CHARACTERIZATION OF A THERMOPLASTIC SANDWICH COMPOSITE

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Abstract

The paper presents experiments conducted on a 100 % thermoplastic sandwich material used in the car industry. Three points are considered because of the common use of optical techniques to enrich the measurements. The first part deals with the identification of the supposed orthotropic behaviour of the sandwich and each constitutive part. The second part describes dynamical experiments performed on two Hopkinson bar devices. The inversed perforation test is applied to a disc of woven composite skin. A digital image correlation program is used to depict displacement fields and the propagation of the flexural wave. The edgewise compression test is applied to the sandwich material and images are captured to follow the qualitative deformation of specimens of various geometries. All the results show the efficiency of image processing for identification and validation experiments. Moreover they are preliminary results to the characterization of a complex structural material.

1 General Introduction

1.1 Industrial background

Due to their light weight, composite materials are widely used in the automotive industry, mainly for under the hood applications. We focus on all-PP long fibre composites that are used in the car industry. The use of composites for structural applications is also of great interest due to their mechanical properties: specific strength and impact properties are the ones studied here, but we can also mention the damping, the corrosion resistance, and the recyclability. Moreover, thermoplastic composites have a good processability. For example the sandwich material considered in this paper can be shaped in a compression moulding process under the action of heat and pressure.

In order to perform numerical simulations necessary to validate the integrity of structures , the characterization of the material under dynamic loadings is necessary [1][2]. We consider here two specific loadings: the crushing of the sandwich material submitted to an in-plane compression, and the deformation of the skins submitted to the impact of a perforating mass.

1.2 The composite material

The considered material is a thermoplastic sandwich composite, made of long woven glass fibres for the skins and 100 % polypropylene for the skin's matrix and the core material. The skins are made of a balanced weave of commercial Twintex: commingled glass and PP filaments that are woven to build a monolayer composite. The core is a commercial extruded polypropylene cylindrical honeycomb. All the components are bonded together with thin films of polypropylene.

Two thicknesses of the sandwich are studied: 7 mm and 15 mm. The variation of the thickness depends only on the thickness of the core material. For particular tests on the skins, the original balanced weave 1:1 Twintex material before assembly with the core is used. Its thickness is 0.8 mm.

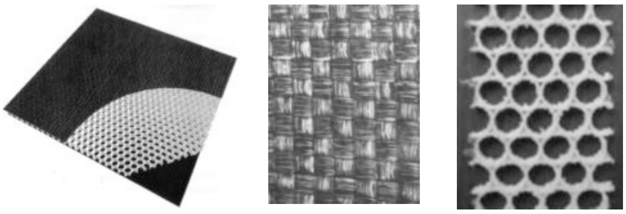


Fig. 1. Sandwich, skin and core materials

1.3 The dynamic characterization experiments

This study deals with a part of the characterization of the dynamic behaviour of the sandwich material. The paper presents various experimental techniques that were implemented in order to study the static behavior and the dynamic response of both the sandwich structure and one of its constitutive parts: the skins. The experiments are complementary to « classic » characterization tests. Thus, the dynamic response of the sandwich is analyzed through edgewise compression tests (EWC tests) complementary to the usual flatwise compression tests (FWC tests) [3]. Even if FWC tests are necessary to characterize the strain rate sensitivity of the core material, they are not sufficient to simulate the crash of a structure. The EWC test allows to characterize the crushing behaviour of the sandwich structure and in particular the effect of the impact velocity and of the geometry on the buckling of the specimen.

As regards the behaviour of the skin, it is studied through an instrumented perforation test that is complementary to the classical drop weight impact test [4]. The benefits of this test are the accurate measurement given by the Hopkinson bar method and the use of fast image captures. For both experiments images are systematically captured during the whole test duration in order to qualitatively follow the deformation or the rupture mechanisms, and also to quantitatively measure strain fields for static and dynamic tests.

2 Experiments

2.1 Identification of the orthotropic behaviour at low strain rates

Tensile experiments are conducted on a hydraulic tensile machine. The sandwich, skins and PP core are tested separately. The specimens are bands that have approximately the following dimensions: length 120 mm, width 30 mm.

The in-plane behaviour of each specimen, considered as orthotropic shells, is identified with 5 parameters E_1, E_2, n_{12}, n_{21} and G_{12}. Three orientations are tested: 0° (direction of the weft fibres), 90° (direction of the warp) and 45°. The prescribed velocity is 0.05 mm/s, which gives a strain rate of about 4.2×10^{-4} s^{-1}. Images of the specimen are captured with a CCD camera at 0.5 frames per second (fps). An image correlation software (Correli^{LMT}) [5] is used in order to calculate the strain field from the digital images. This experimental procedure has been implemented in order to improve the quality of the measurements as compared to extensometers or strain gauges. It allows two major improvements: (i) a non-contact measurement, which is particularly interesting when testing the skins which are highly deformable, (ii) a measurement of the mean strain necessary for the direct plot of the tension curve, which remains reliable even if the microstructure of the material has a large characteristic length.

