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

EVALUATION OF REPLICA SCALE JACKETED PENETRATORS FOR TANK AMMUNITION

G.J.J.M. Peskes[1] and W. Lanz[2]

[1] TNO Prins Maurits Laboratory, P.O.Box 45, 2280 AA Rijswijk, the Netherlands
[2] Swiss Ordnance Enterprise Corporation, Allmendstrasse 86, CH-3602 Thun, Switzerland

In the framework of a co-operative project between Switzerland and the Netherlands experiments have been carried out with tank ammunition on a reduced scale. The used projectiles are slender long rods provided with cylindrical reinforcements, so called jacketed penetrators. The L/D ratio of the tungsten core is about 40. Tests have been performed on two scaled versions (1:6 and 1:3) and two different jacket materials (steel and titanium) have been used. The ammunition has been tested against two different targets: a monobloc and a spaced armour target. Impact velocities are in the range of 1500 to 1700 m/s. Main objectives of the present study are to establish the ballistic behaviour of these types of projectiles, also in view of a selection of the best performing jacket material, and to investigate the possibility to obtain information on full scale performance by extrapolation of reduced scale performance.

INTRODUCTION

It is well known that the normalised penetration (i.e. penetration referred to the third root of the energy of the projectile) capability of long rods with a specified mass increases with increasing length/diameter ratio (see Fig. 2). It is for that reason that modern developments aim at very slender penetrators. However at high aspect ratios the penetration efficiency deteriorates. Small diameters enhance the risk that break up will take place during the flight due to severe bending vibrations. Also at impact the projectile may suffer fracture due to high bending moments, in particular under oblique impact conditions.

To solve these problems the bending stiffness of tungsten penetrators can be increased by applying cylindrical jackets. Obviously these jackets materials should be strong enough to withstand large acceleration forces and to transfer these loads to the tungsten core. In addition the applied materials should have a lower density than tungsten. For the present study steel and titanium have been used. An important objective of the present project is to select the best jacket material with respect to the terminal ballistic performance. For cost saving aspects the experiments are carried out on a reduced scale: scales

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sizes 1:6 and 1:3 have been used. Since the results will be used to support full scale programmes it is important to recognize possible scaling effects and to establish the best scaling factor to be used for future experiments.

In parallel similar experiments are made with L/D=20 and 30 conventional tungsten rods [1].

EXPERIMENTAL SET UP

The experiments have been carried out in the facilities of TNO Prins Maurits laboratory. The experiments on a 1:6 scale have been performed with a 29 mm smooth bore laboratory gun, whereas the scale 1:3 projectiles were launched with a 78 mm smooth bore laboratory gun. The impact velocities are varying from 1500 to 1700 m/s. Since the long rod penetrators were not provided with fins, they had to be launched over a short distance to minimize yaw angles at impact of the target. The distance to the target varied from 4.5 to 6 meters. Specially designed sabots have been used to obtain good launching conditions. Important aspects are a proper support of the penetrator to assure a good transfer of the acceleration forces to avoid buckling of the penetrator or damage to the jacket by shear forces [2]. Also special attention should be given to the separation of the sabot parts, which has to be realised over a short distance without disturbing the flight trajectory.

The inner and outer diameter of the jackets are selected such that the projectiles with steel and titanium jackets have equal bending stiffnesses as presented in [3]. Since two jacket materials have been used (titanium and steel) with different Young's moduli, inner and outer diameters of penetrator core and jackets are different for the two concepts. Geometrical data of the used scaled and full scale penetrators are given in Table 1. The projectiles have been tested against two types of targets, a monobloc target and a spaced armour target (see Figure 1). The single plate target has been used for measuring the limit perforation angle, the Θ_{50} value in RHA (300 BHN). The spaced armour target is a specially designed target. The first plate is built up as a sandwich construction with two steel plates and in between a layer of SBR rubber. The performance of the projectiles against this particular spaced armour provides excellent information to enable the discrimination between good and bad performing penetrator concepts. In front of the target yaw angles have been measured in the vertical and the horizontal plane by means of 1.2 MeV X-ray equipment. In the case of the spaced armour target a triggerfoil has been positioned at the impact side of the first plate. On impact this foil triggers a 1.2 MeV X-ray device, which makes an image of the projectile after it has perforated the sandwich plate.

