Experimental validation of the origin of the bodywork effect (K-effect) in the up-armouring of civil and military vehicles

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Overview

- Introduction
- Experimental setup, results and discussion
- Conclusion

Introduction

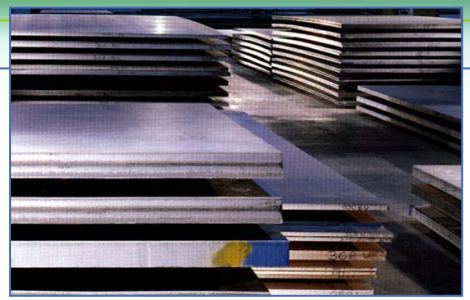
VIP vehicles

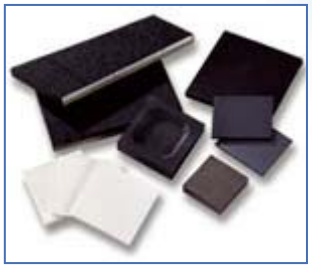
Light armoured vehicles

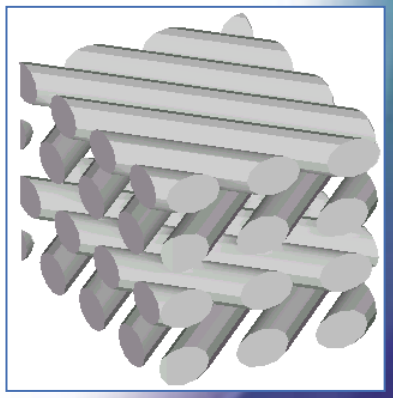
- Small calibre ammunition
- Fragments
- IED
-...

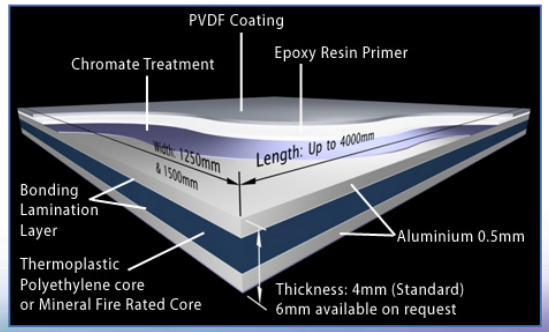
Logistic vehicles

Introduction





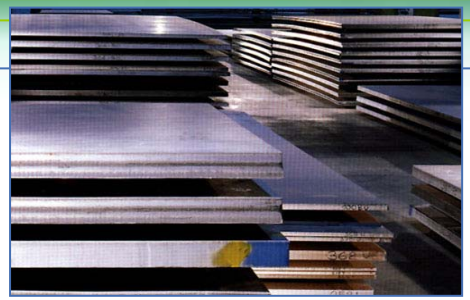




Armour materials:

- -Metals
- -Ceramics
- -Fibre
- -Composites
- -...

Introduction



STANAG 4569 Level 1

High hardness steel plates:

- -Moderate cost
- -Known processing path
- -Not weight-inefficient

Armour materials:

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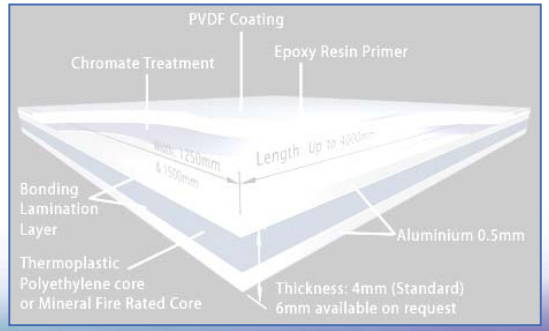
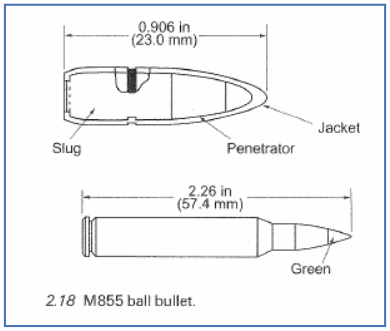
- -...



Introduction

Threat

5.56 x 45 NATO Ball (M855, SS109,...)



