

Blast resistance of UHMW-PE Panels

R.J. Curry^{1a}, G.S. Langdon¹, Long H. Nguyen², Ali Daliri², Huon Bornstein²

¹ Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK.

² Defence Science and Technology Group, Australia

^a r.curry@sheffield.ac.uk

Abstract. This paper reports results from blast experiments performed on different UHMW-PE panel types. The variable thickness panels were exposed to explosive loadings generated by detonating PE4 explosive discs at low stand-off distance from the exposed surface. The impulse applied, permanent displacement and transient deformation were measured. Some tests employed high-speed video photography; the stereo-images were analysed using digital image correlation to extract transient plate deflections from the rear face of the panels. Scant experimental data is available in the literature about the response of UHMW-PE to blast loads. However, results from numerical models have not been reported, due to the complex nature of their response to localised blast loading. The results from the blast experiments performed are presented herein and compared to a numerical modelling approach based on ballistic response applications.

Introduction

Dyneema is an ultra-high molecular weight polyethylene (UHMW-PE) and offered enormous potential for blast protection due to its high strength-to-weight ratio and excellent energy absorption capabilities. Dyneema is a brand name for a type of UHMWPE that is produced by DSM [1]. UHMW-PE is a highly durable and strong synthetic fibre that is made from long chains of polyethylene molecules. Dyneema is ten times stronger than steel and 50% stronger than aramid fibres [1], making it an ideal material for use in body armour and other protective gear such as panels, bulletproof vests, helmets and curtains.

Various failure modes have been observed in literature [2] including permanent deformation, delamination, in-plane shear, buckling around the boundary, localised melting and matrix damage. Total penetration (rupture) at the highest charge masses was also exhibited at high charge masses under very localised blast loading.

While there is some information in the literature on the ballistic performance of Dyneema panels, there is limited information available about the blast characterisation and numerical modelling of these blast experiments. This paper reports a new series of localised blast experiments and a preliminary numerical simulation approach based on ballistic impact modelling.

Experimental work

Materials. Two material types were tested, HB26 and HB210. The thickness of the panels varied between 10-28mm and were all 400x400 mm square. Dyneema HB210 and HB26 are both a thermoplastic cross-ply laminate containing four pre-consolidated unidirectional plies oriented in a [0/90] fiber configuration with each ply comprised of UHMWPE fibers and a thermoplastic polyurethane (TPU) based matrix.

Method. The panels were clamped in a square metal clamp frame measuring 400x400mm with a square exposed aperture of 300x300 mm. The panels were loaded by detonating 50 mm diameter cylindrical discs of PE4, with charge masses from 10-60 g at a constant stand-off distance of 50 mm. The experiments were carried out in the Digital Image Correlation (DIC) blast pendulum outlined in [3] that utilised stereo high-speed cameras filming at 40 kfps.

Results. Four main deformation modes were observed, as shown in Figure 1: (i) global plastic deformation, (ii) interlaminar shear, (iii) burning/melting and (iv) fibre rupture. The extent of interlaminar shear increased with increasing central deformation. There was also significant elastic snap-through buckling observed at lower charge masses. The transient deformation captured with the DIC indicated significant elastic transient deformation.

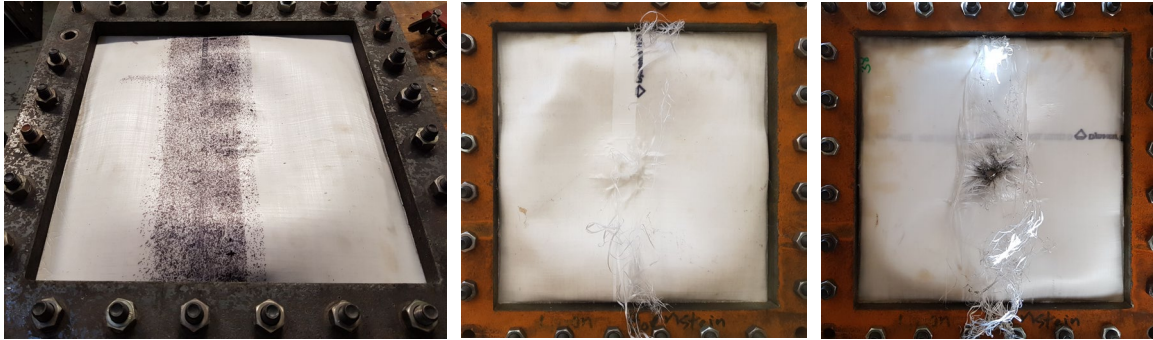


Figure 1: Photographs of blast-tested Dyneema panels showing typical failure modes (a, b, c) the global deformation with some displaying fibre breakage displayed in (b, c) and rupture with burning in (c)

