20th International Conference on Composite Materials
Copenhagen, 19-24th July 2015

IMPACT PERFORMANCE OF COMPOSITE SANDWICH STRUCTURE UNDER HIGH VELOCITY IMPACT

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Keywords: Composite sandwich structure, Projectile impact, 3D Digital Image Correlation

ABSTRACT

Composite sandwich panels are well known for their relatively high stiffness over weight ratio and have been increasing utilized in various applications where the weight of the structure is a key design concern, e.g. in aircraft and aerospace components. However, these structures are vulnerable when subjected to a transverse impact loading. In this paper, the impact performance of composite sandwich structures with foam core is investigated. In particular, the idea of multi-layering the core by foam layers of different density and its effect on the energy absorption under low and high velocity impact is of interest. In this study, composite sandwich panels made of Glass Fibre Reinforced Polymers (GFRP) for skins and PVC foam for the core are used. Two different arrangements of foam core are considered: uniform core (80/80/80 kg/m^3) and graded core (100/60/100 kg/m^3). Both of these core arrangements have the same areal density. Low (up to 5 ms^{-1}) and high (up to 200ms^{-1}) velocity impact tests were performed using a drop tower and a gas gun respectively. In-plane and out-plane properties of composite sandwich samples were measured employing 2-D and 3-D Digital Imaging Correlation (DIC) methods. The results indicate that the composite sandwich structure with graded foam core has a better energy absorption capability compare to the one with uniform foam core.

1 INTRODUCTION

The use of composite sandwich panels are increasing rapidly in aircraft and aerospace structures as main loading components. The threats for these structures are subjected to different energy impacts by tool drop, bird strike, hails and runway debris on take-off and landing, which can produce serious damage to the components and may cause Irreparable consequences. Although quasi-static and low velocity impact response of composite sandwich structures have been investigated in details [2, 3, 7], less attention has been paid toward the high velocity impact response where the deformation can be highly localized. The aim of this research is to address this shortcoming. The idea of grading the core, which has been found to be an effective strategy for improving the blast resistance [1], will be explored for increasing perforation resistance under projectile impact. First, the literature in the impact response of composite sandwich structure will be briefly reviewed.

Hossain et al. [2] experimentally studied the compressive behaviour and energy absorption capability of a functionally graded foam material system under quasi-static loading conditions. The results indicate stepwise crushing from the lower density to the higher density foam layers. Mines et al. [3] investigated the response of sandwich composite structure under low velocity impact. The panels based on both aluminium honeycomb and coremat cores. Their findings show that the energy absorbing capacity of the sandwich panels increases with loading rate, this being due to strain-rate effects in the core crush stress and the skin failure stress. Reyes and Cantwell [4] conducted high velocity impact tests on sandwich panels with fibre–metal laminate skins and an aluminium foam core. They noted that the introduction of metal layers into the composite skins increases the specific perforation energy of the sandwich panels by over twenty percent for a comparable areal density. Dear and Brown [5, 6] undertook research on the impact toughness of reinforced polymeric materials and various lightweight sandwich panels. The purpose of the study was to satisfy the energy absorption and structural integrity requirements of the next generation of advanced aircraft, marine-craft and rail vehicles. Zhou and Hill [7] investigated the parameters affecting damage development and energy absorption in sandwich panels subjected to localized impact loading. They argued that changing the skin thickness not only changes the flexural rigidity of the panels, but also changes the mechanisms of load transfer between the upper and lower skins. This in turn influences the development of damage within the structure.

2 EXPERIMENTAL PROCEDURE

In order to compare the damage and energy absorption difference between uniform and graded foam core. The low and high velocity impact tests were conducted by using a drop-weight tower and a gas gun.

2.1 MATERIAL AND SAMPLE MAKING

The materials used in this research are glass fiber reinforced polymer (GFRP) XE603 by Gurit® for skins and PVC foam: C70.55, C70.75 and C70.90 provided by Airex® for foam core. The material properties of foam are listed below.

	Unit	C70.55	C70.75	C70.90
Density	kg/m^3	60	80	100
Compressive modulus	MPa	69	97	125
Compressive strength	MPa	0.9	1.3	1.9
Compressive fracture strain		0.7	0.7	0.7
Tensile modulus	MPa	45	66	84
Tensile strength	MPa	1.3	2	2.7
Shear modulus	MPa	22	30	38
Shear strength	MPa	0.8	1.2	1.6
Shear fracture strain		0.16	0.23	0.27

Figure 1. Material properties of different foam core (provided by Airex®)

Two samples geometry were made: beam samples with the size of 300 × 75 mm for drop tower test and plate samples with the size of 100 × 100 mm for gas-gun test using resin infusion under flexible tooling (RIFT) method on the hot plate. The sample geometries can be found in Fig. 2.

