Mechanics and failure analysis of stitched sandwich structures damaged by the impact of various energies

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Abstract. In the fields of structural mechanics and failure analysis, the presence of damage to structural materials requires several studies. Expertise, damage, is crucial to understand the behavior of structures under various loading conditions. Generally, this damage affects the most stressed area of the structure and can lead to the accumulation and propagation of damage, leading to the partial or total collapse of the structure. On the other hand, stitched sandwich plates are an innovative structural material with extremely high performance in the fields of building mechanics and others. However, when these plates are damaged, it is essential to study their behavior under subsequent loading conditions to assess their ability to withstand a second impact. After having been damaged by a first impact at low speed, a diagnosis was carried out which showed the capacity of these plates to undergo a new shock. The present work focuses on the study of the behavior of these said plates under the effect of a second impact. First, the plates subject to damage in previous works were subjected to a new constant energy impact in order to observe the cumulative effect. In the second part, repeated impact tests were applied to healthy plates according to two different modes. The diversity of impact modes is based on the cycle (time) factor. An immediate repeated shock whereas for the other mode the specimen only suffers a second shock after a rest of 24 hours. An analysis of the behavior of the sandwich plates under the effect of different shocks (without rebound) was carried out. The results obtained showed once again the effectiveness of these structural materials in the face of the effect of impact compared to traditional sandwiches. The damage seen is characterized by positioning and pivoting around the point of impact and is limited to the edges of the collider's diameter and depth. Fracture analysis of these plates indicated that the damage resulted in a decrease in their bearing capacity.

Introduction

Sandwich composites are defined as two thin layers with high resistance to tensile and compressive loads, called skins, comprising a thick layer of low density, bonded together by an adhesive to resist transverse shear loads called the core [1], and all this with a necessary and important characteristic in various fields of modern engineering (aeronautical engineering, maritime engineering, civil engineering...) where the reduction of structural weight is of utmost importance and priority. It has a high strength-to-weight ratio [2], high bending stiffness, and a high energy absorption capacity. This design is what has given the diversity and the possibility of having several classifications of sandwich composites, where we find in the specialized literature that there are two divisions. The first concerns the nature of the two skins that make up the sandwich.

"Composite skin sandwich _non-composite skin sandwich," while the second core classification is divided into two parts: a solid core (ex: balsa wood...) and a structural core (honeycomb...).

Since their creation, sandwich composites have undergone several tests in order to study their mechanical properties under different loads, and their effectiveness has been proven on several occasions. However, the biggest hurdle was the separation of the "soul" core from the two skins due to adhesive peeling, which was solved by adding a suturing technique to strengthen the bond between the skins and the core [3] , known as a stitched sandwich. The latter gave a new and elegant concept for the use of sandwich composites.

The stitched sandwich composites were initially the subject of several experiments to compare their function with ordinary sandwich panels, and it was found that the majority of the experiments conducted on them were focused on studying the effect of adding welds on the mechanical behavior of the sandwich [4][5][6][7][8][9][10] , and despite its effectiveness compared to the regular sandwich, it has not escaped various tests, perhaps the most important of which is the effect test. On the other hand, this characteristic is carried out in two forms of low-speed impact and is carried out in two ways: Izod and Charpy impact tests, the content of which is aimed at testing the impact resistance of materials and comparing composite materials with different layers, including woven and unidirectional laminates. The second form is the high velocity impact test, which is often used to study aviation-related structures.

Impact testing is of great importance in the characterization of sandwich compounds and is influenced by several factors: "fiber properties, sample thickness, projectile shape and mass and projectile velocity" [11].

