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A COMPARISON OF THE BEHIND ARMOUR BLUNT TRAUMA EFFECTS BETWEEN CERAMIC FACED AND SOFT BODY ARMOURS CAUSED BY BALLISTIC IMPACT

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1. Introduction

Recently published research has characterised the behind armour blunt trauma (BABT) effects associated with high velocity ballistic impact on textile-based armour faced with a ceramic plate. Subsequently dynamic displacements, accelerations and pressures have been characterised both in Gelatine experiments [1], [2], [3], [4] and animal experiments [5], [6] and used to provide test methodologies.

High velocity armour consists of a ceramic plate usually backed with a composite panel, which is worn over the conventional textile body armour. The purpose of the plate is to disrupt and spread the energy of the high velocity projectile such that the resulting displacement can be accommodated and partially absorbed by the textile armour. On its own, the textile armour is only capable of preventing penetration by low kinetic energy density projectiles such as fragments, which are of a similar magnitude to hand gun bullets.

For police officers, civilian security personnel and for the military, in operations other than war, there is a need to protect against low-velocity handgun bullets such as 9mm and 0.375 Magnum; these being the rounds typically used in ballistic test standards. As the purpose of the ceramic plate is to reduce the energy density of a high-velocity projectile to that which can be arrested by a soft armour; it follows that there may be a relationship between the impact of a low-velocity projectile on soft armour and a high velocity projectile on a ceramic faced soft armour.

The purpose of this work was to gather data on the back-face deformation behaviour of soft body armour and compare it to that of hard armour by determining whether there was a correlation between previous ceramic plate data and soft armour tests, and also to determine whether back-face pressure data could be used to rank other simulant materials.

2. Experimental methods

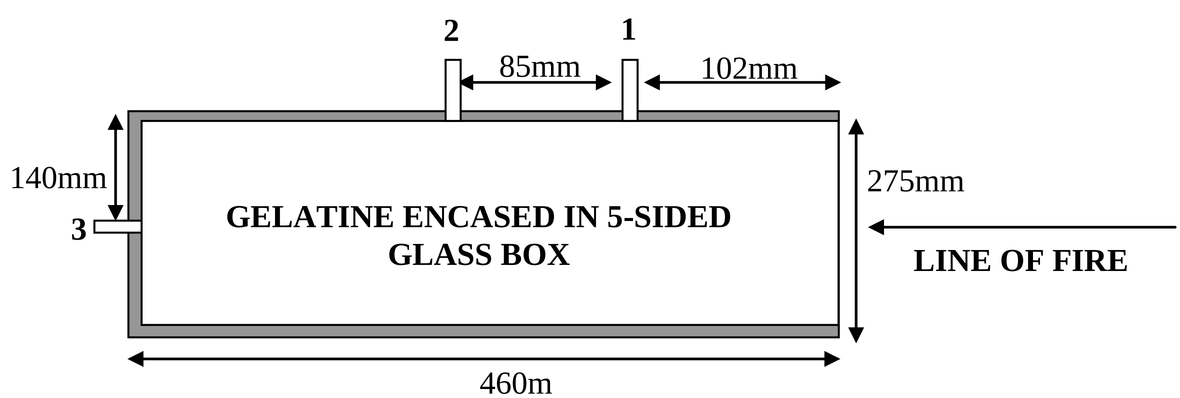
The ammunition used in the ballistic tests were 9 x 19mm Dynamit Nobel DM11A1B2, 0.357'' Magnum Norma soft-point flat nose 19107, and 7.62 x 51mm Royal Ordnance L2A2 ball full metal jacket. Test panels of 20 layers of Kevlar 49 enclosed in a nylon covering were used for all 9mm and 0.357 Magnum tests. The PSDB Standard HG1/A ballistic test method [7] was used to gather back-face deformation data using Roma Plastilina No 1 as a backing material. 9mm and 0.357 Magnum rounds were fired at the armour, and the back-face deformation measurements were recorded.

