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PERFORATION OF SPACED GLASS SYSTEMS BY THE 7.62 mm NATO BALL ROUND

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An experimental and numerical programme was conducted to investigate the mechanics of perforation of the 7.62 mm NATO Ball round through multiple glass systems. Each system consisted of four float glass plates with either 0.0, 1.5, 2.5 or 5.0 mm spacing between each plate. Moreover, the areal density of each system was varied between 30.4 and 121.4 kg/m^2. Reasonable confidence was achieved in the numerical programme by comparing high-speed digital photographs with numerical results. Unfortunately, the simulations did not predict the full dynamic response of the materials observed by the high-speed camera however they did provide an insight into the damage mechanics of the glass. The numerical simulations showed that varying the spacing in-between each plate resulted in little difference to the residual momentum of the penetrator core.

INTRODUCTION

To date, almost all bullet resistant glass comprises of glass laminates with rubbery interlayers (such as polyurethane or polyvinylbuterate (PvB)) and a polymer as a backing layer, usually polycarbonate. The interlayers provide a flexible separation between the layers of glass and serve to contain the glass array. The backing layer is used to prevent spall at the rear face of the target. Depending on the threat level, different combinations of these layers form an array to prevent perforation by the projectile. Whilst manufacturers will trial different materials, few manufacturers in the world are deviating from this approach. For these types of transparent armour systems, the penetration and subsequent perforation mechanics is fairly well documented.

What is lacking however, is an understanding of the perforation mechanics of spaced glass systems where arrays of glass are constructed with air gaps in-between (such as a common double glazing system). In this paper a comprehensive experimental and numerical programme will be presented that describes the perforation of a 7.62 mm NATO Ball round through a multiple spaced glass system.

EXPERIMENTAL PROGRAMME

In each experiment, four float glass plates (supplied by Pilkington plc) were used, spaced at 0.0, 1.5, 2.5 and 5.0 mm. For each experiment the thickness of the plate remained the same whilst the spacing between the individual plates was varied. The thickness' under investigation were 3, 4, 6, 8 and 12 mm. Each plate had a cross sectional area of 120 × 120 mm square.

For each target configuration a 7.62 mm NATO ball round was fired at the centre of the plates using a standard 7.62 mm proof barrel. The velocity of the round was 809 ±10 m/s. A CORDIN model 220 high speed digital camera was used to record the perforation of the plates.

NUMERICAL PROGRAMME

Numerical simulations were conducted using the non-linear transient dynamic Hydrocode AUTODYN-2D. All simulations were two-dimensional using axial symmetry. All material models were retrieved from the existing AUTODYN database. The mesh description for the bullet and the NATO bullet details are given in Fig. 1 and Table 1 respectively.

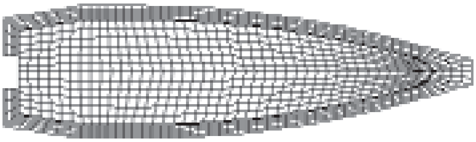

Figure 1: Mesh description of the 7.62 mm NATO Ball round.

Calibre	7.62×51mm NATO
Type	Ball
Core	Lead Antimony
Bullet Diameter	7.82mm
Bullet weight	9.65g
Core weight	7.39g
Muzzle velocity	809±10m/s

Table 1: Bullet details.

The Lead Antinomy core and the Gilding metal models incorporated a Linear equation of state and a Steinberg-Guinan strength model. An instantaneous geometric strain of 300% was chosen for the Erosion model. This model description was chosen, as it has proved effective at modelling the deformation of a 7.62 mm NATO Ball round penetrating a variety of targets [1]. All material parameters were retrieved from the AUTODYN material library [2].

The Float glass was modelled using a Polynomial equation of state and the Johnson-Holmquist failure model [3]. Each glass plate was modelled using square cells of 0.5 mm by 0.5 mm.

Validation of numerical model

Reasonable confidence in the numerical model was attained by comparing the numerical results with high-speed photographs. Correlating the CORDIN digital photographs with the AUTODYN slides revealed a reasonable prediction of damage within the glass and projectile deceleration.

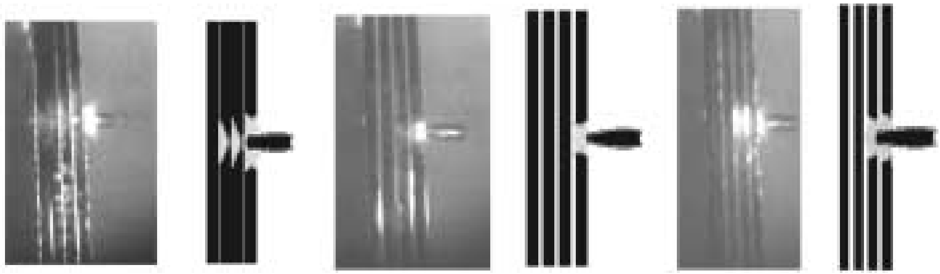

Figure 2: Comparison of experimental and numerical results for 6 mm glass plates separated by (a) 0.0 mm (b) 1.5 mm and (c) 2.5 mm.

