EPJ Web of Conferences **6**, 20012 (2010)
DOI:10.1051/epjconf/20100620012

Study on interlock 3X damage mechanisms under impact loading using a deformable impactor

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Abstract. Analyzing damage mechanisms when a deformable impactor is impacting a reinforced 3D woven composite is aimed in this work. Low energy impact are considered in this soft shock situation using a drop test tower. Materials involved in this study are hemispherical elastomer impactors and carbon fibers in RTM 6 resin for the composite target plate. Elastomer impactors with different hardness and diameters on the one hand and composite plates with different degrees of reinforcement in the thickness on the other hand are available for this study. The experimental measurements are particularly highlighted here. High speed cameras are used and investigations are performed to adapt Digital Image Correlation method in impact situation using Corelli STC software. First results are presented in this paper proving the feasability. They are very encouraging for the future serie of tests to be considered with various impact conditions.

1 Context and objectives

The present study is one part of a national research project dealing with the vulnerability of composite material under dynamic loading. Low velocity impact, from about 2 to 10 $m.s^{-1}$, using deformable impactors, also named soft impactors, on interlock 3X composite woven is mainly considered. Such a velocity range may correspond to remains of tire on composite part of a plane for instance. Such a study can be seen as a preliminary study to high velocity impact of soft body such as birds which will involve higher energy [1].

Understanding of the damage mechanisms in the previous context is the main purpose of this project. How and where the damage mechanisms are they initiated ? What about coupling between inter and intra laminar damages ? How the damage is modified by the loading conditions ? … and finally what is the damage consequence on the residual properties ? … as many questions which can justify this work and very useful to elaborate models based on physical understanding.

Based on experimental design, several tests are envisaged varying some input parameters : mass, velocity and hardness of the soft impactors but also the boundary conditions of the specimen composite target. Output responses are mainly related to the damage : surface delamination, density of cracks, fibers fracture, …) but also to the loading : space/time distribution of pressure induced by

the deformable impactor. Thereafter, this experimental work will allow the validation of models and the development of reliability engineers approach [2].
In this paper, the experimental investigations to answer later the various questions are in particular highlighted. After a description of the materials specifically elaborated for the study, the soft impactors on the hand and the interlock 3X composite plate on the other hand, the means of measurements set up are presented. Finally, first results obtained during a fully instrumented test are demonstrated.

2 Materials

2.1 Soft impactors

They are made of elastomer and their shape is hemispherical, Figure 1. Their behavior is mainly elastic. No significant hysteresis phenomenon is observed in the considered speed range. Various hardnesses are achieved controlling the process development. Thus, three hardnesses levels corresponding to *40*, *60* and *80* 'shore' index [3], are considered for this application with three various diameters of *40 mm*, *70 mm* and *100 mm*. Adhesion between the hemispherical elastomer and the metal plate is made during the process. A screw part allows the fixation of an additional part including a force sensor.

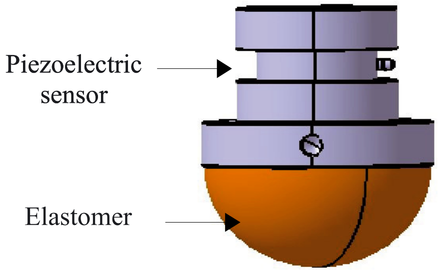


Figure 1: Hemispheric impactor in elastomer

Finally, the impactor equipped with the force sensor is fixed on a carriage constituting the falling weight, Figure 2. The maximum mass compatible with the drop tower capabilities is around *16 kg*.

