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LOW-VELOCITY IMPACT RESPONSES AND CAI PROPERTIES OF SYNTACTIC FOAM SANDWICH COMPOSITES

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1. INTRODUCTION

Sandwich composites usually serve the dual function of carrying loads and absorbing energy, due to their prominent advantages of light weight, high flexural and transverse shear stiffness, and environmental resistance [1-3]. However, they are susceptible to low-velocity impacts because the internal damages induced by impacts often result in a sudden destruction of the structures [4]. Syntactic foam consisted of hollow particle fillers in polymer matrix is one of promising core materials for sandwiches, in which the syntactic foam provides superior compressive strength, high damage tolerance and energy absorption ability [5]. The increasing applications of syntactic foam sandwich composites in marine structures, transportations and civil infrastructures require full understanding of the mechanism of impact responses and reliable assessment of damage tolerance.

The use of a syntactic foam as sandwich core can increase the stiffness and strength of sandwiches significantly without a large weight increase [6-8]. However, there is little work concerned on the evaluation of damage and residual strength of syntactic foam sandwich composites after impact. Therefore, the present study focuses on characterizing the impact damage and CAI strength of sandwich panels with GFRP facesheets and syntactic foam core. Influences of the number of GFRP skin layers, syntactic foam density and the existing of lattice webs, as well as the applied impact energy were discussed.

2. EXPERIMENTAL PROGRAM

Materials and Specimens

E-glass bidirectional woven fabrics with fiber orientation angle 0/90° and vinyl ester resin were used in facesheets and lattice webs. The macrosphere syntactic foams, supplied by Engineered Syntactic Systems, USA, with density of 450 kg/m3 and 480 kg/m3 were used in this study. Vacuum assisted resin infusion process was used to manufacture GFRP-syntactic foam sandwich panels. Total 40 specimens were prepared including 8 bare syntactic foam panels, 16 GFRP-syntactic foam sandwich panels without webs, and 16 GFRP- syntactic foam sandwich panels with lattice webs. The distance between the webs is 50 mm. All the test specimens are of the same width of 100 mm, length of 150 mm and core height of 50 mm.

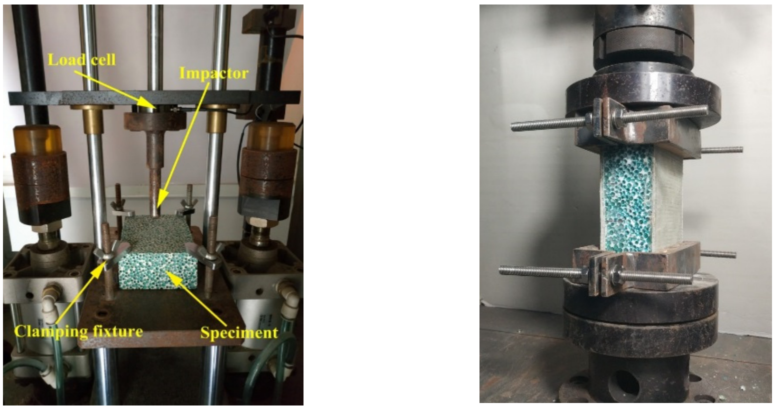
Impact Testing

DTM1203 drop-weight impact testing machine was used to impact the specimens at room temperature. The maximum drop height is 2 m. The steel impactor has a semicircular nose with a diameter of 16 mm and weight of 5.5 kg. During testing, the impactor is raised automatically by an automatic control system. Three different drop heights were used (0, 0.8 m, 1.2 m and 2 m), in which the applied energy can be varied from 0 J to 108 J. Each specimen was impacted only once. Four corners of the test specimens were clamped to avoid slippage and rotation. Fig. 1(a) shows the test set up of low-velocity impact.

The time histories of impact load were captured with a piezoelectric sensor mounted onto the drop hammer. The maximum penetration depth (MPD) was measured by a micrometer gauge with a resolution of 0.01 mm just after impact.

CAI Testing

A universal testing machine with 600 kN capacity was used for testing edgewise compressive strength of damaged and undamaged specimens. The test was conducted in strain control with a loading rate of 1.25 mm/min. During testing, the compressive load was applied through a very stiff steel top panel, and was collected via a load cell mounted directly above the top panel. The displacement of crosshead was recorded by the actuator automatically. Steel fixture systems were applied to both ends of the sandwich columns to minimize the stress concentrations of the facesheets at the contact with loading panels and to ensure uniform load transfer. In accordance with ASTM D7137/7127M-12 [26], all the specimens were loaded until the maximum load was reached and load had dropped off about 30% from the maximum. The test set-up of edgewise compression was shown in Fig.1 (b).



(a) Low-velocity impact (b) Edgewise compression

Fig.1: Test set-up.

3. RESULTS AND DISCUSSION

Impact Responses

The bare syntactic foam panels exhibited a circular dent on the impact face. The increase in applied impact energy from 41 J to 108 J leads to 33% increments in the peak load of impact and 61% ~ 76% increments in the MPD for bare syntactic foam panels, respectively. Under the same applied impact energy, the MPD of syntactic foam panels with foam density of 450 kg/m^3 was 20%~40% higher than the panels with foam density of 480 kg/m^3.

For GFRP- syntactic foam sandwich panels without webs under the applied impact energy 41 J, the damage is concentrated in the facesheets and has a diamond shape due to the breakage of fibers in the longitudinal and transversal directions. The deformation of the core in the impact zone was insignificant. However, with the increase in applied impact energy, the shape of damage turned to be a circle due to the crushing of resin and delamination between FRP layers, and the facesheets in the loading location was penetrated resulting in a deeper MPD in the foam core. The MPD of sandwich panels was much smaller than that of bare syntactic foam panels.