2.18 M855 ball bullet.

Protection

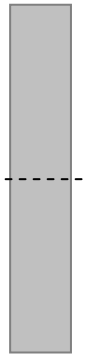
Thyssen-Krupp Secure 500

(high hardness ballistic armour plate, 480-530 HB)

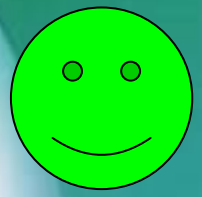
Classification	Weapon		Bullet		Test Conditions		SECURE 500 (480-530 HB)
EN 1063 / EN 1522	Type	Calibre	Type	Mass [g]	Test range [m]	Bullet velocity [1)] [m·s^{-1}]	Minimum thickness for bullet resistance [mm]
BR / FB 3	hand-gun	.357 Magnum	FJ/CB/SC	10.2	5	430 ± 10	3.0 [2)]
BR / FB 4		.44 Magnum	FJ/FN/SC	15.6	5	440 ± 10	3.0
BR / FB 5	rifle	5.56 mm x 45 (SS 109) *twist length: 178 ± 10 mm*	FJ/PB/SCP1	4.0	10	950 ± 10	6.5
BR / FB 6		7.62 mm x 51	FJ/PB/SC	9.5	10	830 ± 10	6.5
BR / FB 7		7.62 mm x 51 (AP) *twist length: 254 ± 10 mm*	FJ/PB/HC1	9.8	10	820 ± 10	15.5
no classification	hand-gun	.44 Magnum	FJ/FN/SC	15.6	3	435 - 455	3.0
	rifle	7.62 mm x 39 (Kalashnikov)	FJ/PB/SC	7.9	25	710 ± 15	4.0
			API	7.7	25	730 ± 15	12.0
		7.62 mm x 51	FJ/PB/SC	9.5	10	785 - 795	5.5
		7.62 mm x 51 (AP)	FJ/PB/HC1	9.8	25	800 - 810	14.5
		5.56 mm x 45 (SS 92)	FJ/PB/SC	3.6	25	965 - 975	9.0

Introduction

Single armour plate

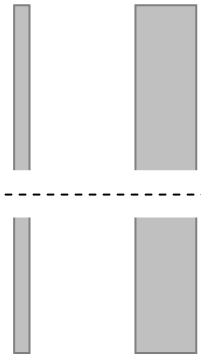


V_{50} OK



More material, less protection!!!

Armour plate behind car door panel



V_{50} not OK!!!

Experimental setup, results & discussion

Explanation

Bodywork effect

Explanation 1:

Steel penetrator loses jacket after penetration of first plate.

Steel penetrator penetrates second (armour) plate due to increased energy density.

Experimental setup, results & discussion

Validation

Analytically*:

Case 1: complete projectile

$$ED = \frac{mass_{projectile}.(speed_{projectile})^2}{2.\left(\frac{diameter_{projectile}}{2}\right)^2.\pi} = \frac{0{,}004kg.(1000m/s)^2}{2.\left(\frac{0{,}889.10^{-3}m}{2}\right)^2.\pi} = 3222kJ/m^2$$

Case 2: steel penetrator and lead slug

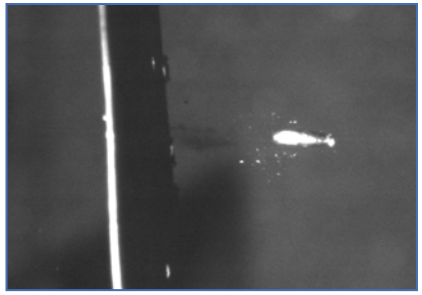
$$ED = \frac{mass_{projectile}.(speed_{projectile})^2}{2.\left(\frac{diameter_{projectile}}{2}\right)^2.\pi} = \frac{0{,}00324kg.(1000m/s)^2}{2.\left(\frac{2{,}68210^{-3}m}{2}\right)^2.\pi} = 457kJ/m^2$$

+ Nsiampa et al. (23rd ISB)

* Based on the technical drawings FN SS109

Experimentally:

High speed photography (1mm mild steel plate)



