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MECHANICAL PROTECTION FOR COMPOSITE STRUCTURES SUBMITTED TO LOW ENERGY IMPACT

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Abstract

Composite materials are widely used in aeronautical structures. These materials can be submitted to low energy impacts like tool drop, routine operations… Such impacts can generate damages in the material that significantly reduce the structure strength. A solution to reduce the severity of damages due to impact is to add a mechanical protection on composite structures (patent n° 2 930 478). In this paper, an experimental study on different concepts of protective layers is presented. This protection is made of a certain thickness of low density energy absorbent material (foam, honeycomb or stacking of hollow spheres) and a thin layer of composite laminate (Kevlar).

Experimental impact tests with a spherical impactor of 20 mm diameter at low velocity and low energy are made on aluminum plates, with different protections, and for different levels of energy. Analyses of Load/Displacement curves enable to study the capability of each mechanical protection to absorb energy. Resistance of these protections is then compared and discussed, taking into account the thickness and the surface density of the protections.

1 Introduction

Composite materials are widely used nowadays in aeronautics. This growing interest is due to the strength/mass ratio relatively high for these materials compared to metals. These materials are sometimes subjected to low energy impacts during manufacture, maintenance or machining, which can have an influence on the residual mechanical properties of the structure [1]. That is why during design of composite structures, damage tolerance must be taken into account ([2], [3]). Several authors ([4]-[7]) studied the resistance of composite structures against impact at low velocity. They tried to explain the scenarios of damage during impact.

However, the core materials (honeycomb, foam, hollow spheres ...) are of significant scientific interest due to their good specific resistance and high capacity of energy absorption. These materials can also be used to protect structures against impact. For example, the cockpit of the aircraft is often protected against bird strikes by a honeycomb sandwich layer covered by aluminum skin to improve the capacity of energy absorption. Wang [8] showed that the energy absorption has a linear increase trend with the increase of relative density of honeycomb cores. Therefore, increasing the relative density of honeycomb cores can efficiently improve the dynamic cushioning properties of the sandwich panels. Yi Li et al. [9] used different materials in their impact at high velocity. They determined and compared the energy absorption of these materials. They concluded that porous silicon carbide materials present a greatest ability to reduce impacting energy. On the other hand, Apetra et al. [10] studied the impact at low velocity of honeycomb sandwich beams with variable density and rigidity in thickness. They showed that the variable features core reduces maximum deformation corresponding to maximum impact effort. Furthermore, Shin et al. [11] presented impact tests at low velocity on several types of sandwiches. They concluded that the glass skin sandwich plates have a better resistance against impact compared to aluminum skin. In the same context, Petit et al. [12] showed that a layer of thermal protection (cork) is also a good mechanical protection against impact. The use of such protections increases the residual strength of compression after impact tests.

Anyway, the main objective is to obtain a maximum residual strength for a minimum mass of the structure. Here, the mechanical protector layers become interesting. These layers must possess an ability to absorb impact energy. The addition of these layers can also help to detect easily the impact on these layers since it is more deformable than the structure.

In this paper, several types of protective layers against impact are tested. Impact tests at low velocity (<10 m/s) and low energy (<90J) are performed using a 20 mm diameter impactor on a falling weight device. Finally, a comparison is made between the different layers tested.

2 Experimental study

2.1 Falling weight device

There are many testing procedures to simulate an impact on a structure. However, the falling weight remains the most used device [1]. Such a device has been used in this study to perform impact tests according to standards AITM 1-0010 [13]. The principle of this falling weight is to drop a mass guided in a tube on a composite plate, as illustrated in Figure 1.