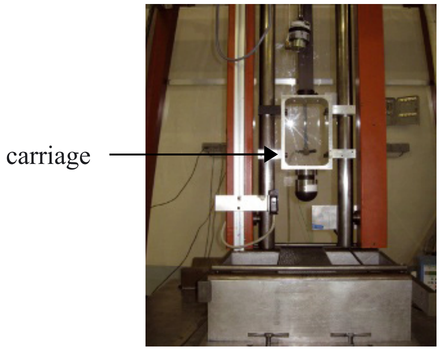
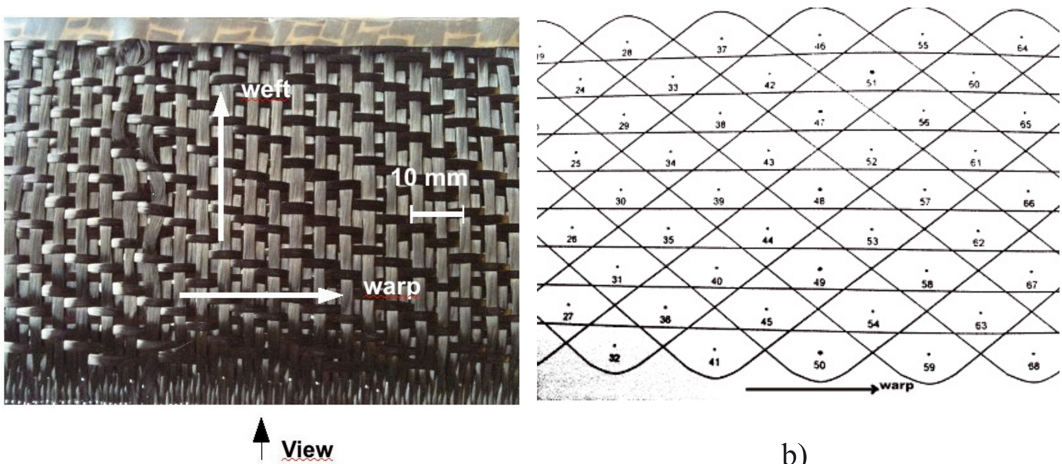


Figure 2 : Hemispheric impactor on the carriage

2.2 Interlock 3X

The target is an interlock 3X composite plate. It is made of fabrics with various reinforcement obtained by deviation of a percentage of warp carbon HR fibers in the thickness direction. Three reinforcements are obtained deviating *30%*, *55%* or *100 %* of the warp yarns, Figure 3. The weave patterns is drawn on Figure 3 b) represented in a plane projection according to the 'view' direction, Figure 3 a). The density of fabrics is of 2720 g/m2.



a) b)

Figure 3 : Interlock 3X sample with 55% of deviated warp yarns

Plates are elaborated by RTM process using a RTM 6 resin injected at *120 °C* and polymerized at *160 °C*. The fabrics dryness has a *10 mm* thickness before injection. The final thickness of the plates is of *2,7 mm*. The dimensions of the plates issued from process are *500 mm x 500 mm*.

3 Impact device

All the tests are performed on a drop tower designed in our laboratory schematically presented in Figure 4. Performances with this device are : a maximum speed of about $10\ m.s^{-1}$, a maximum carriable mass of about *16 kg*. Thus, the maximum input energy with this device is around *800 J.*

Several boundary conditions can be tested : i) simply supported on the all edges ii) simply supported on two edges iii) clamped on the all edges. Present results are related to the boundary conditions set ii).

In order to avoid damage localisation around the boundary conditions, the plates are cut out to constitute the samples respecting a constant l/d ratio with d the diameter of impactor and l the distance between supports, Figure 5. A ratio of *5* is adopted for the present test.

A serie of tests is envisaged in this project varying the (mass, speed) configurations to obtain incident energy between *100 J* and *800 J.*

