Protection of Light Armors Against Shaped Charge Projectiles

Prof. Ph.D. D.Sc. Adam Wisniewski

Military Institute of Armament Technology

Ul. Wyszynskiego 7

05-220 Zielonka, Poland

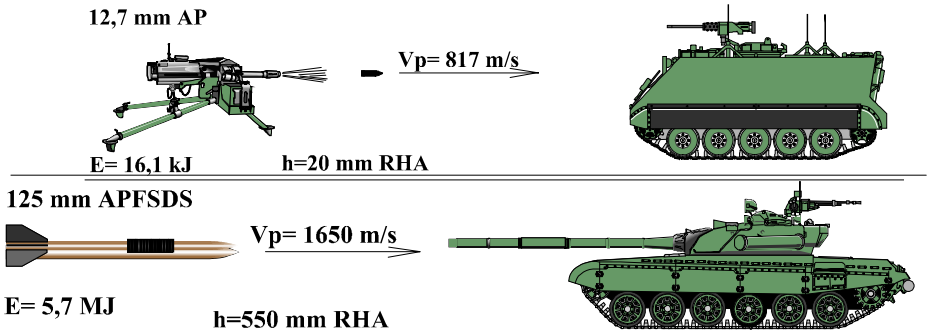
Phone/fax: 48 22 761 46 06

Fax: 48 22 761 44 45

E-mail: adam.wisniewski@witu.mil.pl

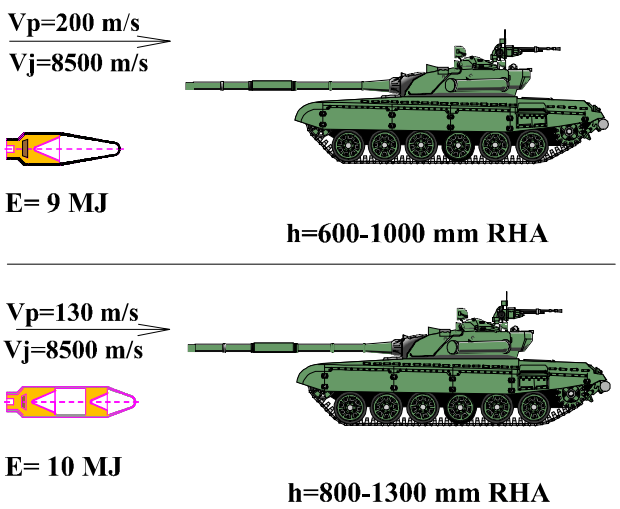
http://www.witu.mil.pl

KE (Kinetic Energy)



CE (Chemical Energy)

HEAT (HIGH EXPLOSIVE ANTI TANK)

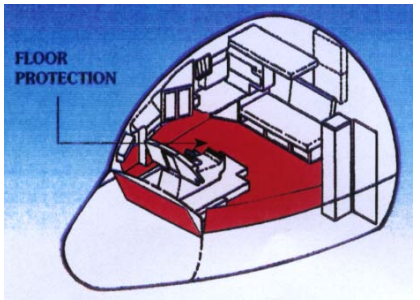


EFP (EXPLOSIVELY FORMED PROJECTILE)

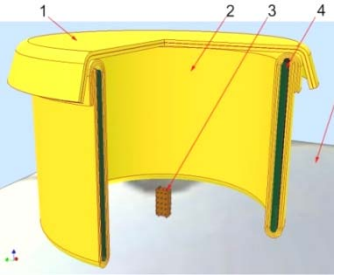
ACTIVITIES

1. **Passive** protection

Protection of helikopters against 7.62 mm and 12.7 mm AP



Protection against blast of terrorist bomb with fragments



2. **Reactive** protection
3. **Passive-reactive** protection
4. **Active** protection
5. **Passive-active** protection

STOPFIRE
Optoelectronic Fire Extinguishing System for armored vehicles and helicopters

Protection enhancement of electrical installations against the effect of „graphite bomb"

Research scheme of composite armor

RESEARCH RANGE

Materials engineering of armors:
- **composite (metal, ceramics, etc.)**
- **reactive**
- **composite-reactive**

Physics of elastic-plastic-fragile body

Computer simulation

Conception of composite armor

Tested model

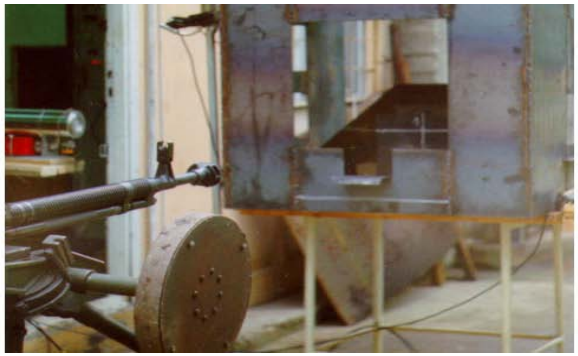
Computer model

Speed camera

X-ray camera

Fire test stand of armors

Thermal scanner



Tested materials:

1. Light metals
2. RHA (rolled homegeneous steel)
3. HHS (high hardness steel)
4. Nanostructural steel:
   - nanostructural maraging steel - new generation,
   - high carbon bainitic steel,
   - amorphous-nanocrystalline steel
5. Ceramics CA (ceramic armor): Al_2O_3, SiC, B_4C, Ti_3SiC_2, AlN
6. Plastic (laminate, polyethylene, etc.)
7. Woven fabric (aramid, textile laminate, etc.)
8. Rheological fluids (STH - Shear Thickening Fluid) - for smart armor
9. Magnetorheological fluid (MRF) - for smart armor
10. Explosives

