The transient behaviour of blast-loaded glass fibre reinforced epoxy sandwich panels with foam cores

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Abstract. This paper reports on the transient response measurements from blast-loaded sandwich panels with lightweight foam cores and asymmetric (different thicknesses) glass fibre reinforced epoxy (GFRE) face sheets. The contribution of the foam core was considered by comparing structural response of equivalent mass GFRE panels with and without foam cores subjected to carefully controlled explosive detonations. The sandwich panel behaviour was more complex, with larger post-peak residual oscillations that did not decay as significantly with time. A probable sequence of damage was proposed, based on the transient displacement measurements, post-test panel inspection and through consideration of stress wave propagation through the multi-layered structure.

Introduction

Lightweight materials, based on fibre reinforced polymers, are attractive for structural applications when mass is an important consideration as they have tuneable structural properties. GFRE structures are popular as they possess high specific strength, stiffness, corrosion resistance and good thermal properties. Sandwich structures, with GFRE face sheets and a lightweight core, can further increase the structural rigidity by increasing the second moment of area [1]. However, the overall strength of the sandwich is often limited by the strength of core, and the thin face sheets may result in a weak sandwich panel, especially in impact and blast applications. Although studies on the blast response of asymmetrical metal sandwich panels have been conducted [2-3], little is known about similar systems based on polymer composites. In this paper, experimental results from blast tests on asymmetrical sandwich panels with GFRE face sheets and closed cell PVC foam cores are used to investigate the influence of the foam core.

Experimentation

Panel Design and Manufacture. GFRE laminate panels were manufactured using vacuum infusion, with 19 layers of 400 g/m^2 plain weave glass fibre and Prime 27 LV epoxy resin. Sandwich panels were manufactured using 18 layers of the same woven glass and Divinycell H80 closed cell foam core (nominal 25 mm core height). The sandwich panels were asymmetrical, with 12 layers on the front face sheet (closest to the blast) and 6 layers in the rear face sheet (see Fig. 1). After vacuum infusion, the panels were cut to planar dimensions of 300 mm x 300 mm and post-cured at 50°C for 15 hours. For information on the material properties and the manufacturing process, see Langdon and co-workers [1, 4].

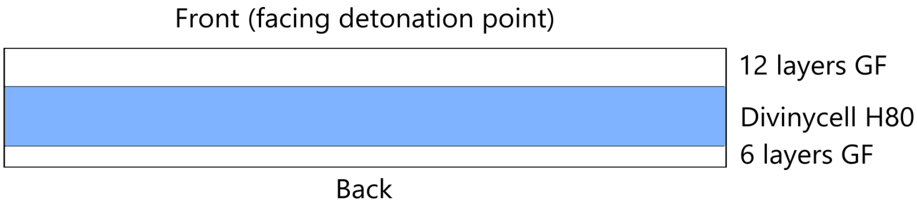

Figure 1: Schematic showing asymmetric sandwich panel cross-section

Blast testing. The 300 mm x 300 mm panels were fully clamped, leaving a square exposed area of 200 mm x 200 mm. The front clamp frame was integral with a square section 200 mm long blast tube to enable spatially uniform blast loading across the exposed area. Blast loading was generated by detonating disk-shaped PE4 explosive charges (with a constant diameter of 40 mm but varying charge heights) at the open end of the tube. Six tests were performed on the laminates and six on the sandwich panels. For selected tests, high-speed stereo-imaging equipment was used to film the panel response, following ref [5]. The back panel surface was speckled to enable transient displacements to be extracted from the footage using digital image correlation. The transient panel response was filmed at 30 kfps with a 31 µs exposure time.

Blast test results. Both panel types exhibited large transient displacements dominated by elastic effects, shown in Fig. 2. The sandwich panels showed greater rebound displacements than the laminates. During the initial rise, compression loading of the core suppressed crack formation. The rebound phase may induce tension in the core, allowing it to recover. The minor post-test core damage suggested that this rebound tensile stress did not exceed its tensile strength. The post-peak oscillation response of the sandwich was more complex than the viscously damped elastic vibration in the laminates. The intensity of the load transmitted to the rear face sheet depended on the front face sheet and core compressive properties.

The sandwich response can be described by three phases of motion, following ref [6-7]. During phase I, a compressive stress wave propagated from the incident face sheet, through the core, to the rear face sheet (see Fig. 3). Core crushing occurred while the face sheets were considered stiff and likely to remain elastic. Due to the boundary restraint, impulsive transverse shear reaction forces were induced. At the end of phase I, the momentum and kinetic energy were transferred to the panel globally and the impulsive shear reaction forces began to propagate towards the centre of the panel. 5. During phase II, bending and shear loads developed behind the transverse stress wave front as the panel deformed, causing damage in the different parts of the sandwich panel. Once the stress wave had reached the centre, the panel reached its peak displacement. At the end of phase II, the plate started to rebound, leading to flexural oscillations in phase III. Further boundary damage, bolt-hole cracking and core thickness recovery may occur in phase III.