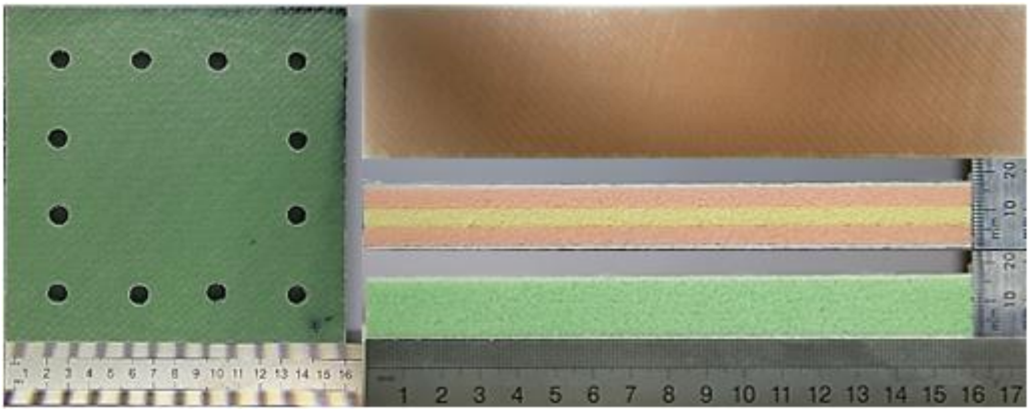

Figure 2. Plate and beam samples used for low and high velocity tests respectively.

In this paper, composite sandwich structures with two core arrangement is investigated: i) uniform foam core which has 3 layers of 5mm thick $80kg/m^3$ and ii) graded core which is two 5mm thick $100kg/m^3$ and $60kg/m^3$ in the middle.

Uniform foam core	Graded foam core
6 layers of glass fiber with 600 gsm (0/90/-45/+45/90/0)	6 layers of glass fiber with 600 gsm (0/90/-45/+45/90/0)
PVC foam 80kg/m^3 (5mm thick)	PVC foam 100kg/m^3 (5mm thick)
PVC foam 80kg/m^3 (5mm thick)	PVC foam 60kg/m^3 (5mm thick)
PVC foam 80kg/m^3 (5mm thick)	PVC foam 100kg/m^3 (5mm thick)
6 layers of glass fiber with 600 gsm (0/90/-45/+45/90/0)	6 layers of glass fiber with 600 gsm (0/90/-45/+45/90/0)

Figure 3. Foam orientation of uniform foam core and graded foam core

2.2 LOW VELOCITY DROP-WEIGHT TOWER TEST

The idea of the drop tower test is based on the 3-point bending. The impactor hit the middle part while the two rollers support at both side. This method would help to get a better understanding of shear crack development and propagation through foam layers. The drop-tower provides up to 300J energy which can give us a big range of selection impact energy. A high speed camera was located on front shooting at the rate of 4000 frame per second. The image sequence was then imported to a commercial software (Aramis®) for post processing. Major strain, shear strain and displacement can be got from the software. The picture showed below is the drop-weight tower test set up.