NSNanoSteel - Development Project - POIG.01.03.01-00-042/08

"Technology of production of superhard nanostructural Fe-based alloys and their application in passive and passive-reactive armours"

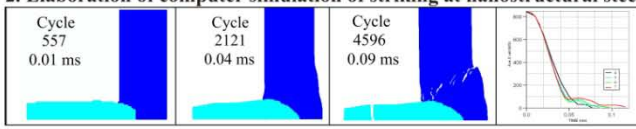
1. Beneficjent: Institute for Ferrous Metallurgy, Gliwice, Poland
Beneficiary: Leader: Ph.D., D.Sc Bogdan Garbarz, tel: +48 32 2345249, bgarbarz@imz.pl

2. Partner: Military Institute of Armament Technology, Zielonka, Poland
Partner: Coordinator: Prof. Ph.D., D.Sc Adam Wiśniewski, adam.wisniewski@witu.mil.pl

1. Elaboration of chemical compositions and production parameters of new nanostructural steels grades

Assumed parameters of nanostructural steels			
Steel grade	R_e	HV	A_5
Maraging steel new generation	>2,5 GPa	> 750	min. 5%
Bainitic nanostructural steel	> 1,7 GPa	> 650	min. 5%
Amorphous - nanostructural steel	> 2,0 GPa	> 700	min. 4%

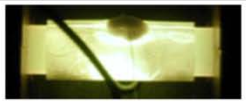
2. Elaboration of computer simulation of striking at nanostructural steel armour



Penetration of 12.7 mm projectile into armour in the function of time - AUTODYN 5 programme

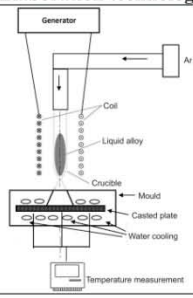
3. Elaboration of production technology of new generation of nanostructural maraging and high carbon bainitic steels

Vacuum VSG 100S furnace (a) for steel and alloys melting (100 kg), copper mould (b)

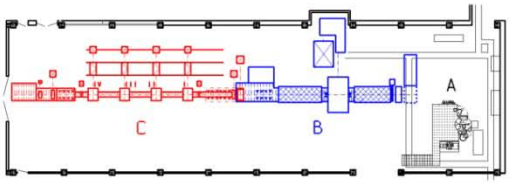


Multi-purpose system for simulations of metallurgical processes Gleeble

4. Elaboration technology of production of amorphous-nanocrystalline steels and Fe-based alloys

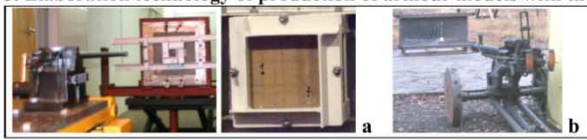


Scheme of the experimental apparatus for manufacturing of amorphous-nanocrystalline steel or Fe-based alloy plates using pressure casting method



Line for simulation of production processes of metals and alloys products **LPS**

5. Elaboration technology of production of armour models with the nanostructures and firing them



The tests of armour firing: a - standard fragments, b - AP projectiles of the different caliber

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

European Union
European Regional Development Fund

1. Institute for Ferrous Metallurgy, Karola Miarki st. 12, 44-100 Gliwice, Poland
2. Military Institute of Armament Technology, Pr. St. Wyszyńskiego st. 7, 05-220 Zielonka, Poland

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

SMARTARMOUR

European Union
European Regional
Development Fund

SMARTARMOUR - SMART PASSIVE BODY ARMOURS WITH THE USE OF RHEOLOGICAL FLUIDS WITH NANOSTRUCTURES

DEVELOPMENT PROJECT NO. POIG.01.03.01-00-060/08

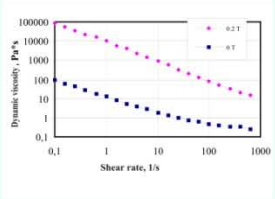
1. Beneficiary: Warsaw University of Technology, Warszawa, Poland
Leader: Prof. Ph.D., D.Sc Marcin Leonowicz, tel: +48 22 234 8450, *mkl@inmat.pw.edu.pl*
2. Partner: Military Institute of Armament Technology, Zielonka, Poland
Coordinator: Prof. Ph.D., D.Sc Adam Wiśniewski, *adam.wisniewski@witu.mil.pl*
3. Partner: Institute of Security Technology "MORATEX", Łódź, Poland
Coordinator: PhD. Eng. Jadwiga Polak, *poigs@moratex.eu*
PhD. Eng. Marcin H. Struszczyk, *poigs@moratex.eu*

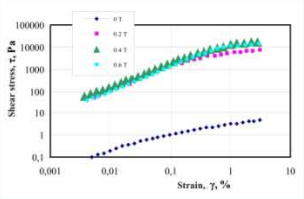
1. Warsaw University of Technology,
Pl. Politechniki 1, 00-661 Warszawa, Poland

2. Military Institute of Armament Technology,
Pr. St. Wyszyńskiego str. 7, 05-220 Zielonka, Poland

3. Institute of Security Technology "MORATEX",
Marii Skłodowskiej - Curie str. 3, 90-965 Łódź, Poland

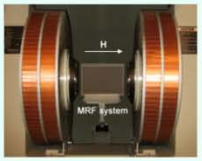
1. ELABORATION OF RHEOLOGICAL FLUIDS FOR SMART ARMOUR





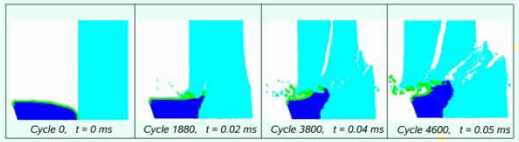
LORD 132 DG fluid under magnetic field

2. ELABORATION AND BUILDING THE MAGNETIZING SYSTEM FOR THE MAGNETORHEOLOGICAL FLUID



Magnetorheological fluid - MRF between magnetic poles

3. ELABORATION AND CARRYING OUT COMPUTER SIMULATION OF PROJECTILE STRIKING INTO SMART ARMOUR

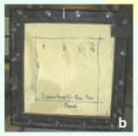


Penetration of 9 mm Parabellum bullet into Kevlar armour in the function of time - AUTODYN 5 software

