Comparative study on the successive impact behavior of composites in ship structures

Houcine Zniker[1,*], *Mohammed Khalil* El Kouifat[2], *Ikram* Feddal[3], *Said* Bouzakraoui[1], and *Bennaceur* Ouaki[2]

[1]Laboratory of Advanced Materials and Process Engineering, Ibn Tofaïl University, Kenitra, Morocco
[2]The National Higher School of Mining of Rabat (ENSMR), Rabat, Morocco
[3]Department of Industrial and Civil Sciences and Technologies, Abdelmalek Essaadi University,Tetouan, Morocco

Abstract. Composite materials are categorized to be highly sensitive to low-velocity impact events. This feature is considered as a serious limitation for their application in engineering. Therefore, understanding impact energy absorption is critical in improving composite material damage tolerance and especially under successive impacts. This work was dedicated to an experimental investigation that aims to study and compare the energy absorption ability and damage behavior of PVC-foam sandwich and GFRP laminated composites under multiple impacts occurring at small energy levels. For this purpose, low-velocity impact repeated tests were carried out until total absorption of the impact initial energy was reached. A relative energy absorption index and a rebound index were proposed in order to assess energy absorption capacity. The results indicated that, directly after the first impact, the sandwich composite formed from two 4mm laminated skins absorbed 80% of the initial impact energy, in comparison to approximately 60% for 8mm laminated composite. This performance of sandwich composite is attributed to the damping ability of the core. Also, the impact velocity rebound rate of this composite was found to be higher than that of laminates. However, impact damage is greater in composite sandwiches than in laminates.

1 Introduction

Laminated composite and sandwich panels are widely used in a various industries such as automotive, aeronautics, and naval. The increasing attention gaining these materials can be attributed to their outstanding properties in comparison to conventional materials. Composites have a high strength (and stiffness) to weight ratio, high fatigue resistance, and high corrosion protection. Furthermore, they allow for a more flexible design to attain desired properties.

However, these materials are highly vulnerable to low-velocity impacts that might arise over their service life. This form of transverse loading has been shown to yield a high risk to composite structures because it causes damage that is difficult to detect [1-2], which could be accompanied with harmful consequences on the residual characteristics of these materials [3-4]. Therefore, low-velocity impact behavior of composite structures has constituted a significant field of research to address this hazard.

Various types of research have been conducted with the aim to study composites resistance to impact and their endurance to damage under different impact loads. Mainly two approaches are more commonly used in the literature. The first one is based on assessing the residual properties of the damaged composites, after impact loading by using compression-after-impact (CAI) and other static tests [1-4]. The second one considers the composites energy absorption ability to evaluate the impact damage [5-8].

The method of energy absorption allows monitoring the impact damage directly from the parameters acquired throughout the impact event [9–13]. However, it is critical to understand how the initial impact energy is introduced into the material. In a non-perforating impact, a portion of this energy is stored elastically resulting in a rebound. The rest of the energy is partially dissipated under a negligible form of heat and vibrations, and absorbed by composites to develop the fracture mechanisms such as matrix cracking, delamination, fiber fracture, intra-laminar splitting, permanent indentation, and fractures at the fiber-matrix interfaces.

The energy absorption investigation appears to be very helpful for better understanding the impact damage of composite materials. This approach is ever more practical and useful in the case of complex loadings, such as repeated impacts, since these might lead to premature failure more with a single impact event [14-16]. Repeated impacts are experienced during maintenance or service conditions, and the impact of an object is not a single occurrence, but a recurring event.

The main characteristic of repetitive impacts is that the subsequent impact energy level is lower than the initial impact because each succeeding impact has the same energy as the prior rebound. The resulting

* Corresponding author: zniker.houcine@gmail.com

cumulative damage pattern could be quite intricate due to the involvement of multiple energy levels. Sadighi et al. [17] have studied the performance of fiber-metal laminates by considering the drop of a tool under repeated impact. They found that the subsequent impacts occurring after the first one do not have an important influence. The authors have claimed that the damage caused by the rebound energy following the impact of a dropped tool is negligible. Other composites such as Glass Fiber Reinforced Polymers (GRFP) laminates and sandwiches have however received little attention under the situation of repeated impact.

