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Comparison Study and Mechanical Characterisation of a Several Composite Sandwich Structures

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Abstract Composite sandwich structures have excellent properties and they are widely used in the fields of high technology such as aeronautics and astronautics, etc. Investigations of the mechanical properties of composite sandwich structures play a vital role in determining their applicability in various engineering fields. In this study, we have developed a new core material, which is an original cellular composite based on polystyren cells named **YmaCell**. Bending and crash properties of YmaCell are determined and compared with a polypropylen honeycomb and a thermoplastic foam panel. The results show that the rigidity of the cellular composite **YmaCell** is better than that of the polypropylen honeycomb structures and the thermoplastic foam. The chemical bonds between the skins are likely to be a major factor for the higher performances of the cellular composite.

Keywords Composite, Short fibres, Sandwich structures, Crash, Bending

1. Introduction

Sandwich panels typically consist of two thin face sheets or skins and a lightweight thicker core. Commonly used materials for face sheets are composite laminates and metals, while cores are made of metallic and non-metallic honeycombs, cellular foams, balsa wood or trusses. The face sheets are typically bonded to the core with an adhesive, and carry most of the bending and in-plane loads. The core provides the flexural stiffness and out-of-plane shear and compressive strength. The structural performance of sandwich panels depends not only on the properties of the skins, but also on those of the core, the adhesive bonding the core to the skins, and the geometrical dimensions of the components.

Sandwich composites with cellular core are widely employed in modern mechanical design, not only in the field of aeronautical constructions, where they have been developed initially, but also in the fields of on-land transportation and marine constructions. Because of their characteristic features, such as the high flexural resistance and stiffness [1], the high impact strength [2, 3], the high corrosion resistance and the low thermal and acoustics conductivity [5, 6, 7], sandwich structures are in fact preferred over conventional materials in various industrial applications. Although large numbers of research projects have been performed by various authors, the design of structural elements made from sandwich composites is often a difficult task. This is mainly because a reliable strength prediction needs the preliminary knowledge of the mechanical behavior of skins and core, as well as of the peculiar damage mechanisms [8, 9, 10], and failure criteria that can be used under a complex loading.

In the last years, the research and development on a large range of cellular composites has been explored. In nature cellular structures can be found in plants and bird bones. Such structures have been reproduced so closely as possible to the natural ones. The basic principal for the production of such a materials is the association of a sophisticated system of stiff-walled, tree-dimensional cells with a short-fibred composite material.

In this paper a sandwich element with a novel cellular core named **YmaCell** are developed. Bending and crash properties of **YmaCell** are determined and compared with a polypropylene honeycomb and a thermoplastic foam panel. The panels are covered with different composite walls.

2. Sandwich Material

A typical simply supported sandwich panel consists of two thin faces with a thickness of t, separated by a light and a weaker core of thickness h_c, as illustrated in Fig.1. The overall depth of the panel is h and the width b. The faces are typically bonded to the core to provide a load transfer

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mechanism between the main components of the sandwich panel.

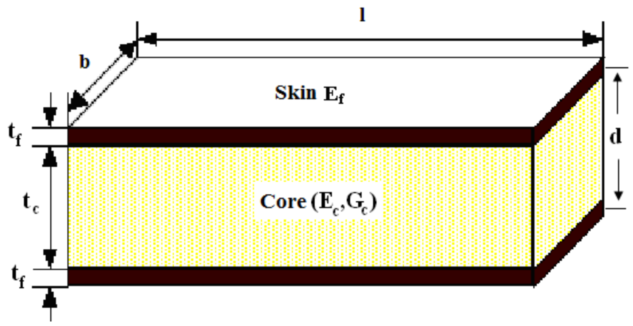

Figure 1. A structure of a sandwich composite [11]

The flexural rigidity for a sandwich beam, denoted as D, is the sum of the flexural rigidities of the faces and the core measured with respect to the centroidal axis of the entire section and can be expressed as:

$$D = \frac{E_f bt^3}{6} + \frac{E_f btd^2}{2} + \frac{E_c bh_c^3}{12} = 2D_f + D_0 + D_c \quad (1)$$