4. ELABORATION OF TECHNOLOGY, BUILDING TEXTILE SMART ARMOURS AND TESTING THEM

Smart armours protection ability tests against white weapon striking

5. ELABORATION OF TECHNOLOGY, BUILDING SMART ARMOURS MODELS AND FIRING THEM



a - balistic tests: fragment- and bulletproofness tests;

b - armour's model.

DEVELOPMENT PROJECT REALIZED
IN NATIONAL COHESION STRATEGY 2007 - 2013
IS FINANCIALLY SUPPORTED BY
EUROPEAN REGIONAL DEVELOPMENT FUND

Nowadays tendency

Constructors gave up the previous tendency that FV armor thickness should be similar to tank armor thickness.

Light armors of FV should be protected:

1. by armor lighter than RHA,
2. against penetration RPG-7 grenade launcher (*DP* = 300 mm RHA)
3. against AP bullets *d* = 25÷40 mm.
4. against radar detecting and recognizing**.**

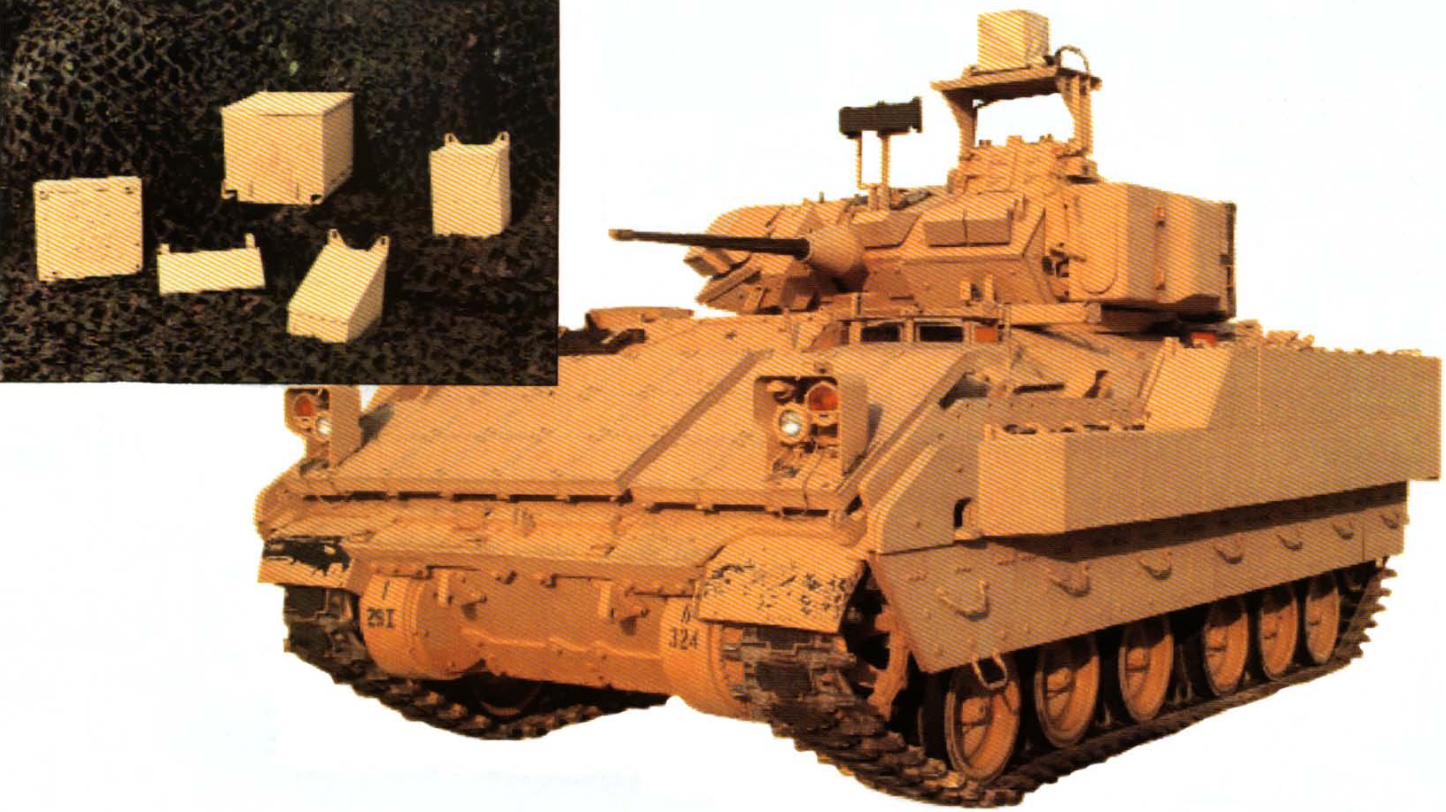
Light fighting vehicles with ERA cassettes

