ASSEMBLED TRUSS CORE SANDWICH STRUCTURE AND ITS FAILURE MODE UNDER IMPACT LOADING

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Abstract

The interlocking assembled technique for manufacture of pyramidal truss core sandwich structures was introduced. The impact response of manufactured sandwich structures under the low velocity impact was investigated. Then the edgewise compression tests are conducted to determine and quantify the effects of impact damage on the overall response of the structure. The compressive behavior of this impact damaged pyramidal truss core sandwich structures is compared to that of foam/honeycomb core sandwich structures in order to evaluate their damage tolerance finally.

1. Introduction

Sandwich constructions are widely used in aerospace, marine and automobile industries where there is need for lightweight structures with high stiffness and strength [1]. More recently, interest in the sandwich structures has concentrated on the lattice sandwich structures because of their excellent specific strength and stiffness, especially the unique open cell architecture for multi-functionality [2, 3].

A number of studies have been focused on response of sandwich structures under low velocity impact and the residual compressive strength. Many experimental studies were conducted to investigate the effects of constituent materials, geometry, facesheet layups and various energies on the impact damage and the compression-after-impact (CAI) strength [4-7]. In order to characterize the impact response and predict the residual compressive strength, various analytical and numerical models have been developed [8-11].

In this paper, the interlocking assembled technique for manufacture of pyramidal truss core sandwich structures was introduced firstly. Then the low velocity impact response of manufactured sandwich structures was investigated. Subsequently, a series of edgewise compression tests were conducted to determine and quantify the effects of impact damage on the overall response of the structure. The compressive behavior of this impact damaged pyramidal truss core sandwich structures is compared to that of foam/honeycomb core sandwich structures in order to evaluate their damage tolerance finally.

2. Assembled interlocking technique

The sandwich cores were fabricated from the 1.4 mm thickness aluminum alloy sheets (2A12-T4) by slot-fitting method. The sheets were firstly cut into the continuous 2-D slot-fitting truss patterns using wire electro discharge machining and then assembled into the pyramidal core topology, as depicted in Figure 1. Finally, CFRP facesheets made from unidirectional carbon/epoxy (T700/3234) pregs were finally bonded to the top and bottom faces of lattice cores using film adhesive (J-272).

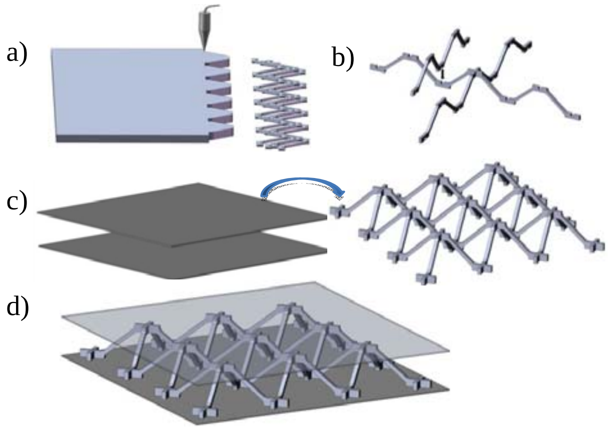

Figure 1. Schematic of the manufacturing process of the aluminium alloy pyramidal core sandwich structures. (a) Cut continuous 2-D snap-fit truss patterns; (b) assemble the lattice core; (c) bond the lattice cores with facesheets; and (d) the fabricated sandwich structure with pyramidal lattice core.

3. Low velocity impact test

The Instron Dynatup 9250HV impact testing machine was used for the low velocity impact tests. During tests, the impactor possessed a hemispherical nose of 12.1 mm in diameter and a force transducer was mounted on the impactor nose with the capacity of 22 kN. The specimens were fixed by the pneumatic clamps, with a 76.2 mm diameter opening, which secured each specimen during impact tests. The clamping pressure of 0.02 MPa was imposed on the pneumatic clamps, which was well below the lowest compressive strength of the lattice cores. During tests, the varied impact energies were achieved by changing the drop height and the impactor mass was assigned 6.15 kg for all tests in the present study. The impact response of the specimens including velocity, displacement, load and energy were recorded and stored by computer using data acquisition software.