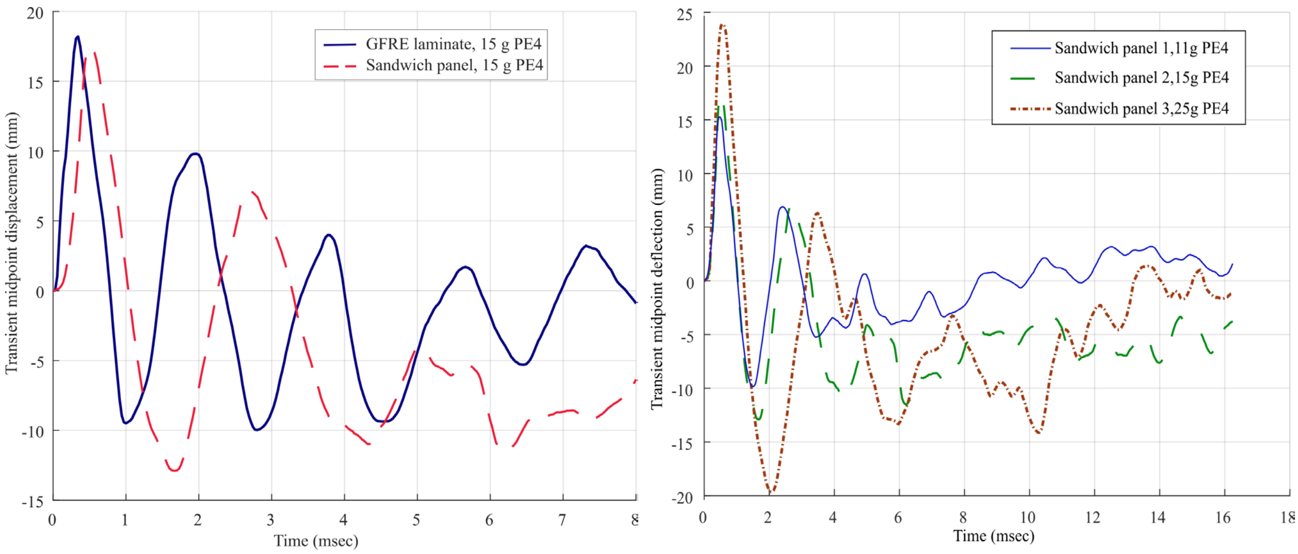

Figure 2: Transient midpoint displacement-time histories for the back surfaces of blast-tested panels (a) GFRE laminate and sandwich panels tested at 15g (b) Sandwich panels at varying charge masses

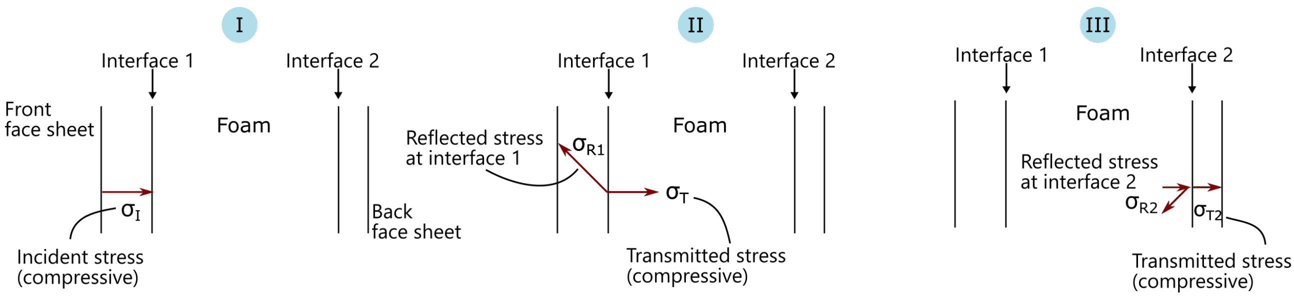

Figure 3: Schematic showing stress wave propagation through the sandwich panel during phase I

Conclusion

The blast tests on sandwich and laminate panels revealed significant differences in their transient behaviour. The laminates behaved as viscously damped elastic vibrations, while the sandwich post-peak response was more complex. The combined effect of the differences in stiffness and speed at which the stress wave travels between the three parts of the sandwich changed the deformation and damage sequence observed.

References

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