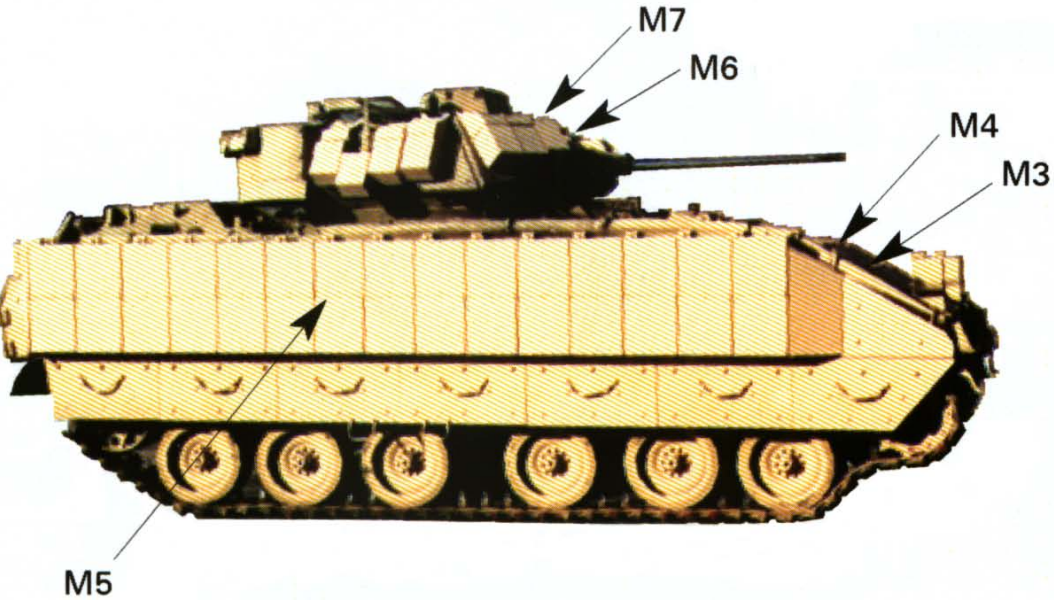
ERA cassettes (1) protecting from shaped charge projectiles of the PG-7 type;

Bradley with different non modular cassettes

FV432 Mk3 BULLDOG with modular cassettes

BRADLEY with ERA





BFVS armor tiles

M3 - wedge	-	26 pcs
M4 - frontal	-	9 pcs
M5 - side	-	55 pcs
M6 - turret	-	7 pcs
M7 - turret wedge	-	8 pcs
Total tiles per vehicle set	-	105 pcs

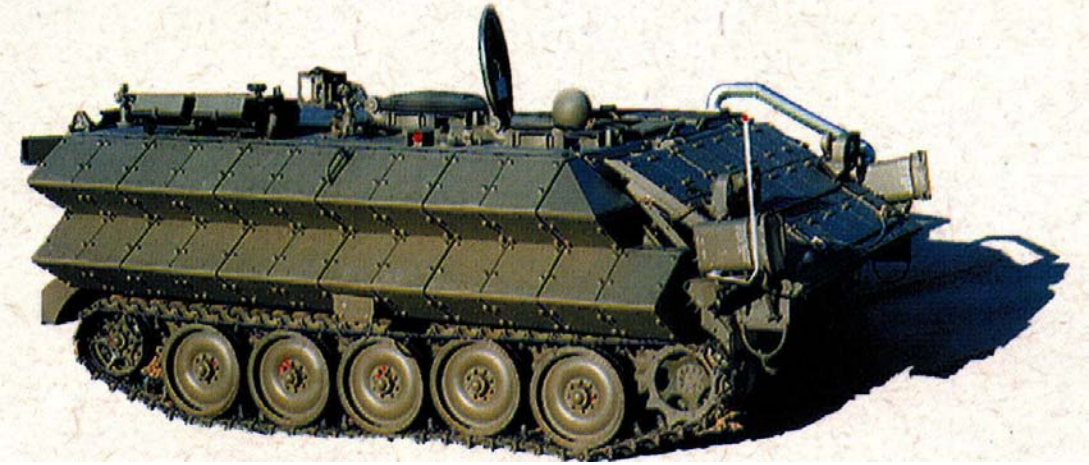
ERA + AFV

ERA for IFV

M113, VCC-1, AA7A1 - Israeli EAAK cassettes of Rafael firm with inertial layers and TOGA armor with metal sheets, which contain holes.

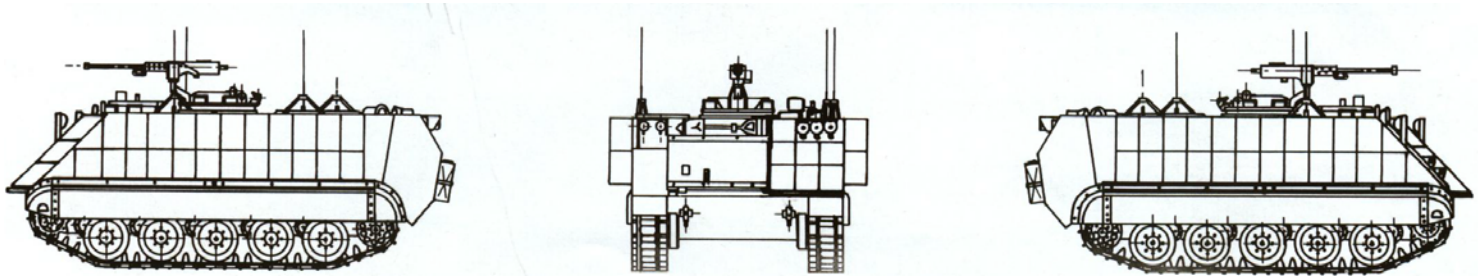
Protecting against HEAT projectiles of RPG-7 type and 14.5 mm AP bullets:

M113A fighting vehicle with Israeli reactive armor



M113 fighting vehicle with Israeli reactive armor

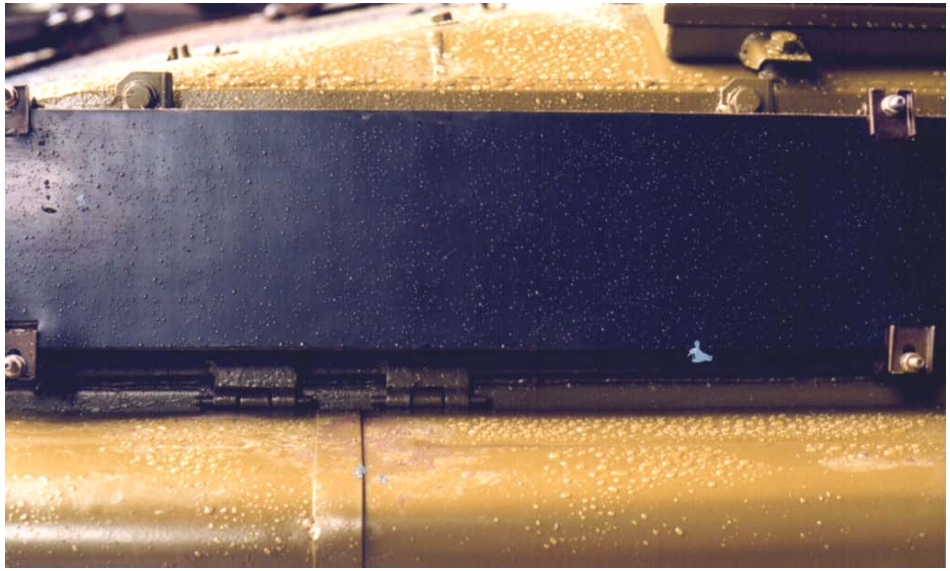
French M113 with ERA



Kind of vehicle	M113 i A2	M113 A3
Total mass	980 kg	1900 kg
Protection area	3,6 m^2	6,6 m^2
Angle of hit for all types of threat	160°	160°
Protection against perforation for the following projectiles	12,7 mm AP z 100 m 14.5 mm AP z 100 m 20 i 23 mm AP z 300 m **RPG-7**	12,7 mm AP z 100 m 14.5 mm AP z 100 m 20 i 23 mm AP z 300 m **RPG-7**
Number of cassettes for 3 different types	30	56

There is no information whether reactive cassettes are resistant to fire from small-calibre ammunition as a result of using in them so-called composite-reactive armor.

The BWP-1 with the CERAWA-1 composite-reactive armor



The CERAWA-1 composite-reactive armor

The CERAWA-1 composite-reactive armor consists of:

1. Unified, mutually replaceable hermetic cassettes (72 pieces of modules - **306x156x44 mm**, area - **3.5 m^2**), which apart from ceramics contain, among other things, explosive material. The cassettes are located on:
   - the plates of the front turret - 9 pieces,
   - the front of all plates of the left and right side of the turret - 2 x 7 = 14 pieces,
   - the front upper plate of the hull and the breakwater - 23 pieces,
   - the front bottom plate of the hull - 12 pieces,
   - the side part of the hull - 2 x 7 = 14 pieces.

2. Frame holding the CERAWA-1 armor.

3. RAM (radar absorber material)

72 pieces of the CERAWA-1 cassettes is a basic equipment of the IFV but it is possible to use greater quantity of the cassettes depending on the requirements.

The CERAWA-1 composite-reactive armor

Protecting features

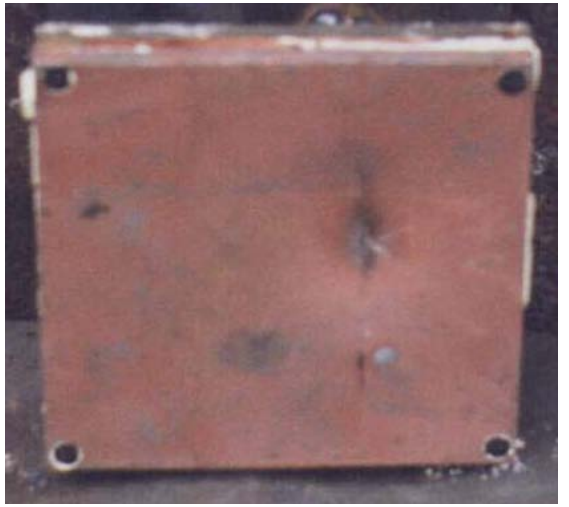
The CERAWA-1 protects main surfaces the BWP-1 (10 mm thickness) in sector of **frontal horizontal fire and observation 70º** (on the right and left from axis of vehicle) against:

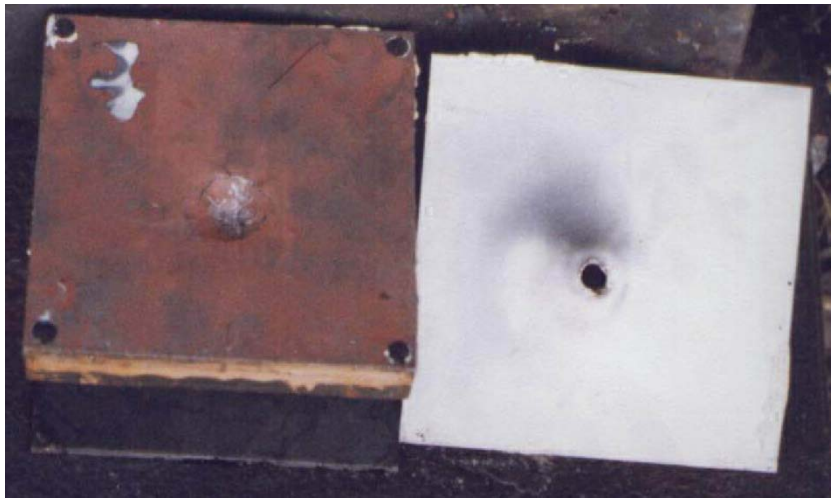
1. penetration with HEAT with penetration capacityof h = 300 mm RHA,
2. penetration with armor-piercing bullets with AP calibre d = 14.5 mm,
3. detection and recognizing by radar.

