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Pre-stressed plates as a mechanism to provide additional under belly blast protection

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The use of curved pre-stressed plates is investigated as this provides a possible additional mechanism to resist both initial folding and later structural collapse. Numerical modelling in Autodyn® and empirical calculations based on the Westine model were used to determine starting conditions for the explosive trials. Trials were conducted in which plates were pre-stressed by the imposition of a large bending moment from two parallel sides resulting in a tensile stress on the outer surface facing the blast. Tests were conducted at approximately one third linear scale using target plates of 500mm x 500mm and a charge of between 100g and 250g buried in dried sand was used to load them. Unstressed but curved plates were tested and then compared to similar shaped curved plates with an imposed bending stress equal to the yield stress or ultimate tensile stress of the plate material.

INTRODUCTION

The majority of the world’s deployed mines use blast as their main mode of attack [1]. Whilst fragmentation is an important consideration, the cases in which the charges are housed are rarely designed to provide a fragmentation effect, and much of the threat is from secondary fragmentation from the vehicle itself [2]. As such, throughout the development of mine-resistant vehicles, most effort has been focused on reducing the effect of the blast impulse, used in conjunction with armour in order to mitigate the less deadly fragmentation hazard.

Currently, the most effective and widespread armour for under-vehicle blast seems to be the V-shaped hull and its derivatives such as the double V-shaped hull [3]. The armour plating used in the hull protects from fragmentation, whilst the V-shape in which it is configured, allows the blast to be deflected out to the side of the vehicle [4]. It is important to note that, given the energy released in an IED blast, V-shaped hulls are designed to deflect blast and absorb as little of the impulse as possible. Furthermore, the angle of the armour created by the V-shape generates a sloped armour effect, increasing the linear distance through the armour plating.

There is some evidence that alternative geometries might be useful and a number of studies have investigated the blast response of curved metallic [5] and composite panels [6]. Other hull, geometries may have applications and although not used in vehicle hulls the effect of curvature on blast response has been studied. In the present work, the use of a curved and pre-stressed plate is investigated.

The concept behind this is that a pre-stress in the direction opposing the applied blast load will increase the work required to deform the plate and therefore resist deformation to a greater degree than a similarly shaped but unstressed plate [7, 8]. In the current work a series of blast tests are described which seek to investigate the effect of pre-stress on curved plates subjected to loading from a buried charge. The development work on the test conditions and test rig is described together with some initial results.

TEST METHOD

Tests were carried out using 3mm mild steel plates measuring 500mm x 500mm. A combination of flat plates, pre-curved plates and plates curved to induce pre-stress were tested. The surface stress level was calculated for different bend radii and compared to the material's strength. For a 3mm mild steel plate of length 500mm a surface stress of 224MPa equal to 90% of the yield stress is induced at a bend radius of 1400mm. Further bending to a radius of 415mm produces a surface stress of 760MPa, equal to 90% of the ultimate tensile strength (UTS) of the material used. Tests were conducted on plates at these two pre-stress levels by holding them at these bend radii during the blast loading. For comparison further identical plates were pre-formed to these radii and then annealed in order to remove any stress. The Westine model [9] and numerical analysis using Autodyn® were used to estimate the final deflection and appropriate charge size.

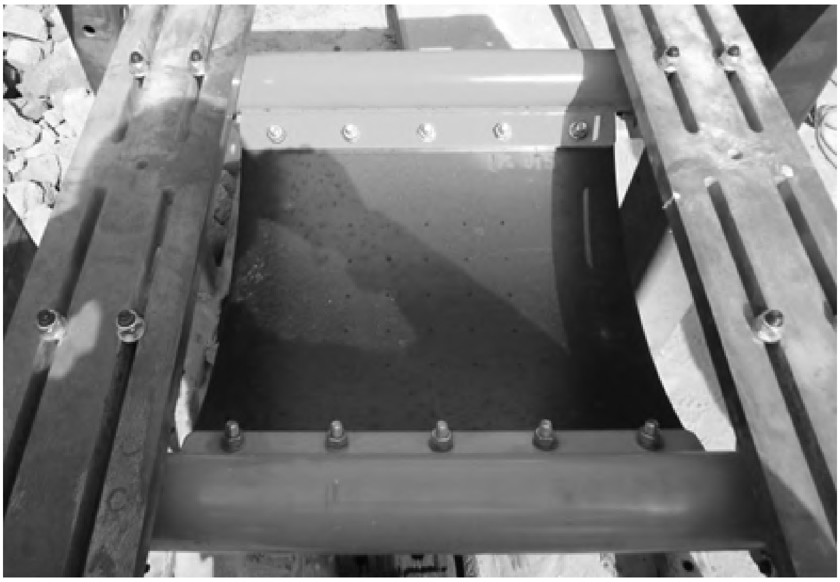

Figure 1 Top view of a target panel prior to test showing the mounting tubes which were rotated to induce the required pre-stress.