Plastilina does not reproduce any important characteristics of the human anatomy or response to ballistic impact and is used in ballistic test as an indicating medium to provide a permanent record of back-face deformation. Gelatine is accepted as an approximation of the acoustic and some mechanical properties of soft tissue. In addition to this its low elastic nature and transparency allows for direct imaging and measurement of back-face deformation and stress wave effects.

Tests were carried out using a block of 15% concentration photographic Gelatine, encased in a glass box with one open end. 9mm, 0.357 Magnum and 7.62 rounds were fired at the armour, which was placed on the open end of the glass box. A different armour construction was used for the 7.62 round. This consisted of an alumina plate of 9mm thickness backed with Kevlar composite with a nylon back and front cover. The ceramic insert was secured to 20 layers of Kevlar 49 test panels as described previously.

Three piezoelectric pressure transducers were placed in the Gelatine to record pressure through the Gelatine block (see Figure1). The transducers were connected to two different Nicolet digital storage oscilloscopes operating at sampling rates of 1 microsecond per point and 0.1 microsecond per point respectively. The ballistic event was recorded using a high-speed video camera, specifically a Kodak Ektapro Motion Analyser Model 4540. This enabled subsequent measurements of the back-face deformation in Gelatine to be made using Image Pro+ image analysis software.

The three pressure transducers were inserted into machined holes in the glass box, two on the top of the block and one on the back face. The transducers were positioned along a straight line running parallel to the centre line of the block, coincident with the line of fire.



Key:
1: 14 bar range piezoelectric pressure transducer (Kistler Type 211B4)
2: 7 bar range piezoelectric pressure transducer (Kistler Type 211B5)
3: 50 bar range piezoelectric pressure transducer (Kistler Type 211BE50)

Figure 1 Positioning of pressure transducers in Gelatine block

3. Discussion of Results

3.1 Back-face deformation measurements in Plastilina and Gelatine

For tests using the Plastilina backing the back-face deformation increased approximately linearly with increasing impact energy for each ammunition type. This relationship was not reproduced when comparing between ammunition types. Compared to the 0.357 Magnum, the 9mm rounds demonstrated both higher values of indentation depth and a steeper increase in depth with increasing impact energy (illustrated in Figure 2).

