COMPARISONS OF UNITARY AND JACKETED ROD PENETRATION INTO SEMI-INFINITE AND OBLIQUE PLATE TARGETS AT SYSTEM EQUIVALENT VELOCITIES

J. Stubberfield[1], N. J. Lynch[1] and I. Wallis[2]

[1]QinetiQ Fort Halstead, Sevenoaks, Kent. TN14 7BP. United Kingdom
[2]QinetiQ Farnborough, Cody Technology Park, Farnborough, Hants. GU14 OLX. United Kingdom

This paper reports experiments for unitary tungsten and jacketed tungsten penetrators fired against semi-infinite and oblique two plate RHA targets. Both penetrator types had L/D ratios of 25:1 and the same external dimensions. The effect of the steel jacket on parasitic sabot mass, launch velocity and in-flight retardation was accounted for in comparing the impact velocities of the two designs. The results from the system study gave the impact velocity for the jacketed penetrator at a range of 2km to be 2.9% higher than an equivalent unitary tungsten penetrator. Against the semi-infinite target the jacketed rod gave a reduced penetration depth compared to the unitary design. However, for the oblique two plate target the jacketed design outperformed the unitary design. It is proposed that the tough jacket in effect reduces the fragmentation of the nose of the tungsten core during oblique plate perforation.

INTRODUCTION

In the last ten years there has been something of a resurgence in jacketed penetrator studies with a number of papers being published [1-5]. Due to the wide number of design approaches that can be used with jacketed penetrators, the method used to compare their performance with an equivalent unitary design is important. Heubeck and Rudolf compared jacketed and unitary penetrator performance at the same impact velocity [4] whilst Pedersen et al compared performance on an equal impact energy basis [5]. Strictly speaking, it could be argued that neither approach is correct if the gun and propelling charge are kept the same, and only the shot design is changed. Sorensen et al [6], in a modelling study, allowed for changes to the parasitic mass and muzzle velocity as a result of jacketing a depleted Uranium (DU) projectile, but the influence of retardation between the muzzle and target was not included in the study. This paper reports experiments which take into consideration the shot design and flight to the target in order to compare performance at system equivalent impact velocities.

SYSTEM STUDY

To obtain the system equivalent velocities, the shot masses for the unitary and jacketed designs were estimated using a shot mass prediction programme. Maximum safe tensile and compressive stresses were calculated in the core, jacket and sabot using compound bar theory, and assuming that the strain in the three components were equal at a given position. The sabot diameter required to keep sabot, jacket and core within the maximum values was calculated using an iterative process until the estimated shot acceleration agreed with the calculated value to within 1%. The accuracy of the process was checked with finite element analysis. A lighter sabot can be obtained for the jacketed projectile than for the unitary projectile due to a better load transfer between the sabot and projectile core. Together with the lighter jacketed projectile this results in a lighter shot mass, and higher muzzle velocity, than for the unitary shot. Some of this muzzle velocity advantage is lost by the lighter jacketed projectile in retardation to the target. The results from the system study gave the impact velocity for the jacketed penetrator at a range of 2km to be 3% higher than a unitary tungsten penetrator having the same external dimensions.

PENETRATOR DESIGNS

An outline sketch of the two penetrator designs is shown at Figure 1. The nose of the penetrator on both designs is slightly tapered and finished with a steel nose tip. For the jacketed design the jacket itself is also tapered towards the nose tip. At the rear, the thread interface for the fin boss is machined into the steel jacket material. The steel jacket is bonded to the inner tungsten core without any thread interface. The L/D ratio of 25:1 for both penetrators is based upon the ratio between the effective length of the core without nose tip (208mm) and the external diameter (8.5mm). The jacket thickness is an important consideration in that it must provide sufficient support to the inner tungsten core, and retain this support once the sabot interface threads are machined on the outside diameter. This consideration of the jacket also applies to the machining of the fin boss thread at the rear of the projectile.

