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Terminal Ballistics of 7.62mm Armour Piercing Projectiles Against Spaced, Oblique RHA Plates

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Spacing and obliquity, when used together, are known to provide one of the most weight efficient solutions for armor protection. Although this configuration has been widely used over almost 100 years there is little quantitative or design data for such systems. In the present study a series of tests were performed using a steel-cored 7.62mm bullet (DAG 7.62x51) against RHA plates of varying thicknesses, spacing and obliquity of the front plate. This work showed that front plate should be substantially thinner than the rear, a ratio of 0.48:1 gave the best results. The highest mass efficiency (2.00) was for a large spacing (400mm) but this could be reduced to 50mm with only a 17% reduction in ballistic efficiency if a slightly more oblique front plate was used.

INTRODUCTION

The use of spaced armor in military applications has a number of benefits as opposed to the use of single-plate monolithic armor in that the ballistic properties of an incoming projectile are altered to benefit the defending structure. It is crucial to understand the dynamics of spaced armor in order to maximize ballistic protection and to also reduce the total system weight. Spaced armor was used in World War II by German forces that fitted their many of their armored vehicles with external thin plates of auxiliary armor which were mounted using brackets or “skirts” along the sides of the vehicle hulls and atop their turrets [1]. This proved effective by causing bullets to tumble after penetration of the first plate. This would greatly reduce the penetrating power of the bullets by causing the bullets to approach the second plate side-on leading to deformation or disintegration of the round. The diminishing penetrative force associated with the resultant change in ballistic geometry is attributed to the change in Kinetic Energy Density (KED) of the projectile.

A numerical investigation into the ballistic performance of 7.62mm armor piercing rounds for monolithic and multi-layered targets made from 700E steel and 7075-T651 aluminum with varying thicknesses was conducted to model and predict the behavior of the armor plates when exhibited to the penetration process [2].

It was found in this study that the effects of dual-plate systems tend to strip the brass jacket of the round and cause yawing. In some cases, fragmentation was observed in the back face of the target plate. However, the difference in ballistic performance between using 2 layers of armored plate as opposed to a monolithic plate was rather insignificant. This is probably as the study did not set out to increase the gap between the layers but instead have one transitioning immediately to the next.

A study by Velentzas [3], supported that of Flores-Johnson et al.[2] suggesting that when taking two plates "spaced by a distance" and comparing the ballistic performance against a zero obliquity attack with a solid plate of the same total thickness, the protection offered by the single plate is superior to that of the separated plates. This infers that the incoming projectile isn't affected in any way by the first plate. It was said that the key basis for a spaced armor system was so that the first plate (the plate that will receive the incoming projectile) would cause significant degradation of the projectile by inducing either "blunting or breaking" in order for the second plate to be much more efficient in absorbing the kinetic energy of the emerging round.

The effect of obliquity has been investigated [4], and it is shown that the initial effect is to increase the shot line thickness. A secondary effect is to introduce bending loads in the projectile which increase the likelihood of projectile breakup. So, for angles of obliquity up to 45° degrees there is a gradual increase in protection, whilst for higher angle protection there is a steeper increase in protection with angle and perforating projectiles are likely to be broken up.

It should be noted that the increase in shot line thickness introduced by obliquity does not reduce the armor weight. The proportional increase in shot line thickness is the same as the proportional size in the armor plate required to cover a particular presented area so there is no gain in ballistic efficiency.

In a report on the anti-penetration properties of spaced armor, Teng et al. [5], used finite element analysis tools to model the ballistic resistance of spaced armor in which a pair of parallel plates were presented at an oblique angle to the projectile. The findings were supported by the previous reports in that analysis of the penetration performance displayed deterioration of the projectile after penetration of the first layer, thus reducing the kinetic energy before collision with the second layer. A number of useful conclusions came from this work. Firstly, although there was initially an increase in protection as the gap was increased there was a limiting value beyond which the protection increased no further. And secondly that the ratio of rear plate thickness to front plate thickness is probably in excess of 3:1.

Whilst in theory the spacing and obliquity can be increased indefinitely, for real armor systems there are usually constraints of space and overall system size. Internal packaging of systems such as armored fighting vehicles demands near vertical wall sections implying zero obliquity, so a study in which the rear plate is held at zero obliquity would be realistic. To limit the thickness of the armor system it would be useful to know the minimum spacing at which the protection level nears the maximum, and the tradeoff between spacing and obliquity.

The main objective of the experimental phase of work was to investigate the effects of obliquity and spacing of armored plates on 7.62mm AP rounds and to optimize the system to defeat the round and minimize weight of the total system.