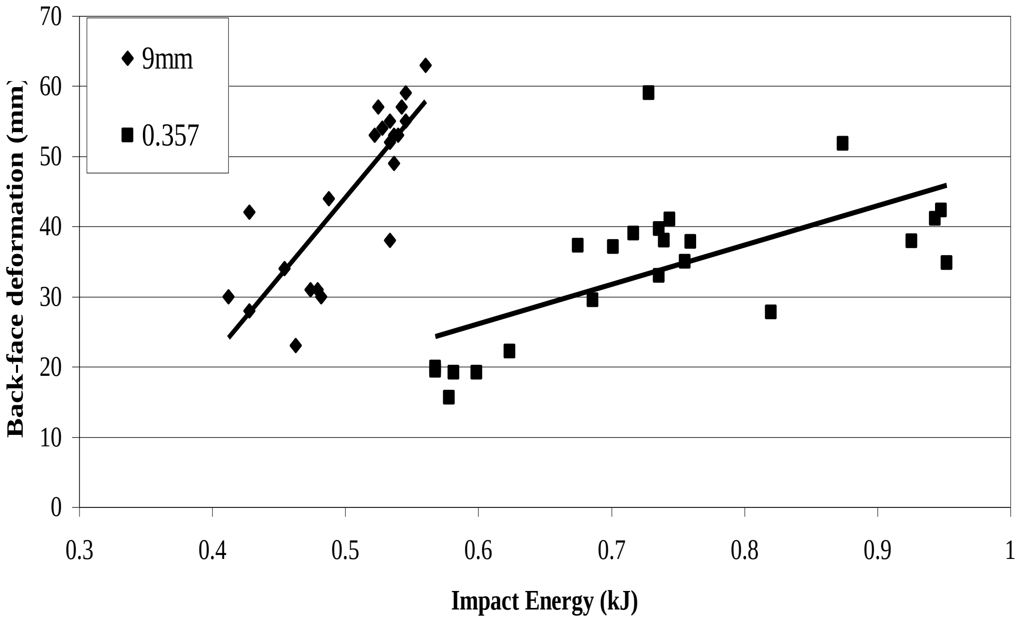


Figure 2 A comparison of the back-face deformation measurements in Plastilina between 9mm and 0.357 Magnum rounds

It was initially expected that the 0.357 Magnum rounds would give rise to greater back-face deformation measurements than the 9mm due to higher impact energies. However, the differences in the construction of the two rounds and consequently the difference in their interactions with the armour, and the rates of deformation of the armour may account for the unexpected results. Upon impact with the armour the 0.357 Magnum round flattens to typically 3 times its initial diameter spreading the energy across a large area, whilst the 9mm deforms less to approximately 1.5 times its initial diameter and as a consequence may penetrate more layers of the Kevlar. This deformation results in a reduction in Kinetic Energy Density (KED) during impact so that in the latter stages the 9mm round has a higher KED than the 0.375 Magnum. At 380 ms^{-1} the 0.357 Magnum round has an initial KED of 11.64 J/mm^2, but on impact this reduces to 1.72 J/mm^2; whilst the 9mm round at 350ms^{-1} has a lower initial KED of 7.8 J/mm^2 and reduces only to 2.85 J/mm^2 after impact.

Figure 3 shows a comparison of back-face deformation in Gelatine and Plastilina produced by the 0.375 Magnum. When body armours are subject to ballistic tests, both the PSDB standards [7] for HG1/A level and the equivalent NIJ standard Level IIa [8] stipulate a maximum back-face deformation of 44mm before an armour system is deemed a ‘fail’. The use of Plastilina as a backing material in PSDB and NIJ Ballistic Tests has been questioned on numerous occasions due to the inability to correlate back-face deformation measurements with possible injury mechanisms

It can be seen from figure 3 that back-face deformation measurements in Gelatine using 0.357 Magnum rounds were almost numerically double that produced in Plastilina, which means that PSDB Standards test conditions would theoretically allow 50mm of deformation into this material and the NIJ would allow almost 70mm.

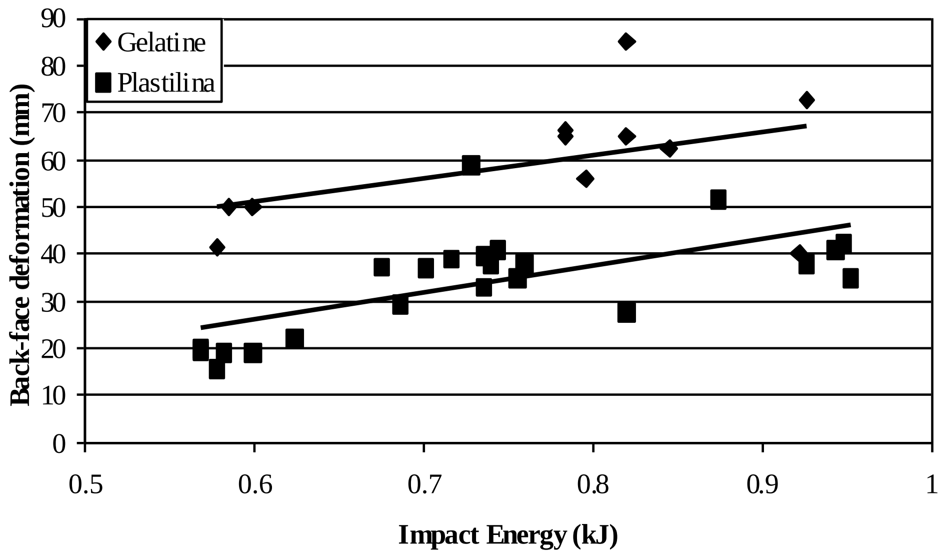


Figure 3 A comparison of the back-face deformation measurements between Gelatine and Plastilina using 0.357 Magnum rounds.