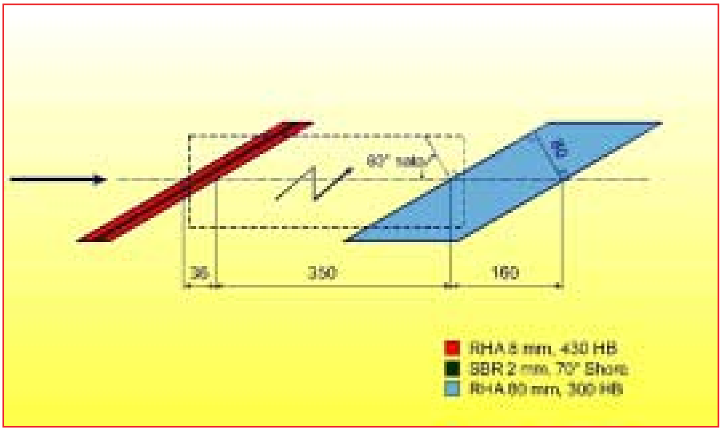

Figure 1: Spaced armour target on scale size 1:3.

Table 1: Geometrical data of used scaled and full scale penetrators

Projectiles	Scale size 1:6	Scale size 1:3	Scale size 1:1
Length (mm)	160	312	850
D(jacket) steel, titanium (mm)	5; 5.6	10; 11	27
d (tungsten) (mm)	4; 4	7.8; 7.8	21
m (g) steel, titanium	52; 45	321; 305	6600

RESULTS

1. Experiments on a single plate target

Θ_{50}-measurements have been performed on a single plate target. The material specifications and the thickness of this single RHA target (BHN 300) are the same as for the second plate in the spaced armour. Per penetrator concept about six valid shots have been carried out. The results for the Line of Sight penetration are given in Table 2.

Table 2: Penetration capability on single plate target (Line of Sight- LOS).

Jacket material	Scaling factor		Full scale
	1:6	1:3	1: 1.1
Steel	68 mm Vimp=1540 m/s	223 mm Vimp=1693 m/s	760 mm Vimp=1510 m/s
Titanium	65 mm Vimp=1532 m/s	183 mm Vimp=1675 m/s	Not carried out

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1. Experiments on a spaced armour target

From the X-ray images made of the projectiles after the perforation of the sandwich plate, information can be obtained about the damage level of the projectile before hitting the second plate. This damage is important for a first evaluation of the penetrator concepts, because it will highly affect the residual ballistic performance on the second plate. The performance on the second plate can be expressed in a stop or a perforation. In the case of a stop the penetration depth in the plates has been measured with ultrasonic techniques. The results are given in Tables 3 and 4, respectively for the scale sizes 1:6 and 1:3.

Between the sandwich plates and the second plate X-ray images of the projectiles have been made. Some typical results for the damage pattern of the projectiles, after the penetration of the sandwich plates are given in Figures 3, 4 and 5.

Table 3: Performance of the projectiles against the spaced armour targets (scale 1:6)

Jacket material	Impact velocity (m/s)	Residual penetration in second plate (mm)	Remarks
Steel	No signal	24	
Steel	1560	30	
Steel	1783	28	
Steel	1758	> 80	Perforation
Steel	1768	28	
Titanium	1540	24	
Titanium	1551	20	
Titanium	1701	= 80	Perforation
Titanium	1856	48	
Titanium	1798	32	
Titanium	1838	48	
Titanium	1768	36	

Table 4: Performance of the projectiles against the spaced armour targets (scale 1:3)

Jacket material	Impact velocity (m/s)	Residual penetration in second plate (mm)	Remarks
Steel	1665	28	
Steel	1669	42	
Steel	1664	> 160	Perforation
Steel	No signal	> 160	Perforation
Steel	1652	100	
Steel	1718	> 160	Perforation
Steel	1684	> 160	Perforation
Titanium	No signal	= 160	Perforation
Titanium	1639	40	
Titanium	1593	50	
Titanium	1630	42	

