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SHAPED CHARGE ATTACK OF SPACED AND COMPOSITE ARMOUR

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This paper describes the mitigation of shaped charge penetration of steel armour by the use of spaced metallic and composite plates. The target consisted of one or more steel plates of 10mm thickness some of which were backed by 25mm E-glass polyester composite panels at various additional spacings from the rearmost steel plate. A 32mm diameter shaped charge warhead was detonated at a standoff of 2CD from the frontal of the armour system.

More than 600 fragments were created by penetration of a single 10mm steel plate, the spall cone (a cone containing 95% of all fragments) had an included angle of almost 80°. Placing a second 10mm steel plate 100mm behind the first reduced the number of fragments by approximately 50% with a similar cone angle. The lowest number of fragments (<100) resulted from a composite plate spaced behind two spaced steel armour plates. However the lowest spall cone angles (<40°) were achieved for a composite plate spaced behind a single steel plate.

INTRODUCTION

Spaced armour is known to be effective against KE attack but there is a lack of data for the effect of spaced armour on shaped charges. It has been shown [1,2] that the shaped charge jet tip is disrupted when it exits from a finite thickness plate. This is due to longitudinal and radial shock wave effects in the jet causing mushrooming of the jet tip or enhanced particulation. This effect has been utilised in the design of ‘Whipple shields’ which consist of multiple thin plates. Previous work [3] has shown that the use of spaced steel armour can reduce the spread of fragments generated behind the rear face of the armour. Conversely the ultimate warhead penetration may actually increase with spacing and/or standoff as the warhead is brought closer to an optimum standoff compared to the normally fused short standoff.

In most modern armoured vehicles metallic armour is backed with a ‘spall shield’ consisting of a fibre reinforced plastic panel which is designed to capture fragments and reduce behind armour effects from weapons which substantially overmatch the main armour. Although the use of such spall liners is more or less universal there is little available information on the geometrical and materials factors which might optimise the armour systems performance.

A previous paper [3] investigated the effect of spaced metallic plates and warhead standoff on the shaped charge jet penetration and spall pattern in purely metallic armour systems. In the present study this is extended to include the use of composite spall liners as the rearmost armour element. In addition an attempt is made to quantify the effect of these spaced systems on other behind armour effects including blast overpressure.

EXPERIMENTAL

The warhead used in this study had an internal cone diameter of 32mm diameter and an integral standoff of 0.5CD. The standoff was increased to 2CD in order to match the test conditions used in previous work [3] as these had shown to produce good penetration and spalling performance. The test setup is illustrated in figure 1 and different configurations are summarised in table 1.