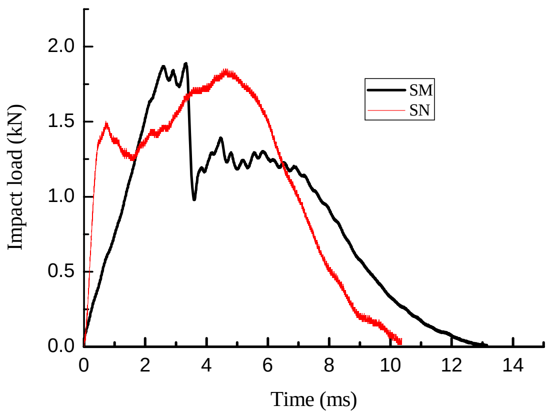

Figure 2. Impact load versus contact time curves

The impact site will affect the response and damage of the structures. Here two representative impact sites are considered. One case is the impact site located on the node (SN) and the other impact site is the middle point of the four adjacent nodes (SM). The impact load versus contact time cure for the impact energy of 5 J is shown in Figure 2. The sharp load drop in the figure indicates that there is considerable damage for the specimen impacted on the middle point of the four adjacent nodes, which is confirmed from the penetration of the top facesheet. This can be explained that a lot of impact energy is absorbed by the truss members under the impactor and the truss members can give additional support to the impactor when the impact location is on the node. Conversely, there is no extra support for impactor when the middle point of the four adjacent is impacted.

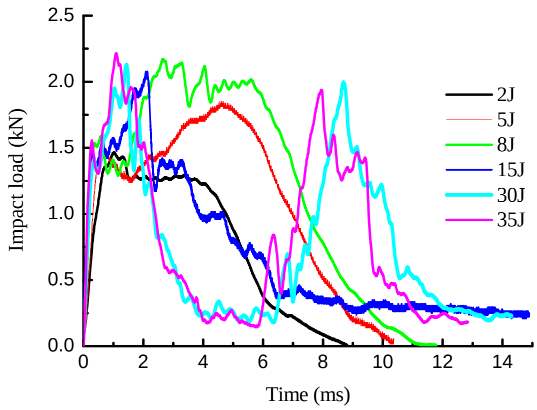

Figure 3. Impact load versus contact time curves with different impact energy

For the case of impact site located on the node (SN), the impact load versus contact time curves of the specimens with different impact energy are plotted in Figure 3. It is found that once the impact energy increases, the recorded impact force shows a sudden drop from the peak point. For the lower impact energy (2 J and 5 J), the smoother impact load curves mean that there is slight damage in the specimen. It is found that there is barely visible indentation on the surface of specimen and matrix cracking emerges along the orientation perpendicular to the fiber. Moreover, delamination is very obvious at the distal surface of top facesheet around the impact region, while the truss members under the impactor suffer buckling. When the impact energy increases to 8 J, a series of oscillations in the impact load curve is found. Examination reveals that the indention is quite visible at the impact location with fiber breakage on the top facesheet. For the impact energy of 15 J, it is quite noticeable that a sharp load drop occurs in the test. This load drop is due to the penetration of the facesheet at the impact region and fracture of truss members. At the impact energy of 30 J and 35 J, it is evident that the impact load-time curves are of a mountain-like shape with two peaks, implying the contact of impactor with the top and bottom facesheets, respectively.

4. Compression-after-impact (CAI) test

After impact tests, all the specimens were subjected to compression to determine their CAI characteristics and strength according to the standardized test method, ASTM C364/C364M-07 [12]. The CAI device was shown in Figure 4. The specimens were fully clamped at both load edges and simply supported on the edgewise sides to prevent global buckling during the compression tests. Solid steel inserts with the dimensions 135×5×15 mm were placed between the facesheets at edgewise sides for gripping of the sandwich structures during the experiment. All tests were carried out under displacement control at a rate of 1.5 mm/min. The compression tests of un-impact sandwich structures were also conducted with the same method, giving the baseline strength for the sandwich structure.