As an example, figure 2 shows the tension curves till fracture for two experiments on two sandwich specimens. Discrete values of strains are calculated with the correlation program.

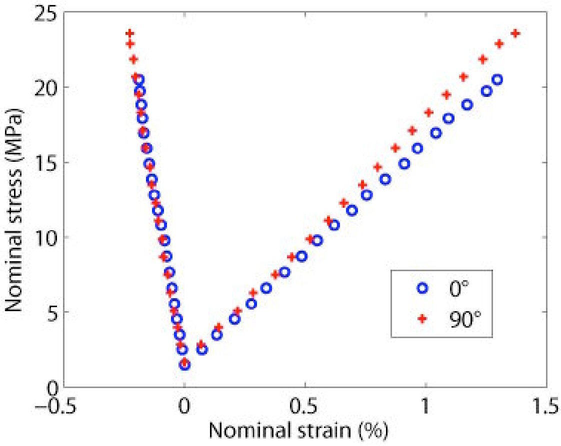


FIG. 2 Tension tests on sandwich specimens. (Positive strains: tension strains; negative strains: Poisson's strains)

The results show that the behaviour of the skin is brittle linear elasticity. Values of Young's modulus, Poisson's ratio and shear modulus are given in Table 1. As regards the core material, the results are less accurate due to the weakness of the material. One can check that for the sandwich material loaded under in-plane tension, the presence of the core material is almost negligible.

	E_1 (GPa)	E_2 (GPa)	n_{12}	n_{21}	G_{12} (MPa)
Sand.	1.5	1.6	0.16	0.19	60
Skin	10.3	7.1	0.20	0.26	292
Core	0.0053	0.0029	0.78	0.91	1

Tab. 1 Identified linear orthotropic behaviour

As a conclusion, it is worth to mention that the results given by the quasi-static experiments show that the identification of a linear orthotropic elastic behaviour for the skins —and naturally the sandwich— is hardly possible to identify accurately, in spite of the geometrical symmetry of the specimens. In fact, the parameters identified during tension tests at 0° and 90° give values of Young's modulus and Poisson's ratio that don't verify the symmetry of the behaviour matrix. The choice of a simple orthotropic elastic law is certainly the reason for this observation on this woven composite.

2.2 Dynamic experiments on Hopkinson bars

In crash situations, strain rates can locally reach thousands of s^{-1}. The dynamic behaviour of the composite has therefore been investigated. Two cases have been studied in particular: the perforation of the skin (SP) material which allows to characterize accurately the dynamic behaviour of the main element of the structural material, and the edgewise compression (EWC test) on the sandwich material.

Two distinct devices were used, both of them based on the common technique of Hopkinson pressure bar tests [6][7]. They are depicted in figure 3.

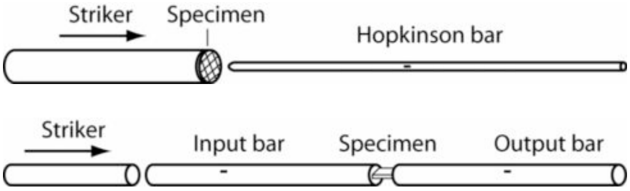


Fig. 3. SP test and EWC test

The first device is adapted for the dynamic characterization of the skins by means of a perforation test (SP test). In this case the skins are loaded mainly in tension so that the use of steel bars is justified given the tensile properties of the composite. In this inversed perforation test, there is only one pressure bar that acts both as measuring and perforating device. The specimen, attached to the striker, is launched directly against the bar that measures the penetration force and the displacement.

The fixation of the specimen on the striker is a key point of the test. In order to avoid sliding, the specimen is glued on a ring with Araldite. The bonded ring and sample are then screwed on the striker so that the skin is kept under clamping during the whole test. Some difficulties were encountered because the impregnated glass fibres of the Twintex material are coated with a thin layer of PP. Sometimes this coating tends to delaminate which makes the gluing not efficient.

The second device is adapted for testing the sandwich composite under edgewise compression (EWC test). Given that the characteristic length of the composite is about 7 mm, a specific large diameter Hopkinson bar apparatus was used (dia. 62 mm). Moreover, in order to satisfy the impedance match [8](the device is adapted to take into account the weak mechanical properties of the composite due to buckling) the bars are made of nylon. A post-processing of the measurements is therefore performed in order to take into account the viscoelastic properties of the bars [9]. The configuration is a classical SHPB test where a striker is launched against the input bar, the specimen being then crushed between the input and the output bars.