A comparison of experimental and numerical results is shown above for a variety of target spacing and time resolution (Fig. 2). The light areas in the high speed photographs indicate comminuted glass.

OBSERVATIONS

Experimental

On impact, the glass material in contact with the projectile fails due to shear induced microcracking. Due to the relatively low fracture toughness of floatglass, only a small proportion of the kinetic energy of the projectile is transferred to the glass for the generation of new fracture surfaces. Instead, a far greater proportion of the kinetic energy is transferred into kinetic energy of the glass fragments. Therefore during each successive perforation, comminuted glass is accelerated from rest toward the next plate until finally a plume of glass exits the array as the final target is perforated. A measure of the amount of momentum given to the glass plume was recorded by a calibrated Ballistic Pendulum. For 12 mm thick glass targets with inter-plate spacing of 0.0, 1.5, 2.5 mm and 5 mm the projectile did not perforate the final glass plate, instead a scab of fragmented glass was accelerated toward the pendulum. Initial measurements of the momentum along the axis of penetration of this material revealed values of around 50% of the initial projectile momentum. Furthermore it was observed that the nature of the material ejected in the opposite direction to projectile motion changed as the spacing was varied.

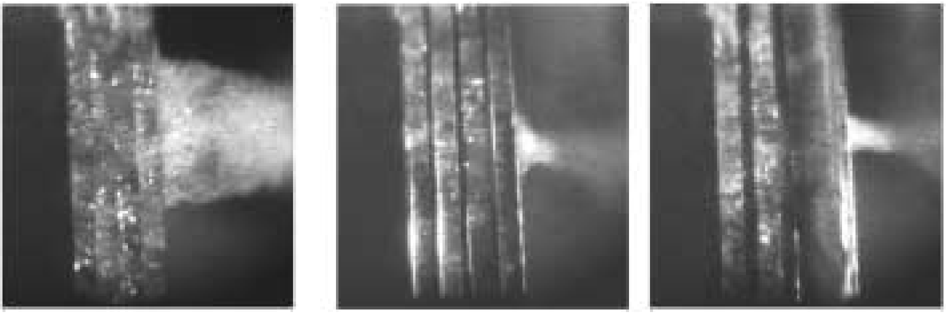

Figure 3: Change of front-plate ejecta with 8 mm plate inter-spacing of (a) 0.0 mm, (b) 2.5 mm and (c) 5.0 mm.

Fig. 3 above shows how the nature of the ejected material during perforation of each target array changes as the spacing in-between the target plates are varied from 0.0, 2.5 and 5.0 mm. With a 0.0 mm inter-plate spacing, a large inverse cone of glass ejecta propagates outward. Increasing the spacing between each glass plate results in a change in the morphology of the ejecta.

It is hypothesised that the reason for this inverse conoid shape is because the penetrator causes a larger diameter of damage (measured from the axis of penetration) as it passes through each successive plate (see Fig. 4). As each successive plate is penetrated, the projectile is blunted. Moreover, the comminuted glass is compressed into the front of the projectile forming a relatively large contact area with the unbroken glass plates. This increase in the contact area results in a larger distribution of contact pressure (according to Hertzian theory [4]) resulting in a larger degree of damage to subsequent plates. This phenomenon was observed in the numerical simulations (see Fig. 4). Due to the confinement offered by subsequent plates, the comminuted material that is formed is then forced to flow in the opposite direction to the projectile due to confinement.

Increasing the spacing in-between each plate results in a reduction in the amount of glass that is ejected via the front plate. This is a result of the reduction of confinement. Instead this material is free to flow into the gaps in-between each plate.

As the projectile perforates each successive plate very little damage can be observed via high-speed photography as the glass is comminuted and therefore its refractive index is changed [5].

The glass arrays were unconfined and therefore extensive fragmentation prevented any meaningful post perforation data being acquired.

In the experiments, the 7.62 mm NATO Ball round was stopped by 4×12 mm glass plates (all spacings). This corresponds to an areal density of 121.4 kg/m^2.

Numerical

The numerical simulations provided some useful insight into the perforation mechanics of the 7.62 mm round through spaced glass targets. However, the results and their interpretation are limited because of the Lagrangian approach used in this programme.

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A comprehensive study of the perforation of the 7.62 mm NATO Ball round through four plates of float glass with thicknesses of 3, 4, 6, 8 and 12 mm was conducted. For each thickness of glass the inter-spacing between each plate was varied: 0.0, 1.5, 2.5 and 5.0 mm. For each simulation, the erosion of the Lagrangian cells was monitored to ensure that no misleading results were produced.