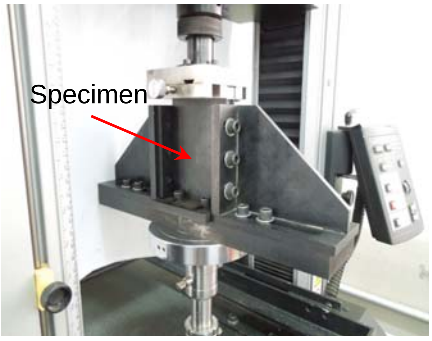

Figure 4. The support fixture for CAI tests

Figure 5 shows the average compressive strength of specimens as the function of impact energy, including those un-impact specimens. The figure shows a trend that the CAI strength of specimens impacted on the node decreases with the impact energy. When the impact energy is small (lower than 8 J), there is a small variation for the CAI strength and it sharply drops when the energy reaches 30 J. This can be explained that the small variation of CAI strength under lower impact energy is attributed to local buckling of facesheet in the test, which is mainly sensitive to the bending stiffness of sandwich specimen, and the total bending stiffness has small reduction due to the slight impact damage. When penetration takes place for the both facesheets at 30 J, the overall stiffness of sandwich structures has a significant decrease which resulted that deflection of the facesheets is prone to occur. Consequently, core debonding is provoked, which is prior to the compressive failure of facesheets. In light of the specimens SN and SM with impact energy of 5 J, it is concluded that CAI strength is related to the impact site.

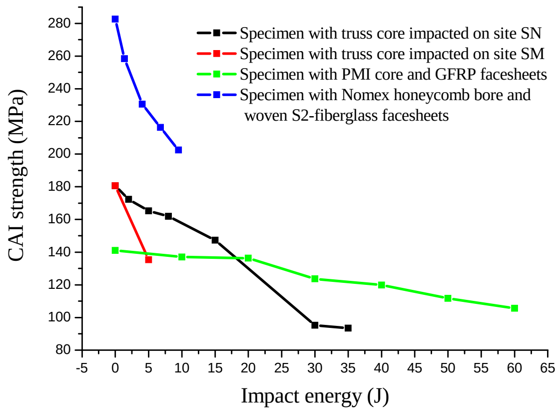

Figure 5. The average CAI strength as the function of impact energy

The compressive response of various core type sandwich structures subjected to low velocity impact were also compared in Figure 5. It can be seen that the CAI strength decreases as the impact energy increase, though the reduction trends for three different core sandwich structures are different. For the PMI foam core sandwich structures, the reduction in residual compressive strength is marginal when the impact energy is lower than 30 J, whereas the reduction achieves 28% for the honeycomb core sandwich structures at the impact energy of 9.5 J. Based on Figure 5, it shows that the PMI foam core sandwich structures have the highest damage tolerance, the lower is the pyramidal truss core sandwich and the most low is the honeycomb core specimen. However, this conclusion is not applicable for all the PMI foam, honeycomb and pyramidal lattice core sandwich structures, because the reduction in residual compressive strength is considerably related to the materials of facesheet and core, dimensions of specimens and the impactor parameters. Compared to the failure modes of foam/honeycomb core sandwich structures under CAI tests, as mentioned above, the local buckling is dominated in the edgewise compression tests for pyramidal truss core sandwich structures due to the weak facesheet buckling resistance, which is contributed to the large open cell core topology. Accounting for the efficiency of structures, the failure mode of buckling is not desirable. Hence, based on the CAI tests, the pyramidal truss core sandwich structures are inferior to the foam/honeycomb core sandwiches.

5. Conclusions

In this paper, the sandwich structures consisting of CFRP facesheets and aluminum alloy pyramidal truss core were fabricated based on the interlocking assembled technique. The design concept is using CFRP laminate as the facesheets to maximize the specific bending stiffness/strength while introducing lightweight metal cores to obtain excellent energy absorption. The low velocity impact tests reveal that the extent of damage is significantly affected by the impact site. When the impact site is on the middle point of the four adjacent nodes, the specimens suffer more serious damage than that impacted on the node. Under compression tests, the local buckling occurs for the un-impact sandwich structures and those impacted under lower energy (lower than 8 J). With the impact energy increase (higher than 15 J), the sandwich structures fail by debonding, which is provoked by bending deformation of the facesheets under compressive load. Compression-after-impact (CAI) strength of truss core sandwich structures has also studied in this paper. The CAI strength of specimens impacted on the node decreases with the impact energy increase. This research is a primary study on the compression of impact-damaged pyramidal truss core sandwich structures, and the results such as the failure modes, the reduction data in residual compressive strength can offer useful information for the further investigation.

Acknowledgements

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