In recent years, several studies have been conducted to understand the impact behavior of stitched sandwich structures, including those with carbon fiber-reinforced polymer skins, aluminum foam cores, 3D woven composite sandwich panels with stitched Z-pins, and sandwich structures with stitched composite skins [12][13][14]. These studies have significantly contributed to our understanding of the behavior of sandwich composites under different loads and their potential for use in various engineering applications. In this context, tests were carried out for the second time on stitched sandwich panels made of glass fiber-reinforced polymer, which had already been damaged by impacts of varying intensities. Therefore, in this work, tests were carried out on damaged samples to study their response to repeated shock loads, paying attention to the damage mechanisms that occur and their impact on the dynamic behavior of the stitched sandwich.

The paper consists of four sections that explore the structural behavior of stitched sandwich plates under the effect of a second impact after being damaged by a first impact at low speed. Section I provides an introduction to the problem being studied and a brief literature review. Section II focuses on the experimental study of the impact on samples. In Section III, the effect of the impact on samples is analysed and discussed. Finally, Section IV concludes the paper by summarizing the findings and presenting the conclusion.

Experimental research

Methodology

In this study, a test rig based on a falling weight impact test, was performed involving impact energy provided by an impact head collider that falls and collides with the target "in our cases are stitched sandwich panels' thus realizing the principle of soft shock. First, the stitched sandwich panel samples were subjected to a low velocity impact test with progressively increasing energies. This study not only considered and resolved the damage observed at the upper skin level resulting from the first was interested in the vibrational behavior of the lower skin due to the progression of the damage (ie; diameter and depth of the indentation) of the impacted skin. In order to evaluate the effect of the cumulative shock phenomenon over time, the samples were subjected to a second impact test with a lower energy than that of the first impact. Finally, in order to study the effect of time on the behavior of these panels, two samples were subjected to a shock test repeated without and after relaxation for 24 hours. The details of the experimental methodology are as follows:

Materials and specimen preparation

The specimens shown in Figure 1 of this study consist of stitched sandwich panels to woven composite skins. These panels measure 200 mm by 150 mm and are 23 mm thick. The skins themselves are composed of two identical layers of woven glass fibers 1.5 mm thick each, with a density of 400 kg/ m3. They envelop a polyurethane foam core 20 mm thick and with a density of 35 kg/ m3. The integrity of the "skins-foam core" suit is reinforced by a seam composed of 2400TEX glass rovings.

Fig. 1: Specimen

Test device and impact method

The operating mode shown in Figure 2 consists of a test bench ensuring the principle of soft impact by falling weight (steel disc + impact head) totaling a mass of 11 kg. The collider thus formed is equipped with a hemispherical impact head with a diameter = 25 mm which allows the impact to be focused. The support system is made to ensure a perpendicular application of the load on the embedded plate in order to avoid any parasitic movement of the specimen Figure 3.

Fig.2: Experimental impact setup

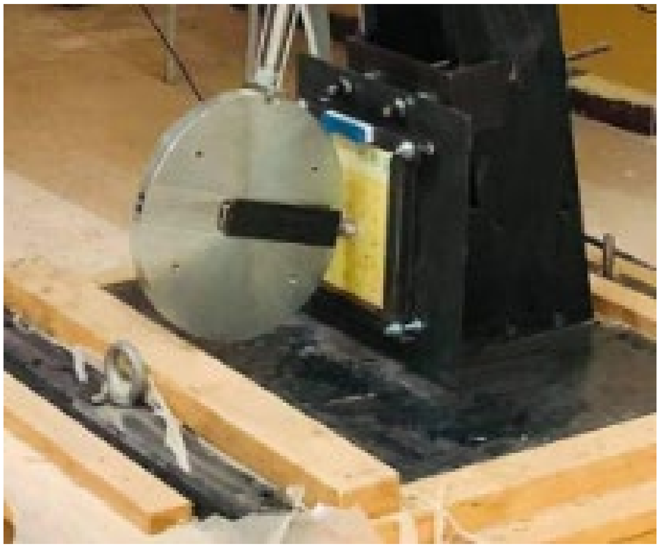

Fig.3: Collision between the collider and the embedded sample

•The energy is given using a graduated disk which makes it possible to lift the mass to the height corresponding to the desired energy Figure 4.