Back-face deformation measurements into Gelatine from 7.62 and 5.56 rounds impacting ceramic- faced armour were compared with the back-face deformation from 0.357 Magnum and 9mm impacting 20 layers of Kevlar 49 (See Figure 4). It was shown that there did not appear to be a correlation between the different rounds of ammunition and their respective back-face deformation measurements. However, it was clearly visible that even at lower impact energies both the 0.357 Magnum and the 9mm rounds caused greater back-face deformation than the higher velocity rounds.

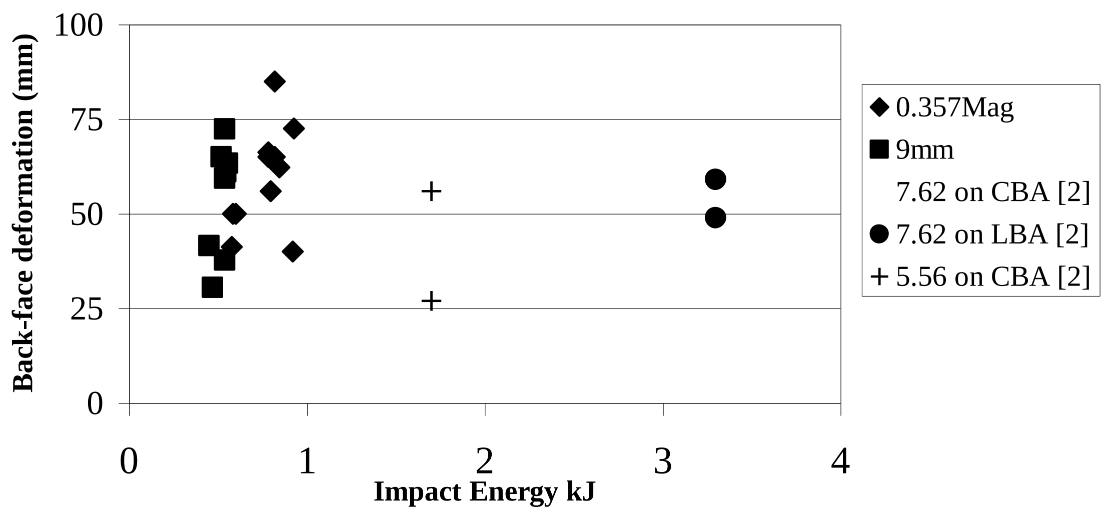


Figure 4 A comparison of the back-face deformation between 0.357 Magnum and 9mm rounds impacting 20 layers of Kevlar 49 and 7.62 and 5.56 rounds impacting ceramic-faced armours

3.2 Pressure readings

For tests against 20 layers of Kevlar 49 on a Gelatine backing the pressure waves measured from 9mm ammunition test showed considerable variation in both general form and magnitude. In some tests pressure waves of up to 8500kPa were recorded (see Figures 5 and 6); pressures that were higher than many recorded in previous experimentation with rigid personal armour systems [2] and considerably higher than those recorded for 9mm ball rounds against 24 layers of Aramid [1]. However pressure outputs of significantly less (up to 2600kPa) were recorded when 0.357 Magnum rounds impacted the Kevlar layers, correlating well with previous experimentation [2].

