BALLISTIC PERFORMANCE OF MONOBLOCK AND JACKETED MEDIUM-CALIBER PENETRATORS AGAINST COMPOSITE ARMOR AND SPACED TARGETS

H. Kaufmann[1], S. Lampert[2], G. Heizmann[2], B. Lehmann[2]

[1] *RUAG Land Systems, Allmendstrasse 86, CH-3602 Thun, Switzerland*
[2] *armasuisse, Feuerwerkerstrasse 39, CH-3602 Thun, Switzerland*

This paper presents ballistic performance data of L/D 20 and L/D 30 monoblock and of a L/D 40 jacketed medium-calibre penetrators against composite armor and spaced armor targets. With this contribution we complete our former studies restricted to the comparison of a L/D 20 and the L/D 40 jacketed penetrator. We selected SiC/GFRP and SiC/Ti as composite armor components. These were placed in a steel confinement and tested with both shaped charges and KE rods.
The main purpose of these tests was to confirm the rather high mass equivalence factors we have got for the composite targets and to add new data of a L/D 30 monoblock rod with a slenderness comparable to the jacketed design to the existing data base [1-8]

EXPERIMENTAL TARGETS

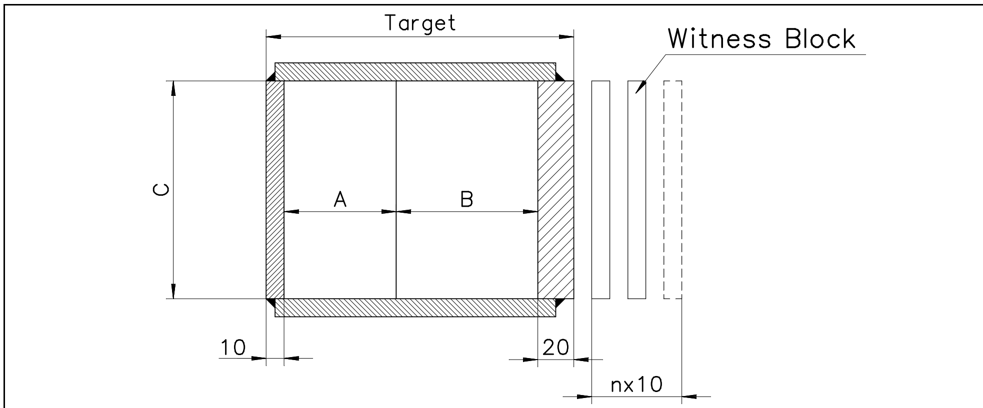
The targets are placed in a steel confinement with adjacent witness plates (Figure 1). The tightly packed target materials are:

- Silicon Carbide (SiC) from Cercom, Vista Ca, USA
- Titanium Ti6Al4V from President Titanium, Hanson MA, USA
- Vetresit, a glass fibre reinforced plastic (GFRP) from Micafil, Zürich, CH

The design of the square shaped targets is shown in Figure 1. A similar design has been used for tests with the shorter tungsten penetrator of the Swiss DPA (armasuisse) having an aspect ratio of L/D 22. For this study we investigate the penetration power of a new L/D 29 tungsten penetrator and compare it to that of the L/D 40 jacketed tungsten penetrator, which has been presented at the ISB 2002 in Orlando [10].

The two penetrator types are also tested in the spaced armor target as presented in Figure 2. The first plate is built up as a steel/rubber/steel sandwich. Using this type of target we get valuable information about the penetration performance of new KE-projectile concepts [6].