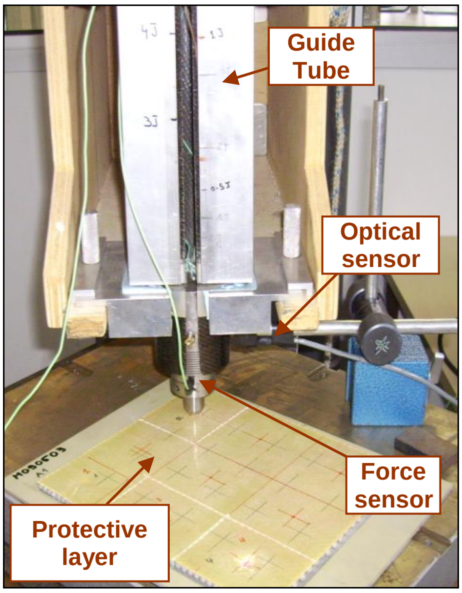


Figure 1 : Falling weight device

This device is dedicated to impact tests at low velocity (<10 m/s) and low energy (<90J). A 4.02 kg impactor with a 20 mm diameter hemispherical head is used. The impactor is instrumented with a force sensor, installed between the impactor head and its body. This KISTLER piezoelectric sensor having a max capacity of 120 kN is calibrated to measure the impact effort. An optical sensor (Laser diode, Figure 1) measures the initial velocity of the impactor just before the impact. By integrating the equations of the fundamental principle of dynamics, velocity and displacement versus time curves are obtained from the measured effort provided by the sensor KISTLER, knowing the impact velocity.

2.2 Protective layers

Two configurations of protective layers have been tested. Configuration 1 is designed for 50 J energy impacts (see Figure 2). It is composed of a skin having a number (a) of Kevlar fabric plies (aK) and of three types of core: hollow spheres made by ATECA Company, honeycomb (Nomex Aramid fiber/phenolic resin honeycomb, HRH-10-3/16-3.0) and foam (HEREX 70.75). The patent "Peau amortissante de protection de pièces composites" n° 2 930 478 has been filed about the hollow spheres protective layers [14]. The mechanical properties of the skin and the different cores are given in Table 1 and Table 2 respectively. The assembly is glued onto an aluminum plate. Configuration 2 consisting of two skins and two core layers is developed in order to withstand 90 J energy impacts. The design of this configuration is based on a gradual stop of the impactor. The two core layers are separated by a number (b) of Kevlar fabric plies (bK) as shown in Figure 2. The thickness of core layers is about 6 mm.

Table 3 sums up the material and geometrical configurations for each different tested protective layer, and the global surface density obtained.

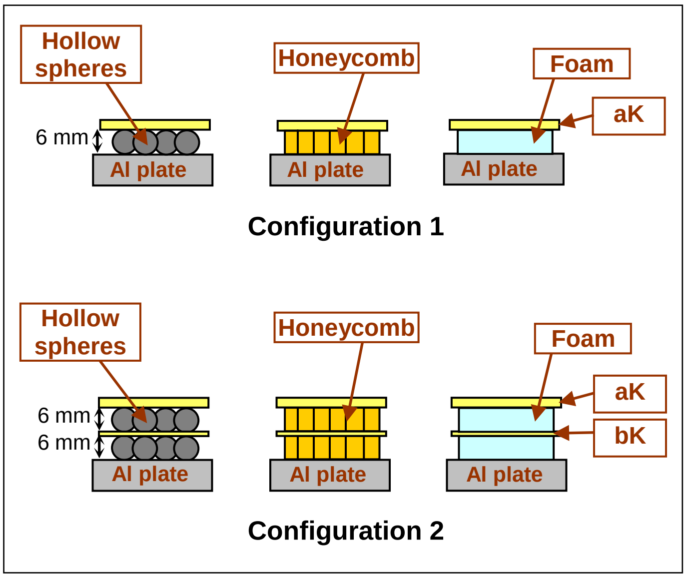


Figure 2 : Geometry and material configuration of protective layers

Material	Failure stress in compression (MPa)	Failure stress in traction (MPa)	Failure shear stress (MPa)	Young's modulus (MPa)	Density (kg/m^3)
Kevlar (skin)	170	500	150	22000	1330

Table 1 : Skin properties

Material	Failure stress in compression (MPa)	Young's modulus in compression (MPa)	Density (kg/m^3)
Hollow Spheres (HS)	0.35	30	166
Honeycomb (HC)	2.2	137	48
Foam (F)	1.3	83	80