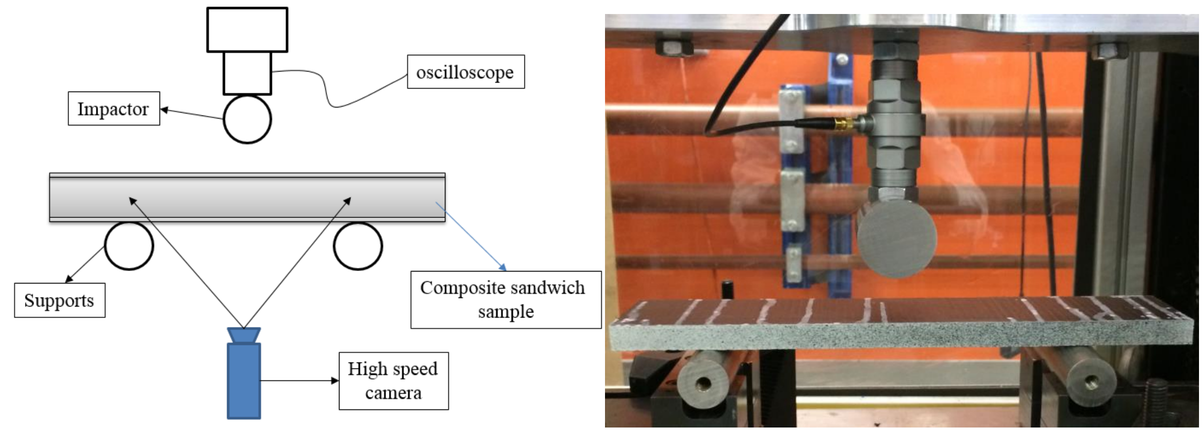

Figure 4. Drop-weight tower set up

2.3 HIGH VELOCITY GAS-GUN TEST

The high velocity impact was conducted using a gas-gun machine. Velocities up to 300 ms^{-1} can be achieved depending on the mass of projectile. Regarding this series of test, the projectile is make as a cylinder shape with 24.8mm diameter 50mm length and 23g mass, The projectiles are accelerated through a 3m long barrel. The impact test was done at the speed of 196 m/s. The target plate was clamped to a rigid frame in the middle of a target chamber. The chamber has transparent windows allows observing the impact while protect the surrounding from fragments. The speed of projectile was measured using two IR gauges. The signal generated by these gauges was used to trigger two high speed camera positioned at the back of the target. These high speed cameras, which were synchronized, were located with 25 ° angle regarding each other. This is the recommenced angle which allows both of in-plane and out of plane deformation is measured accurately [8]. The images captured by high speed cameras were then imported to Aramis® for post processing. A Schematic of the test set up is shown in Fig. 5. The strain gauges were also used in order to compare with the DIC data to make sure the reliability of DIC system. The major strain, shear strain and also out of plane displacement can be captured which can help us have a better understanding of energy absorption under different velocity impact and different foam orientation.

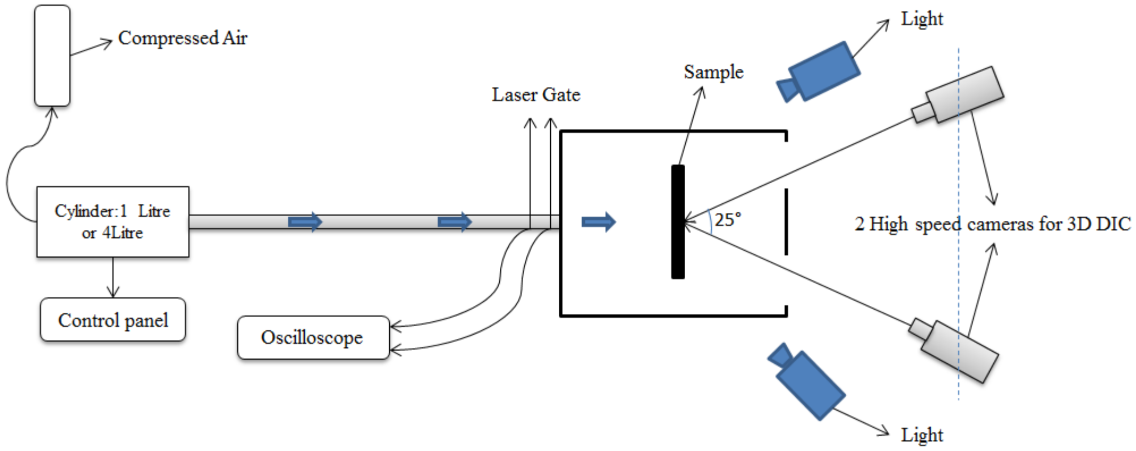

Figure 5. Gas-gun test set up

3 RESULTS AND DISCUSSION

3.1 LOW VELOCITY DROP-WEIGHT TOWER RESULTS

The low velocity impact with 100J energy has been tested with drop-weight tower for both uniform and graded foam core. From the figure 6, it can be seen that the uniform foam core trace has a higher peak load than graded foam core at the same contact time, which is 3.5KN and 2.9KN. For both uniform and graded foam core, after the peak load, they have fluctuate loading phase before the total failure. But the graded foam core has a longer duration of fluctuate loading until the total failure which is 7ms for graded foam core and 5ms for uniform foam core.