Fig.4: Graduated disk

•The bench is equipped with a braking system which makes it possible to avoid the rebound of the collider.

•The acquisition mode is ensured by Pulse software which is linked to the non-impacted face of the specimen by a sensor Figure 5 bellow.

•For the survey of the deformations of the impacted face (diameter of impact and depth of indentation) they are carried out by an electronic caliper.

•The tests, as can be seen in the previous figures, were carried out according to the above methodology.

Fig.5: A sensor linked to the non-impacted face of the specimen

Analysis of experimental results

Constant impact at 10 [J] on already damaged plates

After evaluating the behavior of the stitched sandwich under the effect of the first impact, a second impact was applied with a constant energy of 10 J for all the specimens already impacted (13.75-24,75- 35,75 and 55 J). In this experiment the effect of the accumulation of shocks was observed. The following figures 6, 7, 8 and 9 explain the results where the graphs showing the vibration behavior of the non-impacted skin are superimposed, while the photo shows the cumulative effects of the two shocks on the impacted face.

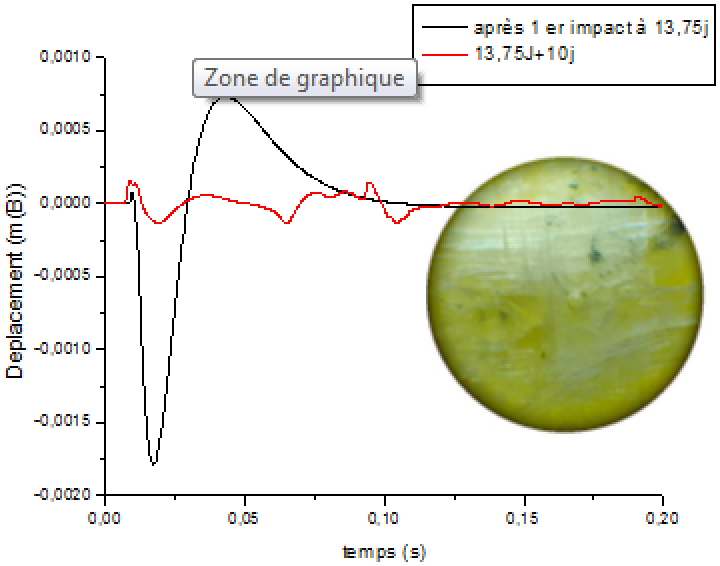

Fig.6: The vibrational response (displacement history) of the non-impacted skin resulting after two impacts: 13,75 J and 10 J

The photo in figure 6, show the vibrational response (displacement history) of the non-impacted skin resulting from the first impact at 13.75 J and the second impact with an energy of 10 J where we notes that the deformation effect of the second impact is negligible. In fact, this is well expressed on the graph of the vibrational responses of the non-impacted skin, where lower amplitudes are observed for the second impact. On the other hand, the impacted skin did not show an increase in the diameter or depth of the impact table 1.

Tab.1: the variation of the parameters of the indentation after two impacts: 13,75 J and 10 J

First Impact energy : 13,75 J		Second Impact energy : 10 J	
Diameter [mm]	Depth [mm]	Diameter [mm]	Depth [mm]
0	0	0	0