Where E_f and E_c are the Young's modulus of the face sheet and core, and $d = t + h_c$. D_f is the bending stiffness of a face sheet about its own neutral axis, D_0 is the stiffness of the face sheets associated with bending about the neutral axis of the entire sandwich, and D_c is the stiffness of the core [12]. Since the core is stiff in shear but soft generally, its Young's modulus is much smaller than that of the face sheet. By assuming $E_c << E_f$ and the face sheets are thin, then

$$D \approx E_f \frac{b\left(h^3 - h_c^3\right)}{12} \quad (2)$$

The shear stiffness Q is given by equation (3):

$$Q = G_c \frac{b(h-t)^2}{h_c} \quad (3)$$

The face stress is given by equation (4):

$$\sigma_f = \frac{P(L_2 - L_1)}{2tbd} \quad (4)$$

In the core the shear stress is given by equation (5):

$$\tau_{c\max} = \frac{P_{\max}}{2bd} \quad (5)$$

The elastic deflection w_t for a sandwich beam at loading points $\frac{(L_2 - L_1)}{2}$ is the sum of the flexural and shear deflections, for a four-point bending (Fig. 2.).

$$w_t = w_1 + w_2 = \frac{P(L_2 - L_1)^2 (L_2 + 2L_1)}{24D} + \frac{P(L_2 - L_1)}{2S} \quad (6)$$

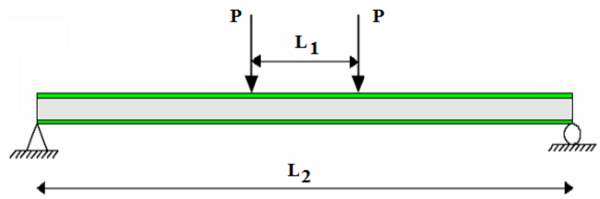

Figure 2. The four-point bending test [13]

3. Experimental Procedure

3.1. Material and Specimens

The structural composite sandwich beams used in our experiment are made up of three core materials provided by PA Technologie, Fig. 3:

- AIREX Foam;
- Honeycomb polypropylen;
- **YmaCell** is an original cellular composite based on polystyrene beads coated by epoxy resin which can be loaded with different short fibers or nanoparticles.

Figure 3. Schematic of the cellular cores, (a) YmaCell, (b) poplypropylen honeycomb and (c) AIREX thermoplastic foam

Table 1. Characteristics of the cellular cores

Characteristic	Polypropylen honeycomb	AIREX foam	YmaCell Polystyren cells
Shear modulus (MPa)	8	37	20
Shear stress (MPa)	0.5	1.85	0.5
Density (kg/m^3)	80	63	100

These cellular cores are covered with different composite skins:

- **Roving 3 Folds**: Laminates based on epoxy resin and glass roving fiber consists of 3-folds and 300 gm^{-2}. The overall fiber volume fraction is 28% for the composite,
- **T800/M300 ±45° and 0°/90°:** Laminates with glass fiber MAT (300 gm^{-2}) and complex woven roving (800 gm^{-2}) reinforced with epoxy resin. The overall fiber volume fraction is 28% for the composite. The fibers directions 0°/90° and ±45° correspond to the arrangement of the roving fibers relative to the loading direction,
- **Carbon 2 Folds:** Laminates based on epoxy resin and carbon fiber consists of 2-folds and 500 gm^{-2}. The overall fiber volume fraction is 28% for the composite,
- **Twintex**: The fabric made of E-glass fiber and polypropylene resin.

The sandwich panels used in these experiments were fabricated using the VARTM process, Fig. 4. Table 2 summarises the thickness and mechanical properties of various composites used in this work.

3.2. Mechanical Testing

3.2.1. Bending Test

In order to characterize and compare the mechanical properties of the different cellular cores, experimental test series were conducted on a four point bending machine. The bending test is done with respect to the NF 54-606 norm using an INSTRON BE209 machine, Fig. 5. To check the reproducibility of the results, five beams by composite type were tested. The crosshead displacement rate was 3mm/min. The sample dimensions are grouped in Table 3.