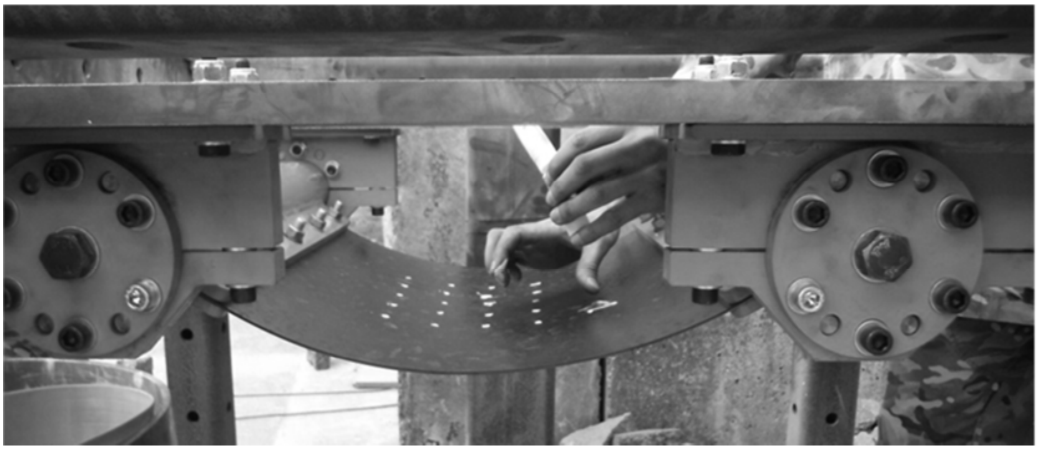

Figure 2. Side view of a target prior to testing, markings on the target were used in conjunction with an oblique high speed video recording to assess the plate deformation during the blast loading.

Some initial tests were conducted on a instrumented drop tower using a 50kg mass at 10m/s to provide a realistic loading and to the pre-stress rig. The final rig design is shown in figures 1 and 2 in which it can be seen the test panel is bolted between two tubular mounts which is then rotated and locked. This allows the pre-stress to be adjusted within wide limits by rotating and then locking the tubes within the end fixtures. The end fixtures are free to move laterally during the pre-stressing process but are locked prior to blast loading.

A grid pattern was applied to the upper surface of the target plates and was then used in conjunction with an oblique high speed video camera to map the target deflection during blast loading. A laser displacement gauge (Keyence LK-G507) was used to measure displacement at the centre of the target plate and an aluminium foil crush tube was also used as a backup measure of dynamic displacement. Explosive products and sand tended to block the video and laser gauge late in the test and the crush tube was used to check that no further deflection occurred after this point.

Blast test were performed using a spherical PE7 charge (88% RDX, polymeric binder) with a detonator oriented vertically from underneath. The charge was buried in dry sand in a 50 litre frangible container below the test rig. The depth of burial was 100mm and the standoff from the sand surface to the bottom of the test plate was 250mm. Initial tests used 250g of PE7 but this was found to be too severe and so the charge was reduced to 100g for later tests.

RESULTS

Initial trials used a 250g PE7 charge and although useful data was gathered on the rig performance it was found that the curved plates were completely inverted and only finally arrested by collision with the support rig structure. The final deflection was controlled by the clearance with the test rig and the initial deformation behaviour up until collision was similar. These tests also showed that for the configuration tested, a flat plate provided the lowest final deflection as the bolted retention allowed the plate to act as a membrane. This both slowed initial deflection and reduced the maximum displacement of the target centre when compared to a curved plate which could buckle and invert. As this membrane mode was not the purpose of this investigation no further tests were conducted on flat plates. Subsequent comparisons were conducted only between targets of similar geometry with only the level of pre-stress being varied.

A second series of trials used a reduced charge size (100g PE7), but retained the same burial depth (100mm) and standoff (250mm). Target plates were pre-stressed to 90% of the yield stress and 90% of ultimate tensile stress and both were compared to annealed plates of the same geometry. The results are summarised in table 1, and the deflection as a function of time for the targets pre-stressed to 90% of UTS and corresponding annealed plate are shown in figure 3

TABLE 1. PEAK DEFLECTION MEASURED FROM HIGH SPEED VIDEO

Target type	Bend radius (mm)	Stress (MPa)	Final deflection (mm)
Annealed	1400	0	92
90% YS	1400	224	88
Annealed	415	0	29
90% UTS	415	760	22