2.3 Image captures device and motivation

For both experiments, a fast camera has been used with two objectives in mind. First, the qualitative observation of the testing sequence. Indeed, in the case of the EWC test, the sandwich specimen is a structure whose deformation during the loading is a basic feature that cannot be measured otherwise. For the SP test, the sequence of images has been used to validate the clamping of the specimen on the striker by checking that no sliding is detected.

The second aim of the imaging was to provide additional quantitative information for the SP test. The penetration test is commonly used as a validation test because of the three-dimensional stress state that the specimen undergoes. The aim of these measurements was to perform image correlation in order to have an accurate measurement of the strain field on the backward of the specimen and by this way head towards the use of the penetration test as an identification test in the case of a multiaxial loading. Such technique has been implemented on dynamic experiments on metallic foams [10][11].

The device used is a Photron fast camera. For the SP tests the frame rate was 30'000 fps, and 45'000 fps for the EWC tests. The shutter speed is chosen so that the images are not blurred: 1/90000 s. As a consequence, the specimen was strongly enlightened with two spotlights for the EWC test and only one spotlight for the SP test. For the EWC test, the Hopkinson bar measurement and the image capture are performed simultaneously. This is not possible for the SP tests because the camera and the bars should be at the same place. Two complementary tests are therefore necessary. A second configuration of the perforation test, dedicated to the image capture, is therefore used, which is depicted in figure 4. In this configuration, the specimen is clamped on a fixed frame and is being impacted by the perforator. A mirror is also used, placed with an angle of 45 degrees, which makes possible not to put the camera in the direction of the impact.

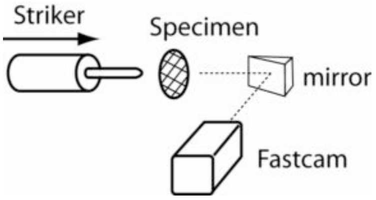


Fig. 4. Apparatus for image captures (SP test)

3. Dynamic perforation on skins (SP tests)

The disc skin specimen is attached to a projectile and launched at about 45 m/s.
An image correlation program, Correli^{LMT}, is used to calculate the bidimensional strain field on the surface of the observed specimen. This strain field is not accurate because the specimen does not keep its initial flat shape and undergoes out-of-plane displacements. These issues will be discussed in a further publication. But as a preliminary study, two results are presented here: (i) the dynamic propagation of the strain into the skin, (ii) and the displacement field.

3.1. Hopkinson bars results

A perforation curve is presented in figure 5, in comparison with a quasi-static test. The curve exhibits a non linear loading and a sharp decrease of the stress due to fracture. During the unloading the stress is different from zero due to crack opening and friction forces.

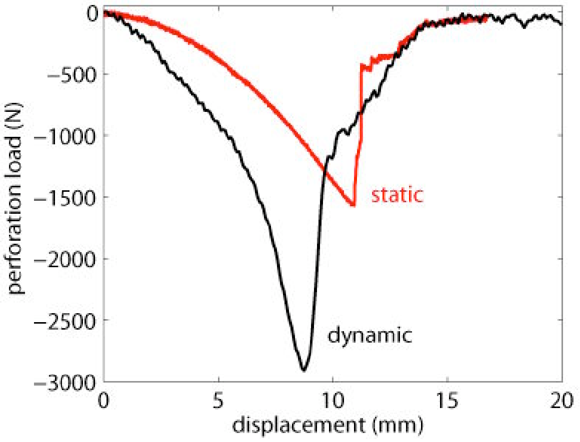


Fig. 5. Perforation response (static, solid line ; dynamic, dashed line)

For quasi-static tests, post-mortem observations show the presence of two cracks. These two cracks don't open simultaneously as it can clearly be seen on the measurements. For dynamic experiments, the damaged area is diffuse whereas for static perforation, the damage is localised along the two aforementioned macrocracks (figure 6).

Concerning the impact velocity effect, the results show that under dynamic loading there is a significant enhancement of the perforation force of about 50 %. The strain value at rupture cannot be accurately defined. In fact since the specimens are woven, the crimping effect is clearly visible under quasi-static loading i.e. the initial stage when the load tends to straighten the fibres instead of loading them in tension. This effect is less significant for dynamic loading.