Table 2 : Core materials properties

Specimen	Core	Number of skins	Thickness (mm)	Surface density (g/dm²)
HS1	Hollow spheres	1	7.4	50
HC1	Honeycomb	1	7.6	29
F1	Foam	1	7.8	27
HS2	Hollow spheres	2	13.3	100
HC2	Honeycomb	2	14.7	50
F2	Foam	2	14.6	48

Table 3 : Characteristics of protective layers

2.3 Test results

The specimens were impacted at several impact energies. Indeed, configuration 1 specimens were tested at 15, 30 and 50 J impact energies. Impact energies of 15, 50 and 90 J were used for the thick layers (configuration 2). An example of Load/Displacement curve is presented in Figure 3, for a 50 J energy impact, on a configuration 1 specimen with hollow spheres. The other tests on protective layers present similar curves. The initial impact velocity measured in this test is 5.1 m/s. The maximum displacement of the impactor is then about 6.8 mm. This displacement is lower than the layer thickness (7.4 mm, represented on the curve by the vertical line). Hence, the impactor will not touch the aluminum plate, which is not the case for highest energy impacts.

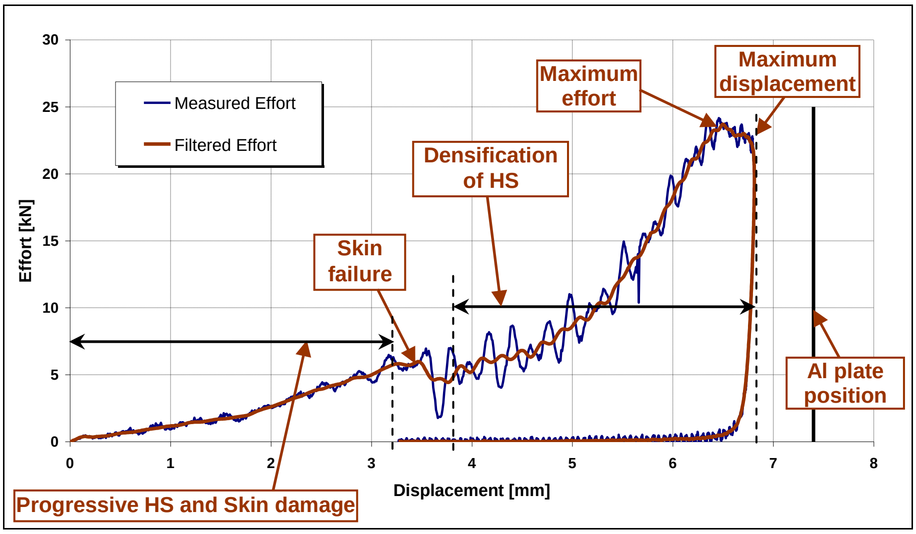
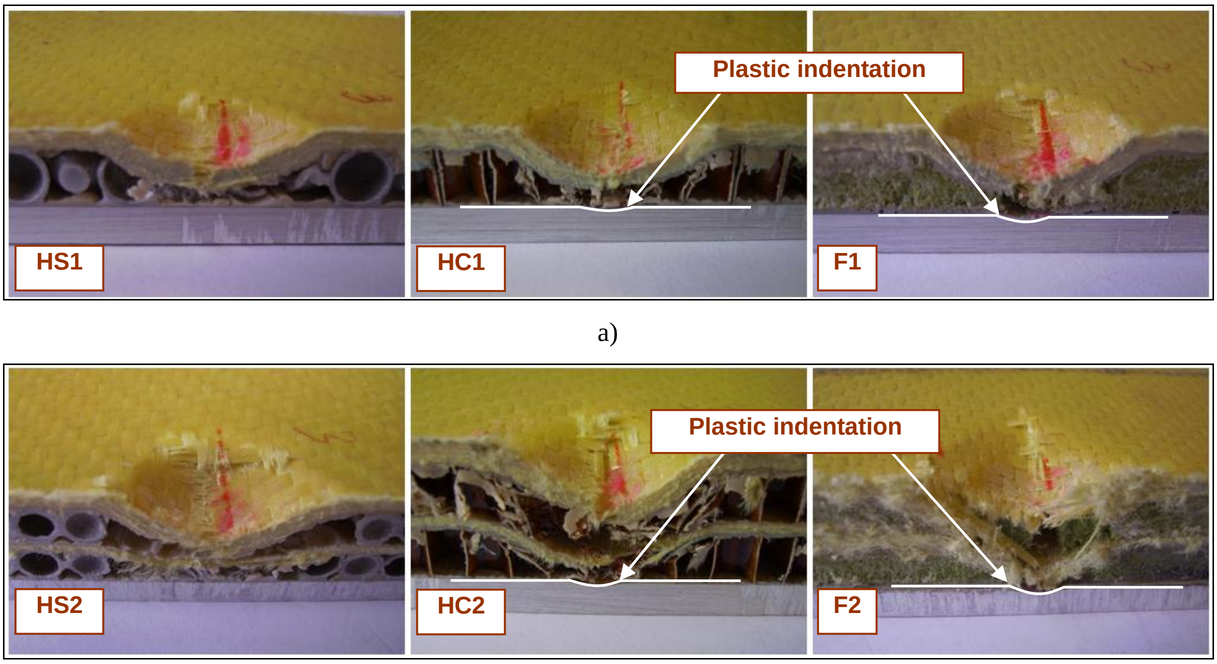