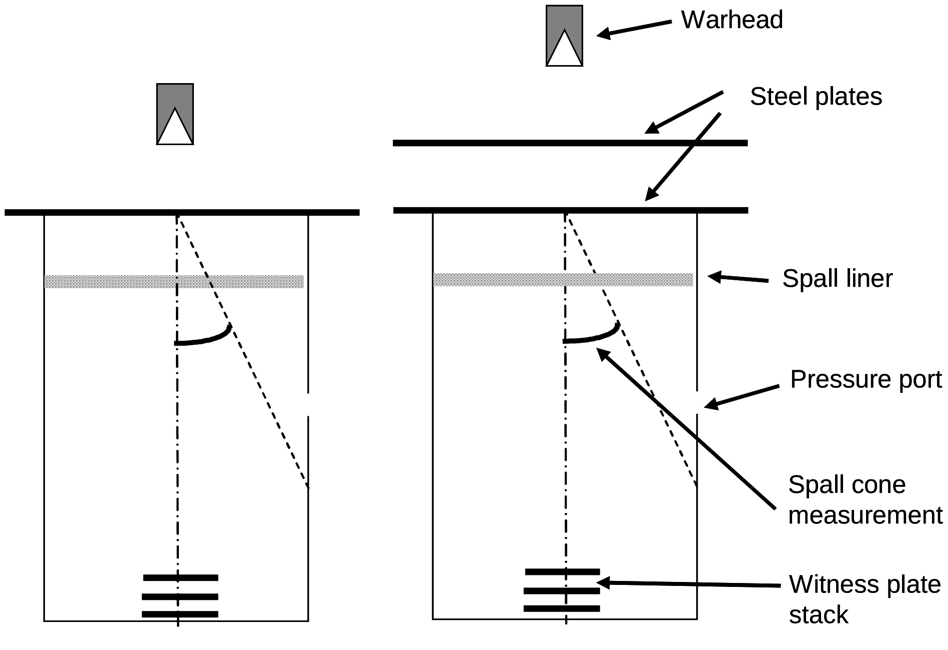

Figure 1. Test arrangement (Left) single plate armour with or without a spall liner inside the box, and (Right) test arrangement for a spaced steel armour with or without a spall liner.

The armour was mounted on one face of a sealed steel box in order to allow pressure measurements to be made and also to provide a support for the strawboard witness cards. In all cases the warhead was placed on a spacer tube to give a standoff of 2CD (64mm) from the front-most 10mm steel plate. The warhead fired downwards through the top of a steel box which measured 1m from top to bottom with a base of 0.7m x 0.7m. For single plate firings the plate formed and sealed the top of the box. Double plate firings used two 10mm mild steel plates at 100mm spacing with the second (i.e. rearmost) steel plate forming and sealing the top of the box. The composite spall liner, when used, was placed within the box at various spacings below the plate forming the top of the box.

Table 1. Summary of test configurations

Metallic armour	Composite spall liner		Areal density
	Present	Spacing	
Single plate	No		81
Single plate	Yes	In contact	124
Single plate	Yes	50mm	124
Single plate	Yes	100mm	124
Double plate	No		162
Double plate	Yes	100mm	205

In the current study the steel armour elements consisted of 10mm thickness mild steel plates, the composite spall liner was a 22mm thickness plain weave E-glass polyester composite. Six different target configurations were used as listed in table 1, and two tests were performed at each of these configurations.

A high bandwidth piezoelectric pressure gauge was positioned within a tubular port in the box wall such that it was side-on to the pressure wave emanating from the box. Strawboard witness cards were placed against the inside walls of the box and a stack of 10mm thick mild steel witness plates was placed on the box floor to catch the residual jet.

RESULTS

Two firings were performed at each condition and from these the spall pattern and number, peak overpressure and residual penetration were measured. Figure 2 plots the fragment distribution (averaged from two tests) as a function of angle from the warhead axis.

