

IMPACTS ON FOAM STABILISED COMPOSITE STRUCTURES : EXPERIMENTAL AND NUMERICAL STUDY

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Abstract : A dropweight tester is used to make low velocity tests on specific sandwich type structures. Sandwich are made of glass-epoxy skin and polyurethane foam core. The skins can be straight or little curved, and impact direction is the global skin direction. The aim of these tests is to study the initiation of rupture in such structures : local buckling of skin and foam core rupture. Experimental results are given. They show the evolution of buckling critical stress in the skin when impact velocity increases. The rupture mode in curved skin specimen is also studied : rupture is no more provoked by buckling. A numerical analysis is proposed to model the behaviour of the structure and the rupture initiation. Finally, a method is developed, in order to predict the propagation of skin debonding during impact : an element layer under the skin is damaged with a specific law to simulate debonding.

1. INTRODUCTION

Structures made of foam core and composite skin are widespread in aeronautical industry, because of their good mass/resistance ratio. But one of the main problem of sandwich structures is local buckling which appears in skin, and can lead to partial destruction of the structure.

An helicopter blade is a characteristic example of complex sandwich structures : the leading edge is made of unidirectional glass-epoxy, reinforced with a thin layer of titanium. The core is made of a polyurethane foam, and covered with a hybrid glass-epoxy and carbon-epoxy skin. During impact on the leading edge, buckling of the skin or rupture of the foam can lead to a partial rupture of the structure. Therefore it is important to understand the mechanics of the rupture initiation.

To have a better understanding of the phenomenon, low velocity impacts are made on specific sandwich structures. The apparatus we use is the common dropweight tester [1]. Both straight skin and curved specimen are tested. Measures allow to know the impact load, acceleration of impactor and deformations of the specimen skin, which is sufficient for a numerical correlation. Results are given, discussed and compared with static tests results.

Numerical calculations are proposed to model the impact and the initiation of rupture. A spring-mass model describes the structure behaviour of no rupture tests, and the beginning of every test, till rupture. To have a better understanding of the rupture initiation and the stress repartition in the core, a dynamic explicit code is used. A fine mesh is needed to model the rupture initiation.

These models do not take into account the post-rupture behaviour of the structure. A debonding propagation model is proposed, which works for static loads.

2. EXPERIMENTS

2.1 Description of impact tests

Impact tests are made with a dropweight tester : a 900 g impactor (figure 1), equipped with a load cell and an accelerometer is guided by a tube. The velocity of the impactor before impact is measured with optical sensors. Acceleration, velocity, displacement and impact load can be deduced from sensors measures.

Tests are made with different impact velocities, to see the influence on rupture apparition. Specimens are represented on figure 2. They are made of a polyurethane foam core, between two steel masses, covered with a glass-epoxy skin. Two kinds of specimen are tested : straight skin specimens and curved ones. The foam is a quasi-isotropic material, with $E=10$ MPa, $G=5$ MPa, $\nu=0.01$. The skin is made of two glass-epoxy tissue plies, with a 20000 MPa Young modulus.

Strain gages are used to measure skin deformations during impact. Acquisition of load and acceleration is made with a 1 MHz frequency, whereas strain acquisition is limited to 100 KHz. Different velocities are given to impactor, going from 0.35 m/s to 4.3 m/s.

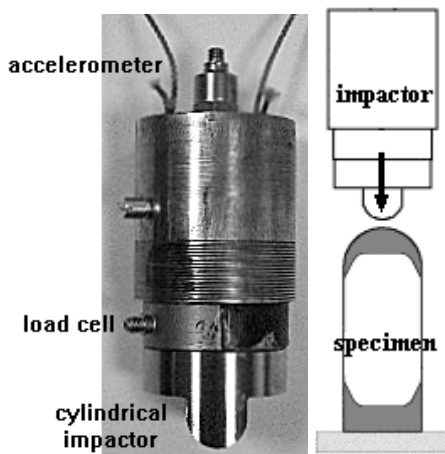


Figure 1 : impactor with sensors



Figure 2 : specimens before and after impact

2.2 Results

2.2.1 rupture observation

Figure 2 shows two specimens after impact. Impact load provokes the debonding of both skins (except for one test). The analysis of rupture location shows that rupture appears in the foam core, close to the skin, and propagates along the skin. Contrary to usual debonding or delamination, it is not an interface rupture, because of the weak mechanical properties of foam.