The objective of this work is to evaluate experimentally, under repeated low-energy impacts, the energy absorption ability and damage pattern of composite panels made of laminated GFRP or PVC-foam sandwiches as they exist in real naval and aeronautical structures. Multiple impact tests performed by means of an adapted Charpy test machine are considered with various impact energy levels between 5J and 50J. The absorbed impact energy is calculated after each impact, and the induced damage is investigated.

2 Materials and methods

In the following, two different composite structures are investigated. The first composite is a (0/90) cross-ply laminate which is fabricated by using a polyester resin matrix reinforced by a one-way fiberglass fabrics. This composite is made of 24 layers; each layer has 0.32mm thickness. The average volume fraction of this composite is about 50% and the total thickness of 8mm (see Fig.1a and Fig.1a'). The other composite is a typical sandwich which is made by using as skins plates with thickness of 4mm from the previous laminates. The core material is PVC foam with 80kg/m^3 in density and a 20mm of thickness (see Fig.1b and Fig.1b').

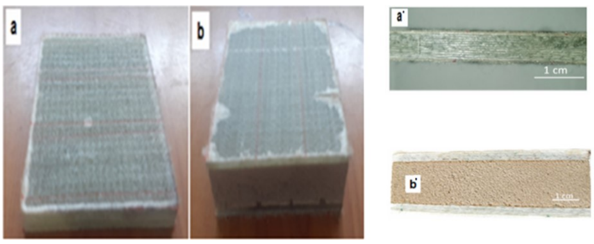

Fig. 1. Composites tested in this work: (a): laminated GFRP; (b): sandwiche; (a'): laminate section of GFRP composite; (b'): sandwich section.

Tests with low-velocity impact were performed by means of an adapted Charpy testing machine. Fig. 2 shows the experimental set-up. The samples were simply supported on all edges with steel plates. These connecting plates have a 45mm square spot in the middle which allows the impactor-composite contact as shown in Fig.2. A 12.7mm diameter hemisphere steel impactor is used to apply the impact load at the center. The initial energy impact was regulated by altering the falling height of the Charpy machine hammer. This last was connected with an ADXL345 accelerometer to measure the acceleration of the impactor through an acquisition card controlled by an ARDUINO application. The velocities just before and just after impact were obtained by means of integral calculus operated on the measured acceleration history. The absorbed energy was calculated by measuring the timing and location of the hammer after each impact with a video camera.

In order to carry out impact testing, the following sequence of impact energies were selected (5J, 10J, 20J, 30J, 40J, and 50J). The impact energy after impactor/sample contact was measured for each test until the moment where the imposed initial energy is entirely damped. Following each test, the absorbed energy was evaluated and the sample damage area was also investigated. A scanning electron microscope (SEM) was used to investigate the damage mechanism of the two composites.

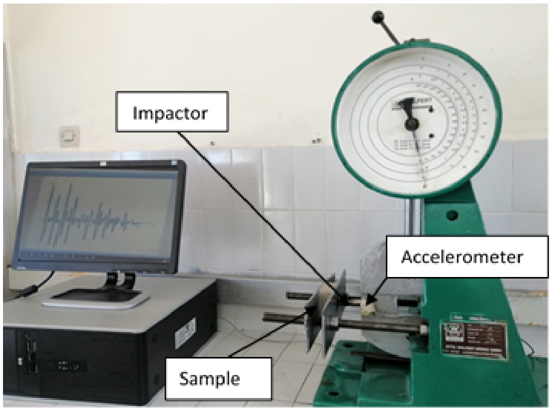

Fig. 2. Impact test setup (modified Charpy test machine).

3 Results and discussion

3.1 Comparison of energies absorption

Fig. 3a and Fig. 3b show the evolution of the absorbed energy for respectively the GFRP laminated and sandwich composite during dynamic impact tests. This include all rebounds that have occurred until total damping of the imposed initial energy is reached.