Figure 3 : Load/Displacement curve example: 50 J impact test on HS layer

The various steps of the impactor displacement through the layer are identified during impact. Thus, in Figure 3, the impact effort starts to increase after the contact of the impactor with the skin. The skin remains in bending until the beginning of the hollow spheres crash. During the first phase, the damage of the skin and the hollow spheres is shown until the failure of the skin. Breaking the skin is identified by the significant drop in effort. After this break, the skin damage continues and the hollow spheres densification is held up to the maximum effort and the return of the impactor.

Figure 4 shows the cross-sections of the different layers after impact, at the centre of the impacted area. The skins failure and the cores crushing are clearly visible on this figure. In some cases, under the impactor head, the whole thickness of the protective layer is crushed, leading to a plastic indentation of the aluminum plate (visible on the figure).



a)

b)

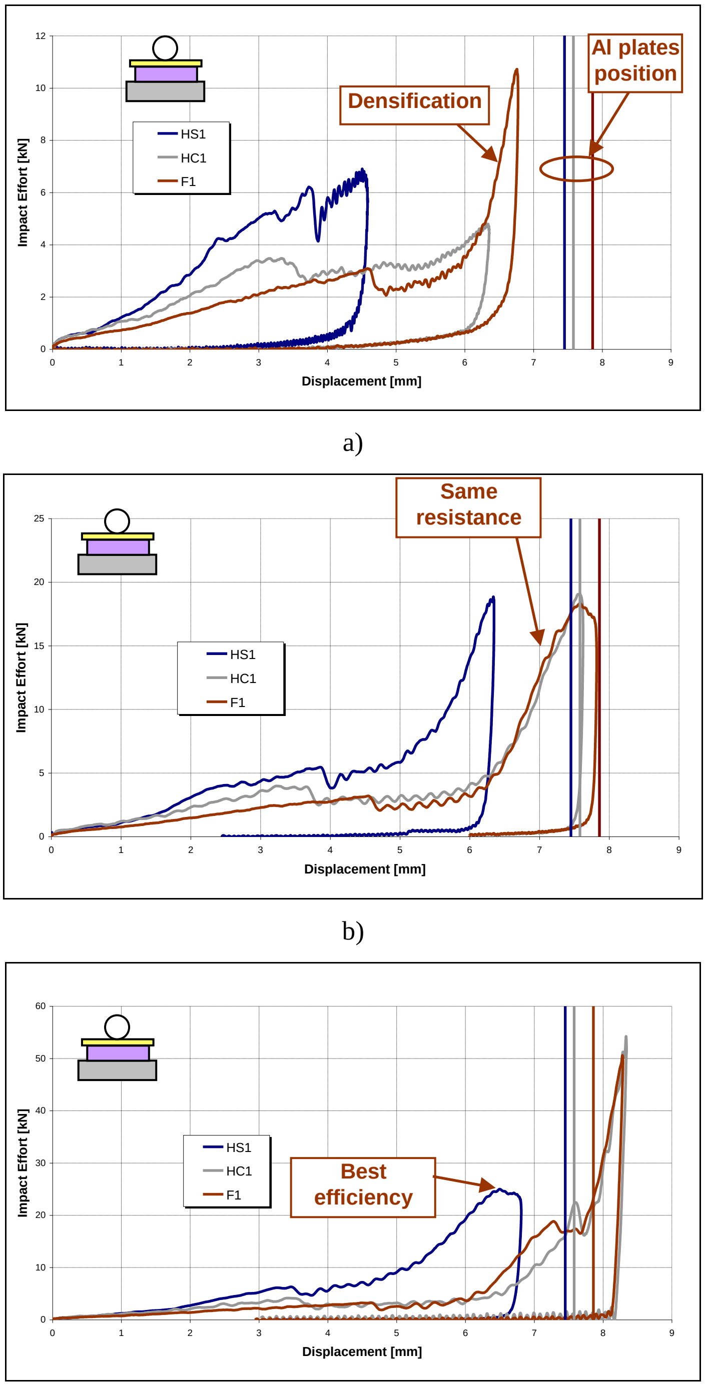
Figure 4 : Cross-sections of impacted protective layers
(HS: Hollow Spheres, HC: Honeycomb, F: Foam - 1 for configuration 1, 2 for configuration 2)
a) at 50 J impact energy - b) at 90 J impact energy