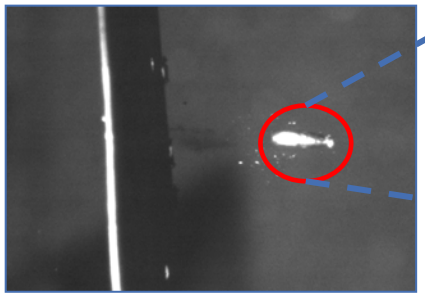
Soft recovery

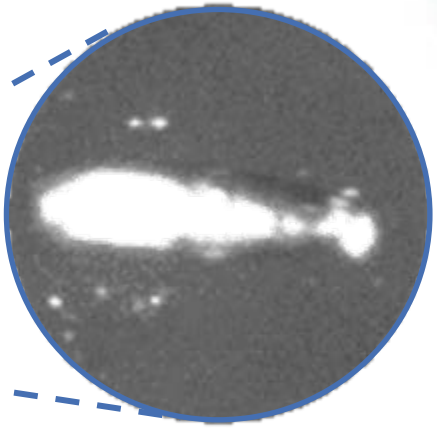
Experimental setup, results & discussion

Validation

Experimentally:

High speed photography (1mm mild steel plate)





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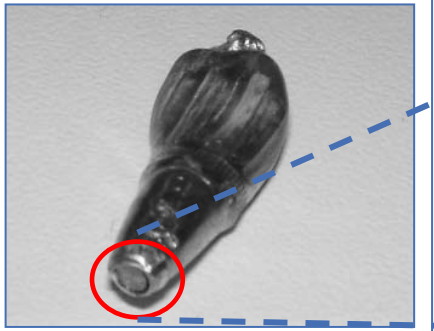
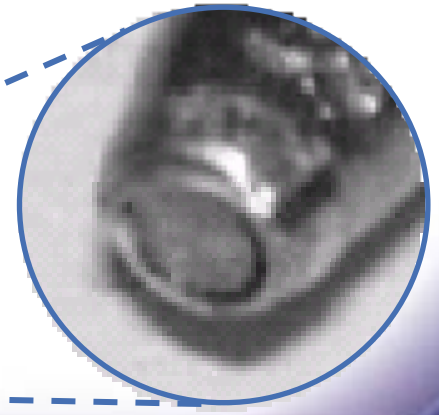




Experimental setup, results & discussion

Explanation

Bodywork effect

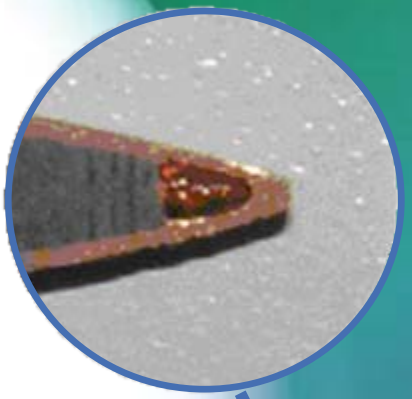
Steel [illegible]tor loses jac[illegible] after [illegible]etra[illegible] of first pla[illegible]

Steel [illegible]netrator p[illegible]trates [illegible]cond (armou[illegible]late due to [illegible]eas[illegible] energy density.

Experimental setup, results & discussion

Explanation

Bodywork effect



Explanation 2:

Penetration through first plate changes geometry of projectile nose (flattening).

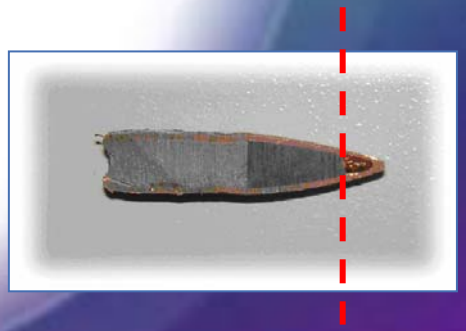
Changed geometry changes penetration mechanism during impact on the second (armour) plate.

Experimental setup, results & discussion

Validation

- Adapted projectile geometry:

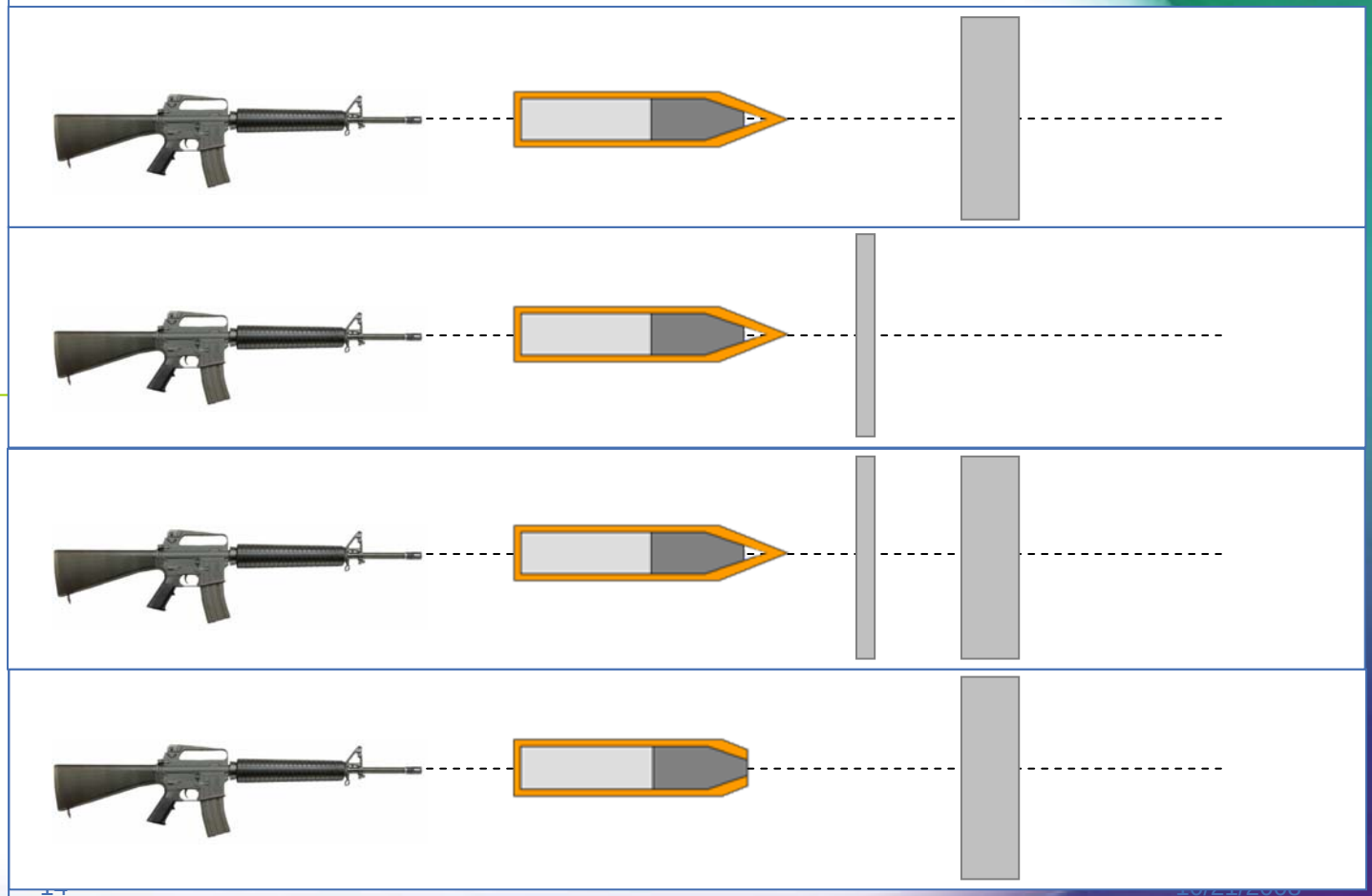
Truncated nose



Experimental setup, results & discussion

Validation

4 different projectile – target combinations:



Experimental setup, results & discussion

Validation

Test	Projectile	Thickness bodywork plate (mm)	Thickness armour plate (mm)	V_{50} (m/s)
1		/	6.5	**1002.5**
2		1	/	**40.2****
3*		1	6.5	**963.9**
4		/	6.5	**910.2**

