19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

HIGH VELOCITY JACKETED LONG ROD PROJECTILES HITTING OBLIQUE STEEL PLATES

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A combined numerical and experimental study has been carried out on the interaction between carbon fibre jacketed WHA long rod penetrators and oblique steel plates. A comparison is made with a non-jacketed reference penetrator with equal mass per length. Experimental results show that the jacket is stripped off at an early stage. Neither the numerical simulations nor the experiments indicate that a carbon fibre jacket improves the terminal ballistic performance of equal length and mass long rod penetrators in oblique plate targets. On the other hand, no obvious degradation of the terminal ballistic performance could be found either. This means that carbon fibre jackets could very well be of interest to enable launch of longer, more efficient penetrators.

INTRODUCTION

High velocity long rod kinetic energy penetrators constitute a major threat to armoured vehicles. Since the penetration capability is strongly dependent upon penetrator length, a lot of effort has been put into developing ammunition with longer penetrators. The mass of the launch package (sabot and penetrator) cannot be increased without a reduction of the muzzle velocity. Thus, for the muzzle velocity to be maintained, an increase in penetrator length implies a decrease in penetrator diameter. A thinner and longer penetrator means lower flexural strength, which may cause bending and breaking of the penetrator during launch. One way to solve this problem is to strengthen the penetrator with a jacket of a light and strong material, for example carbon fibre. Such a jacket would strengthen the projectile during launch, reduce the possibility of buckling and suppress bending oscillations. For the jacket to be able to transmit the acceleration loads from the sabot and to maximize flexural strength, it needs to be firmly attached to the penetrator. This coupling can be done in a number of ways, most of them resulting in the jacket being attached to the penetrator when hitting the target. For this reason, it is of interest to study how the jacket affects the penetration performance.

Modern tank armour often includes one or several oblique steel plates placed at a distance in front of the main armour. The purpose of these plates is to induce yawing, bending, and break-up of the penetrator by the application of lateral forces. In the study presented here, the interaction of carbon fibre reinforced plastic (CFRP) jacketed penetrators and oblique plates was investigated. This problem has previously been investigated in for instance [1].

The projectiles were idealised to be smooth cylinders, without the geometric details of real projectiles. Both numerical simulations and experiments were carried out.

NUMERICAL SIMULATIONS

Numerical simulations were performed for a jacketed penetrator and a reference projectile without a jacket. The two projectiles were of the same length and mass and the impact velocity was 1800 m/s. The projectile and target plate geometries are shown in Fig. 1.

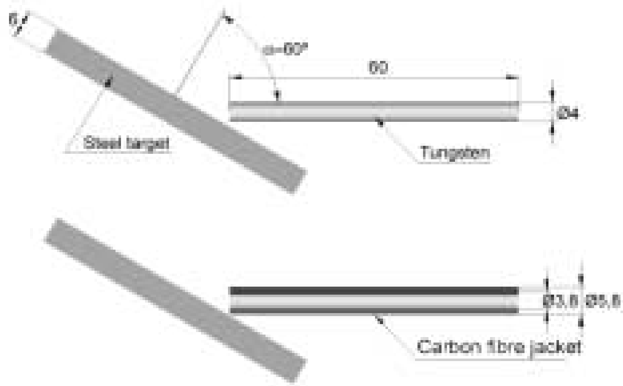

Figure 1. Penetrator and target initial geometries.

The numerical simulations were done using the AUTODYN 3D v. 3.1.15 code [2], with the Lagrange technique. Material modelling for both the projectile and the target was done with a linear equation of state and the Johnson-Cook [3] constitutive equation. Data used for the tungsten penetrator material (DX2HCMF) and the steel target plate (SIS 2541-03) have been published in [4]. For the penetrator material, no failure criterion was used, whereas a bulk strain failure model was used for the steel plate material. The CFRP jacket was modelled as an elastic orthotropic material with a bulk strain failure model. The stiffness in the axial direction was 0.3 GPa and in the radial direction 0.01 GPa. The jacket was not joined to the core since the low shear strength of the plastic binder cannot be expected to contribute significantly to the coupling. The target plate was unsupported. The simulations were run to 150 ms after impact and grid data were then exported to MATLAB where centre of mass (C), angular momentum (H) and impulse (P) were calculated for the residual penetrator. In Fig. 2, the residual penetrator is depicted at 150 ms after impact for the two cases studied.

