:467-475.
8- Guillon D., Rivallant S., Barrau JJ., Petiot C., Thevenet P., Pechnik N. : “Initiation and propagation mechanisms of progressive crushing in carbon-epoxy laminated plates”. *13th European Conference on Composite Materials*, Stockholm, Sweden, June 2008.
9- Feraboli P., Deleo F., Garattoni F., “Efforts in the standardization of composite materials crashworthiness energy absorption”, *22nd American Society for Composites Technical Conference*, Seattle, September 2007.
10- Daniel L., Hogg P.J., Curtis P.T. “The crush behaviour of carbon fibre angle-ply reinforcement and the effect of interlaminar shear strength on energy absorption capability” *Composites: Part B* 2000;31:435-440.