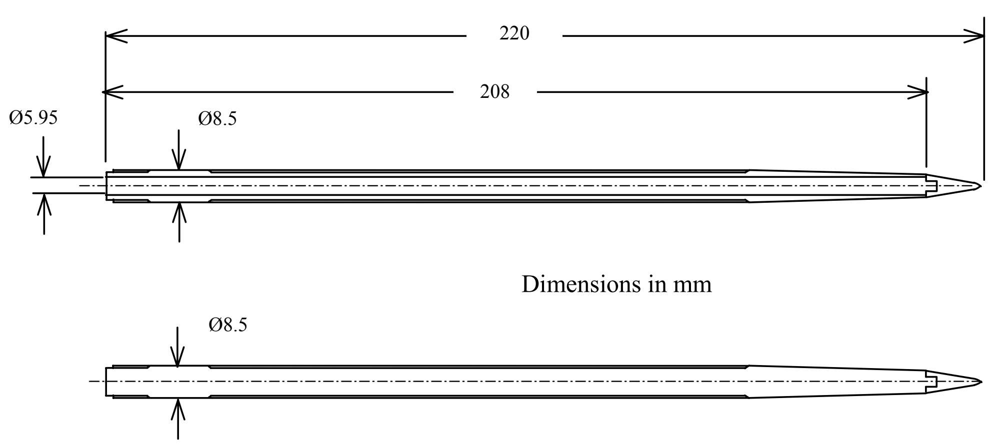

Figure 1. Outline sketch of the jacketed and unitary penetrator designs

A ratio of jacket thickness (t) to outside diameter (D) of 0.15 was chosen for the jacketed penetrator design. This was considered to provide sufficient structural strength for the jacketed design in order to survive launch and initial impact conditions. The ratio is also an important consideration as far as penetration performance is concerned. Hydrocode simulations [6] indicate that semi-infinite penetration performance reduces rapidly when t/D ratios exceed 0.1.

The mass of the unitary penetrator was 190g and the mass of the jacketed penetrator was 139g. Both penetrators were designed to be fired from a 40mm calibre smooth bore gun system and used an aluminium sabot and interface thread that was common to both penetrator types.

PENETRATOR MATERIALS

The unitary penetrator and the core of the jacketed penetrator were manufactured from a typical Tungsten-Nickel-Iron alloy with a density of 17.6g/cc. The jacket was manufactured from EN 24 steel and was heat treated to ‘T’ condition with an ultimate tensile strength of 1.09 GPa. Table I shows the composition and properties for the relevant materials that have been used.

TABLE I. PENETRATOR AND JACKET MATERIAL PROPERTIES.

Penetrator material	Composition					Properties			
Unitary tungsten penetrator and inner core of jacketed penetrator	W %	Ni %	Fe %	Cu %	Co %	0.2% Proof stress MPa	UTS MPa	Elongation %	Density g/cc
	92.1	4.95	1.4	-	1.5	1071	1142	23	17.6
Jacket material	Composition					Properties			
EN24 Steel (heat treatment condition 'T')	Fe %	C %	Ni %	Cr %	Mn %	0.2% Proof stress MPa	UTS MPa	Elongation %	Density g/cc
	~96	0.36-0.44	1.3 – 1.7	1 – 1.4	0.45 – 0.7	735.9	1092.3	12.9	7.8

TARGETS

Two target designs were selected to assess the penetration capability of each penetrator type. Semi-infinite penetration was assessed for both the unitary and the jacketed tungsten penetrator using two 150mm thick Rolled Homogenous Armour (RHA) blocks positioned end to end at zero degree obliquity.

An oblique two plate target was used to assess the finite plate perforation characteristics. This target used two 14mm thick RHA plates at 65° obliquity, separated by a 50mm air gap, with an overmatch block positioned 120mm behind the plate array. Radiography was used to observe the penetrator interactions and condition of the residual penetrator for the oblique two plate target.

Both target types used RHA materials manufactured in accordance with the UK Defence Standard 95-13/1. Figure 2 shows the target arrangements that have been used for these experiments.