* 10 mm air gap
** Residual velocity measurement

Experimental setup, results & discussion

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±40m/s

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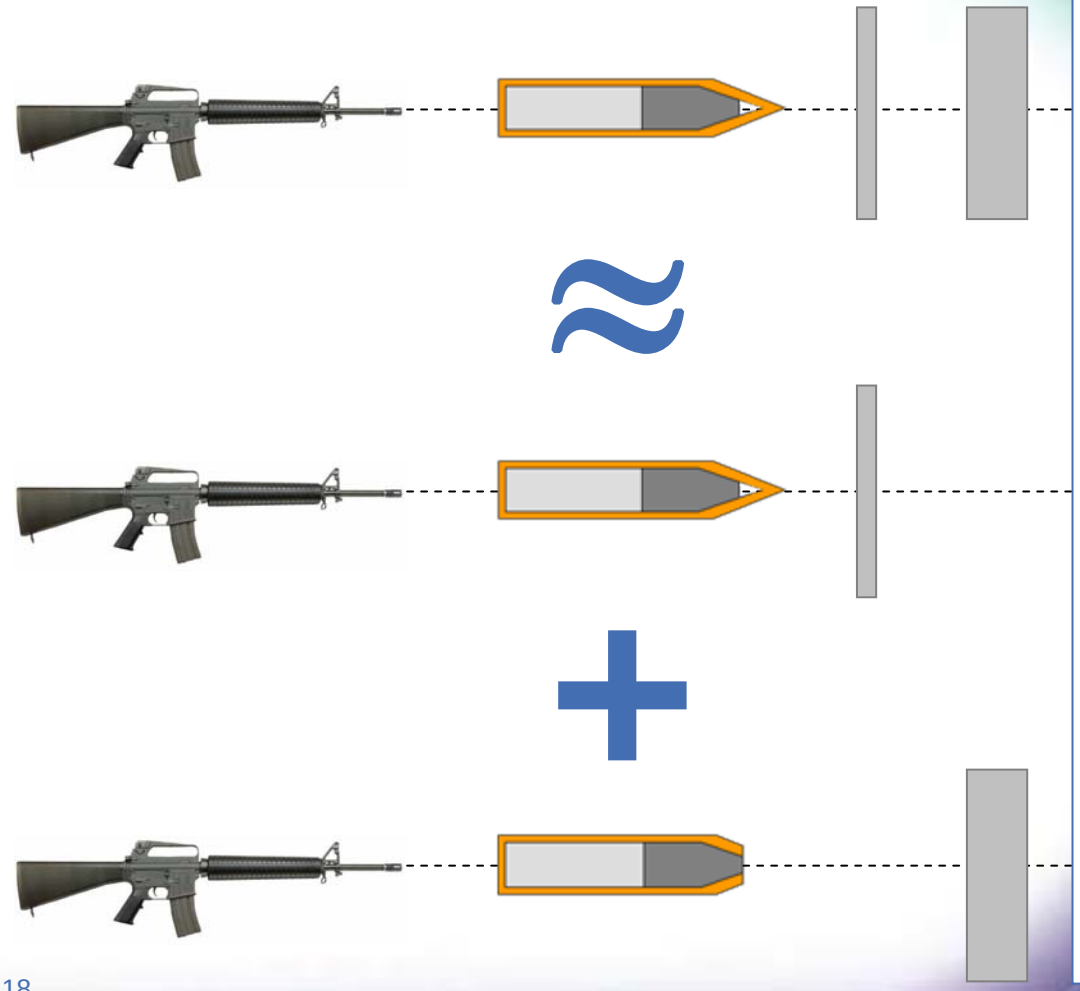


V_{50}:

963 m/s

≈

40 m/s

+

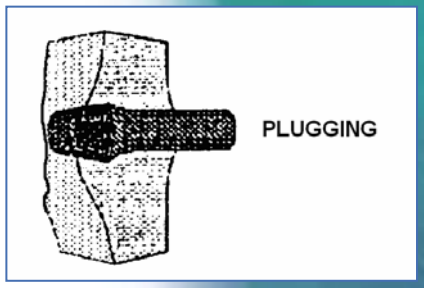
910 m/s

Experimental setup, results & discussion

Failure mechanism

Limited ductility even further reduced due to shear localization

Plugging



Adapted projectile

Standard projectile

Conclusion

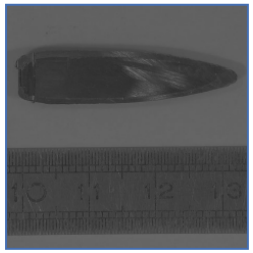
Summary

- Bodywork effect caused by changed projectile shape, which leads to enhanced plugging failure.
- Importance of in-situ testing!!!
- Be careful with norms and standards!!! Check real value.

Conclusion

Further work

- Numerical simulation
  - Dynamic material characterization
- Other projectiles
  - 7.62 x 39 M1943 Soviet
  - AP (hard core)



Questions??