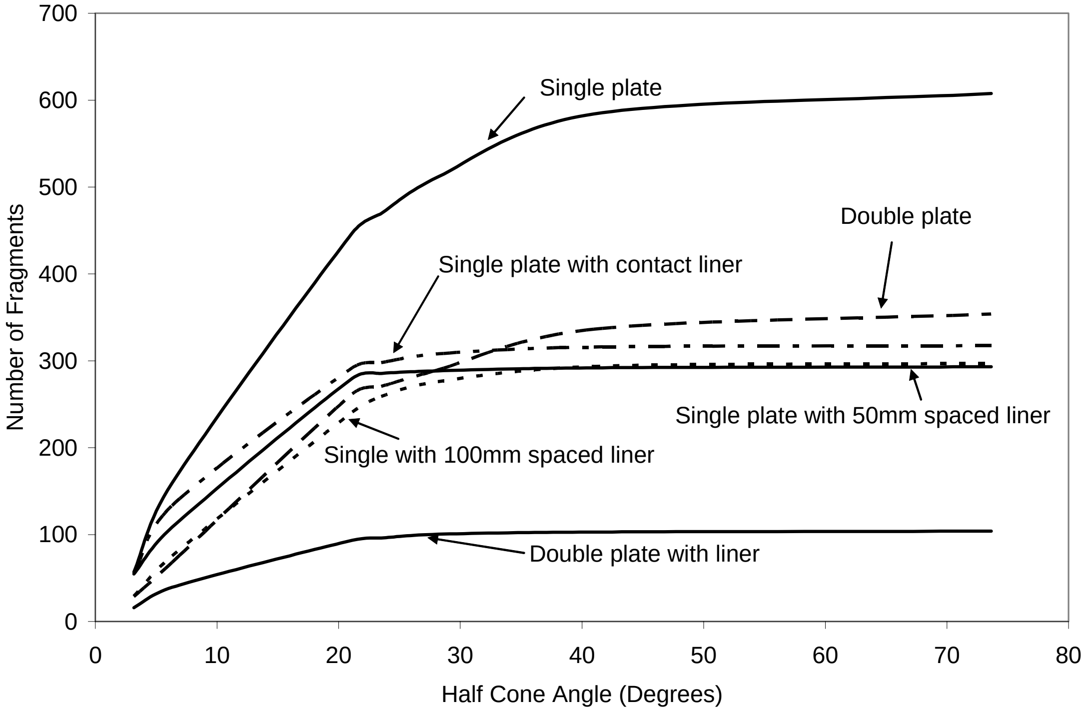

Figure 2: Data for fragment count as a function of half cone angle, averaged from 2 tests

It can be seen that the single steel plate without a spall liner has the largest number of fragments and that the number of fragments increases to a relatively large angle (>40°). All the spall lined single plate systems and unlined double plates produced similar results with typically half the number of fragments of the single plate test. The double steel plate with liner was by far the best in terms of reducing the numbers of fragments and most of these fragments are generated within a cone of less than 20° half angle.

Figure 3 shows examples of spall liners at different spacings behind a single plate steel armour. The spall liners spaced off the rear of the metal plate show fragment impacts over a diameter of approximately 200mm (at 100mm spacing) and 100mm (at 50mm spacing). The liner that was in contact with the plate simply shows a clean hole punched through. In all cases the only perforation of the spall liner was the single central hole cut by the jet.