Result of firing of the CERAWA-1 cassettes with 12.7 mm AP bullets

a

reactive cassette which was not perforated after perforation of passive layer





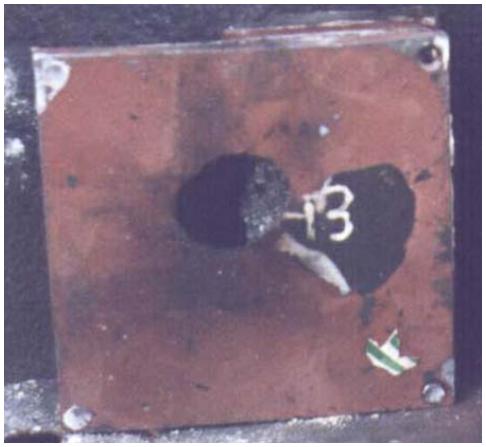
b

reactive cassette which was not perforated and perforated passive layer

Result of firing of the CERAWA-1 cassettes with 14.5 mm AP bullets

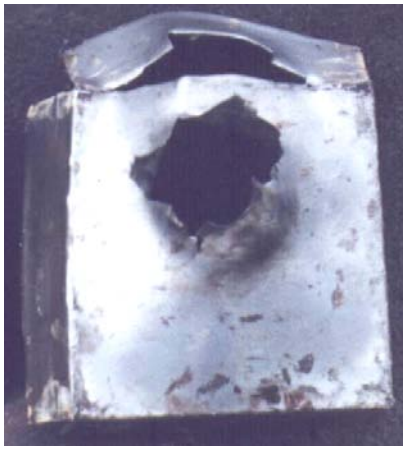
a

reactive layer which was not perforated



b

perforated reactive layer

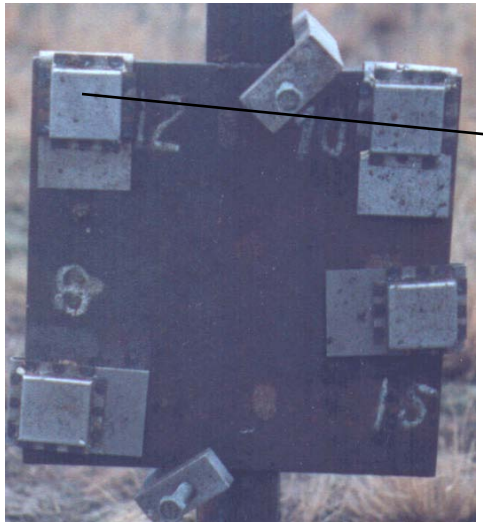


c

d

perforated and torn passive layer

Impact test of the CERAWA-1 cassettes with the fragments of 122 mm projectile

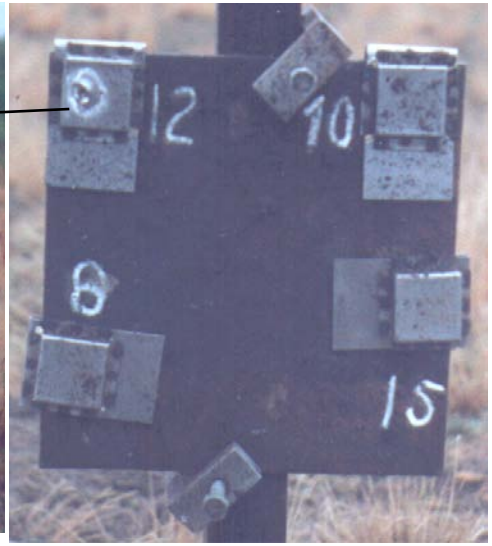


before initiation

steel plate
with cassettes
No: 6, 10, 12, 15

before initiation

projectile arrangement
in relation to cassettes



after explosion

hit result
of the CERAWA-1
cassette No 12
with the fragment
of 122 mm
projectile

The results of static test of the PG-7M + CERAWA-1 composite-reactive armor on the RHA plate with the thickness *b* = 10 mm

penetrated of the RHA plate

only deep deformation without penetration

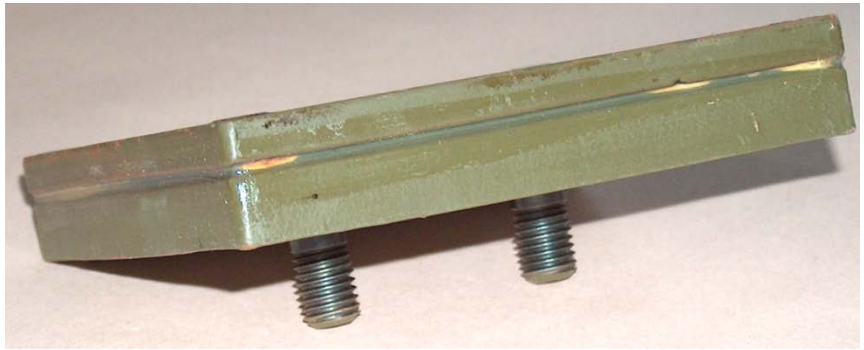
PG-7M with capacityof the RHA penetration *h* = 300 mm