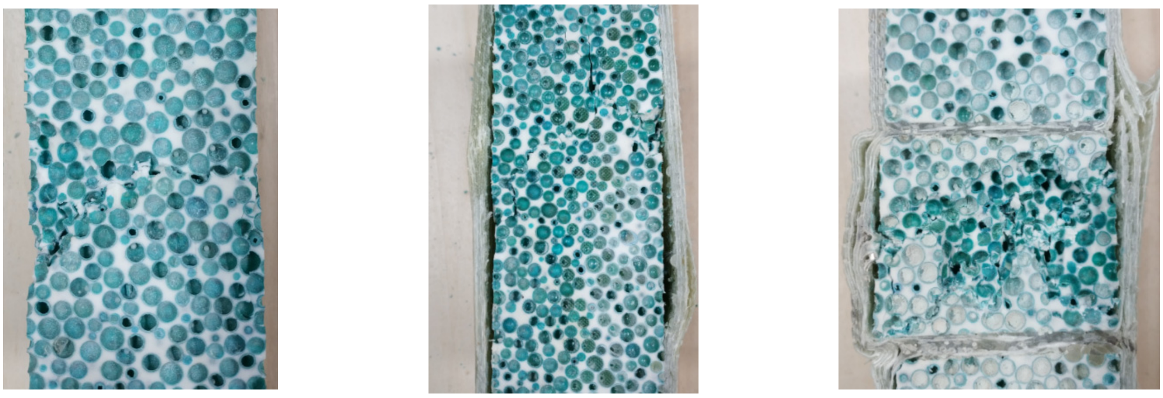
The damage mode of GFRP- syntactic foam sandwich panels with webs was similar with those sandwiches without webs. However, the sandwich panels with webs have smaller damage width and penetration depth than the counterparts without webs.

Given the same thickness of core and skins, the peak load of impact of GFRP-syntactic foam sandwiches was about two times that of GFRP- polymethacrylimide (PMI) foam sandwiches under 40 J in Ref [9], and the corresponding MPD of GFRP-syntactic foam sandwiches was much smaller than that of GFRP- PMI foam sandwiches.

Damaged Sandwich Panel Compression

Fig.2 shows the condition of damaged specimens after edgewise compression. The cracks of damaged syntactic foam columns were initiated from the impact dent due to the stress concentration in this region, and then propagated in transversal and vertical directions. For damaged sandwich columns without webs, widespread debonding between the facesheets and core occurred on both sides accompanied by vertical crack propagation in the foam core. The sandwich columns without webs were failed due to the facesheets being buckled into a half-wave and shear buckling of the foam core. The failure mode of damaged sandwich columns with webs is comprised by the debonding of facesheets, core being crushed between two webs, as well as delamination in GFRP layers, especially in the facesheets contained impact damage. The debonding area of panels with webs was much smaller than that of panels without webs because the debonding between the facesheets and the foam was controlled by the webs. Meanwhile, wrinkling occurred at the intersection of facesheets and webs. The indention of the facesheets under edgewise compression propagated from the top surface of facesheets to the intersection of facesheets and the top web until this intersection reached to the critical location, resulting in local buckling at the top intersection. Then the indention continued to propagate to the intersection of facesheets and the bottom web and caused local buckling at this intersection. This wrinkling process not only causes the delamination of facesheets, but also results in shear buckling of the foam core between two webs.

The ultimate load of damaged bare syntactic foam panels after 108 J was only reduced less than 8% in comparison with the undamaged panels. Although the damage depth of sandwich panels was much lower than that of bare syntactic foam panels, the ultimate load of damaged sandwich panels with and without webs after 108 J was reduced by about 8%~14% in comparison with the undamaged panels. This is attributed to the fact that the impact dent aggravates the debonding of facesheets and core and delamination of GFRP layers.



(a) Bare foam panels (b) Sandwich panels (c) Sandwich panels with webs

Fig.2: Edgewise compressive failure mode of damaged specimens.

4. CONCLUSIONS

The impact and post impact behavior of GFRP- syntactic foam sandwich panels were investigated. The results obtained from this study are summarized as follows:

(1) The damage shape of sandwich panels under impact is relative to the applied impact energy and layers of GFRP facesheets. The GFRP- syntactic foam sandwich panels have a diamond damage shape for specimens with 2 or 4 layers of facesheets after 41 J due to the fracture of fibers in orthogonal directions. Further increasing the number of GFRP layers or impact energy resulted in resin crushing and debonding of the facesheets and foam core, thus causing a circular damage on the impacted facesheets. The MPD of sandwich panels is much smaller than that of bare syntactic foam panels. Moreover, the existing of lattice webs contributes to decrease the MPD of sandwich panels. This is because the core in the central of the panel is confined by GFRP, resulting in the increase in the strength and stiffness of the core.

(2) The cracks of damaged syntactic foam panels under edgewise compression were initiated from the impact dent due to stress concentration, and then propagated in transversal and vertical directions. The damaged sandwich panels without webs failed predominantly by debonding between facesheets and core, the buckling of facesheets and the shear buckling of the foam. The existing of lattice webs contributes to prevent the debonding of the facesheets from the foam core, and delamination and local buckling of facesheets prevailed in sandwich panels with webs.

(3) All the sandwich panels, with and without webs, exhibited a four-phase displacement: linear-elastic phase, plastic phase, foam compaction phase and facesheets buckling phase. However, the sandwich panels with webs exhibited much larger plastic deformation than the sandwich panels without webs. After 108 J, the ultimate load of damaged bare syntactic foam panels was only reduced less than 8% in comparison with the undamaged panels, while the ultimate load of damaged sandwich panels with and without webs after 108 J was reduced by about 8%~14%. This is attributed to the fact that the impact dent aggravates the debonding of facesheets and core and delamination of GFRP layers.

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