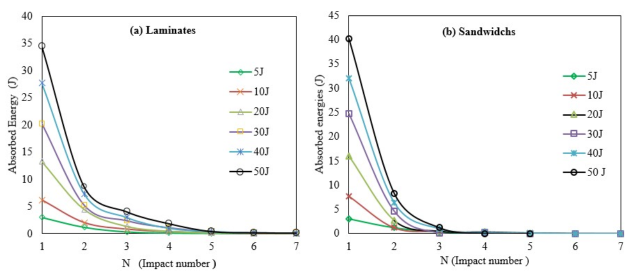

Fig. 3. Absorbed energies versus impact number: (a) laminate, (b) sandwich.

Because of the core of sandwich composites can undertake high energy dissipation; the total damping of the imposed initial energy was achieved more quickly for sandwiches than laminates.

To analyse the energy absorption capability for both composites, the following relative energy absorption index (REA) is introduced:

$$REA_i = \frac{E_i}{E_0} \tag{1}$$

where E_0 and E_i are the starting impact energy and the absorbed energy after i-th rebound impact. The relative energy absorption index (REA) calculation results are presented in Fig. 4.

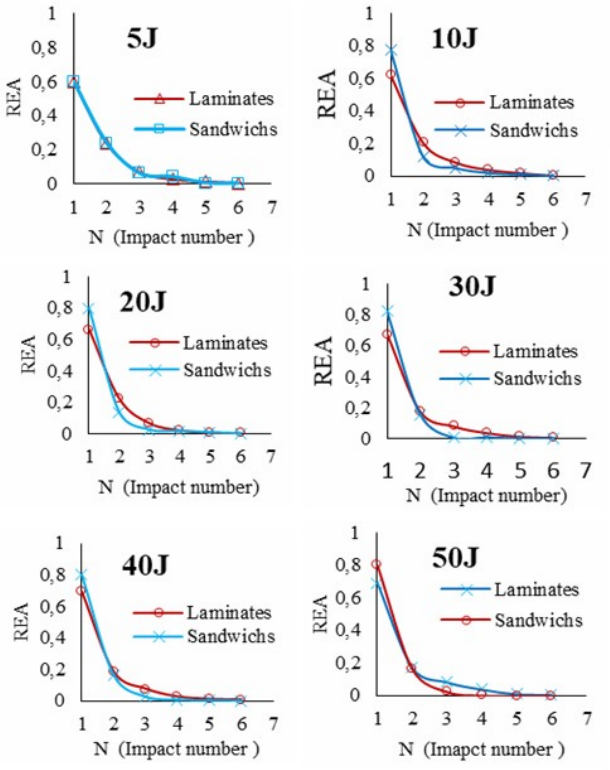

Fig. 4. Comparison of REA index for laminated and sandwich composites.

From these results, it was first found that at the first applied energy of 5J, there was no difference in energy absorption under impact loading between the two tested composites. On the opposite, for initial energy exceeding 10J, sandwich composites appear to be more capable of absorbing impact energy than laminated composites, because of the favourable damping participation of the core. Furthermore, it can be noticed that up to 80% of the initial energy is absorbed by the sandwich composite immediately after the first impact, while only about 60% was absorbed by the laminated composite. In both cases, one can observe that the applied initial energy is completely absorbed after the fourth impact.

To describe energy absorption, a rebound index (RI) is introduced. It represents the ratio of velocities before and after the first impact:

$$RI = \frac{v_i}{v_0} \tag{2}$$

where v_0 is the velocity just before the first impact and v_1 is the velocity just after the first impact.

Fig. 5 presents the evolution of RI versus the initial impact energy. This figure shows that the rebound rate of impact velocity for composite sandwiches is greater than that of laminates. This difference is approximately 20%.

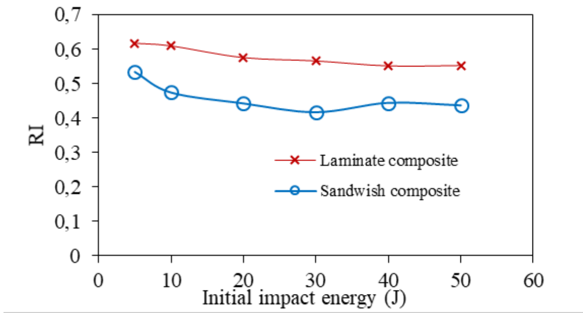

Fig.5. Evolution of the rebound index (RI) versus initial impact energy.