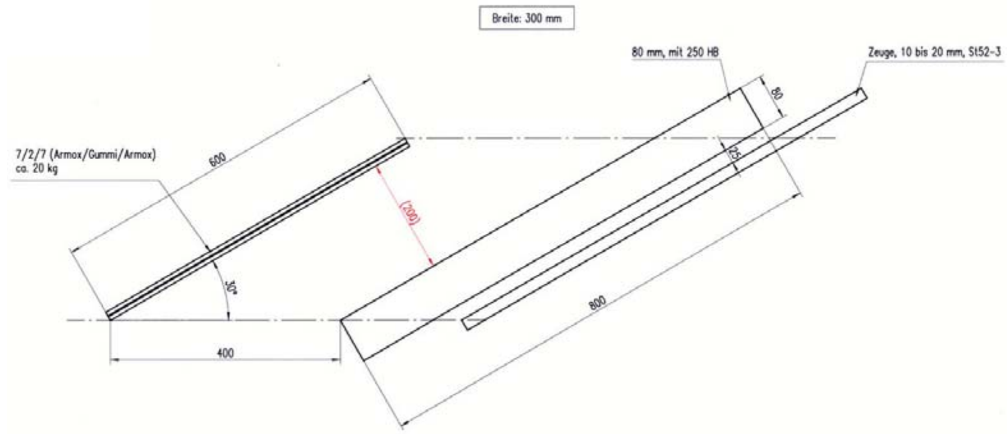
FIGURE 1: COMPOSITE ARMOR TARGETS: SIC AND GFRP OR TI6AL4V IN A TIGHTLY WELDED STEEL CONFINEMENT



Target Type	A	B	C	Projectiles
S 60 / GFRP	2 x 30 mm SiC	3 x 22, 1 x 10 mm GFRP	□ 200	8.3x237 KE and 8,3/6,5x260 jacketed KE
S 60 / Ti*	2 x 30 mm SiC	3 x 25 mm Ti6Al4V	□ 200	8.3x237 KE and 8,3/6,5x260 jacketed KE

* Having an armor steel front plate of 7.5 mm thickness

FIGURE 2: SPACED ARMOR TARGET



TEST AMMUNITION AND GUN

In this report we complete the comparison of the penetration power of monobloc and jacketed tungsten KE penetrators in models of practically feasible composite armor arrangements as presented on the ISB 2002. The main goal of those tests was to compare the projectile/target interaction of a conventional L/D 22 tungsten rod and a novel, L/D 40 steel jacketed tungsten projectile. Here we add test results of a new, L/D 29 tungsten penetrator whose ballistic parameters come closer to the L/D 40 one. Below and in Figure 3, the chosen ammunition is described in detail.

L/D 22 Monobloc rod (Figure 3A, used in [10])

Details see Figure 2A
∅ 8 x 173 mm, m ~ 150 g, V_z = 1510 m/s
terminal energy, ~170 kJ
aspect ratio ~ 22
tungsten from Cime-Bocuse, France
tensile strength ~ 1300 N/mm^2

L/D 29 Monobloc rod (Figure 3B)

Details see Figure 2B
∅ 8.3 x 237.5 mm, m ~ 221 g, V_z = 1530 m/s
terminal energy, ~260 kJ
aspect ratio ~ 29
tungsten from Hertel, Germany
tensile strength ~ 1400 N/mm^2

L/D 40 Jacketed rod (Figure 3C)

Details see Figure 2B
tungsten core ∅ 6,5 x 260 tensile strength ~ 1700 N/mm^2
steel jacket ∅ 8,3/6,5 x 200 tensile strength ~ 1900 N/mm^2
mass ~ 185 g, V_z ~ 1530 m/s
terminal energy E_z ~ 220 KJ
aspect ratio ~ 40