TEST METHOD

A 7.62x51mm armor piercing ammunition manufactured by DAG was used in this study. The core is an ogive nosed hardened steel and this is enclosed in a guiding metal jacket. The construction of this projectile is similar to that of the 7.62x51 P80 and US 7.62 x 51 M61 projectiles. The ammunition was fired from a proof housing fitted with a 720mm long barrel and all tests were conducted at a range of 10m from muzzle to target. The impact velocity of the projectile was measured with a pair of sky screens spaced 2m apart and centered 2m from the front plate. Doppler radar was also used as a backup velocity measure.

A pair of target frames were used to mount RHA plates measuring 150 x 200mm. Plates were available in four thicknesses 2.7mm, 3.7mm, 4.6mm and 5.6mm. The rear plate was kept vertical so that it was presented at zero obliquity to the initial shot line. The front plate was then moved to adjust the obliquity relative to the shot line and rear plate and to vary the spacing from the rear plate. A strawboard witness pack was positioned behind the rear plate to capture projectiles that fully perforated the pair of plates.

The method used to assess target performance was to fire a set of rounds against a specific configuration and fine tune its weight (thickness), spacing and obliquity to find the most lightweight and penetration resistant arrangement. For the results section, all the firings will be group together in accordance with their thickness arrangements and measuring obliquity vs spacing. On the front RHA plate, the distance from its rear face to the rear plate's front face was manually measured at a chosen point and marked with a white marker. This allowed the laser designator to align its shot such that the ballistics of the round would be subject to that particular spacing (Figure 1). For firings on the same front-rear plate arrangement, frames were manually adjusted in accordance with the required spacing and the aim point was marked.

Figure 1 Target arrangement showing (from left to right) moveable front plate holder, rear plate holder and strawboard witness pack.

RESULTS

An initial test was conducted to determine the penetration into a pseudo monolithic target. This was achieved by clamping together multiple thinner plates. It was found that 3x5.6mm plates just arrested the projectile. This was achieved with a projectile velocity of $850ms^{-1}$ which was then used for all further tests. The results for spaced and oblique armor were compared to the performance of this 16.8mm pseudo monolithic target. The next series of trials used a pair of 5.6mm plates and varied the spacing and obliquity. With no obliquity the projectile is just stopped at a spacing between the plates of 275mm. Applying an obliquity of just 10 degrees to the front plate is sufficient to prevent perforation at 150mm spacing: the results are shown in figure 2.

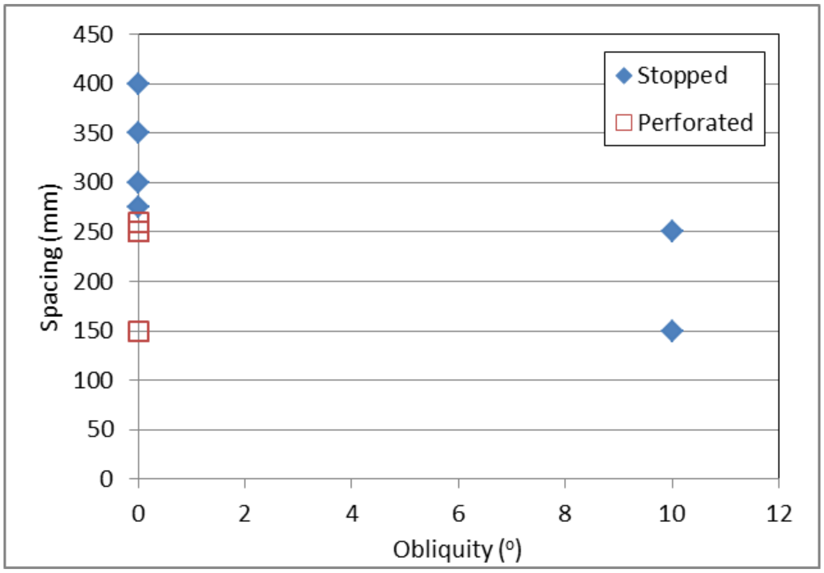

Figure 2. Target result for a pair of 5.6mm thickness RHA plates.