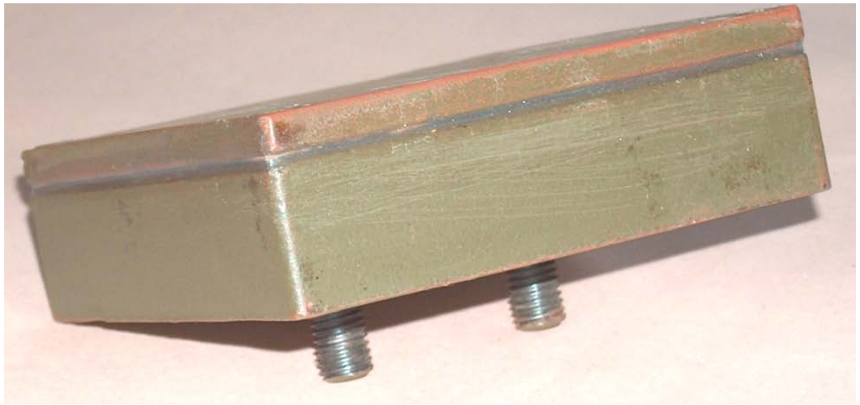
ERAWA-1 and ERAWA-2 cassettes

Marking:

ERAWA-1 - TX01 - 24-02 – WITU

ERAWA-2 - TX02 - 24-02 - WITU





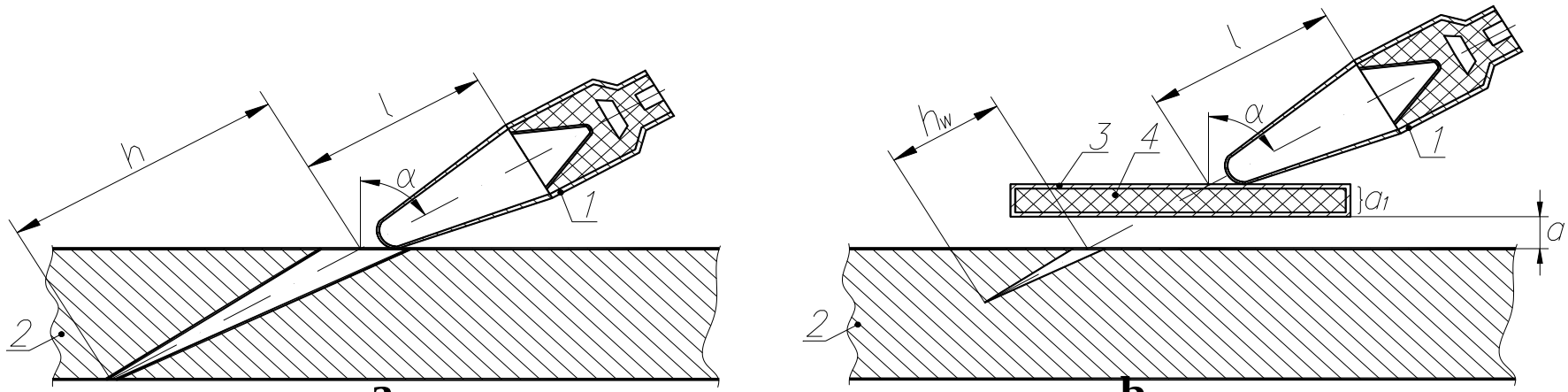
Easy and very fast to install
ERAWA-1 and ERAWA-2

Explosive reactive armor -
III generation

I. Parameters

1. **Size of the ERAWA-1 cassette - 150x150x26 mm**
2. **Size of the ERAWA-2 cassette - 150x150x46 mm**
3. **Mass of the ERAWA-1 cassette - 2.9 kg**
4. **Mass of the ERAWA-2 cassette - 4.7 kg**
5. **Number of the ERAWA-1 cassettes - 164 pieces**
6. **Number of the ERAWA-2 cassettes - 95 pieces**
7. **Protected area (glacis plate, hull, skirts) - 5.9 m^2**

Scheme of test of protection capacity of the ERAWA-1 cassette



a **b**

a - warranted capacity of penetration of the RHA with thickness *h*

b - depth of penetration *hw* in witness plate, protected with the ERAWA-1 cassette