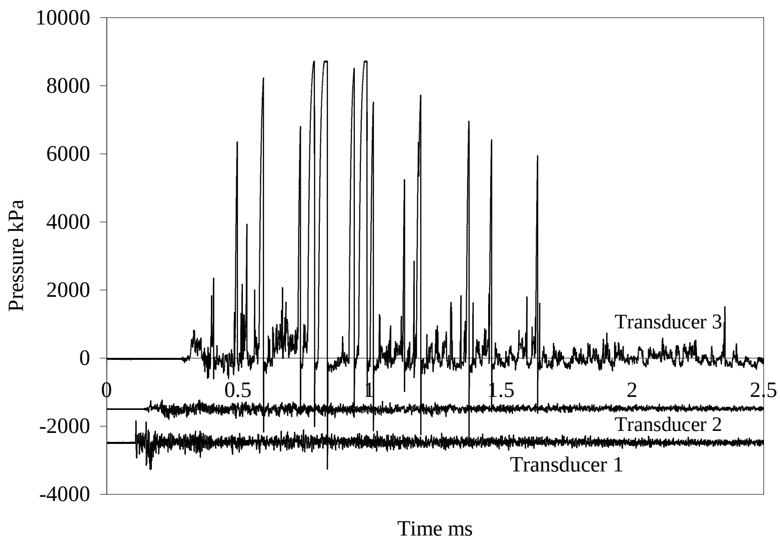


Figure 5 The pressure output generated from a 9mm impact on 20 layers of Kevlar49 on Gelatine backing showing all the full sweep time from the faster data rate oscilloscope. The plots have been displaced vertically for clarity.

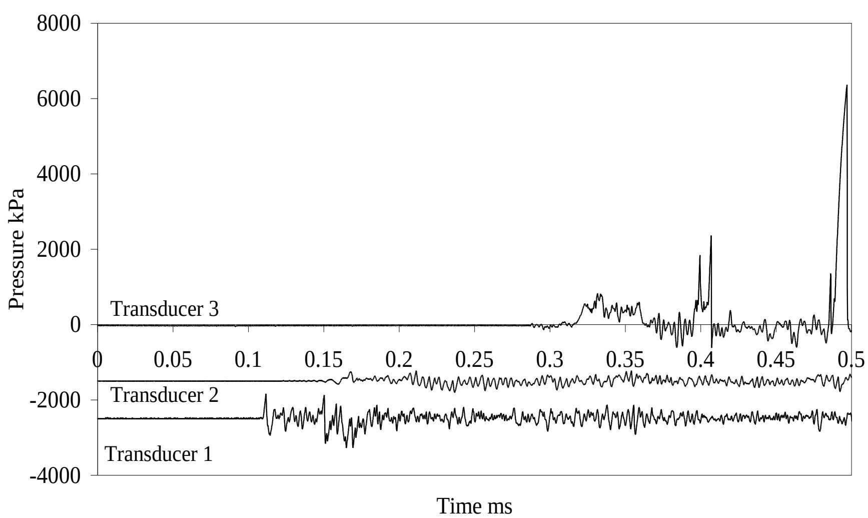


Figure 6 The initial part of the data from Figure 5 showing the staggered pressure wave arrival at each transducer.

Pressure data from the 0.357 Magnum firings into Gelatine was plotted against velocity and a generally rising trend of pressure magnitude with velocity was seen. This information was used to determine if there was a relationship between 0.357 Magnum pressure and velocity data and 7.62 data. It was possible to fit a linear relationship to the 0.357 pressure velocity data and extrapolate this to 7.62 impact velocity. It can be seen from Figure 7 that there is good agreement between this extrapolated 0.357 data and data for 7.62 impact from van Bree [4].