FIGURES 3: TEST PROJECTILES

FIGURE 3A: ∅ 8 X 173 TUNGSTEN PENETRATOR (BY DPA) M = 150 G, V_Z = 1510 M/S

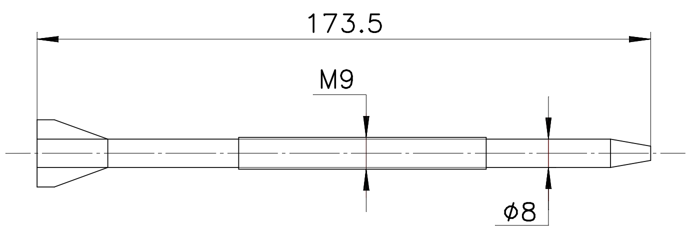


FIGURE 3B: ∅ 8.3 X 237.5 TUNGSTEN PENETRATOR (BY DPA) M = 221 G, V_Z = 1530 M/S

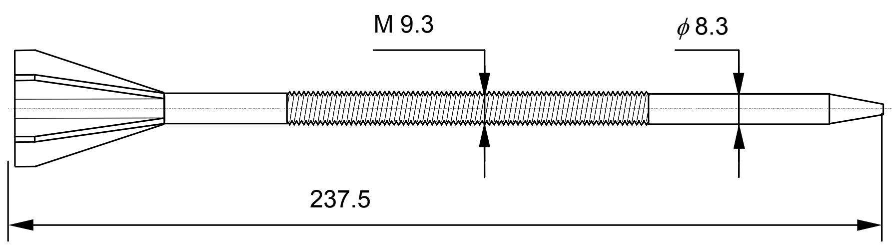
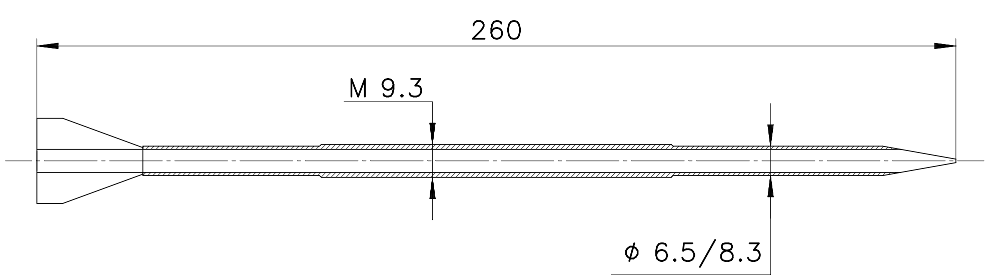


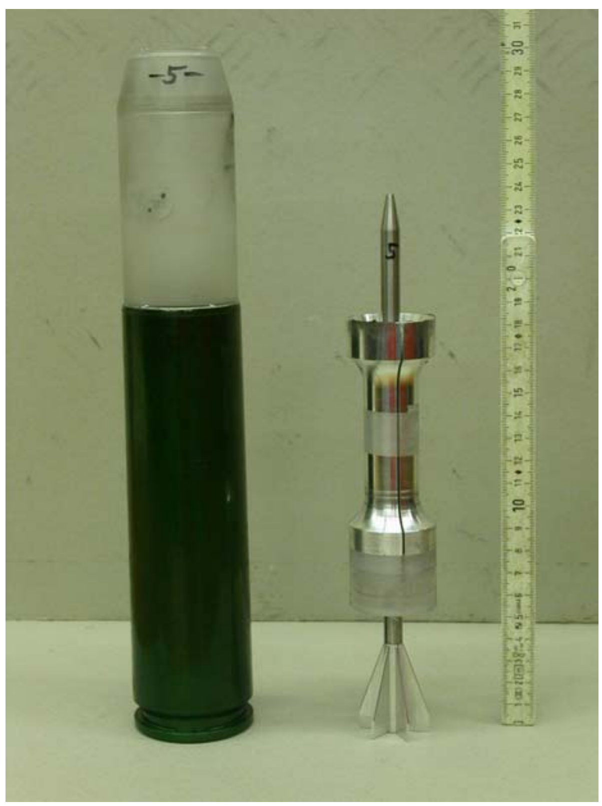
FIGURE 3C: ∅ 8,3/6,5 X 260 STEEL/TUNGSTEN JACKETED PENETRATOR (BY RUAG LAND SYSTEMS) M = 185 G, V_Z = 1530 M/S



All threee rods are launched from a 38 mm smooth bore gun (Figure 4), a modified 35 mm anti-aircraft gun barrel [10]. Joined with a simple turn lock breech the barrel is fixed to the mount of a 105 howitzer (Figure 4).

FIGURE 4: 38 MM SMOOTH BORE GUN

FIGURE 5: L/D 29 MONOBLOC TUNGSTEN KE-PENETRATOR WITH ORIGINAL 35 MM STEELCASE, STRECHTED BY 80 MM APPLYING AN ADD-ON PLASTIC CONTAINER



MEASURING EQUIPMENT

During the tests the muzzle velocity and the yaw angle of the rods were measured. The velocity was registered with photo-electric barriers and the yaw angle was determined from cardboards arranged in the gun shot line in front of the target.