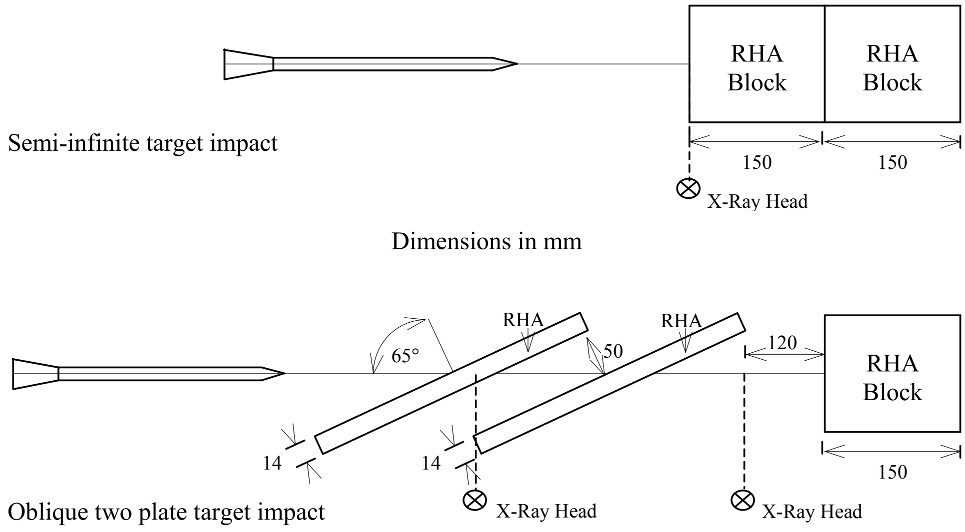

Figure 2. Target arrangements used for the experiments

RANGE LAYOUT

The penetrators were fired from a 40mm calibre, 6.6m long extended barrel smooth bore powder gun. The maximum muzzle to target distance was 16.15m. Initial firings with a fin stabiliser fitted to the penetrator resulted in high impact yaw at the target; therefore subsequent firings were conducted using a flare stabiliser instead of the fin.

The flare improved the yaw at the target, but with the disadvantage that yaw card signatures were only useable when the yaw was greater than 3°. Orthogonal X-ray heads were also used at the approximate midway position for the penetrators whilst in-flight, to gave an indication of the penetrator orientation at this point. A pair of horizontal X-ray heads was also used at the target impact. The first X-ray head observed the penetrator pitch orientation at impact for the semi-infinite target and the penetrator interaction for the oblique two plate target design. The second X-ray head observed the condition of the residual penetrator prior to impact with the overmatch block for the oblique two plate target design.

RESULTS

Table II gives the impact velocity and impact pitch angle for the 12 tests. The velocities for system equivalence are 1475m/s for the unitary and 1520m/s for the jacketed, although there are some results whose velocities lie outside these groups. A positive pitch value means that the nose of the penetrator is upwards.

Figure 3 shows a bar chart of the 12 experimental results obtained with both penetrators fired at both target types close to the system equivalent velocities. The penetration depth is expressed as a percentage of the unitary performance into the semi-infinite target. For the two plate target, the path thickness through the plates is added to the residual penetration depth.

Semi-infinite target penetration

For the semi-infinite targets (columns 8 to 12), the unitary tungsten penetrator has penetrated 12% deeper than the jacketed penetrator from test 9. The higher velocity of the jacketed penetrator was unable to overcome the lower nett penetration efficiency of the tungsten core and steel jacket. Hydrocode simulations with shorter steel jacketed penetrators have indicated that during semi-infinite penetration, the jacket does not contribute to penetration [1]. This characteristic appears to be confirmed with the results that are shown.

Oblique two plate target penetration

The oblique two plate target results are shown at columns 1 to 7 of Figure 3. Three of the four results for the jacketed penetrator (tests 5, 6 and 7) show a 17% gain compared to the average of the unitary results from tests 1 and 2. The result from test 3 has the best overall penetration of this target by a unitary penetrator; however, the impact velocity was 43 m/s higher than the designated system equivalent velocity. Test 3 does however indicate that at the same velocity (nominally 1520 m/s), the performance of the unitary and jacketed designs is similar. A similar comparison of the two designs at the 1477 m/s nominal velocity (tests 2 and 4) supports this finding. The number of tests is relatively small and additional results are ideally required to improve the statistical confidence in the trends observed.

Figure 4 shows two radiographs, one for a unitary penetrator (test 3) the other for a jacketed penetrator (test 5). The target interaction and residual penetrator delays are the same in both cases and the semi-infinite overmatch block can be seen on the right hand side of the radiographs. The radiographs show that the jacket is retained on the tungsten core and is not stripped off by the target interaction. Careful examination of the two radiographs also shows that more fragments are produced around the body of the unitary penetrator than can be seen for the jacketed penetrator. The jacket would appear to reduce the fragmentation of the inner tungsten core at the front of the penetrator after the plate perforation, thus allowing more tungsten to be available for penetration of any subsequent plates.