Table 2. Characteristics of various composites used in this work

Characteristic	Roving 3 folds	T300/M800 90-0 (±45°)	Carbone 2 folds	TWINTEX
Young modulus (MPa)	13406	6385	37300	13000
Shear modulus (GPa)	12.96	21.05	15.15	-
Poisson's ratio	0.11	0.16	0.08	-
Tensile strength (MPa)	384	321	-	280
Laminate thickness (mm)	1.66	1.52	1.5	1.60

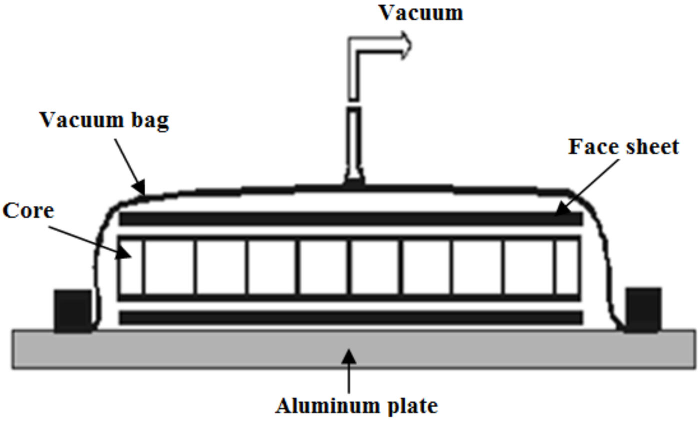

Figure 4. Schematic of the VARTM Process

Table 3. Specimen dimensions

Length, L (mm)	Span, b (mm)	Skin Thickness (mm)	Core Thickness (mm)	distance between inner supports L_1 (mm)	Distance between outer supports L_2 (mm)
300	20	1	8	125	250

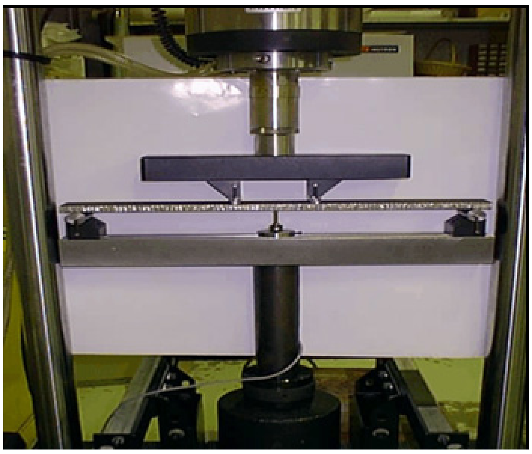

Figure 5. INSTRON BE 209 machine used for the bending test

3.2.2. Crash Test

For the crash test a specific apparatus has been developed in our laboratory, Fig. 6. The impactor is a system with interchangeable masses (from 440 g to 4 kg) with a steel sphere of 10 mm de diameter as bloc profile, the drop height varying from 10 to 85 cm. Impact energies up to 30 J can be developed with this system. Samples have been cut out in different areas of the panels to verify the mechanical homogeneity and the efficiency of the production conditions. The dimensions of the specimens were chosen as 60 x 60 mm^2. The tests were performed on a non-instrumented machine. Comparator measuring apparatus was used to record the indentation length of the sandwich material.