A series of tests were then conducted in which thinner front plates were used and the spacing and obliquity varied. For each target configuration the mass efficiency was calculated. The mass efficiency is normally taken as the mass of a monolithic RHA divided by the mass of the candidate system. For candidate systems composed of RHA then the thicknesses of the plates provides the same ratio. However as a plate is rotated to provide obliquity, the coverage of the plate diminishes. The increase in span needed to maintain the coverage is the same as the increase in shot line thickness achieved for that obliquity. Therefore in the present study the mass efficiency E_m becomes;

$$E_m = \frac{t_{RHA}}{t_r + t_f Cos\theta}$$

Where:

t_{RHA} Thickness of pseudo monolithic RHA target (16.8mm)
t_r Thickness of rear plate
t_f Thickness of front plate
θ Angle of obliquity of front plate

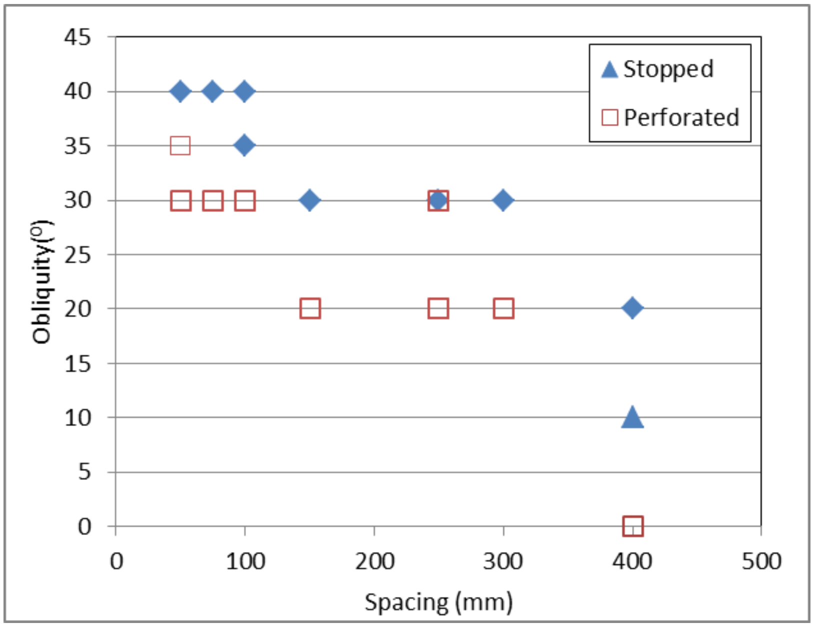

Figure 3. Target result as a function of spacing and obliquity for 5.6mm thickness rear plate and 2.7mm front plate.

Figure 3 shows the results for targets consisting of a 5.6mm rear plate and a 2.7mm thickness front plate with both spacing and obliquity being varied. It can be seen that there is an approximately linear tradeoff between spacing and obliquity for this set of configurations. Figures 4 and 5 show the same set of results with either the effect of spacing or obliquity respectively against mass efficiency.

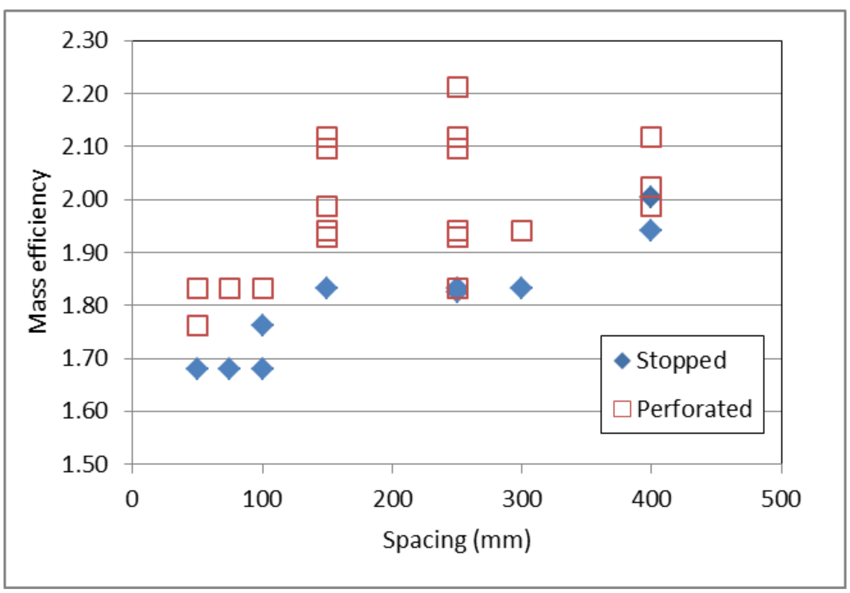

Figure 4. Target result as a function of spacing and mass efficiency for all target configurations.