3.2 Analysis of resultant damage in composites after impact tests

Fig. 6 shows examples of specimens damaged by repeated impact loading for GFRP laminates and sandwich composites.

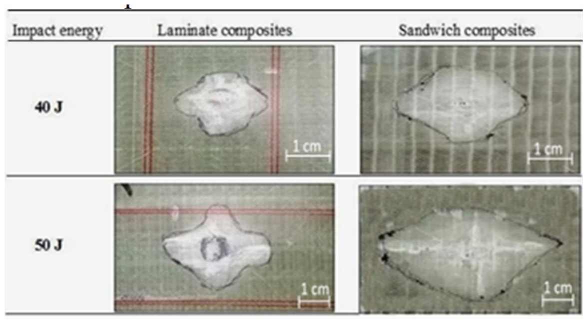

Fig. 6. Examples of damaged samples after impact testing for laminates and sandwich composites

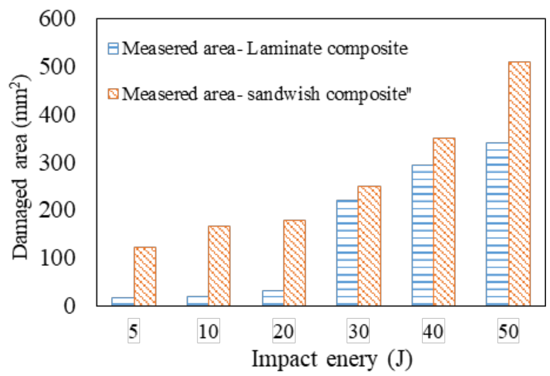

Fig. 7. Damage areas versus initial impact energy for laminates and sandwich composites.

For all tests of repeated impacts, damage regions for both composites (laminated and sandwich) were localised and their areas measured by means of a Perfect Image Analyzer (PIA). These were evaluated for all imposed starting energies. Fig. 7 presents the obtained results. Using the penetration measurement system which is designed with an LVDT, the maximum penetration depth of impactor after tests was determined. Fig. 8 presents the obtained results versus the initial impact energy.

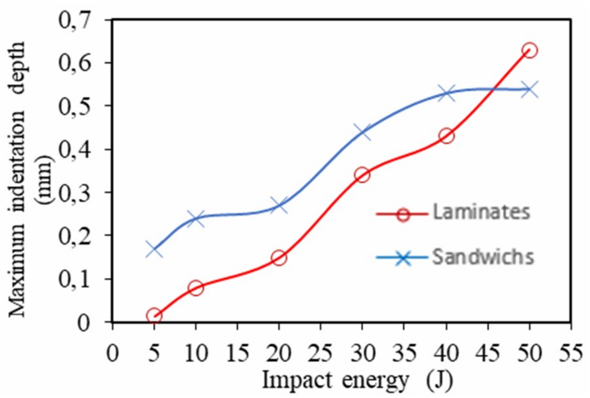

Fig. 8. Evolution of the maximum penetration depth versus the initial impact energy.

From these results, one can observe that sandwich composites exhibit higher damage regions and higher maximum penetration depth than laminate composites. This effect is caused by the sandwich composites' thin skin (4mm) in comparison to laminate composites (8mm).

4 Conclusions

The conclusions that can be drawn from this work can be summarized as follows:
- Based on the results under successive low-velocity impacts, it was found that the sandwich composite with 4mm laminated skins can absorb 80% of the initial impact energy, while the GFRP laminated composite absorbs about 60%. This can be justified by the additional damping resulting form the PVC core. The initial impact energy was completely absorbed after just the 4th impact for both types of composites.
- The results of rebound index (RI) demonstrate that the rebound rate of impact velocity for composite sandwiches is greater than that of laminates. This variation reaches approximately 20%. Compared to laminated composites, sandwich composites are therefore more suitable for the design of structural parts that can undergo repeated impacts.
- Examination of the samples damage pattern that occurs after low-velocity impact loading tests has indicated that sandwiches undergo larger damaged areas and higher maximum penetration depth than laminates in comparison to laminates.

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