TABLE II. IMPACT VELOCITY AND PENETRATOR PITCH

Test number	Impact velocity (m/s)	Pitch at impact (degrees)	Projectile	Target
1	1492	+ 0.7	Unitary	2 oblique plates
2	1474	+ 1.0	Unitary	“
3	1518	+ 0.5	Unitary	“
4	1489	+ 1.0	Jacketed	“
5	1524	0	Jacketed	“
6	1510	+ 0.15	Jacketed	“
7	1521	0	Jacketed	“
8	1437	< 0.5	Jacketed	Semi-infinite
9	1511	~ 0.5	Jacketed	“
10	1473	+ 0.12	Unitary	“
11	1472	+ 0.1	Unitary	“
12	1505	< 0.5	Unitary	“

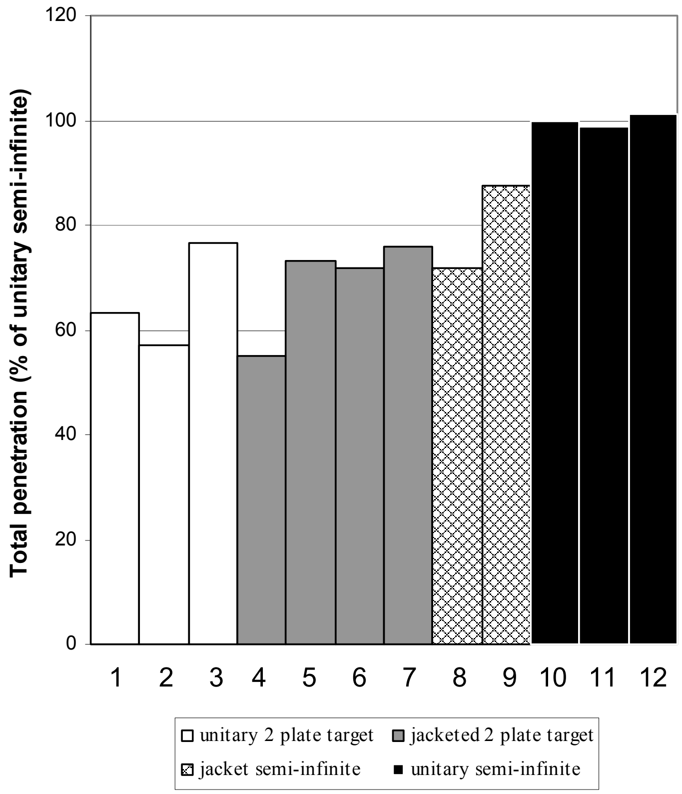

Figure 3. Histogram of the experimental results

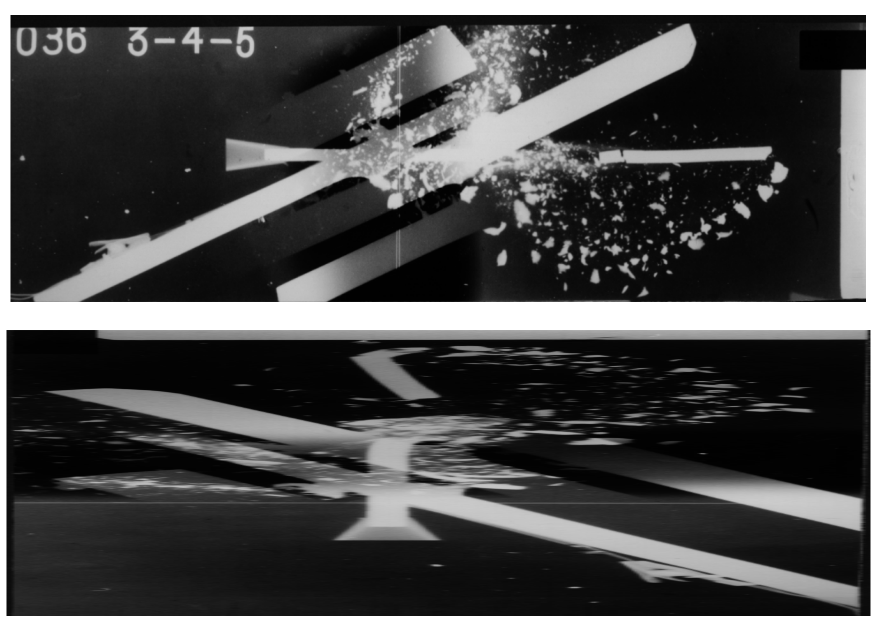

Figure 4. Unitary tungsten (top) and steel jacketed (bottom) penetrators impacting at system equivalent velocities.

Analysis of the produced crater size

Figure 5 shows the second oblique plate from tests 3 and 5. These tests correspond with the two radiographs in Figure 4. The second plate for the unitary tungsten firing on the left has produced the larger crater dimensions (15mm wide by 29mm long) when compared to the crater dimensions produced by the jacketed penetrator on the right (14mm wide by 26.5mm long). The trend for the jacketed penetrators producing the smaller crater is similar to the results obtained in [1]. Whilst the crater size only reduces slightly, this will have an effect on the yaw angle at which the tail of the penetrator will strike the crater wall (called the critical yaw angle). Jacketed penetrators could therefore be expected to be more sensitive to yaw at impact compared to unitary penetrators when of the same exterior diameter. The damage to the front face of the target plate below the main crater for the unitary tungsten penetrator is more extensive than that seen with the steel jacketed penetrator. This supports the observation from the radiographs that the debris from the nose of the steel jacketed penetrators is more contained than that from the unitary penetrator.