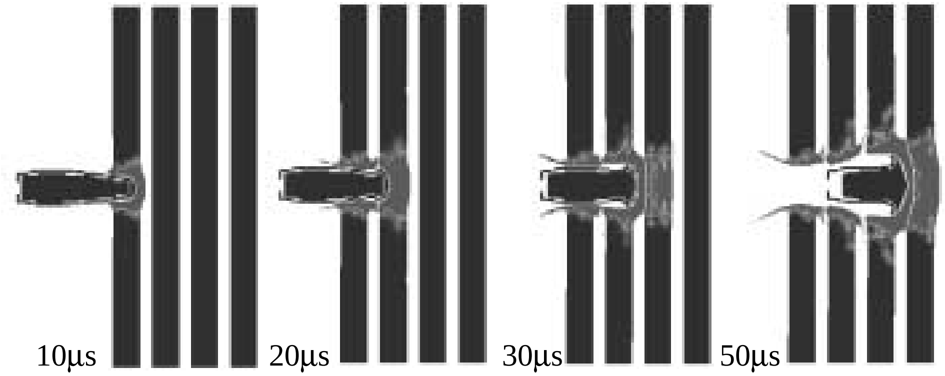

Figure 4: Perforation of 6 mm thick glass plates separated by 2.5 mm.

For each target system, a solid glass block consistently reduced the momentum of the bullet better than a target system using spaced glass. At higher areal densities, the effect of spacing on the bullet's residual momentum was negligible. The effect was more pronounced with glass arrays with lower areal densities (see Fig. 5). Increasing the spacing between each glass plate generally reduced the array's protective capability by a small amount.

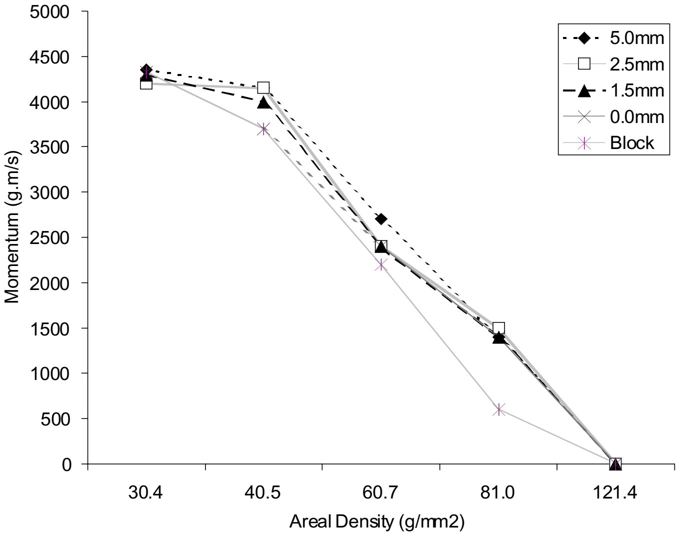

Figure 5: Variation of the simulated residual momentum of the lead core with areal density of the target array.

Fig. 4 shows the simulated progression of the bullet through a glass target array of 4×6 mm plates each separated by 2.5 mm. Initially the projectile penetrates the first plate causing extensive damage to the localised area around the axis of penetration. This comminuted material is accelerated forward to the second glass plate. As the projectile passes through each successive plate, it is blunted thereby suffering a reduction in kinetic energy density. Moreover, a relatively wide hemisphere of comminuted glass is pushed ahead of the penetrator causing damage to the next plate. As the fully comminuted material posseses no shear strength, it readily flows into the gap in-between the plates. If the comminuted material is confined and unable to move into the gap in-between the plates, the projectile is subjected to a small amount of erosion. As each successive plate is perforated the diameter of damage in that plate extends further than that experienced by the previous plate.

The numerical model did not replicate successfully the inverse conical debris cloud ejected from the front plate of the 12 mm plate array (see Fig. 3a). However, some correlation was observed between the numerical and the experimental results for the arrays consisting of thinner plates. Due to the limitations of the meshed Lagrangian approach used in this numerical programme (namely erosion and material tracking), it is intended to explore this phenomenon further using gridless methods.

The numerical simulations correctly predicted that the bullet would be stopped by 4×12 mm floatglass plates (any spacings).

CONCLUDING REMARKS

An experimental and numerical programme has been conducted to evaluate how a 7.62 mm NATO ball round perforates a spaced glass system. In this instance the numerical programme provided an insight into the failure mechanisms associated with spaced glass perforation. However, it did not exactly replicate the experimentally observed phenomena.

The mechanics of perforation is affected by the degree of spacing between each successive plate. The main influence on the projectile is the formation and dissipation of the comminuted glass. Where spacing exists, the comminuted material is able to flow in-between the glass plate resulting in a clearer path for the projectile. However, the protective capability of the array was only reduced by a relatively small amount. Consistently the solid float glass block provided the best protection.

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