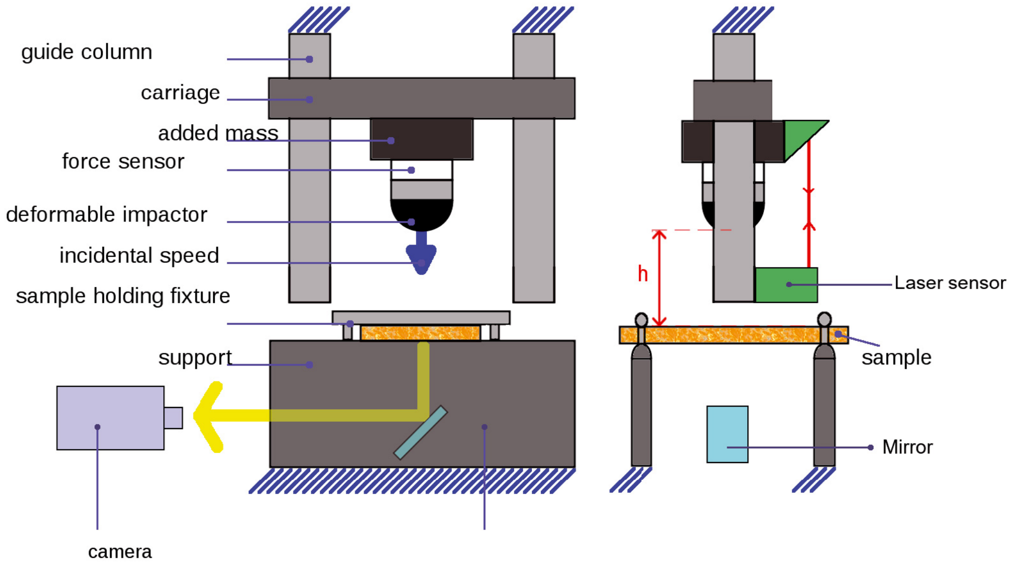


Figure 4 : Drop Tower

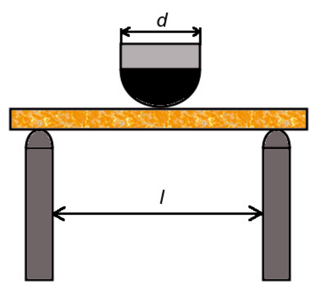


Figure 5 : *l/d* ratio in case of boundary conditions ii)

4 Measurements

Classical and specific measurements are investigated to study both impactor and target behavior during impact. Accelerometers, piezoelectric sensor and displacement laser sensors but also high speed cameras with a powerful lighting are especially used, Figure 4 and Figure 6.

4.1 Force and displacements sensors

The contact force history between the elastomer and the composite sample is measured by a piezoelectric sensor. A first laser sensor is placed just underneath the center of the specimen to provide the out-of plane displacement history. A second laser sensor (not represented on Figure 4) measures the carriage displacement versus time so that the velocity of the dropping mass can easily be assessed.

4.2 Contact pressure

Measurement of the contact pressure during impact is one of the challenge in this study. The space-time evolution of the contact pressure during impact is mainly expected. Several techniques are considered for this purpose but not yet experimented [4, 5]. These results will be useful to validate a Discrete Element Model developed in parallel [6, 7].

4.3 High speed cameras

Two high speed cameras PHOTRON APX RS and SA3 with a powerful lighting are used to follow the global behavior of the impacted plate and the damage progression on the free face opposed to impact, Figure 6. Using such cameras, the challenge will be to adapt the Digital Image Correlation (DIC) method [8, 9] in impact situation with Corelli STC software [10].

A third camera could be added to follow the impactor behavior, Figure 7.

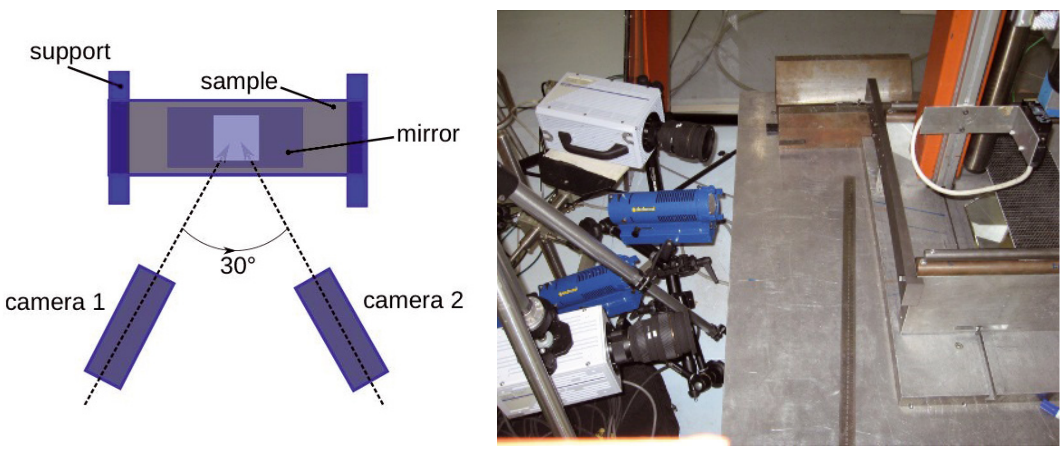
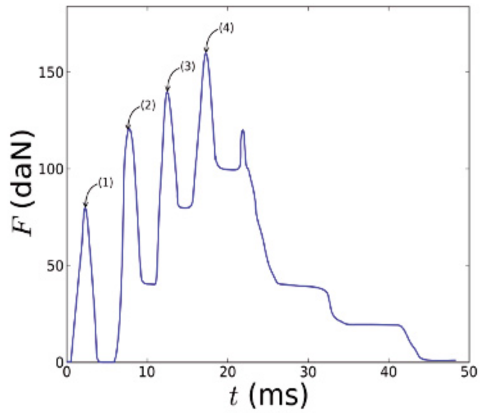