Results observed on the different layers are compared and discussed in the following paragraph.

3 Comparison and discussion

3.1 Impact energy absorption capability for a given layer thickness

In this subsection, the impact resistance of configuration 1 and configuration 2 of various specimens is studied. The different Load/Displacement curves, corresponding to the specimen’s core of hollow spheres, honeycomb or foam, are compared. Figure 5 shows the impact curves of various specimens of configuration 1 at three levels of impact energy 15, 30 and 50J.



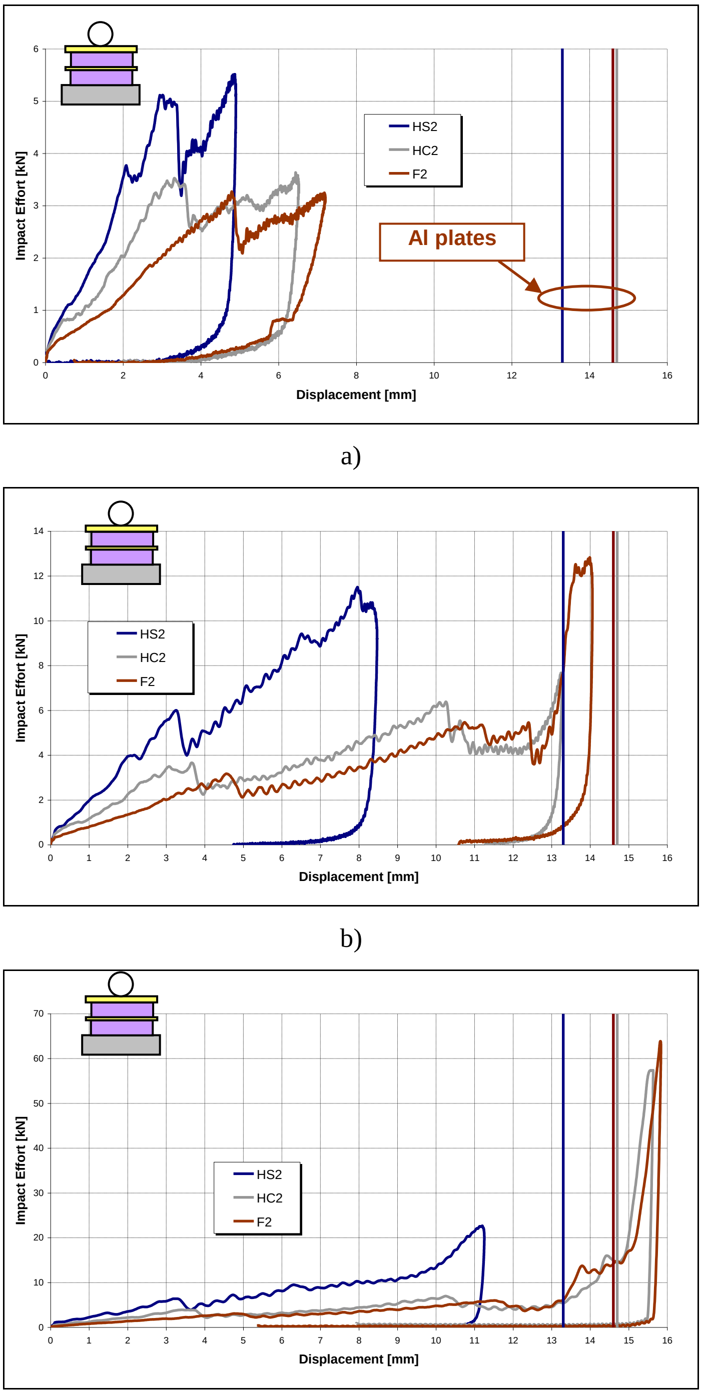
a)