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Tungsten projectile with carbon fibre jacket

Tungsten projectile with no jacket

Figure 2. Residual penetrator geometries at 150 ms

EXPERIMENTS

The experiments were performed using the reverse impact technique. The projectile was placed in front of the muzzle of the gun, and a special sabot was used to launch an oblique plate, as is shown in Fig. 3.

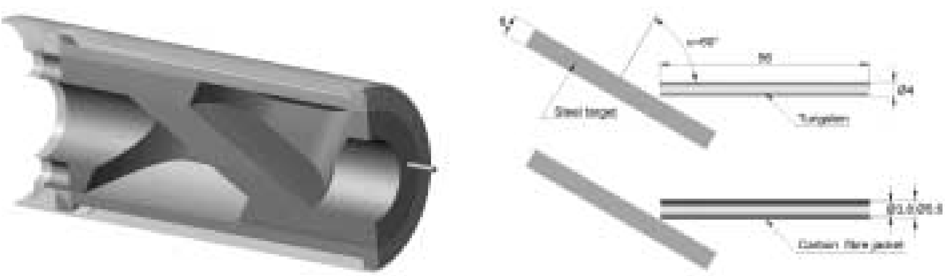

Figure 3. Oblique plate launch package and experimental geometry.

Experimental Set-up

The experiments were conducted using a two-stage light-gas gun. Three shots were fired, two with CFRP jacketed projectiles and one with no jacket for reference. The jacket consisted of a high modulus CFRP with all fibres in the axial direction. The fibre content was 65% by volume and the density was 1600 kg/m^3. The jacket dimensions were chosen to keep the mass per length equal to that of the reference projectile. The tungsten core was made from Plansee Densimet 176 FN and the plate from SIS 2541–03, comparable to the AISI 4340 quality. Five 150 kV X-ray flashes were used, three for registration of the residual penetrator behaviour and two to determine the impact velocity.

Registrations and Evaluation Method

In Fig. 4, X-ray pictures of the residual penetrator at 150 µs are depicted. From the X-ray pictures, the residual penetrator outline was traced using a CAD-program. The outlines were then corrected for the projection displacement as shown in Fig. 5.

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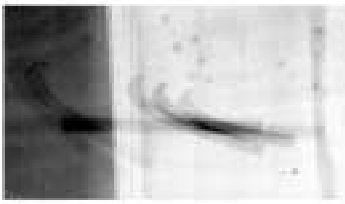


Figure 4a Shot 1. Projectile with CFRP jacket. 1654 m/s.

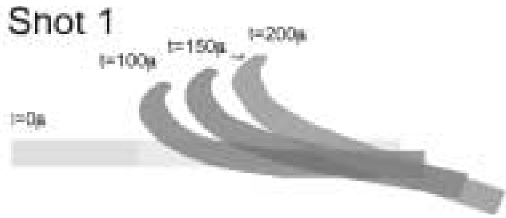


Figure 5a Projectile position compensated for projection displacement.

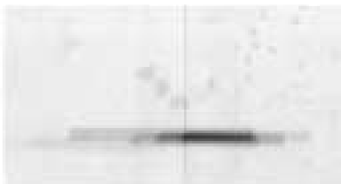


Figure 4b Shot 2. Projectile with CFRP jacket. 1678 m/s.

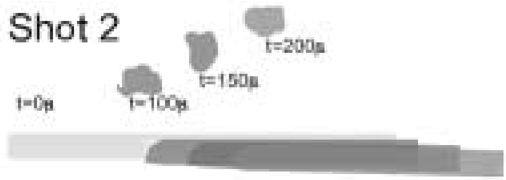


Figure 5b Projectile position compensated for projection displacement.