DISCUSSION OF RESULTS

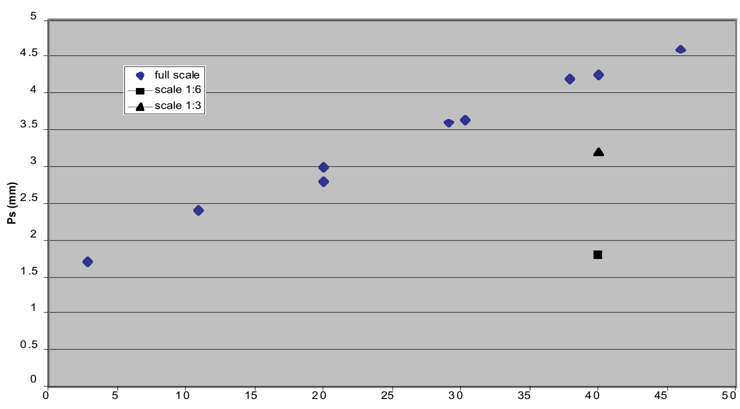
1. Experiments against the single plate target

From Table 1 it can be observed that the results obtained with the experiments carried out on a scale 1:6 do not show a significant difference between the titanium and steel jacketed penetrators. The steel jacket shows a slightly better performance, but taken into account the limited number of experiments and variations in the penetration capability due to small differences of impact yaw, no reliable conclusion can be drawn from these results.

A more significant difference in penetration capability has been found with the experiments performed on the 1:3 scale. Based on these results it is safe to conclude that the steel jacketed penetrators perform better than the titanium concepts.

Summarizing the results it can be concluded that the results of the experiments on a scale 1:6 are heavily affected by scaling effects. The scaling effect has been also shown in [4], but not clearly explained. With the experiments on a 1:3 scale size quite significant differences between the performance of the titanium and steel jackets could be found. The conclusion is justified that this scale is suitable for the evaluation of future tank ammunition, but mainly for comparing purposes. It should be realised that results obtained with the reduced scale of 1:3 also are affected by scaling effects and will underestimate the perforation capability of the full scale penetrator, as can be clearly infered from the normalised penetration capability given in Fig. 2. It seems that the scaling effect is considerably more distinct for jacket penetrators than for conventional monobloc penetrators.

Figure 2: Specific penetration Ps in RHA (260 BHN) of various full scale and scaled penetrators.



$$P_S = \frac{P}{\sqrt[3]{\frac{1}{2} \cdot m \cdot v^2}}$$

2. Experiments against the spaced armour target

Also in the case of experiments against spaced armour target there is a significant difference in results between the the two scaled versions. On a scale of 1:6 only one steel and one titanium jacketed penetrator could perforate the second plate. Penetrators on a 1:3 scale and provided with steel jackets perform very well. In 4 of 7 tests a perforation of the second plate could be observed, which corresponds well with full scale experiences. For the 1:3 titanium concepts only in one case a marginal perforation could be obtained. These results clearly show that the steel jacketed penetrator is the better performer of the two concepts.

Studying the X-ray photographs it can be seen that in some cases some nose damage could be observed. Although the penetrators are bended, the jackets remain intact. Typical examples of penetrator geometry after the perforation of the sandwich plates are given in the Fig. 3, Fig. 4 and Fig. 5. In Fig. 6 a full scale steel jacketed penetrator has been shown. The deformation is quite similar to that of a scale 1:3 penetrator (compare with Fig. 5). The impact velocity was 1510 m/s and a full perforation of the second plate could be observed.

CONCLUSIONS

Scaling effects can be observed for both the scale1:3 and the 1:6 experiments. For the reduced 1:6 experiments this implies that the differences in ballistic performance between the two jacket material concepts are marginal and do not yield sufficient information to select the best performer. For that reason this scale will not be recommended for future studies.

With the scale 1:3 experiments clear differences have been found between the two concepts. Results show a better performance of the penetrator provided with the steel jacket. This is valid for both the performance against the monobloc and the spaced armour target.

Scaled experiments on a scale 1:3 may well be used for a comparative study of tank ammuniton concepts. Hovever due to scaling effects the penetration capability of full scale ammunition will be underestimated.