RESULTS AND INTERPRETATION

The penetration power of the projectiles is represented by the mass and space equivalence factors F_m and F_s of the ceramic/ titanium and of the ceramic/GFRP composite. The mass equivalence factor is calculated with Eq. 1.

$$F_m = \frac{(P_{Ref} - P_{St})\rho_{St}}{D_{SiC}\rho_{SiC} + P_{T,G}\rho_{T,G}} \quad (1)$$

Additionally, the space equivalence factor is quoted applying the definition in Eq. 2.

$$F_S = \frac{P_{Ref} - P_{Res}}{P_{TOT} - P_{Res}} \quad (2)$$

The definitions of the variables and the material properties are listed below.

P_{Ref}	Penetration into a semi-infinite steel block of 250 Brinell hardness
P_{Res}	Residual penetration into witness plate
P_{TOT}	Total penetration into target and witness plates
P_{St}	Sum of penetration through/into steel layers (front plate, rear plate and witness plates)
ρ_{St}	7.85 g/cm^3
D_{SiC}	Thickness of SiC layer
ρ_{SiC}	Density of SiC, 3.2 g/cm^3
P_T	Penetration into titanium layers
ρ_T	Density of titanium, 4.5 g/cm^3
P_G	Penetration into GFRP layers
ρ_G	Density of GFRP, 1.9 g/cm^3

Performance of the targets

The replacement of GFRP with titanium clearly increases the protection performance of the composite armor against the monobloc tungsten rods. Yet we don’t observe the same high values for the SiC/Ti target as observed with the L/D 22 tungsten rod. This is mainly due to the smaller SiC layer and to the increased slenderness ratio of the new tungsten rod.

The spaced armor targets show relatively low stopping performance against the jacketed rod. As x-ray pictures reveal, the tungsten cores pass the sandwich without breaking which explains the low protection effect.

TABLE I: TEST RESULTS / F_M, F_S VALUES FOR THE SIC/GFRP-, SIC/TI- AND FOR THE SPACED ARMOR TARGET

Projectile	Target (see Figures 1,2)																
	S60 / GFRP						S60 / TI						Spaced armor				
	Shot No	P_{TOT} (mm)	P_G (mm)	P_{ST} (mm)	F_m	F_s	Test No	P_{TOT} (mm)	P_{TI} (mm)	P_{ST} (mm)	F_m	F_s	Test No	P_{TOT} (mm)	P_{ST} (mm)	F_m	F_s
∅ 8.3/6.5x237.5 Tungsten pen.	5	214	76	78	**2.6**	**0.9**	5	130	63	(7.5)	**3**	**1.5**	16				
	6	224	76	88	**2.4**	**0.8**	2	118	50	(7.5)	**3.4**	**1.7**	17				
P_{Ref} 195 mm (250 BHN)							3	153	75	18	**2.5**	**1.3**	18				
							4	126	58	(7.5)	**3.1**	**1.6**					
∅ 8,3/6,5 x 260 Jacketed pen.	10	233	76	98	**2.3**	**0.8**	8	228	75	93	**1.5**	**0.8**	20	612	227	**0.8**	**0.4**
	11	229	76	93	**2.4**	**0.8**	9	145	75	10	**2.7**	**1.4**	21	570	184	**1.1**	**0.4**
P_{Ref} 200 mm in (250 BHN)													079	480	144	**1.4**	**0.4**
													082	690	184	**1.1**	**0.3**

Penetration performance of the KE rods

The L/D 29 tungsten rod clearly shows better penetration performance (Table I) than the L/D 22 rod in the preceding study (F_m-values: SiC/GFRP: ≅2.5 compared to ≅3, SiC/Ti: ≅3 compared to ≅5). This is consistent with the known dependency of the penetration performance from the aspect ratio.

The new penetrator has smaller penetration performance than the L/D 40 jacketed penetrator in case of the SiC/Ti target but not in case of the SiC/GFRP target. Since the experiments with the jacketed penetrator had to be executed without registration of the muzzle velocity and the yaw angle we will complete these results with further experiments.

The relatively high equivalence factors presented in Orlando can't be confirmed for both composite target designs with this study. On the one hand we can't execute the necessary number of experiments for good statistical evaluation as sheduled. On the other hand, we can't apply the same thickness to the composite behind the SiC layer as for the last report.

Scaling factor

The experiments presented here are model tests with a scaling factor of 1:3. Full size specimen of the applied rounds would be 120 mm KE. Corresponding full size tests are being prepared primarily against SiC/titanium targets. However, referring to light and medium weight vehicles the presented results may be directly applied.