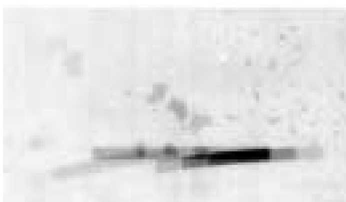


Figure 4c Shot 3. Reference projectile with no jacket. 1656 m/s.

Figure 5c Projectile position compensated for projection displacement.

In evaluating the X-ray pictures, a good approximation of residual penetrator mass can be obtained by assuming that the ratio between penetrator volume and projection area is the same as for that of a cylinder. With this assumption the volume is given by $V = \pi \cdot r_0 \cdot A/2$, where A is the projected area on the X-ray film and r_0 the original penetrator radius. This assumption should give good accuracy for the main penetrator, which is close to cylindrical form even after interaction with the target. The smaller fragments, however, are less suited for this method of evaluation since they cannot be approximated as cylindrical segments with the same degree of accuracy.

The angular momentum, given by

$$\overline{H}_O = \sum J_{zz}^{C_i}\omega\hat{k} + \sum \overline{r}_{OC_i} \times m\overline{v}_{C_i} \qquad (1)$$

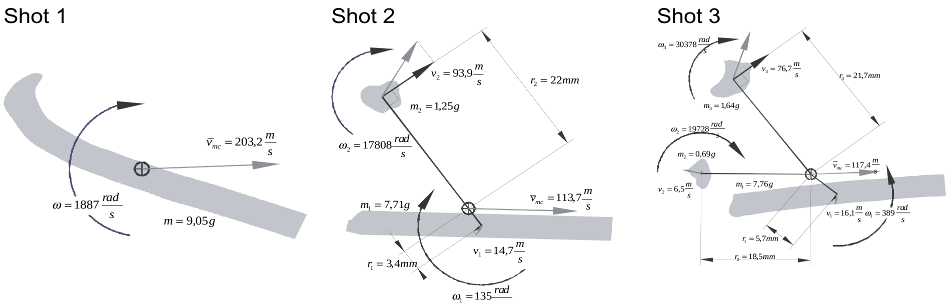
and the impulse

$$\overline{P} = m\overline{v}_c$$

was then calculated using the projection corrected residual penetrator outlines shown in Fig. 5.

RESULTS

Fig. 6 shows the linear and angular velocities for the different parts of the residual penetrators in the experiments, as well as the corresponding angular momentum and impulse.



H = 2866 kg(mm)²/s   *H = 23186 kg(mm)²/s*   *H = 3373 kg(mm)²/s*
P = 1818 kgmm/s   *P = 1019 kgmm/s*   *P = 1184 kgmm/s*

Figure 6. Projectile linear and angular velocities and corresponding angular momentum and impulse.

Fig. 7 shows simulated and experimental results for the four response parameters angular momentum, impulse, velocity reduction and residual mass.

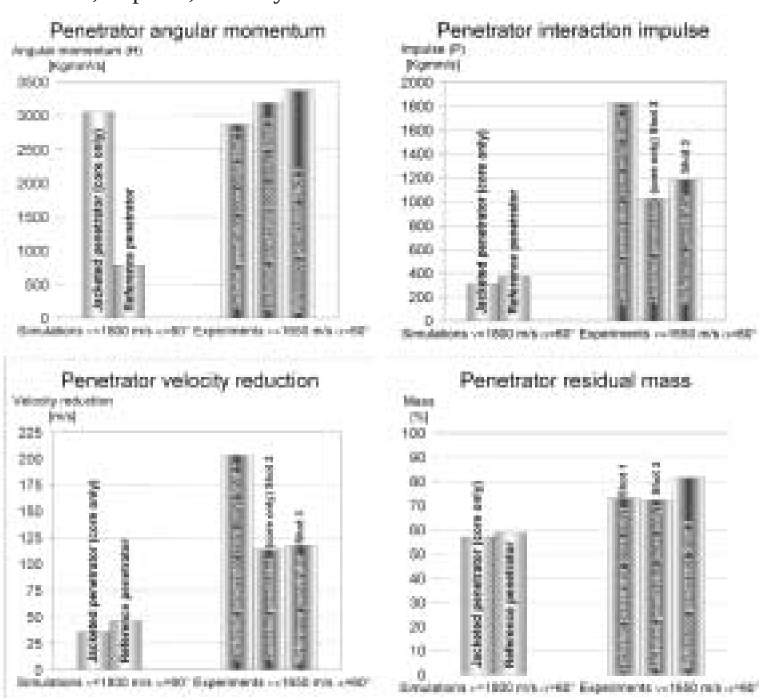


Figure7. Results from numerical simulations and experiments.