Figure 6 : High Speed cameras PHOTRON placement

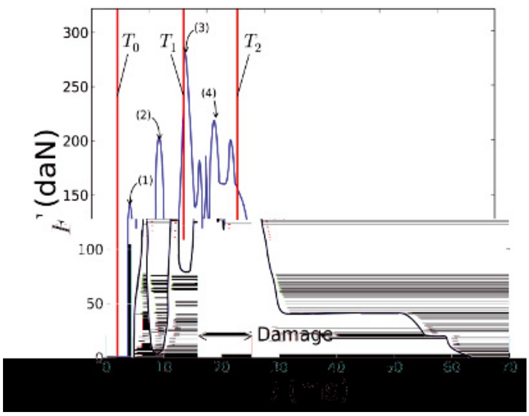

Figure 7 : Elastomer impactor during impact

5 Results

First of all, the responses issued from piezoelectric sensor (force sensor) and laser displacement sensor placed on the carriage are presented. Figure 8 gives the time history force responses between the elastomeric impactor and the plate while the time history displacement of the carriage is plotted on Figure 9. When a drop height *h* of *90 cm* with a mass *m* of *6 kg* is tested, no damage occurs. In this case, a vibratory response can be observed revealing four peaks whose amplitude increases, Figure 8 a). The frequency of their appearance is governed by both the plate and the impactor vibratory behavior. On the contrary, when a drop height of *220 cm* is tested with the same previous mass, damages are generated. The damage can be revealed by the time history force response, Figure 8 b). In this case, the fourth peak's amplitude significantly decreases from T1 to T2 moment corresponding to the time of damage development visually observed with cameras. Damages can also be visually observed, Figure 10. They are essentially made of matrix cracks which principally appears on the impacted side. Only three warp yarns are failed in the impact area (not visible on the picture). The matrix cracks initiates around the warp yarns and propagates along a *68°* direction compared to the bending axis.



a) without damage : *h=90cm, m=6 kg*



b) with damage : *h=220cm, m=6 kg*

Figure 8 : Time history force

On the other hand, first investigations using the Digital Image Correlation (DIC) method in impact situation are performed. The beginning of the loading can be captured by the two successive images proposed on Figure 11. Unfortunately, the mirror has been broken during the test before to reach the damage initiation.