2.2.2 behaviour of the structure during impact

The graph of impact load and deformation in the skin (figure 3) describes the different stages of impact for a straight skin specimen (impact velocity : 2.3 m/s).

There are three main stages during the impact :

- from 0 to 0.45 ms : the upper mass of the specimen is accelerated : there are two load peaks, but the deformation in the gages increases regularly (figure 3, detail)

Then, debonding appears, and deformations become suddenly positive, due to traction component of skin bending.

- from 0.45 ms to 6.5 ms, the impactor and the specimen remain in contact : the rigidity of the structure has changed, thus the load measured is lower. Bending in the skin provokes high positive deformations in the gages.
 - after 6.5 ms, there is no more contact between the impactor and the specimen. The structure vibrates freely : gages show the frequency of oscillations.
- Every test presents a similar behaviour, even for the curved skin specimen.

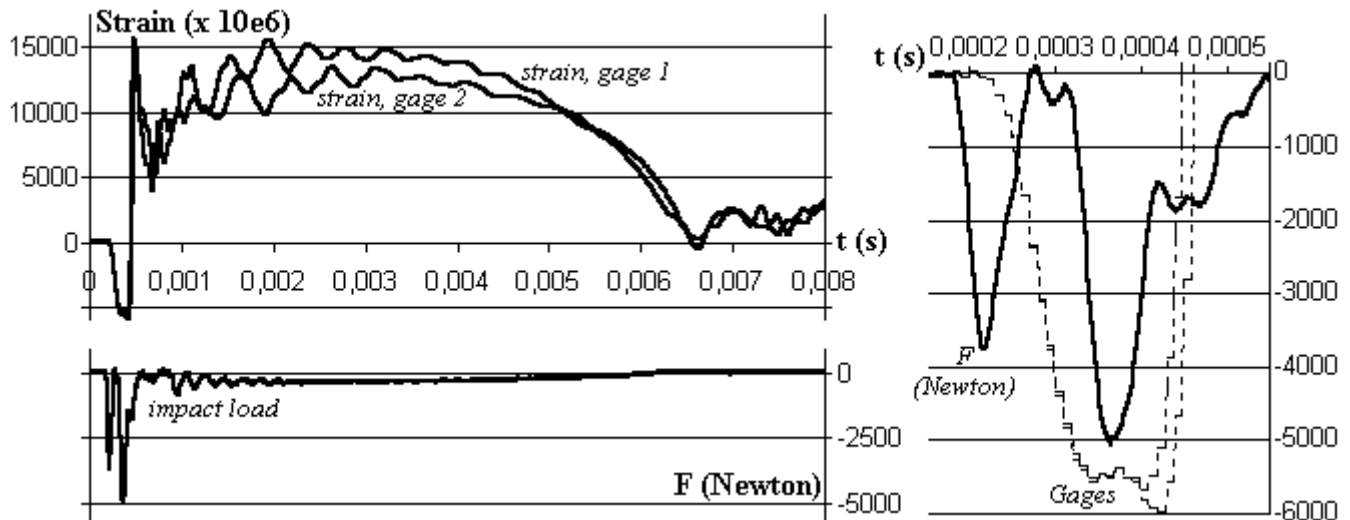


Figure 3 : impact load and strain in the skin, for 2.3 m/s impact velocity : whole test (left) and detail (right)

2.2.3 Evolution with impact velocity

Figure 4 shows how the deformations in the straight specimen evolve when impact velocity increases from 1.14 (no rupture) to 4.3 m/s.

The deformations in the skin increase faster when velocity increases, that is due to the increase of load peaks (not represented). However, as shown on the graph, rupture does not appear for the same stress in the skin : the maximum stress increases with velocity.