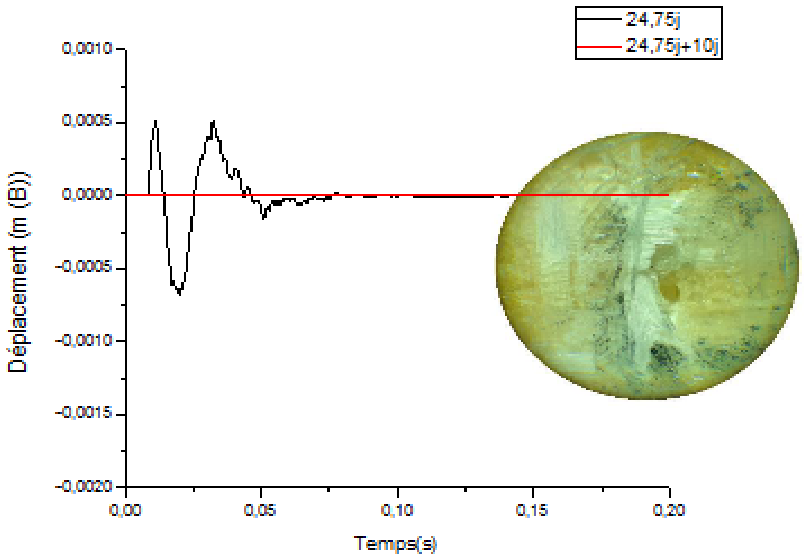

Fig.7: The vibrational response (displacement history) of the non-impacted skin resulting after two impacts: 24,75 J and 10 J

For the specimen in figure 7, it is noted that the vibrational response of the non-impacted skin to the second impact is weaker compared to its response to the first. The phenomenon is certainly due to the absorption of the shock by the fiber debris and resignation resulting from the first damage. On the other hand, the impacted skin shows a 28% increase in the impact diameter (table 2). For the depth, the exaggerated increase (5 times) is indeed justified by the low resistance of the foam.

Tab.2: the variation of the parameters of the indentation after two impacts: 24,75 J and 10 J

First Impact energy : 24,75 J		Second Impact energy : 10 J	
Diameter [mm]	Depth [mm]	Diameter [mm]	Depth [mm]
14,63	1,84	18,8	11,16

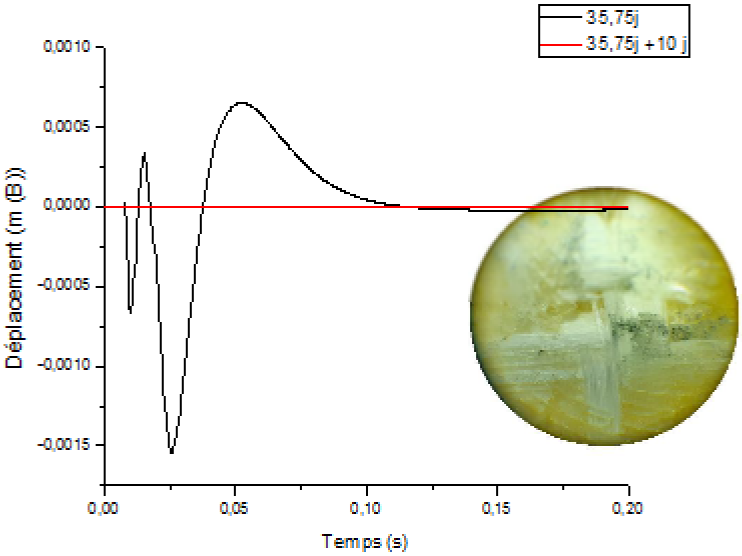

Fig.8: The vibrational response (displacement history) of the non-impacted skin resulting after two impacts: 35,75 J and 10 J

For the test specimen in figure 8, we find ourselves in the particular case where the plate undergoes two impacts on a sewing knot. The vibrational response of the non-impacted skin to the second impact is weaker compared to its response to the first. The phenomenon is due to the absorption of shock by the presence of the seam. On the other hand, the impacted skin shows an increase of 4% in the diameter of the impact (table 3) and 35% in the depth of indentation.