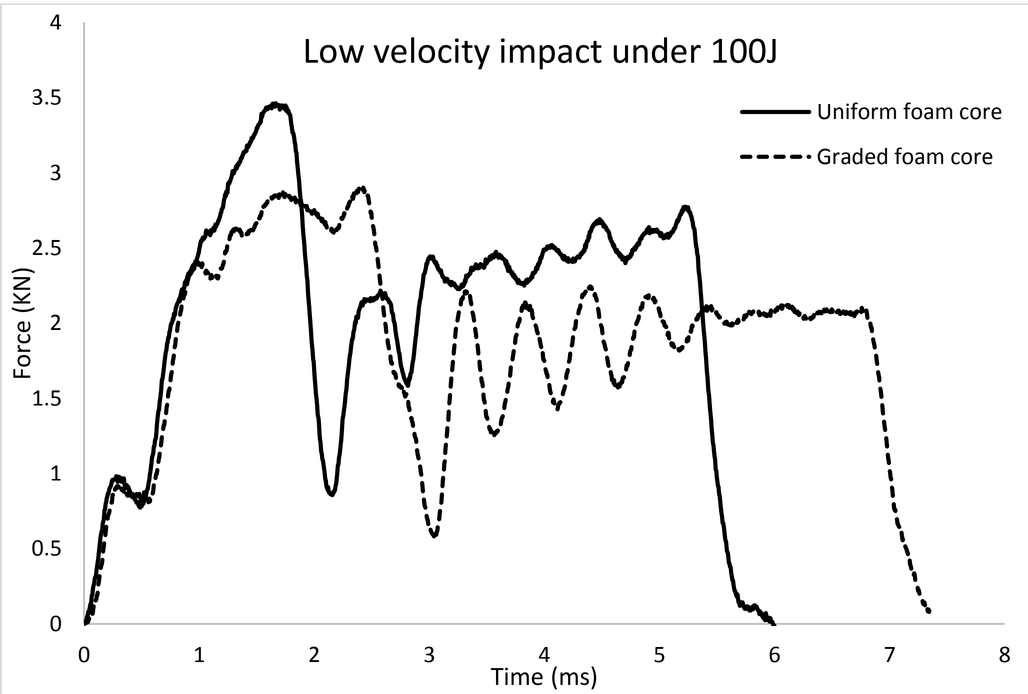

Figure 6. Force and time curve for graded and uniform foam core under 100J energy low velocity impact