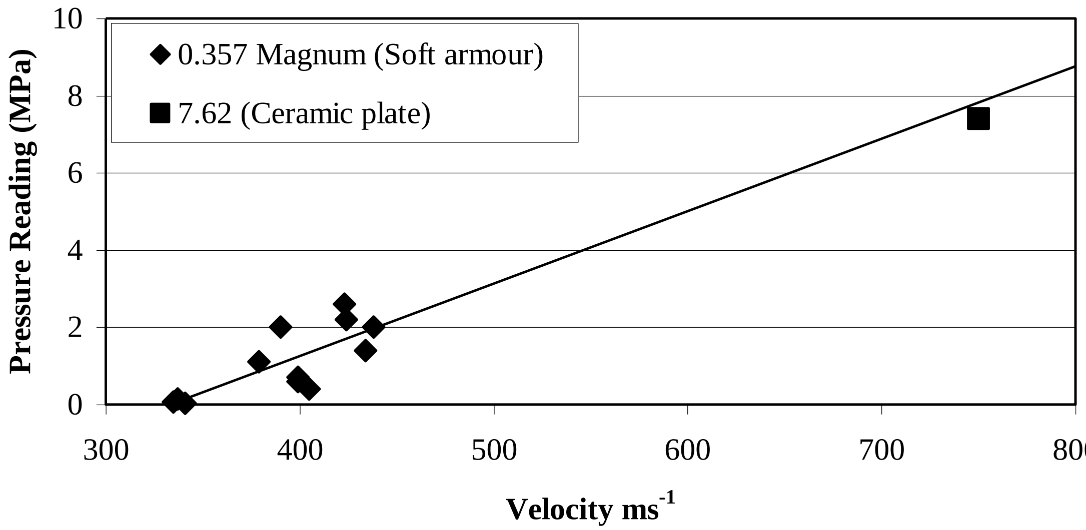


Figure 7 Pressure *vs*. velocity data for 0.357Magnum tests extrapolated for comparison with data by van Bree [4].

The pressure data from all the firings showed variability. The type and the shapes of the curves were variable even when the experimental conditions were constant, and the experimental pressure readings varied from as low as 200kPa to over 8500kPa. It was evident from the high-speed video that there was significant conduction of pressure waves along the exterior of the glass box, which added to the complexity of the waveforms. It was also noted that the transducer at the rear of the glass box measured significantly higher pressures compared to the other two transducers situated on the top of the glass box.

The propagation of high-velocity pressure waves through the Gelatine block was not observed in this work therefore it was impossible to compare timings of waves with data from previous experimentation or in fact to confirm their existence. All the firings at Gelatine were captured by the high speed video and although waves were observed propagating from the back-face of the Gelatine block, their velocities were not in the same order of magnitude as seen in previous experiments [1], [2], [9].

It was initially thought that the velocities of the rounds were too slow to produce pressure waves, or that interfering waves from the glass box and large-scale movement of the Gelatine made interpretation difficult. However, low velocity projectiles impacting Kevlar armour panels have previously demonstrated this pressure wave phenomenon [1], [9], therefore refinement of the experimental technique for future work may be necessary.

4. Conclusions

Behind armour blunt trauma is a phenomenon not solely associated with high-velocity projectiles impacting ceramic-faced armour systems. Significant back-face deformation is produced behind soft body armour when impacted by handgun bullets at relatively low velocities. This occurs when either Plastilina or Gelatine is used as a backing material. The 9mm rounds were especially of concern as the back-face deformation was still significant at low impact energies and increased at a greater rate with increasing impact energy when compared to the 0.357 Magnum round. Despite their lower impact energies the 9mm and 0.357 Magnum rounds fired against the test panels had greater back-face deformation than the 7.62 and 5.56 rounds fired at the ceramic-faced armour.

Currently, back-face pressure data is not a reliable method to compare back-face effects. This work has shown that Plastilina is still an adequate method to obtain information on the back-face behaviour of armour systems. Although it is not a flesh simulant it has been demonstrated the back-face deformation measurements in Plastilina can be correlated with Gelatine to give approximate measurements. However measuring high-speed pressure wave propagation through Gelatine is a method in need of refinement, to enable the correlation of data from previous work and consequently with injury mechanisms.

With the age of new flexible armour systems demanding less layers for comfort, mobility, and heat transfer; consideration must be given to the behind armour blunt trauma effects to the wearer. The back-face deformation itself is significant enough in soft body armour to cause concern and better understanding of its relationship to injury mechanisms is still required.

References

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