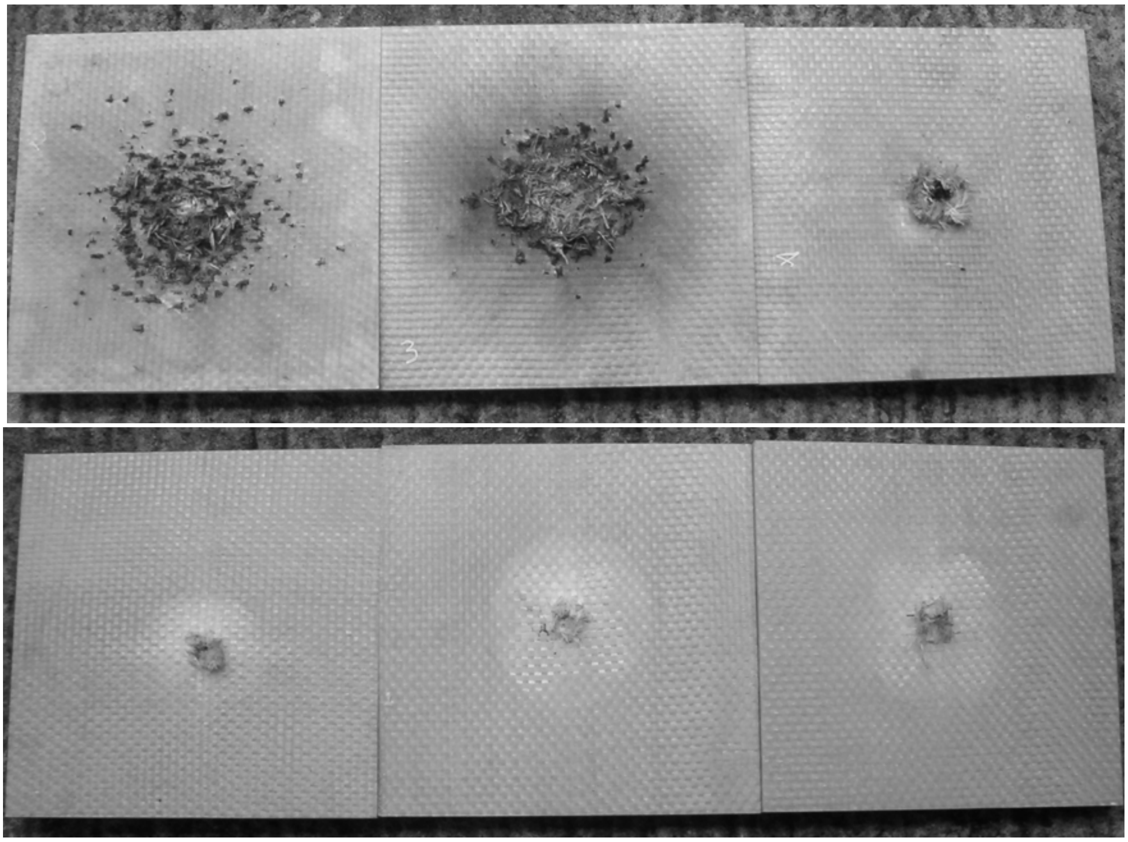

Figure 3: Photographs of composite spall liners showing the impact face (top row) and corresponding rear face (bottom row). These were (from left to right) 100mm behind, 50mm behind and in contact with the metallic plate.

Figure 4 shows an example of the pressure data, in this case for the single steel plate without spall liner. The waveform shows a large fully reversing oscillation with little evidence of either initial shock waves or any positive overpressure. The pressure data was of a similar form for all test conditions.

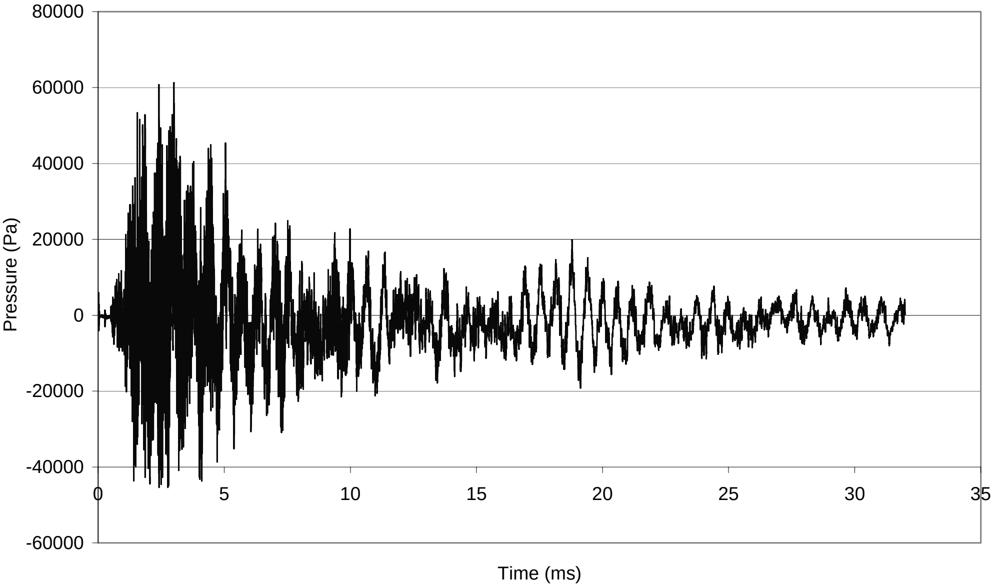

Figure 4: Pressure time data for a test against a single steel plate.

DISCUSSION

The test results are summarised in table 2, this includes data for number and spread of fragments where the spread is described as the half cone angle which contains 95% of the fragments. This shows that as expected the effect of the composite spall liner is to significantly reduce the number of fragments generated behind the steel plate. Although the number of fragments is reduced by the presence of a spall liner its effect on the cone angle is less obvious. Neither the spread nor the number of fragments is particularly sensitive to the spacing of the spall liner. However in this study all the fragments striking the witness screens were counted. This method may fail to discriminate between the relatively low mass and energy fragments generated by the spall liner and the more penetrative fragments generated by the metallic plates. In terms of behind armour lethality it would be expected that the composite fragments would have relatively low lethality against personnel and little chance of causing secondary effects such as fires. Whilst molten or hot steel fragment might be expected to be lethal and more likely generate fires or other damage. If the fragment count had been limited to relatively penetrative fragments then it may have been possible to discriminate differences as a result of spall liner spacing.