DISCUSSION

Since the initial operation tests with the new L/D 29 projectile needed two attempts to get good ballistic parameters, the experimental investigation has started rather late. Consequently, the number of tests is too small to draw statistically confirmed conclusions but still big enough to elaborate certain statements with respect to the following considerations.

Terminal ballistic tests often suffer from a considerable scattering of the results [2]. This is principally due to the terminal yaw value and its dynamic behaviour. Therefore, we generally do not refer to the average value of the results but to the best single value.

To reduce effects of the production quality on the terminal ballistic results all targets are manufactured in the same workshop by the same mechanics. Thus the target materials fit almost perfectly into the steel confinements.

Based on these considerations we propose statements for both the stopping performance of the target and the penetration performance of the rods.

Due to the delayed start of the experiments the results listed in Table I are affirmed after the printing of the report and the penetration results for the L/D 29 projectile in the spaced armor target will be completed on the ISB in Adelaide.

CONCLUSIONS

In case of the SiC/Ti target, this experimental study confirms the higher penetration performance of jacketed steel/tungsten rods compared to conventional ones as presented on the ISB 2002. In contrary to the earlier study this values are found using a L/D 29 tungsten instead of the L/D 22 tungsten rod. The new rod has almost identical ballistic parameters as the jacketed rod.

The same effect can't be confirmed in case of the SiC/GFRP target. As a matter of fact, the higher aspect ratio of the new penetrator leads to an increased penetration performance in the SiC/GFRP target. And that reveales to be equal to the one of the jacketed rod.

Additionally, the jacketed penetrator shows very good penetration behaviour in the spaced armor target. This is consistent with results from our 120 mm jacketed KE penetrators. On-going experiments will show if the same similarity can be observed for the monobloc L/D 29 rod and its 120 mm full scale version.

ACKNOWLEDGEMENTS

All tests have been accomplished at the underground shooting range of the Swiss DPA (armasuisse) in Thun. We are very grateful to everyone contributing to the success of this work.

REFERENCES

1. H.-J. Ernst, W. Lanz, T. Wolf; "Penetration comparison of L/D=20 and 30 mono-block penetrators with L/D=40 jacketed penetrators in different target materials", Proceedings of the International Symposium on Ballistics 2001 in Interlaken
2. H.-J. Ernst, W. Lanz, T. Wolf; "SiC-Target against differently scaled KE-Threats", Proceedings of the International Symposium on Ballistics 1998 in Johannesburg
3. W. Lanz, H.F. Lehr; Ballistics "Craters caused by Jacketed Heavy Metal Projectiles", Proceedings of the International Symposium on Ballistics 1996 in San Francisco
4. W. Lanz, W. Odermatt; "Minimum Impact Energy for KE-Penetrators in RHA-Targets" Dieser Bericht wurde im Rahmen des "European Forum of Ballistics of Projectiles" im April 2000 in St. Louis publiziert
5. A.M. Diederen, J.C. Hoeneveld; "Replica Scale Modelling of Long Rod Penetrators", Proceedings of the International Symposium on Ballistics 2001 in Interlaken
6. G.J.J.M. Peskes, W. Lanz; "Evaluation of Replica Scale Jacketed Penetrators for Tank Ammunition", Proceedings of the International Symposium on Ballistics 2001 in Interlaken
7. W. Lanz, W. Odermatt, Dr. G. Weihrauch; "Kinetic Energy Projectiles: Development History, State of the Art, Trends", Proceedings of the International Symposium on Ballistics 2001 in Interlaken
8. O. Andersson, J. Ottosson; "High Velocity Jackted Long Rod Projectiles Hitting Oblique Steel Plates", Proceedings of the International Symposium on Ballistics 2001 in Interlaken
9. I.G. Cullis, N.J. Lynch; "Hydrocode and Experimental Analysis of Scale Size Jacketed KE Projectiles", Proceeings of the International Symposium on Ballistics 1993 in Quebec
10. W. Lanz, H. Kaufmann; "Comparison of L/D 21.5 standard and L/D 40 jacketed penetrators in composite armor", Proceedings of the International Symposium on Ballistics 2002 in Orlando