The same evolution is observed for curved skin specimen (figure 4, right).

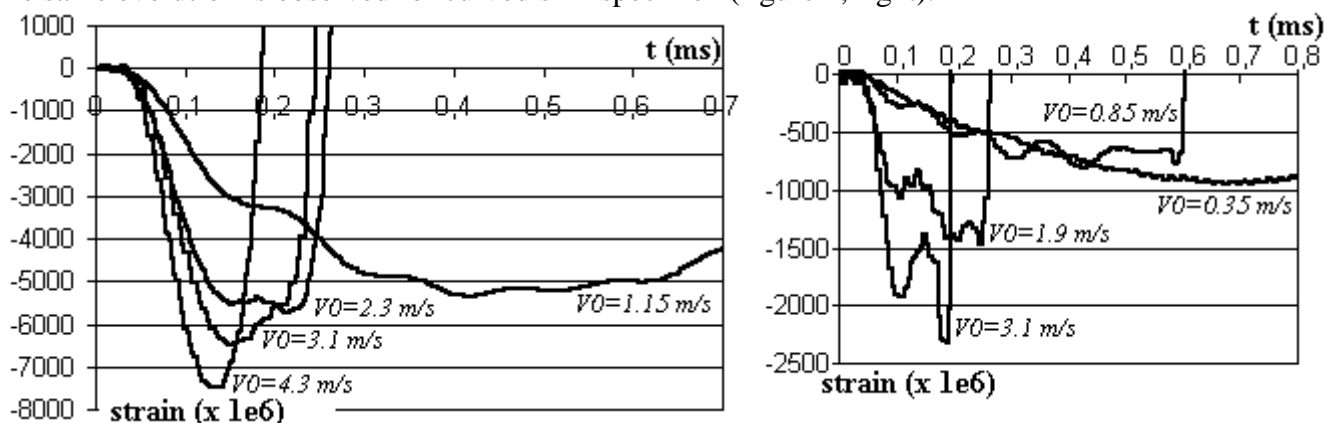


Figure 4 : deformation in the skin for different velocities : straight skin (left) and curved skin (right)

3. NUMERICAL ANALYSES

3.1 No rupture analyses

A spring-mass model (figure 5) with an explicit Newmark type calculation describes well the behaviour of the structure when rupture does not occur [1]. It allows to verify the global stiffness of the structure, and then, to correct the mechanical characteristics of the structure's components.

The model is made of a mass which represent the impactor, a spring for the interface stiffness, a mass for the upper extremity of the specimen, and a spring with damping for the foam core plus the skin. Before skin debonding, stiffness of the core can be neglected. The interface stiffness is linear in compression, and equal to zero in traction.

Calculations are also made with an explicit dynamic code (Radioss). They give good results for no rupture analysis, as seen on figure 6.

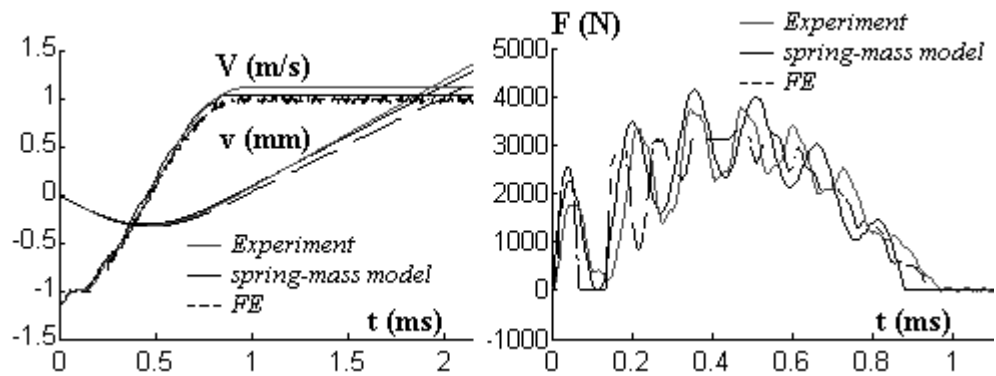
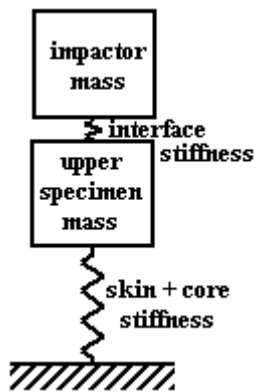