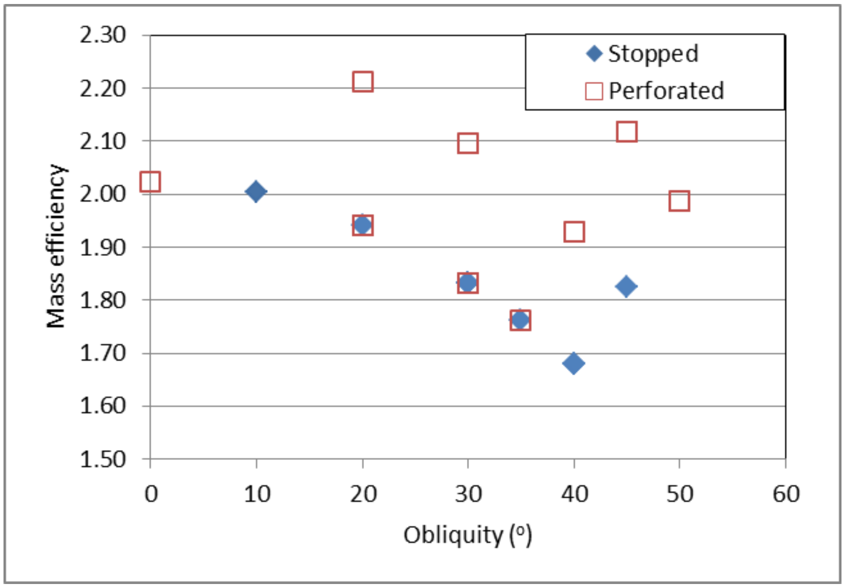

Figure 5. Target result as a function of obliquity and mass efficiency for all target configurations.

The arc of solid points in figure 5 shows the highest mass efficiencies achieved in this study. All are for 2.7mm front plates and 5.6mm rear plates. Using the data in figures 4 and 5, the mass efficiency achieved in this study was 2.00 which was a 2.7mm front plate at 10° and 400mm from a 5.6mm rear plate. Increasing the obliquity to 20° reduced the mass efficiency to 1.94. Increasing the obliquity to 30° allowed the minimum spacing to be reduced to 150mm (E_m1.83) and increasing obliquity further to 40° reduced the required spacing to just 50mm (E_m1.66).

DISCUSSION

The pseudo monolithic target required a thickness of 16.8mm (3x5.6mm) to just prevent perforation of the test ammunition. The assumption that three tightly clamped RHA plates is equivalent to a monolithic block is reasonable as was found in work by Flores-Johnson et al [2]. A pair of 5.6mm plates with no obliquity prevented perforation at a spacing of 275mm which equates to a mass efficiency of 1.5.

For significant levels of obliquity it was possible to reduce the thickness of the front plate to the minimum available which was 2.7mm. This provides thickness ration of 0.48:1 with the rear plates which is not as great as the 0.3:1 seen in other studies. This initially reduces the mass of the system by 25% but this is balanced by the need for a larger panel to provide the same area of coverage. The action of the front plate was to cause yaw and sometimes breakup of the projectile. For the range of targets used, there was no obvious correlation between projectile breakup and either angle or front plate thickness. Perforation of the rear plate was seen for projectiles whether they had broken or not after the first plate. This is to be expected as the kinetic energy density of a fully and intact projectile is the same as that of each of the components of a partially fragmented projectile. Thicker plates at higher obliquity did cause complete fragmentation of the projectile, but these configurations have necessarily low ballistic efficiencies. Thinner rear plates tended to be perforated by yawed or broken projectiles. Therefore the best mass efficiency was seen with 5.6mm rear plates.

Two clear tradeoffs are seen in the data. The first is that for spaced oblique plates the spacing and obliquity can be traded against one another. For the range of thicknesses available the increase in performance for larger spacing was marginal and it seems probable that substantially thinner plates (i.e. much less than half the rear plate thickness) could be used. The second tradeoff is between mass efficiency and spacing. Although optimum mass efficiency was achieved for relatively large spacing (400mm), reducing the spacing to just 50mm only decreased the efficiency by 17%. Therefore, for practical applications it appears that spacing of up to 10 calibers probably offers a good compromise between mass efficiency and armor volume.

CONCLUSIONS

Spaced and oblique armor offers a cost effective and efficient mechanism to increase armor performance. Obliquity and spacing can be traded against one another to achieve a range of solutions. For practical applications a spacing of no more than 10 calibers is required and front face obliquity does not need to exceed 45°.

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