Tab. 3: the variation of the parameters of the indentation after two impacts: 35,75 J and 10 J

First Impact energy : 35,75 J		Second Impact energy : 10 J	
Diameter [mm]	Depth [mm]	Diameter [mm]	Depth [mm]
15,96	3,12	16,62	4,24

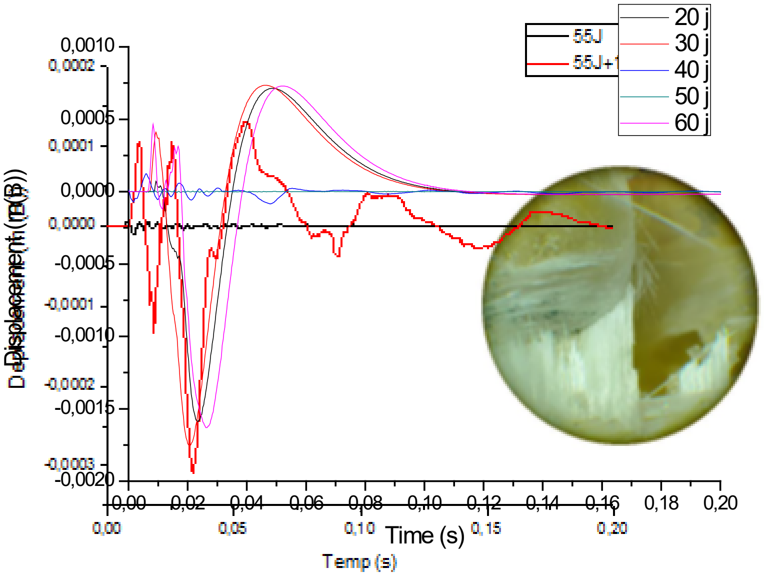

Fig.9: The vibrational response (displacement history) of the non-impacted skin resulting after two impacts: 55 J and 10 J

Figure 9 shows the vibration response of the non-impacted skin resulting from the first and second impact at 55 and 55+10 d. It is noted that unlike the previous plates, the response of the non-impacted face in this case is greater. In fact, at the first impact, the impacted face has been completely perforated, which causes the non-impacted skin to undergo the second shock directly. The impacted skin on its side showed a 9% increase in impact diameter (Table 4) and 15% in indentation depth. It can be seen that the compression of the debris prevents the sinking of the collider head.

Tab. 4: the variation of the parameters of the indentation after two impacts: 55 J and 10 J

First Impact energy : 55 J		Second Impact energy : 10 J	
Diameter [mm]	Depth [mm]	Diameter [mm]	Depth [mm]
17,29	14,94	18,92	17,25

Repeated shock

In this experiment, two healthy plates were impacted according to two impact modes with an energy step of 10 Joules. The first mode in Figure 10 consisted in repeating a series of successive impacts without rest of the plate. For the second mode in Figure 11, the succession of impacts is spaced 24 hours apart in order to allow the specimen to rest. The results were recorded in the same way in order to obtain comparable results.

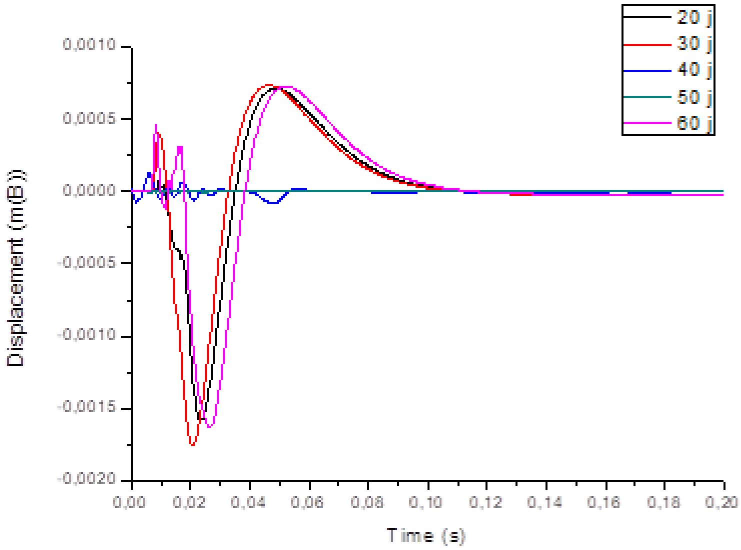

Fig.10: Non-impacted skin vibrational response (displacement history) resulting from successive impacts without rest

As can be seen in Figure 10, the resulting curves of the different energies form a spindle which gives the same behavioral appearance. The shock without rest gives very similar response curves in amplitude with very small differences. The phenomenon is certainly due to the fact that the successive shocks without rest do not allow the material to regain its strength to receive the next impact.