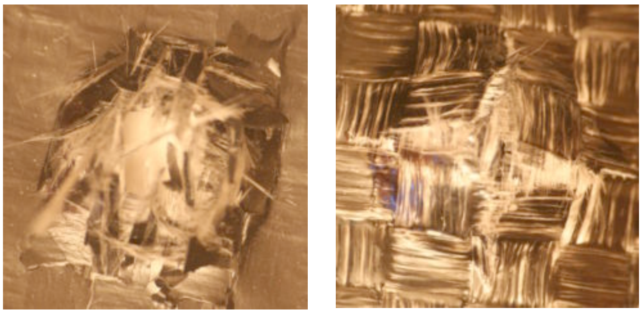


Fig. 6. Damaged area for dynamic / static perforation

3.2. Dynamic propagation of strain

The calculated strain field allows to observe the propagation of the discontinuity of the strain along the radial direction: from the impact towards the boundaries. The results are plotted in figure 7.

The plotted field is the residual error given from the minimization procedure of the correlation program [5]. The error has the largest value in the area of maximum strain rate (visible as the bright area in the figure). The discontinuity is considered to be located at the external boundary of this bright area. Two directions of propagation are considered, leading to two values of the velocity. They are estimated at 204 m/s along the direction of the yarns and 164 m/s along the bisecting line.

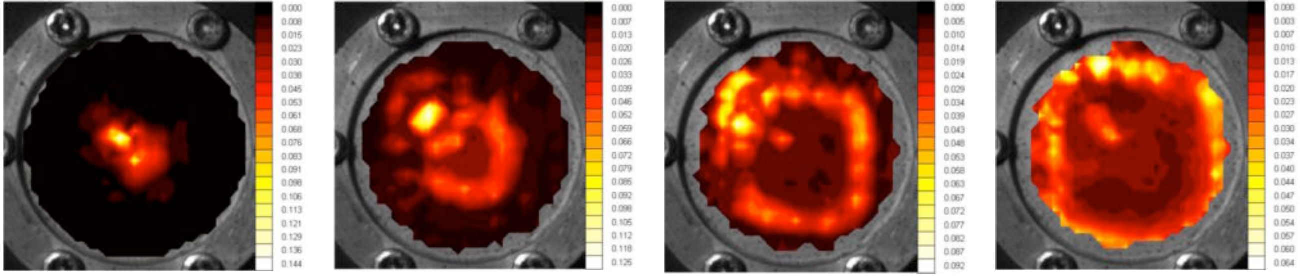
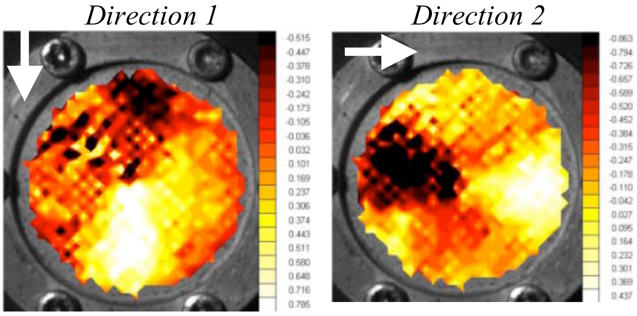


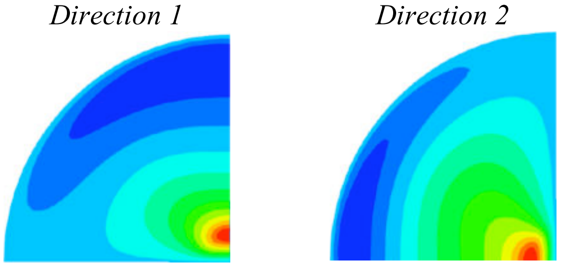
Fig. 7. Successive pictures of the error indicator. Time btw pictures: 1/30’000 s

3.3. Displacement field

Figure 8a shows two displacement fields calculated with the correlation program on the same picture taken at time 5/30’000 s. Figure 8b shows the same displacement field computed on the FE code Abaqus Standard with the orthotropic behaviour identified. Shell elements were used on a quarter of the geometry. The penetrator is supposed to be an analytical rigid surface with a prescribed displacement. The external boundary of the shell is clamped.



a) Measured by digital image correlation



b) Simulated on Abaqus Standard

Fig. 8. Displacement maps

As a preliminary result, one can see that the images taken during the experiment coupled to the correlation program can qualitatively catch the displacement field.