Figure 5 : spring-mass model

Figure 6 : velocity, displacement and interface load for a no rupture test

3.2 Rupture analyses

3.2.1 Initiation of rupture

Studies have been made for static loads, on the same type of specimen. Buckling has been studied [2,3], and a new buckling calculation method proposed [4]. For straight skin, it has been shown that rupture appears because buckling provokes a local increase of stress in the core, under the skin. For curved specimen, rupture starts before the critical buckling load, due to an increase of stress just under the skin, at the middle of the specimen.

To verify whether the behaviour is the same for impacts, we use the Radioss explicit FE code [5]. A fine mesh of the foam under the skin is necessary. Foam is considered to be linear elastic, with a 0.5 MPa tensile limit. In the case of straight skin, it allows to find stress concentration under the skin, due to buckling (figure 7). In the case of curved skin, conclusions are the same : the displacement of the upper extremity of the specimen lead to the increase of skin curvature and stress. No buckling appears before rupture of the foam.

A quite accurate estimation of the debonding initiation moment is obtained for both types of specimen, which confirms the increase of skin maximum deformation when velocity increases.

At the moment, the post-rupture behaviour is not simulated. In the next part of the paper, a model for debonding propagation is proposed.

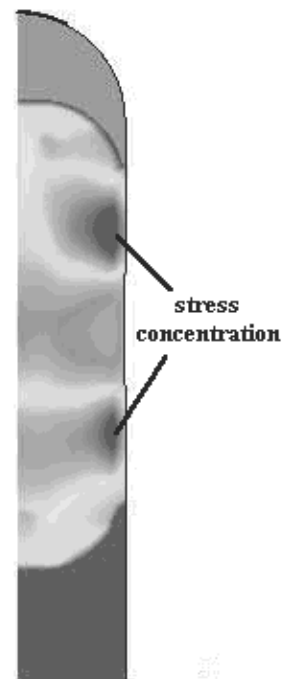


Figure 7 : stress concentration in the core when buckling appears

3.2.2 Propagation of debonding

A model for debonding is being studied, in order to simulate the behaviour of the structure from rupture till the end of impact.

This model is based on damage mechanics : debonding is considered as propagation of damage in the foam, close to the skin (figure 8). Many authors have worked on interface damage models to modelize delamination [6]. The problematic here is different since it is not an interface damage model. The propagation of damage in a layer of elements situated under the skin is chosen to model debonding.

Theory is inspired by Ladeveze works [6,7] : a damage parameter d rules the evolution of Young modulus and shear modulus. x is the skin direction, y the transverse direction :

$$E_y = (1-d) \cdot E_y^0, G_{xy} = (1-d) \cdot G_{xy}^0 \quad (1)$$

No damage law is applied to E_x . Only the mode I rupture is taken into account. The only energies taken into account for the damage calculation are W_y and W_{xy} . The associated Y variable is defined as :

$$W_y = \frac{1}{2} \cdot \frac{\sigma_y^2}{E_y^0 \cdot (1-d)}, \quad Y_{d1} = \frac{\partial W_y}{\partial d} = \frac{1}{2} \cdot \frac{\sigma_y^2}{E_y^0 \cdot (1-d)^2}, \quad \text{with } Y = Y_{d1} + Y_{d2} \quad (2)$$

$$W_{xy} = \frac{1}{2} \cdot \frac{\tau_{xy}^2}{G_{xy}^0 \cdot (1-d)}, \quad Y_{d2} = \frac{\partial W_{xy}}{\partial d} = \frac{1}{2} \cdot \frac{\tau_{xy}^2}{G_{xy}^0 \cdot (1-d)^2}$$