Second oblique plate for Unitary tungsten penetrator (Left)

Second oblique plate for Steel jacketed penetrator (Right)

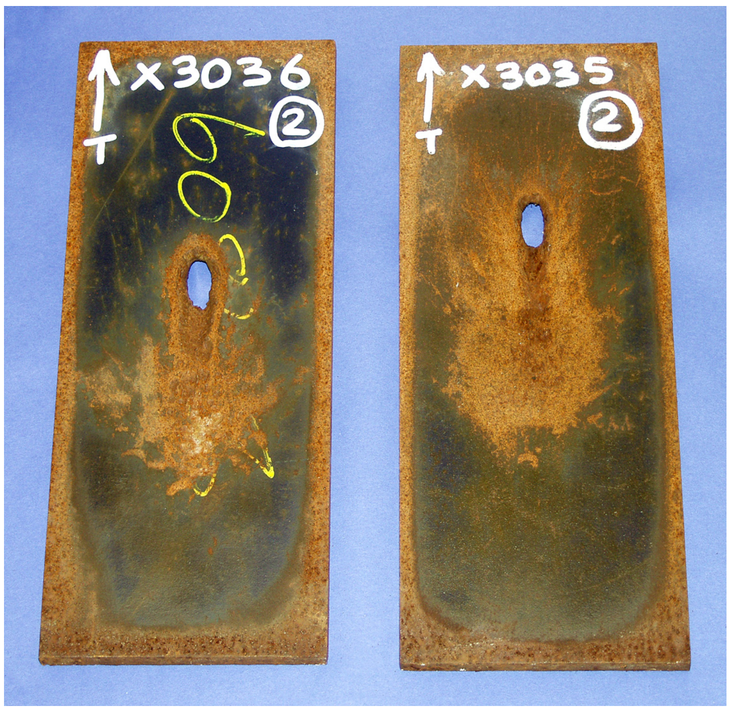

Figure 5. Photographs of the front face of the second oblique plate

CONCLUSIONS

A steel jacketed tungsten alloy penetrator gave 12% less semi-infinite RHA penetration performance when compared to a unitary tungsten penetrator with the same exterior dimensions at the system equivalent impact velocity.

Against an oblique two plate target with an overmatch block, a 17% increase in total penetration depth was found for the steel jacketed penetrator compared to the unitary tungsten penetrator with the same exterior dimensions at the system equivalent impact velocity.

It is concluded that the tough steel jacket reduces the fragmentation of the nose of the tungsten inner core when the penetrator perforates the oblique finite thickness plate. However, the results have been obtained for only one inert oblique two plate target design. Whether there is a definitive gain in penetration performance for a steel jacketed penetrator will depend upon the actual armour content.

REFERENCES

1. Cullis I.G. and Lynch N.J. Hydrocode and experimental analysis of scale sized jacketed kinetic energy projectiles, Proceedings of the 14th Intnl Symposium on Ballistics, Quebec, Canada 1993.
2. Lehr, H.F., Wollmann, E. and Koerber, G. Experiments with jacketed rods of high fineness ratio, Int. J. of Impact Engng., Vol 17, pp517-526, 1995.
3. Lanz, W. Lehr, H.F. Craters caused by jacketed heavy metal projectiles of very high aspect ratios impacting steel targets, Proceedings of the 16th Intnl. Symp. on Ballistics, San Francisco, USA, pp599-608, 1996.
4. Heubeck, C. and Rudolf, K. Behaviours of tungsten fibre and heavy metal alloy model penetrators against a performance discriminating target. Proceedings of the 15th Intnl. Symposium on Ballistics, Jerusalem, Israel, 1995.
5. Pedersen, B. A., Bless, S. J. and Cazamias, J. Hypervelocity jacketed penetrators, Int. J. of Impact Engng., Vol 26, pp603-611, 2001.
6. Sorensen, B., Zuzas, J.A. and Kimsey, K.D. Numerical analysis of sheathed kinetic energy penetrators: influences on penetration and cartridge integration, ASME Conference on pressure vessel and piping, Minneapolis, Maryland, USA, 1994, pp 183-186.