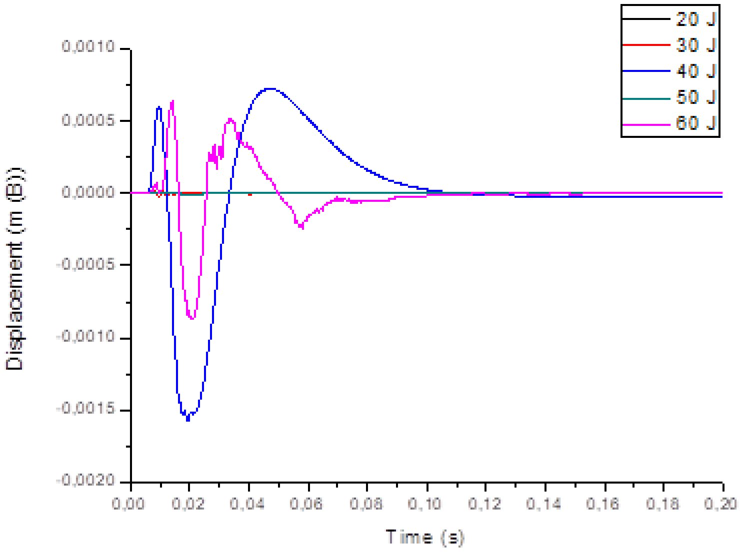

Fig.11: Non-impacted skin vibrational response (displacement history) resulting from successive impacts spaced 24 hours of rest

In figure 11 one can notice the influence of the rest of 24 hours given to the specimen. Although the resulting curves of the different energies have the same behavioral appearance, they differ in the amplitude values. Indeed the phenomenon, noticed in the first experience of the plates impacted at different energies, manifests itself once again and we note the role of the debris which dampens the shock and gives a lesser amplitude in spite of the increase in energy.

Conclusion

In this work, we studied the performance of shock-loaded stitched sandwich plates when subjected to a second shock with an energy level lower or higher than the first. The study was conducted using a test bench under real operating conditions. The performance of these shock-loaded panels was measured after receiving a shock with lower energy. It was observed that the panel charged with higher energy did not respond to the shock direction when a higher-energy shock occurred.

The results of the study revealed several important findings. Firstly, despite the perforation of the impacted skin, the second skin displayed elastic behavior. This indicates that the shock-loaded stitched sandwich plates have the ability to maintain their structural integrity even after being impacted.

Secondly, the debris from the previous shocks formed a layer that acted as a damping mechanism during the second shock. This layer effectively absorbed some of the energy from the subsequent shock, thereby reducing its impact on the plate.

To complete the study, we compared the response to shocks with the same intensity for two stitched sandwich panels. One panel was subjected to repeated shocks without interruption, while the second panel received the same number of shocks with the same intensity but with a 24-hour break between each shock. The results showed that the inclusion of a rest period between shocks proved to be beneficial. The rest allowed the plate to regain its strength and better resist the next shock. This finding suggests that the stitched insulation panels can recover and adapt to repeated shocks when given sufficient time for recovery.

Overall, the results highlight the high performance of the stitched insulation panels, emphasizing their elastic behavior, the dampening effect of debris, and the positive impact of rest periods. These findings also underscore the need for further studies in this area, as they simulate real-world conditions more accurately than studies that solely investigate the behavior after the first impact.

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