The following functions can be used to relate parameter d to variable Y [6] :

$$d = \frac{Y - Y_0}{Y_c}, \quad d = \frac{\sqrt{Y} - \sqrt{Y_0}}{\sqrt{Y_c}}, \quad d = \frac{\langle Y - Y_0 \rangle^n}{Y_c^n} \quad (3)$$

The energies needed to propagate debonding and to damage the element layer are compared in order to determinate the damage parameters Y_0 and Y_c [6,8].

$$\partial W = G_{lc} \cdot \partial a \cdot b = \iiint_{interface} Y \cdot \partial d \cdot \partial V \quad (4)$$

Tests were made with different functions. They lead to different results of the damage parameter Y_c . The problem is that, with an element layer which have an arbitrary thickness, it is not possible to estimate correctly the stresses in these elements, and to correlate with the theoretical Y_0 and Y_c values, contrary to interface elements [7,9]. However, it is possible to find values for Y_0 and Y_c which allow to describe the debonding of the skin.

The graph on figure 9 represents the debonding of a foam covering skin. The reference curve is given by an energy release rate method, the other curve is the result of the damage propagation method using the linear d/Y function. Data are : $G_{lc}=0.2$, $Y_0=0.0125$ (initiation of damage in the foam). Calculation gives $Y_c=0.1$.

At the moment, this model works on a standard implicit FE code.

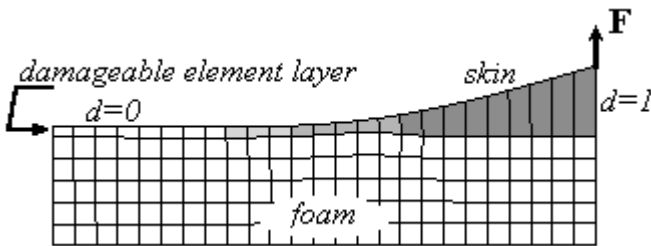


Figure 8 : A model for debonding propagation

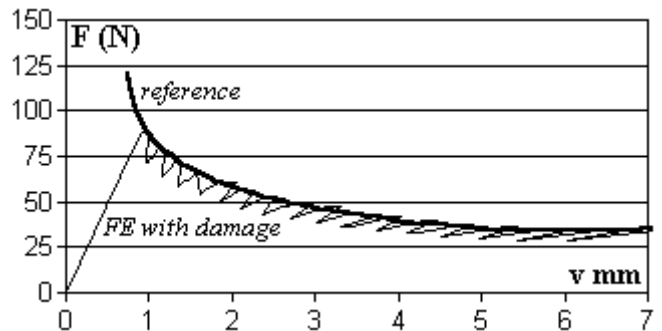


Figure 9 : F vs v debonding FE result for static calculation

4. CONCLUSION

Tests on specific specimen were made to understand global rupture mechanics during impact on sandwich structures. They give interesting results. They show clearly the evolution of the buckling load when the impact velocity increases. Tests on curved skin specimen and numerical calculations revealed that buckling does not appear before the rupture. In fact, rupture is due to the increase of stress in the foam. For both cases, rupture appears in the foam, due to its low mechanical properties.

A spring-mass model is proposed to represent the structure. It gives a good representation till the rupture, but does not represent neither the damage initiation nor the post-rupture behaviour. On the other hand, a fine modelling of specimen with an explicit dynamic FE code can show damage initiation in the core. The post-rupture behaviour is not modeled. A model is being developed to propagate skin debonding under static loads. This model gives accurate results, but requires the calculation of the representative parameters.

The main limitation of this study is that, for a complex real structure, the number of elements necessary to have a fine mesh can be time prohibitive. A coarse mesh must then be used. Therefore the method used in this paper may be inefficient to determine rupture initiation. At the moment, works are carried out to develop a criterion that takes into account the initiation of skin debonding due to local buckling.

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