Table 2. Summary of test data

Armour	Areal Density Kgm^{-2}	Fragments		Peak pressure kPa	Penetration mm
		Number	95% Half Cone Angle		
Single steel plate	81	608	38	42	26
Single + spall contact	124	318	25	49	22
Single + spall 50mm	124	293	21	46	28
Single + spall 100mm	124	297	31	52	27
Double steel plate	162	354	41	65	28
Double + spall 100mm	205	104	25	82	30

The pressure measurements were similar for all the combinations used. The absolute pressure levels were quite low and would not generally be expected to be immediately lethal. It has been suggested [4] that separate effects such as supersonic shock from the jet tip and overpressure from burning of metal fragments may be witnessed at different times in the pressure history. However in this trial the overall characteristics were simple and consisted of an oscillating signal which increases steadily over about 2ms to a maximum then decays logarithmically. In particular it was not possible to see an initial shockwave as might be expected from the passage of the jet. This is probably due to using a side-on pressure gauge within the port rather than one exposed directly to the blast. This ported arrangement was used as previous trials using this rig with an internal pressure transducer had always resulted in destruction of the sensor or associated wiring due to the high fragment density within the box.

Spectrum analysis of the pressure data showed a peak in all cases at approximately 100kHz which is close to the second harmonic for bending of the side plates in the box. This suggests that even though the pressure gauge is acceleration compensated it is still being swamped by the mechanical vibrations within the box. Although the pressure characteristics did not match published data the absolute values were in good agreement with previous studies, i.e in the range 10-100kPa.

The residual penetrations measured in the witness stack were similar for all firings and relatively low (<1CD). The arrangements which were trialled were not expected to have significant variability in penetration as the total plate thickness is only 20mm (0.6CD) and the warhead is known to be able to penetrate over 5CD after passing through spaced armour [3]. The main reason for the low penetration seen in these trials is the large distance of 1m (32CD), between the armour and the witness stack.

If the fragment pattern and spread are compared with the areal density values of the systems then the main feature is that a single steel plate with a spall liner (124kgm^{-2}) performs as well as double steel plate (162 kgm^{-2}). So a spall liner appears to offer an efficient method to reduce behind armour effects. The best overall effect is achieved with a double steel plate with a spall liner but at the cost of a high areal density.

CONCLUSIONS

The effect of a composite spall liner behind a metallic armour system is to reduce, typically by half, the number of fragments produced when penetrated by a shaped charge. This provides a significant mechanism for mitigating the effect of shaped charge attack with only a limited increase in armour weight. A similar and additional decrease in behind armour effects is produced by using a spaced metallic armour with a composite spall liner.

REFERENCES

[1] A.S.Vlasov, E.L.Zilberbrand, A.A.Kozhushko, A.I.Kozschuk, G.S.Pugachev, A.B.Sinani, Whipple Shields Against Shaped Charge Jets. *19th International Ballistics Symposium*, 1045-1051, 2001

[2] O.V.Svirsky, N.P.Kovalev, B.AKlopov, V.V.Bashurov and V.A.Krutyakov, The Shaped Charge Jet Interaction With Finite Thickness Targets, *International Journal of Impact Engineering* 26, 735-744, (2001).

[3] I.Horsfall, The effect of spaced armour on the penetration of shaped charge warheads, *22nd International Symposium on Ballistics*, 941-947, 2005

[4] J.R.Jacobson, E.M. Schmidt, E.M. "Environment Internal to a Simulated Crew Station Perforated by a Shaped Charge", *18th International Symposium on Ballistics*, 1334-1339, 1999