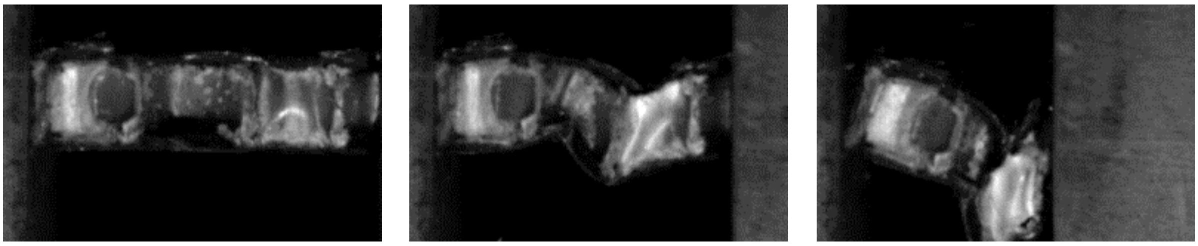
4. Dynamic EWC tests on the sandwich material

The recordings of sequences of deformation show the complex deformation mode of the specimen during the impacts. In figure 9, 3 sequences are shown. Each specimen is 35 mm wide and the length, in the direction of impact, is varied. Three tests are presented: 7 mm thick sandwich samples with two different lengths 25 mm (a) and 50 mm (b), and a 15 mm thick, 50 mm long sample (c). The impact velocities are adapted so that the nominal strain rate is the same for all experiments 320 s^{-1}).

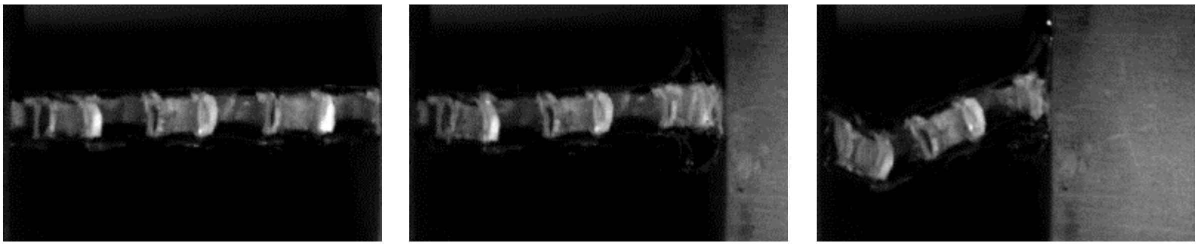
In sequence (a), the specimen undergoes a first stage of compression and then the rotation of the cell located in the middle initiates the global buckling of the structure (at about 15 % of nominal strain).

In sequence (b), the specimen undergoes a first stage of compression accompanied by the delamination of the skin on the impact side. Then after a nominal strain of about 30 % there is a global buckling of the remaining part of the specimen. This observation clearly shows the effect of the dynamics on the global behaviour of the structure: in spite of the increase of the specimen length, the buckling is delayed.

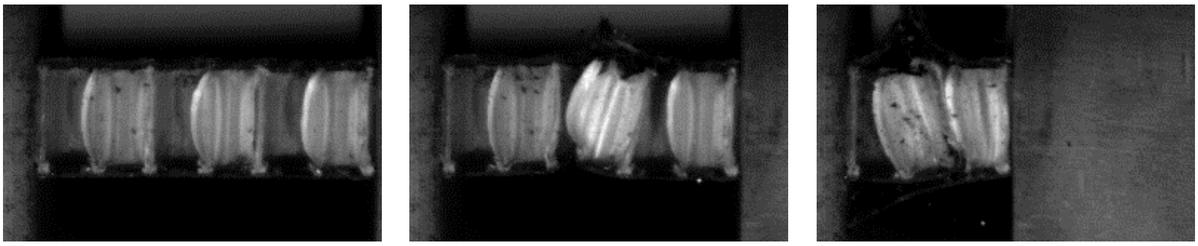
In sequence (c), the specimen undergoes only a compression. One can see the rotation of a cell located in the middle that does not initiate any buckling but the local fracture of both skins. Once broken, the skins slide on each other until the complete delamination of the skins at the end of the compression. In this case, the low aspect ratio of the specimen prevents buckling and forces the fracture of the skins that delaminate.



a) Length 25 mm. Impact velocity 8 m/s



b) Length 50 mm. Impact velocity 16 m/s



c) Length 50 mm. Impact velocity 16 m/s

Fig. 9 EWC tests on different sample geometries

5. Conclusions

The experimental work presented in this paper shows the complexity of the dynamic response of a thermoplastic sandwich composite in crash situation. The use of fast image captures and digital image correlation is basically necessary to validate or improve the experimental data. Preliminary results show the efficiency of the technique to catch the displacement field of the skin composite during perforation. The coupling of numerical modelling and image correlation is the next step of this work in order to quantitatively study the dynamic behaviour of the skin material submitted to impacts.

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