# Transient response and failure of composites containing sustainable materials subjected to air blast loading

S. Gabriel[1a], G.S. Langdon[1,2], C.J. von Klemperer[3] and S. Chung Kim Yuen[1]

[1]Blast and Impact Survivability Research Unit (BISRU), Department of Mechanical Engineering, University of Cape Town, Rondebosch, 7700, South Africa

[2]Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK

[3]Department of Mechanical Engineering, University of Cape Town, Rondebosch, 7700, South Africa.
[a]GBRSHE003@myuct.ac.za

**Abstract.** The blast response of various composites was investigated and compared to a baseline synthetic composite, namely glass fibre reinforced Prime 20 panels, to determine the comparable strength and failure characteristics. The transient response of these composites was also examined. Using natural fibres had significant effect on the failure observed. Substituting an epoxy resin for a more sustainable option had little influence on the blast performance of the composite.

**Introduction** To further sustainable developments of products, natural fibres and bio-based resins have been considered due to their environmentally friendly attributes, low disposal energy requirements and low fossil fuel dependence [1]–[3]. As the use of these materials in different applications (in automotive, architecture and mass-transportation industries) increases, there lies a constant possibility of explosive threats, yet little is known about the blast response of such materials. In this study, the blast response of various composites with sustainable constitute materials was investigated under a uniform blast load.

**Materials and Manufacturing** Composites were manufactured using fibre reinforcements and polymer resins, using VARTM as a manufacturing method. Large flat panels were manufactured in a single shot process, and quasi-static testing and blast testing specimens were prepared. Plain weave 400 g/m$^2$ E-glass fabric was chosen as a suitable control reinforcement as the material has been used in blast-related studies reported on in reference [4]. Natural fibre reinforcements used included a twill weave 550 g/m$^2$ flax fibre fabric and a twill weave 400 g/m$^2$ jute fibre fabric. A Gurit epoxy resin (Prime 20 LV) and Super Sap CLR bio-based epoxy resin from Entropy resins were utilised.
The details for specimens used for blast testing are listed in Table 1.

| Reinforcement material | Epoxy resin system | Number of plies | Average thickness [mm]/ Average specimen mass [kg] | Blast testing details |
|---|---|---|---|---|
| Glass fibre(control) | Prime 20 LV | 19 | 6.20 / 1.00 | 5 tests, 5 – 25 g PE4 |
| Flax fabric | Prime 20 LV | 9 | 9.81 / 1.09 | 5 tests, 5 – 11 g PE4 |
| Flax fabric | Super Sap CLR | 9 | 9.93 / 1.09 | 5 tests, 5 – 11 g PE4 |
| Jute fabric | Prime 20 LV | 13 | 0.91 / 1.03 | 6 tests, 4 – 11 g PE4 |

Table 1: Details for the blast specimens tested

**Experimental Blast Work**

Blast loading testing was performed on 300 x 300 mm specimens using a horizontal ballistic pendulum with a nominal single degree of freedom. A square blast tube was mounted onto the front of the specimens such that a disc (diameter of 30 mm) of PE4 explosive could be positioned at a standoff distance of 200 mm and the blast load directed on the specimen. The impulse was measured from the initial velocity of the pendulum using a laser displacement sensor. For each material set, two experiments further were conducted using modified pendulum containing high speed imaging equipment shown in Fig 1. Further information of the equipment is detailed by Curry and Langdon [5].

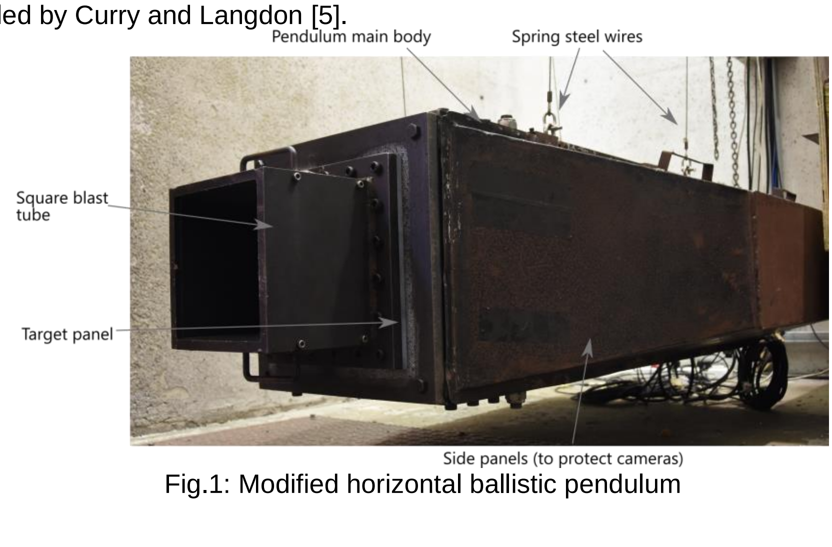


Fig.1: Modified horizontal ballistic pendulum

The transient deformation of the central strip, shown in Fig 2, through the middle of the test plate was recorded using two high speed monochrome IDT NRS4 cameras at 30 kfps. Specimens were speckled and the deformation was computed using Digital Image Correlation (DIC).