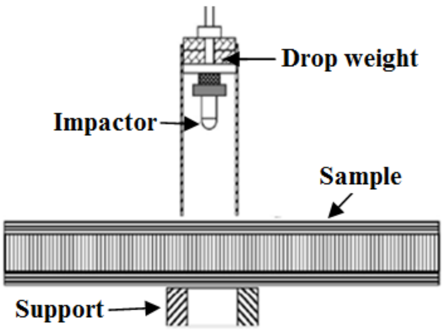

Figure 6. Crash test

4. Results and Discussion

4.1. Bending Results

Fig.7 shows the results from the four-point bending tests for the three core materials: **YmaCell** alone, **YmaCell** reinforced with a short carbon fibers and **YmaCell** reinforced with a short glass fibers. The skins are made of the Twintex (thermoplastic composite composed the glass fiber and polypropylene resin). These panels have been produced to study the effect of short fibers additions in the **YmaCell** core (20% of glass fibers and 4% of carbon fibers). From this figure, the bending behavior is similar and can be described in three principal phases: the first phase is initial linear elastic behavior followed by a phase of nonlinear one in which the maximum loading is reached. In the last phase, a reduction in the load applied is observed till the total rupture of the samples. The linear behavior corresponds to the work of the skins in traction and compression, whereas the nonlinear behavior mainly depends on the core properties under the effect of the shear stress. This figure clearly shows the effect of the adding reinforcements in the core material. The flexural stiffness is improved at the fact that the reinforcements increase the shear modulus of the **YmaCell**. Figs. 8 and 9 represent the three retained cores with two different walls, roving 3 folds and carbon 2 folds. If the general behavior appears to be the same, the ratio loading/displacement and the bending strength are different. The sandwich with carbon 2 folds skin has higher bending properties than the roving 3 folds. For two lower the curves the walls are stuck on the cores. For the other one, the walls are impregnated with the same resin as used to prepare the composite mixture. These results show also that the **YmaCell** presents the high flexural rigidity relative to that of the polypropylen honeycomb and thermoplastic foam AIREX. Comparison the maximum load of the sandwich with carbon fiber 2 folds skin, we found 400 N for **YmaCell** core, 250 N for Polypropylen honeycomb and 150 N for AIREX foam. This is can be explained by the presence of chemical bonds between the skins and the core contrary to the other structures where the bonding is simple. Fig. 10 show the results obtained with an **YmaCell** core covered with two different walls. These walls consist of the same thickness but the Young modulus different. It is observed that the increase of the Young modulus fosters the increase of the bending stiffness which given by:

$$D = EI \qquad (7)$$

Where D is the bending stiffness, E is the Young modulus and I is the Moment of inertia.

In Fig. 11, we keep the same thickness, the same Young modulus but we have introduces an orientation factor of the fibers in the skin. The bending stiffness obtained in the case of perpendicular fiber is higher that the fiber with ±45° orientation. This is can be explained by the Changes of orientation factor which is ½ for T800/M300 0°/90° fibers and ¼ for T800/M300 ±45°.

4.2. Crash Test Results

The Figs. 12 and 13 illustrate the same behavior during a crash test of three cores: **YmaCell**, AIREX foam and polypropylen honeycomb which is covered with two types of composite skins, roving 3 folds and carbon 2 folds. It is observed that the structures which have the high shear stiffness are the most indented. This allows us to conclude that the increase of the core shear modulus or skin flexural modulus promotes the increase of the contact energy and thus the indentation. The impact response of our structures is suitable in comparison with other structures [14]. From Fig. 14, it is found that the same behavior for two cores which are **YmaCell** and polypropylen honeycomb covered with different skins (T800/M300, roving 3 folds, carbon 2 folds and twintex). It is noted that the structures which have the high flexural stiffness are the most indented. It absorbs low energy during bending which leads to conclude that the kinetic energy of the projectile is transformed mainly into indentation energy. However, the indentation values vary between 2.5 and 3 mm for the structures with **YmaCell** core, while for the structures with polypropylen honeycomb, the indentation values vary between 0.7 and 1.5 mm. Then, the indentation length is more important for **YmaCell** than for polypropylen honeycomb. This allows us to justify the results obtained and outlined above in Figs. 12 and 13.