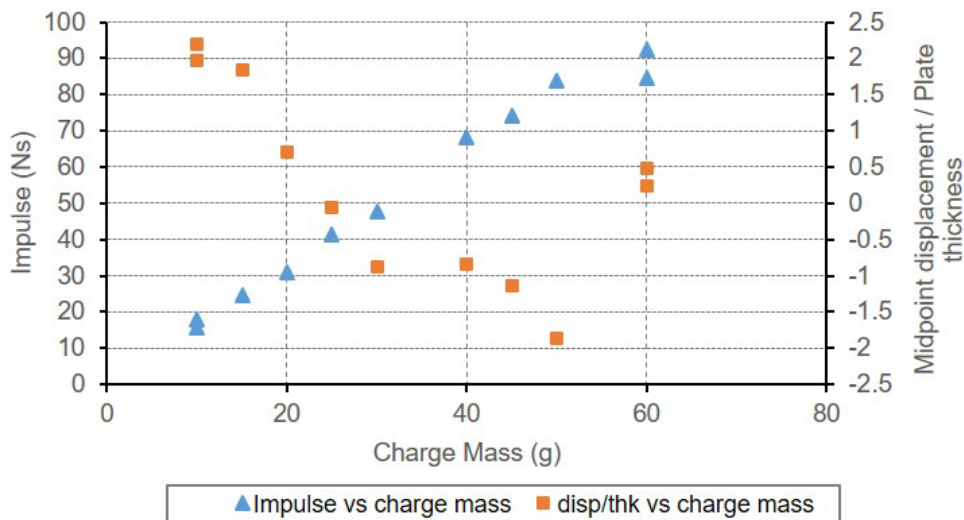


Figure 2: Blast tests results for permanent displacement/thickness ratio and impulse vs. charge mass

FEM description and purpose.

A quarter symmetry Multi Material ALE was set up using LS-Dyna to investigate the response of the blasted panels. The material model developed by Hazzard et al. [4] for ballistic impact was selected for the blast modelling as it included shear failure in the material deformation (MAT162). The PE4 was modelled as a cylinder using an initial volume fraction description, which filled the container with the explosive material. The JWL equations of state, in conjunction with the high explosive burn model, were used to describe the explosive shown in Curry and Langdon [5]. The volume of the explosive cylinder was discretised into elements that fill the air mesh. The coupling between the explosive products and the test plate was modelled using a penalty-based approach. The ALE fluid flow through the boundary was controlled by implementing an ALE essential boundary.

Conclusion

The experiments showed the importance of capturing the transient response, as it included a significant elastic post-peak reverse snap-through buckling mode. The numerical modelling approach shows promise, with initial modelling giving reasonable agreement. The model was only able to reproduce the global and shear failures reliably as it was not calibrated to deal with the fibre breakage and burning and melting.

References

- [1] J.L.J. van Dingenen, Mater Des, Vol. 10 (1989), 101-104.
- [2] A.S. Fallah, K. Micallef, G.S. Langdon, W.C. Lee, P.T. Curtis, L.A. Louca, Int J Impact Engng, Vol. 73 (2014) 91-100.
- [3] R.J. Curry, G.S. Langdon, Int J Impact Engng, Vol.102 (2017) 102-116.
- [4] M.K. Hazzard, R.S. Trask, U. Heisserer, M. Van Der Kamp, S.R. Hallett, Compos A: Appl Sci Manuf, Vol. 115 (2018) 31-45.
- [5] R.J. Curry, G.S. Langdon, Int J Impact Engng, Vol. 151, (2021) 103822.