In Fig. 8, the recovered residual penetrators are depicted.

Figure 8. Recovered penetrators.

When comparing the calculated mass with the measured mass of the recovered penetrators, the errors were found to be rather small. In shot one, the main residual penetrator mass differed 1.1%, in shot two 0.08% for the main residual penetrator and 6% for the tip fragment and in shot three 1.4% and 0.42% respectively.

DISCUSSION

Numerical Simulations

Fig. 2 shows that the jacketed penetrator is more disturbed than the reference penetrator. No stiffening effect of the CFRP jacket is obtained since it was stripped off during the perforation of the plate.

The response parameters shown in Fig. 7 are very similar for the jacketed and the reference penetrator except for the angular momentum, which is considerably higher for the jacketed penetrator. This could possibly be explained by the larger contact surface, due to the larger diameter, in the case of the jacketed penetrator.

Experiments

From the X-ray pictures, the following observations can be made. Shots one and two, fired with identical CFRP jacketed penetrators and nearly the same impact velocity, resulted in quite different behaviour. In shot one, the penetrator deforms substantially, but does not fracture. In shot two, part of the tip breaks off in a large fragment which is accelerated laterally, while the main residual penetrator remains straight with limited yaw. This could be interpreted as if the applied load on the penetrator is close to the failure load. The behaviour of the reference penetrator is very similar to that of the fracturing jacketed penetrator, but the main residual penetrator is shorter and with greater yaw. An abundance of jacket material was found on the front surface of the plate and no signs of jacket material can be found in the X-ray pictures of the residual penetrator. This indicates that the jacket is stripped off when perforating the plate, in accordance with the simulated results. It can also be concluded that the penetrator break-up must have taken place inside the plate or immediately on exit.

The response parameters accounted for in Fig. 7 are very similar for the fracturing CFRP penetrator and the reference penetrator. This would indicate that the addition of the jacket has little effect on penetration performance. It can be noted, however, that for the nominally equal shots one and two, the velocity reduction and impulse differ considerably. The penetrator impulse is greater in the case where no tip fracture occurs. Since the residual mass is very similar, the difference in impulse must be due to a different force-time history for intact and fragmenting penetrators.

No jacket material was found on the recovered penetrators, which further indicates that the jacket is stripped off in the penetration process. In the penetrator from shot one, the distinctive mushrooming of the tip is accompanied by a plastic bending of the front half of the penetrator. Some small cracks are also evident just behind the mushroomed tip. The tip fractures in shot two and three are located in nearly the same position, which would indicate that the addition of a carbon fibre jacket at the expense of tungsten diameter does not affect the position of the tip fracture, if fracture occurs. The similarity of the two tip fractures might also indicate that the location of the fracture is not governed by material inhomogenities, but rather the effect of a distinctive tensile stress concentration due to the dynamic bending of the penetrator tip.

Comparison between Numerical Simulations and Experiments

The mass reduction is much larger in the simulations than in the experiments, which might be explained by the numerical erosion algorithm used. The erosion could also explain the considerably smaller velocity reduction and impulse due to the relaxation effect of numerically eroding elements under pressure.

CONCLUSIONS

Neither the numerical simulations nor the experiments indicate that a CFRP jacket improves the terminal ballistic performance of equal length and mass long rod penetrators in oblique plate targets. On the other hand, no obvious degradation of the terminal ballistic performance could be found either. This means that carbon fibre jackets could very well be of interest to enable launch of longer, more efficient penetrators.

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