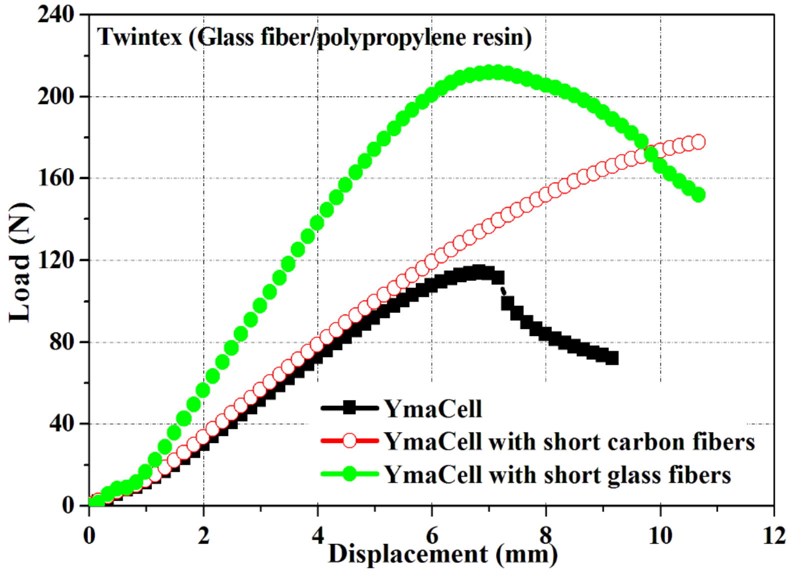

Figure 7. Bending 4 points of the **YmaCell** alone and **YmaCell** reinforced with short carbon and glass fiber