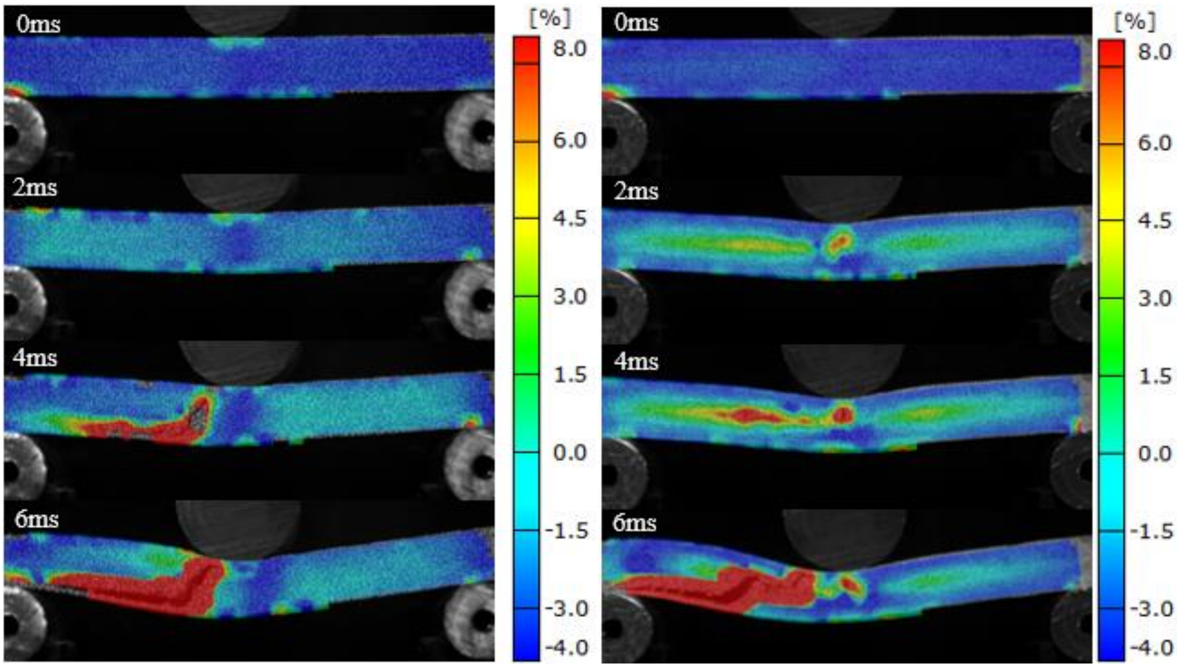

Figure 7. Major strain of uniform foam core (left) and graded foam core (right) under 100J low velocity impact

The figure 7 shows the DIC results for composite sandwich beams with uniform and graded foam core under low velocity impact with 100J energy. From the images it can be seen that for the uniform foam core, the initial crack happened at the top foam layer and directly propagate through the three layers to the back composite skin, then the delamination arise between the back foam layer and the back composite skin. From the graded foam core DIC result, it can be seen that the initial crack also happened at the top layer foam, but the crack propagate along the middle foam layer which is lower density, then the shear crack propagate into the back foam layer, and finally the delamination arise between back foam layer and back composite skin. So the middle low density foam layer helps the whole structure to absorb the impact energy, prolong the failure process and increase the crack propagate duration into back composite skin, that is why the graded foam core has a longer loading duration than the uniform foam core.

3.2 HIGH VELOCITY GAS-GUN TEST RESULTS

Figures 8 (a) and (b) are the images taken from front (impacted side), back (non-impacted side) and sectioned view of composited sandwich plates with uniform and graded core impacted at the velocity of 196 ms^{-1}. For both samples the front composite skin is completely perforated with the similar damage area. However, the main different can be seen in the photos taken from back and sectioned sample. In the sandwich plate with uniform core, crushing occurs in the first two foam layers. The failure then proceeds by formation of shear cracks in the last foam layer followed by delamination of the foam from the back composite skin. It can be seen that the back composite skin also fails in this case. The failure of the first two layers is similar in the case of the sandwich plate with graded core. However, the back foam layer damage for both foam cores are significant different. For the uniform foam core, the shear crack transferred through the first two foam layers into the back foam layer, and this also cause the delamination between the back foam layer and the back composite skin. For the graded foam core, the back foam layer is just compressed without any shear crack, and no delamination arise between the back foam layer and back composite, so that is why there is no damage on the back composite skin of graded foam core, while the damage accrued on the back composite skin for uniform foam core.

(a) Uniform foam core (80kg/m^3, 80kg/m^3, 80kg/m^3)

(b) Graded foam core (100kg/m^3, 60kg/m^3, 100kg/m^3)

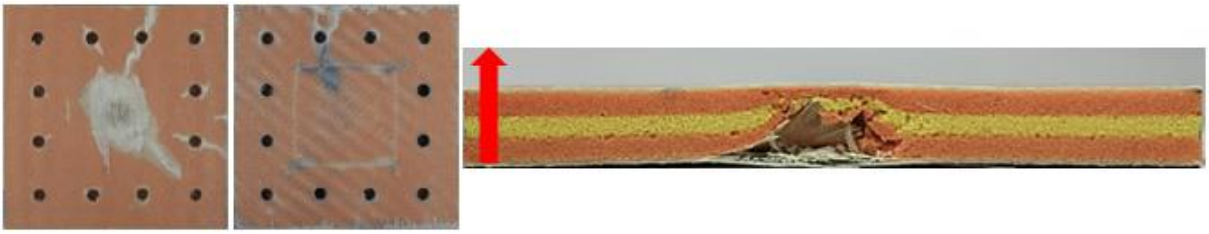

Figure 8.front & back & side view of graded and uniform under 196ms^{-1} high velocity impact for both specimens

4 CONCLUSION

The performance of composite sandwich structure with uniform and graded foam core is evaluated under low and high velocity impact. The results show that grading the foam core can improve the energy absorption capability of composite sandwich structures. .

ACKNOWLEDGEMENTS

The strong support from The Aviation Industry Corporation of China (AVIC), First Aircraft Institute (FAI) and Beijing Aeronautical Manufacturing Technology Research Institute (BAMTRI) for this funded research is much appreciated.

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