b)

c)

Figure 5 : Load/Displacement curves of configuration 1 layers. a) 15 J - b) 30 J - c) 50 J

For best efficiency when impacting with a given energy, maximum impact effort must be the lowest possible. This leads to securely protect the structure impacted. In Figure 5-a, the significant difference between slopes of different impact curves at 15J proves a significant difference between the efficiencies. Indeed, the hollow spheres (HS1) exhibit the highest capability to absorb energy without a peak of load, and with a short displacement, followed by the honeycomb (HC1). The foam core (F1) has low efficiency due to lower compression resistance at this energy compared to other materials. The densification occurs when the impactor tends to touch the aluminum plate, thus the core material is crushed. At impact energy of 30J, the best efficiency of hollow spheres is confirmed. The behavior of the foam and the honeycomb is nearly identical. In this case, the impactor tends to plastify the aluminum plate and the layer is no more protective against impact (Figure 5-b). In Figure 5-c, it is remarkable that the impactor plastify the aluminum plate in both cores HC1 and F1. By cons, it is still at a distance of approximately 1 mm in the case of HS1 and therefore only the layer HS1 continues to be a good candidate for protection against impact. These results was identified and observed on the Figure 4-a after impact. This first study shows the advantage when using hollow spheres and its better efficiency to 50J impact energy in the case of configuration 1.



a)

b)

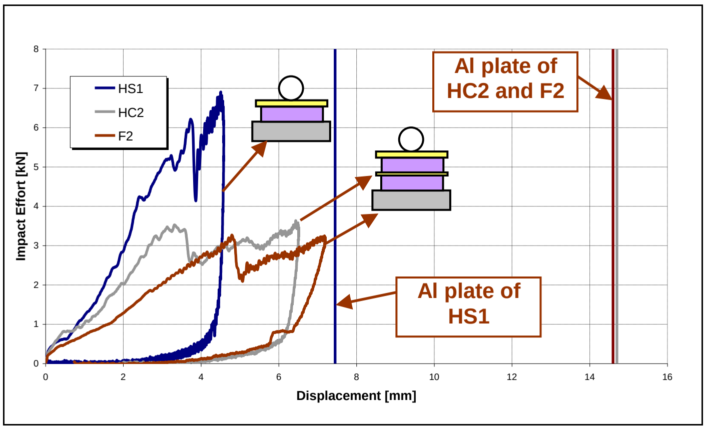
c)

Figure 6 : Load/Displacement curves of configuration 2 layers. a) 15 J - b) 50 J - c) 90 J