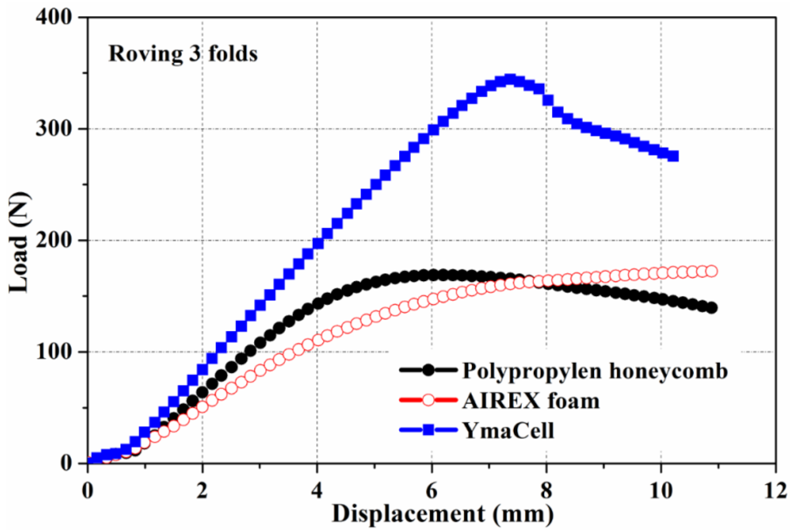

Figure 8. Bending comparison of the cores with a roving 3 folds wall

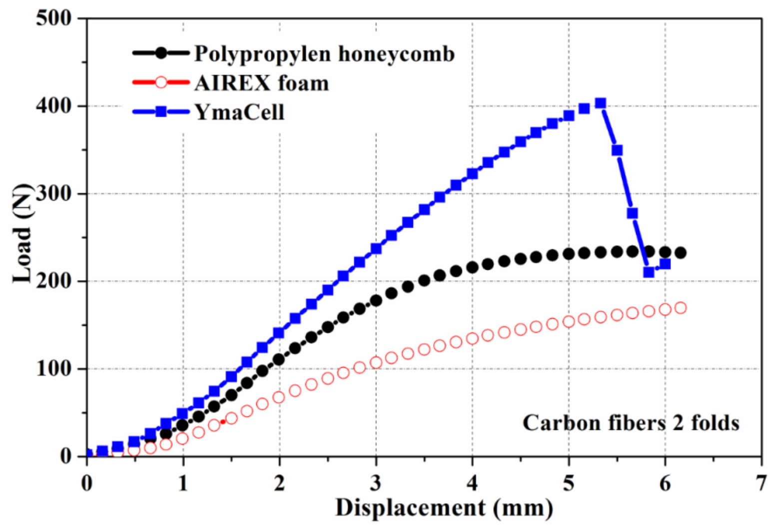

Figure 9. Bending comparison of the cores with a carbon 2 folds wall

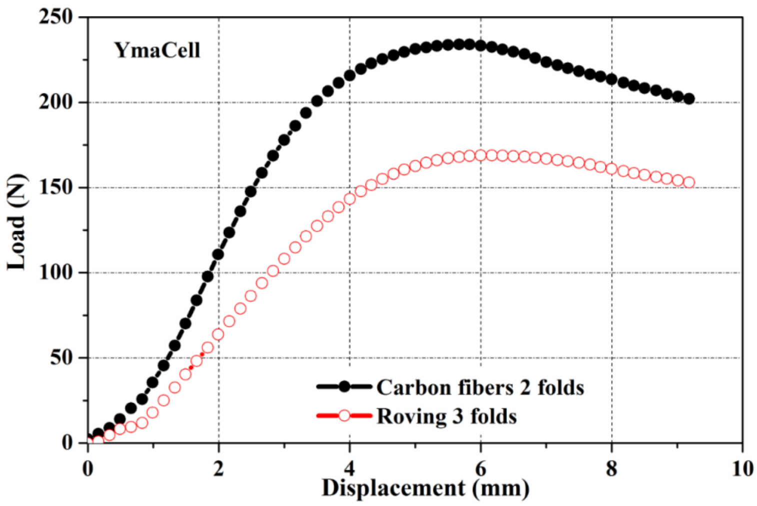

Figure 10. Bending comparison of the **YmaCell** covered with two different skins

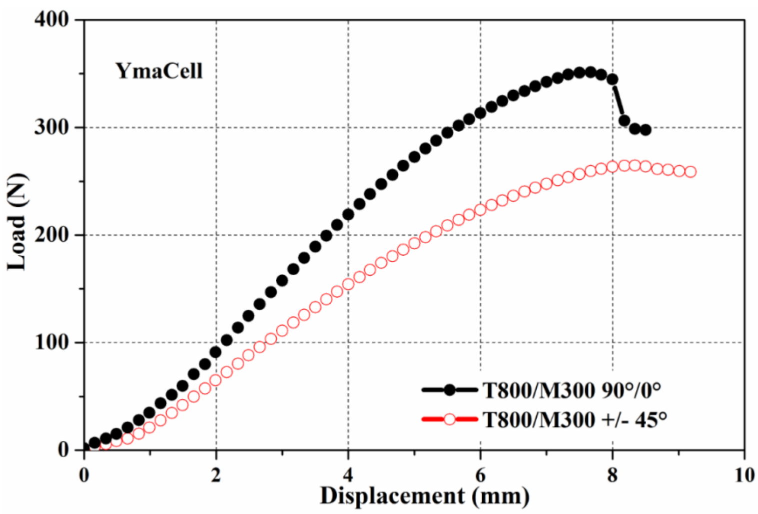

Figure 11. Bending comparison of the **YmaCell** covered with two same skins having different orientations