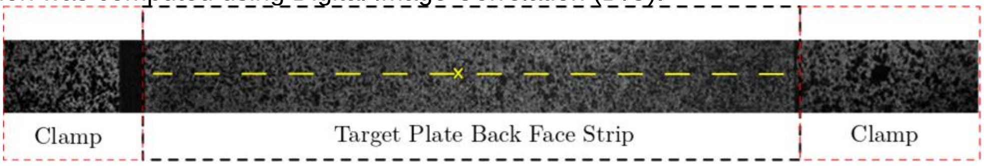


Fig. 2: Example of the speckled central strip captured using high speed cameras

## Results and Discussion

**Transient Response.** The dynamic response of the different composites followed a consistent pattern; panels initially deformed in the direction of the blast wave before deflecting in the opposite direction back towards the detonation position. This was due to the elasticity of the FRP material. Additionally, the peak transient deformation observed was significantly greater than the final deformation of the panel. For most transient displacement profiles, the highest displacement was located near the centre of the panel with the displacement decreasing symmetrically on both sides away from the centre as shown in Fig 3. In general, a global dome shaped profile was observed where little damage was sustained. However, the profile changed from initially dome-shaped to a more cone-shaped profile on the natural fibre composites as cracking occurred and reverted back to the dome-shape for the rebound and later oscillations as shown in Fig 3b.

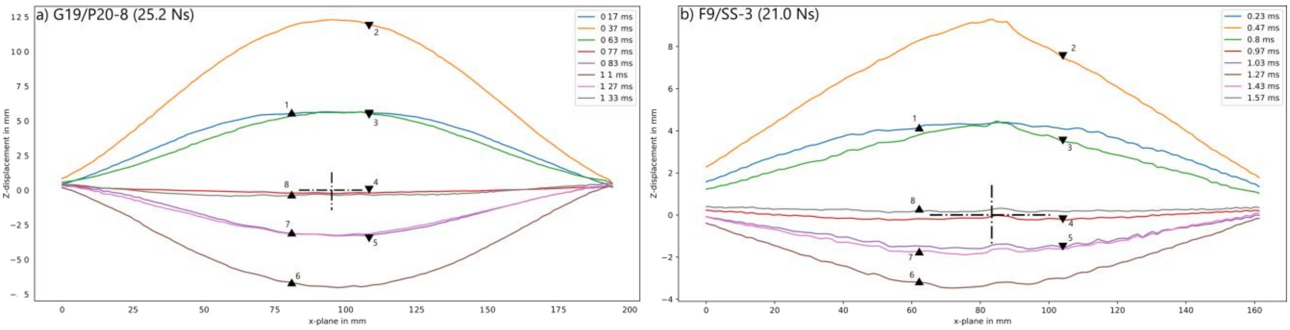


Fig. 3: Deformation profiles of a) (Left hand image) GFRP specimen subjected to 25.2 Ns and b) (Right hand image) flax fibre reinforced Super Sap specimen subjected to 21.0 Ns

**Failure Modes.** The main failure mode observed on the natural fibre composites was cracking with large amounts of inelastic deformation observed. The flax fibre reinforced composites sustained progressive damage (where with there appeared to be a relationship between impulse and cracking), however the jute fibre reinforced composites behaved in a brittle manner. In the flax fibre reinforced composites, the resin had little influence on the damage observed. The glass fibre reinforced composites showed progressive damage n in the form of delamination. The impulse required for complete failure was approximately 40 Ns and 20 Ns for the flax and jute fibre reinforced composites, respectively. In comparison, the glass fibre reinforced composites had not fractured when tested at 55 Ns.

## Conclusion

A range of composites containing materials deemed sustainable was tested under air-blast loading and compared to a baseline GFRP composite. The glass fibre reinforced composite had superior blast protection capabilities to the natural fibre composites. Whereas the jute fibre reinforced composites were the weakest material tested. The transient deformation showed that the panels undergo an oscillated elastic response where cracking influenced the deformation profile observed.

## References

[1] S. V Joshi, L. T. Drzal, A. K. Mohanty, and S. Arora, “Are natural fiber composites environmentally superior to glass fiber reinforced composites?,” *Compos. Part A Appl. Sci. Manuf.*, vol. 35, no. 3, pp. 371–376, Mar. 2004.

[2] S. Thomas and L. . Pothan, “Natural fibre composites - State of the art, new challenges and opportunities,” in *Natural Fibre Reinforced Polymer Composites: From Macro to Nanoscale*, Old City Publishing Inc. & Editions des Archives Comtemporaines Ltd, 2009, pp. 3–6.

[3] J. E. McDevitt and W. J. Grigsby, “Life Cycle Assessment of Bio- and Petro-Chemical Adhesives Used in Fiberboard Production,” *J. Polym. Environ.*, vol. 22, no. 4, pp. 537–544, Jun. 2014.

[4] G. S. Langdon, C. J. von Klemperer, and G. M. Sinclair, “Blast response of sandwich structures: The influence of curvature,” in *Dynamic Deformation, Damage and Fracture in Composite Materials and Structures*, Woodhead Publishing, 2016, pp. 365–389.

[5] R. J. Curry and G. S. Langdon, “Transient response of steel plates subjected to close proximity explosive detonations in air,” *Int. J. Impact Eng.*, vol. 102, pp. 102–116, Apr. 2017.