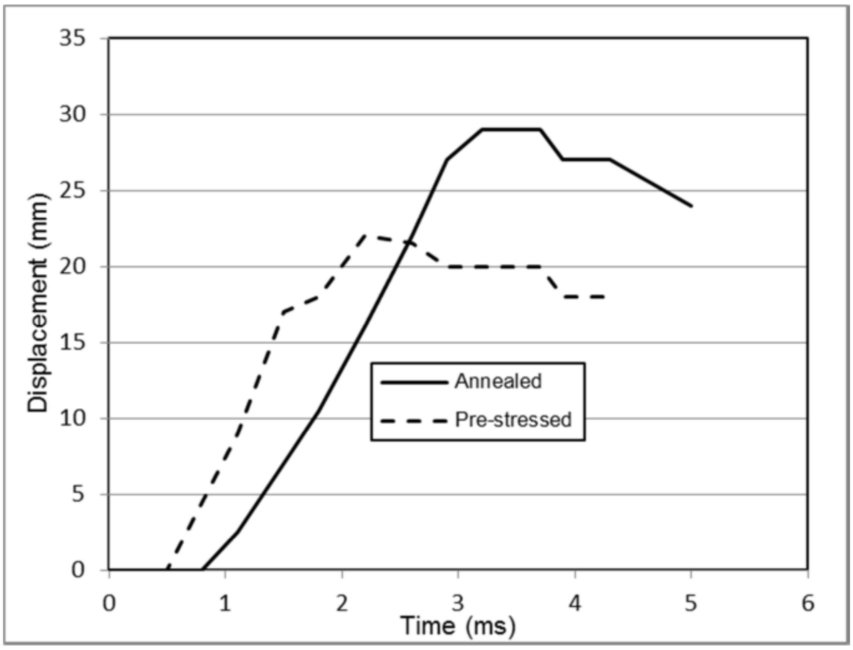

Figure 3. Displacement vs time response assessed from high speed video data for an unstressed and 90% UTS pre-stressed panel of 415mm radius curvature

DISCUSSION

Previous studies have shown that curvature can be used to increase the resistance of panels to blast loading and that resistance may increase with the degree of curvature [5]. A flat panel would be expected to have less resistance to bending than a curved panel, but for the edge constraint used in the present study the flat panel was able to form a membrane which caused additional resistance under large deformations. In vehicle hull applications these membrane effects would be limited by the hull strength and flat panels are also subject to the most severe impulsive loading from a face on blast. Curved panels provide the possibility of deflection of the blast loading due to the angle of incidence from a blast and this is further enhanced by the additional standoff further from the centreline.

The present work shows that a further increase in bending or deformation resistance is added by the use of pre-stress in the panels. This effect is necessarily limited in the relatively thin steel plates used here but might be expected to be more significant for thicker panels.

CONCLUSIONS

A method has been developed to introduce pre-stress into metallic panels in order to assess its effect on deflection during blast loading. Initial tests with mild steel panels show some promise with the conclusion that introducing higher pre-stress level does appear to be able reduce the deflection experienced during blast loading.

The order of magnitude of the increased deformation resistance induced by the pre-stress was as much as 25%, which showed that whilst these tests were limited in scope, the technology can considerably improve the performance of blast resistant passive armours, and would outperform similar blast resistant technologies.

Further research has been conducted with The Welding Institute (TWI), University College London (UCL) and University of Greenwich, which support, and extend beyond the concluding findings. Further information is available upon request to the technology owners.

REFERENCES

1. Showichen, A. 2008. Numerical Analysis of Vehicle Bottom Structures Subjected to Anti-tank Mine Explosions, PhD thesis, Cranfield University.
2. Lester, C. 1997. “Protection of Light Skinned Vehicles Against Landmines - A Review”, Weapons Systems Division Aeronautical and Maritime Research Laboratory, Melbourne, Australia.
3. Farhadi, K. Paykani, A. 2013. Numerical Simulation and Optimization of an Off-Road Vehicle Floorboard for Mine Blast Damage Reduction, *International Research Journal of Applied and Basic Sciences*, Vol 4 (3):531-536
4. Chung Kim Yuen, S. Langdon G. Nurick, G. Pickering, E. 2010. Response of V-shape Plates to Localised Blast Load, *Proceedings of the IMPLAST 2010 Conference, Providence*, Rhode Island USA.

5. Kumar, P. LeBlanc, J. Stargel, D.S., Shukla, A. 2012. Effect of Plate Curvature on Blast Response of Aluminum Panels. Int. J. Impact Engng. 46:74-85
6. Shen. J, Lu, G. Wang, Z. Zhao, L. 2010. Experiments on Curved Sandwich Panels Under Blast Loading. Int. J. Impact Engng. 37:960-970
7. De-Gale, S. Shelley, T.R. 2010. Reinforcing System and Method, European Patent EP2480845 A1.
8. Shelley, T.R. 2012. Is the V-shaped Hull History? Defence IQ http://www.defenceiq.com/armoured-vehicles/articles/a-new-approach-to-armour-is-the-v-shaped-hull-hist/ (accessed 22nd February 2016).
9. Tremblay J. 1998. “Impulse on Blast Deflectors from a Landmine Explosion”. Valcartier, Quebec. Defence Research Establishment. Report No: DREV-TM-9814.