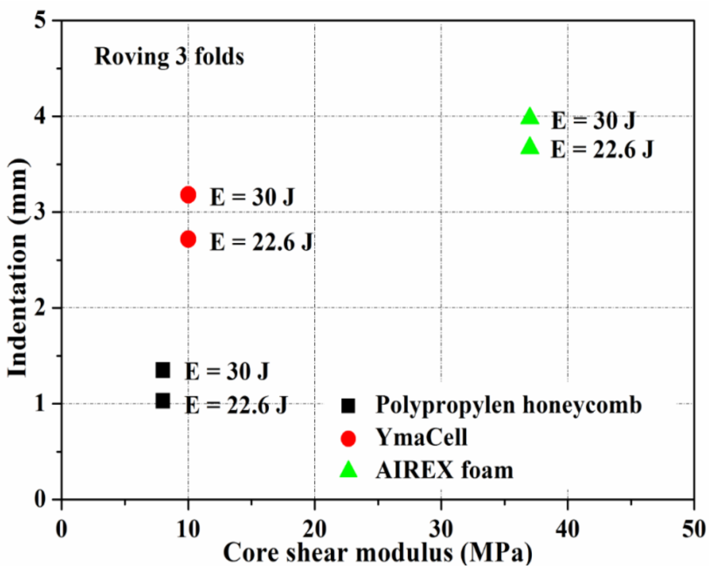

Figure 12. Crash test – comparison of the cores with a roving 3 folds wall

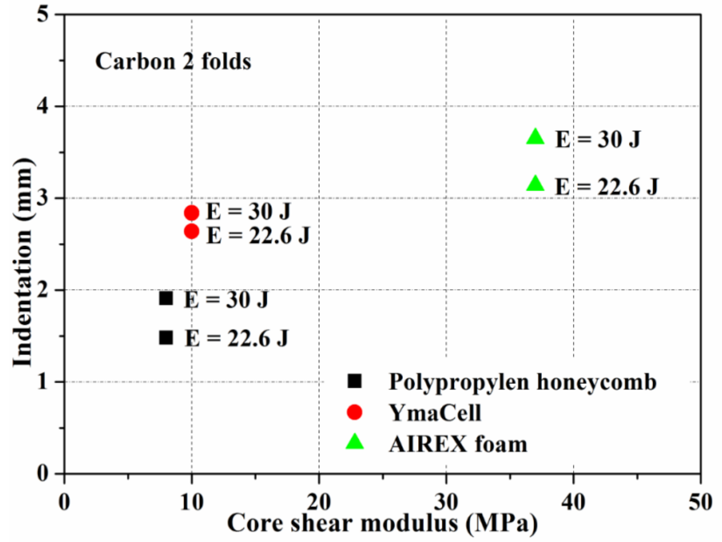

Figure 13. Crash test – comparison of the cores with a carbon 2 folds wall

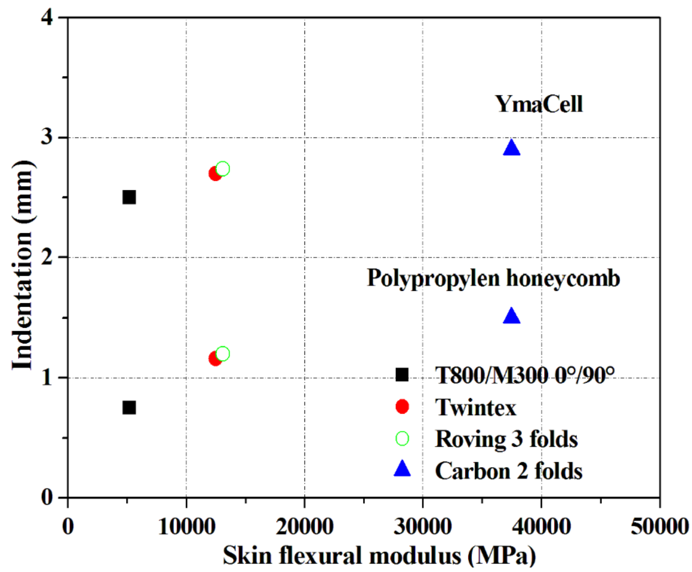

Figure 14. Crash test- indentation comparison of the various structures

5. Conclusions

In this paper, the core material, which is an original cellular composite, based on polystyren cells called **YmaCell** is developed and compared with a polypropylen honeycomb and a thermoplastic foam panel which already exists in the composite industry. Bending and crush properties of these materials are determined and compared.

Some specific conclusions drawn from the bending and crash test are the following:

- Adding glass or carbon fibers allows to increase strongly the maximum loading charge.
- The intended bending performances (**YmaCell** better than the other composites) are attained. The bending properties are higher for the different walls. On the other hand, the crash energies are lower than those measured for the thermoplastic foam.
- YmaCell has performances close to or better than AIREX foam with T800/M300 0°/90° walls.
- The rigidity of the cellular composite is better than that of the honeycomb structures.
- The **YmaCell** also enables to obtain very powerful chemical bonds in comparison with other core materials.

These experimental results will be used to develop numerical models using finite element method (FEM) calculations.

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