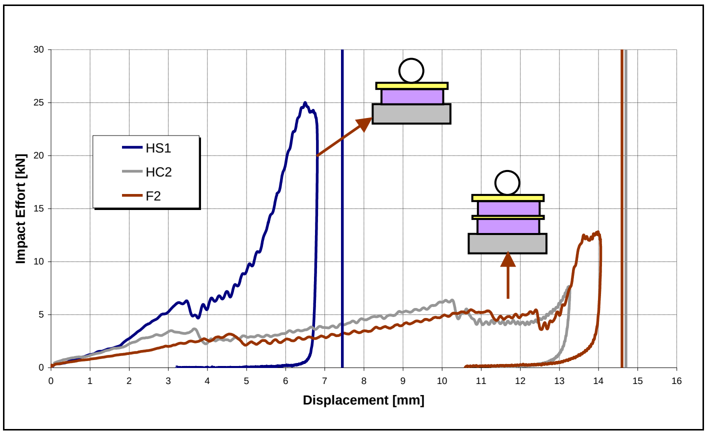
In the case of configuration 2, the three energies tested are 15, 50 and 90J (see Figure 6). Similarly, on the different Load/Displacement curves obtained, the best efficiency and capability to absorb energy are found for the hollow spheres. In Figure 6-c, it is remarkable that the impactor plastify the aluminum plate in the case of HC2 and F2 and stays at about a distance of 2 mm in the case of HS2. This shows that the layers HC2 and F2 are not candidate to absorb impact energy of 90J without load peak. However, the layer HS2 can rather resist to this energy. Similarly, observations on the Figure 4-b prove these results deducted from the impact effort curves. The comparison between the same configurations (or same thickness) shows initially the better efficiency of hollow spheres. Nevertheless, the mass is an important interest in the aeronautical domain. Moreover, for a given mass, it is preferable to optimize the thickness of protector layers in order to obtain less volume. A comparison between different specimens of the same surface density must then be made.

3.2 Impact energy absorption capability for a given surface density

The layers of the same configuration have different surface densities. The surface density of hollow spheres is about twice that of honeycomb and foam of the same configuration (see Table 1). To obtain the same surface densities, configuration 1 of the hollow spheres must be compared to configuration 2 of honeycomb and foam. The corresponding surface densities are then respectively 50, 50 and 48 g/dm² for the hollow spheres, honeycomb and foam. However, configuration 2 has a further advantage in that it contains intermediate skin of fabric Kevlar plies (bK).



a)



b)

Figure 7 : Load/Displacement curves for same surface density layers : a) 15 J - b) 50 J

Figure 7 shows the impact effort curves of layers referred at 15 and 50J impact energy as a function of the displacement. The difference of the energy absorption capability is also remarkable in Figure 7-a at 15J impact energy. At 50J impact energy, the curves are different. The thicknesses are not equal and thus the displacement of the impactor. This entails a max impact effort for the hollow spheres larger than honeycomb and foam. However, the distance between the impactor and the aluminum plate is about 1 mm in all cases. This follows close efficiency for the three layers of the same surface density but with different thicknesses. Note that the intermediate Kevlar skin increases significantly the resistance against impact. The hollow spheres present then an important efficiency and acceptable energy absorption capability when impacting. Furthermore, the hollow spheres can be used to optimize the thickness when this thickness is a constraint for a given structure.
Note that the hollow spheres have an advantage over other materials for energy absorption due to their easy installation on non-flat structures.

In a subsequent study, these protective layers must be tested on composite plates to compare the different residual strength and thus to check the best protection against impact.

4 Conclusion

In this paper, the efficiency of composite structures mechanical protection against impact has been studied. This protection includes a Kevlar skin and cores of several types. The tested cores consist of hollow spheres, honeycombs or foams. Two configurations of two different thicknesses have been impacted at several impact energies. The curves comparison of impact effort for a given constant thickness shows better energy absorption capability for the hollow spheres. Another comparison between different types of cores at different configuration with constant surface density was conducted. The hollow spheres have also increased capacity to absorb energy comparable to two stages layers of foam or honeycomb separated by a number of fabric Kevlar plies and having the same density. These results can be used to protect composite structures with hollow spheres having important resistance against impact. Theses composite structures can have complex shapes such as non-flat surfaces as well as a circular surface. This paper is limited to study the protective layer against impact, on metallic plates. A future study on composite plates protected by these layers will be lead.

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