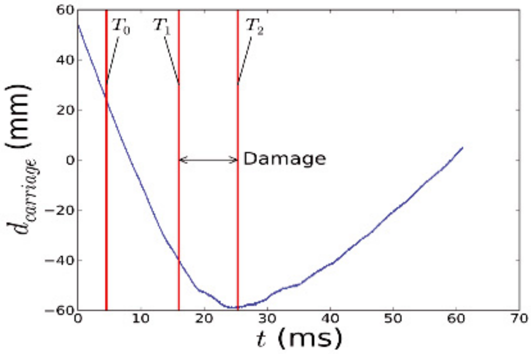


Figure 9 : time history displacement of the carriage

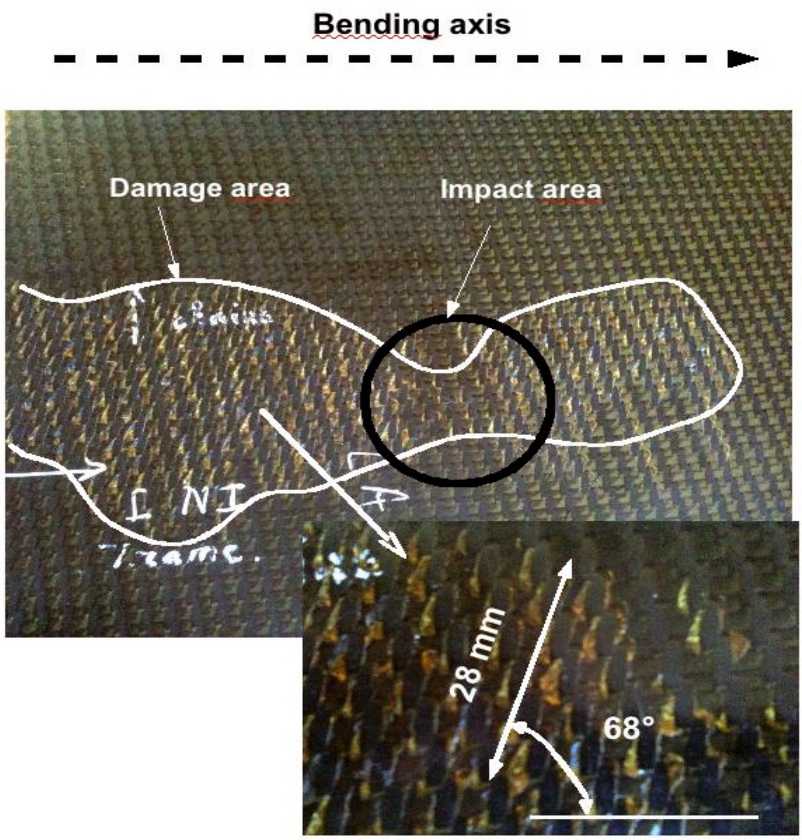


Figure 10: Damage visualization on impacted side

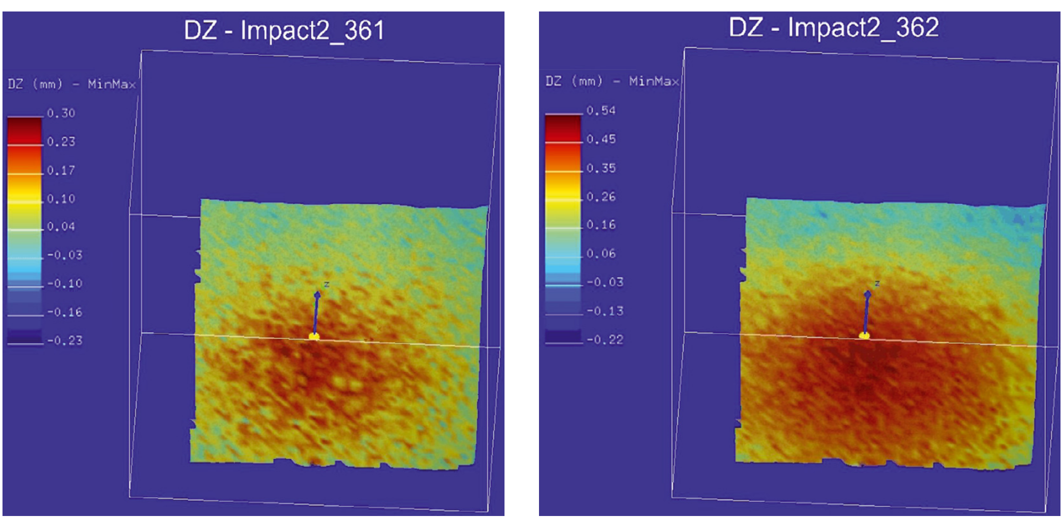


Figure 11: Transversal displacement issued from DIC method performed on the opposite impacted side at the beginning of loading

6 Conclusions and future works

This work is a first step in the study of damaged interlock 3X plate impacted by an elastomer impactor. Low energy impact are considered in this soft shock situation using a drop test tower. The challenge for this work was to adapt Digital Image Correlation method in impact situation using Corelli STC software. First results are presented proving the feasibility in spite of some difficulties of measurements encountered. Some adjustments remain necessary for the following tests.

Future investigations for this work relate to :

- stopped tests to achieve the time-history damages [11, 12],
- tests with various impact conditions (mass, velocity and hardness of impactor, boundary conditions of the specimen target) based on an experimental design to elaborate responses surfaces representative of the target damages and loading due to the deformable impactor and to perform reliability analysis.

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