REFERENCES

1. A.M. Diederen, J.C. Hoeneveld, “Replica Scale Modelling of Long Rod Tank Penetrators”, *Proceedings of the 19th Int. Symp. on Ballistics*, Interlaken, Switzerland, 7–11 May, 2001
2. H. Fang, J. Hölzle, R. Knobel, W. Lanz, “Joining Jacket and Core in Jacketed Steel/Tungsten Penetrators”, *Proceedings of the 19th Int. Symp. on Ballistics*, Interlaken, Switzerland, 7–11 May, 2001
3. W. Lanz, H.F. Lehr, “Craters Caused by Jacketed Heavy Metal Projectiles of Very High Aspect Ratios Impacting Steel Targets”, *Proceedings of the 16th Int. Symp. on Ballistics*, San Francisco, USA, 1996
4. L. Magness, W. Leonard, “Scaling Issues for Kinetic Energy Penetrators”, *Proceedings of the 14th Int. Symp. on Ballistics*, Québec, Canada, 1993

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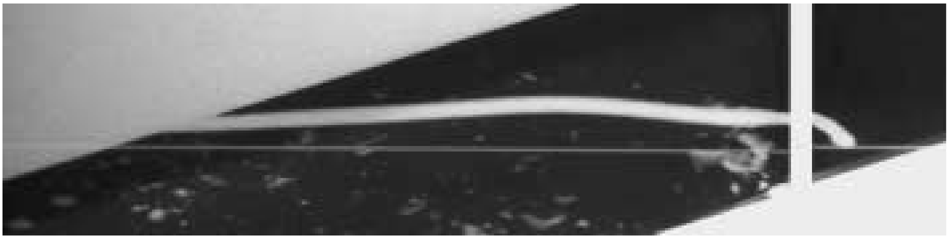

Figure 3: Steel jacket, impact angle 60° NATO, impact velocity 1758 m/s, scale 1:6, perforation.

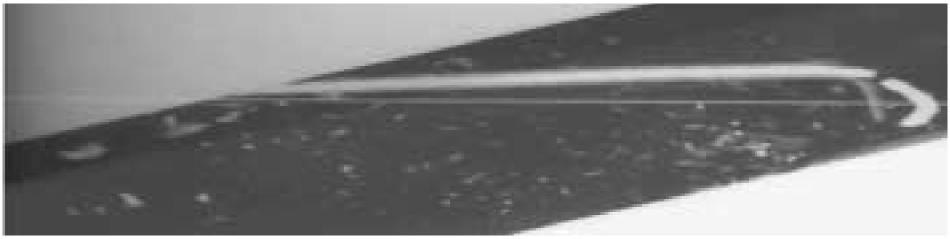

Figure 4: Titanium jacket, impact angle 60° NATO, impact velocity 1768 m/s, scale 1:6, perforation.

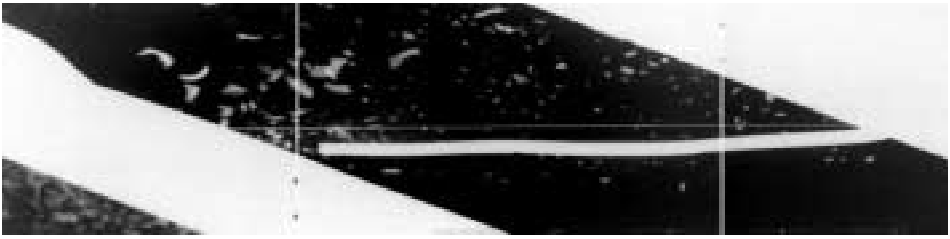

Figure 5: Steel jacket, impact angle 60° NATO, impact velocity 1718 m/s, scale size 1:3, perforation.

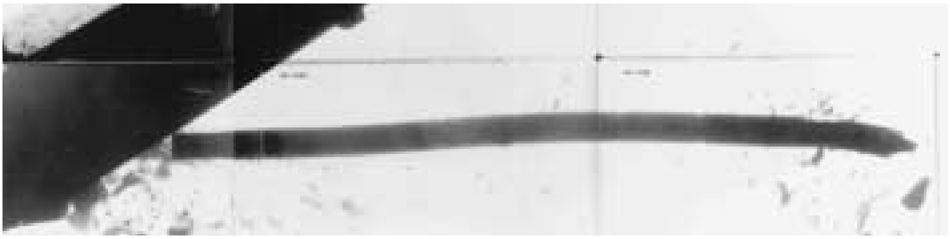

Figure 6: Full scale penetrator with steel jacket. (X-ray by GR/FS264, Thun Switzerland) Impact angle 60 NATO, impact velocity 1510 m/s, perforation.