1 - shaped charge before detonation

a_1 - the ERAWA-1 cassette before detonation

2 - the RHA

3 - casing of the ERAWA-1 cassette

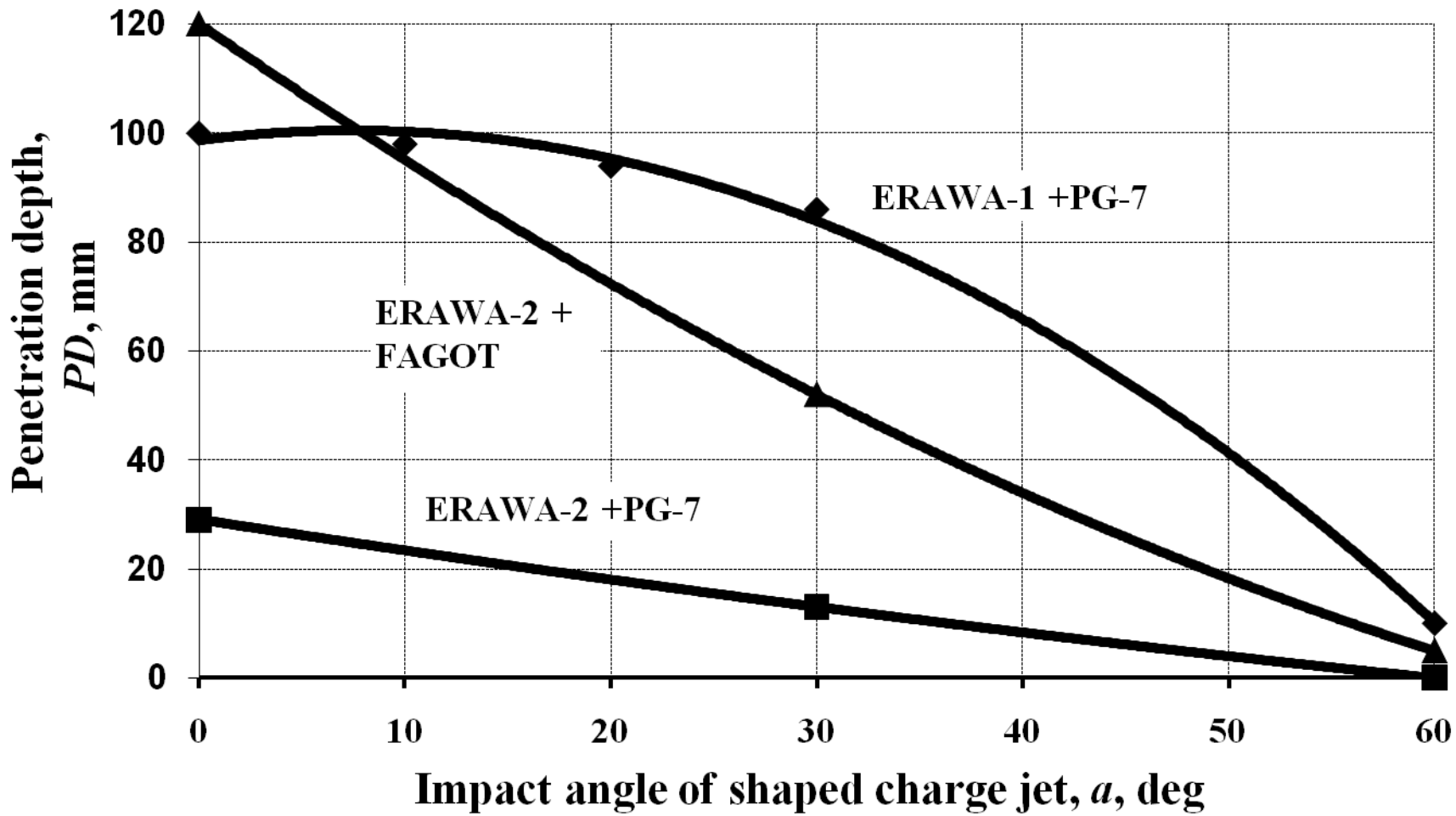
4 - explosive

h - warranted depth of the RHA penetration

hw - depth of penetration of the RHA protected with cassette

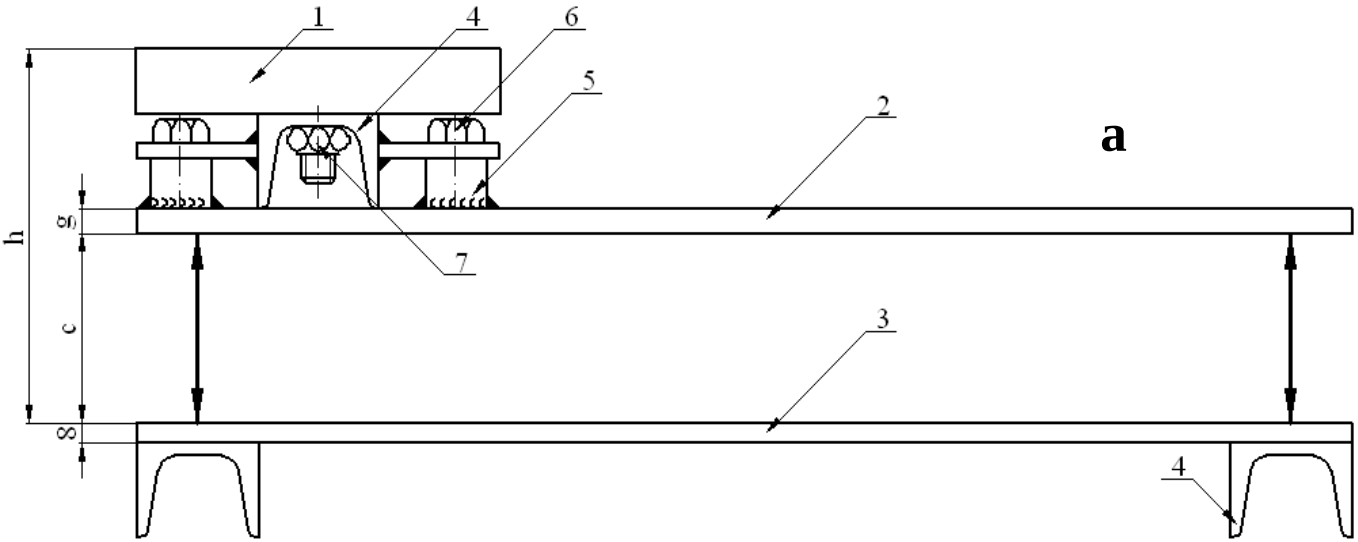
α - angle of shaped charge jet penetration of the ERAWA-1 cassette and the RHA

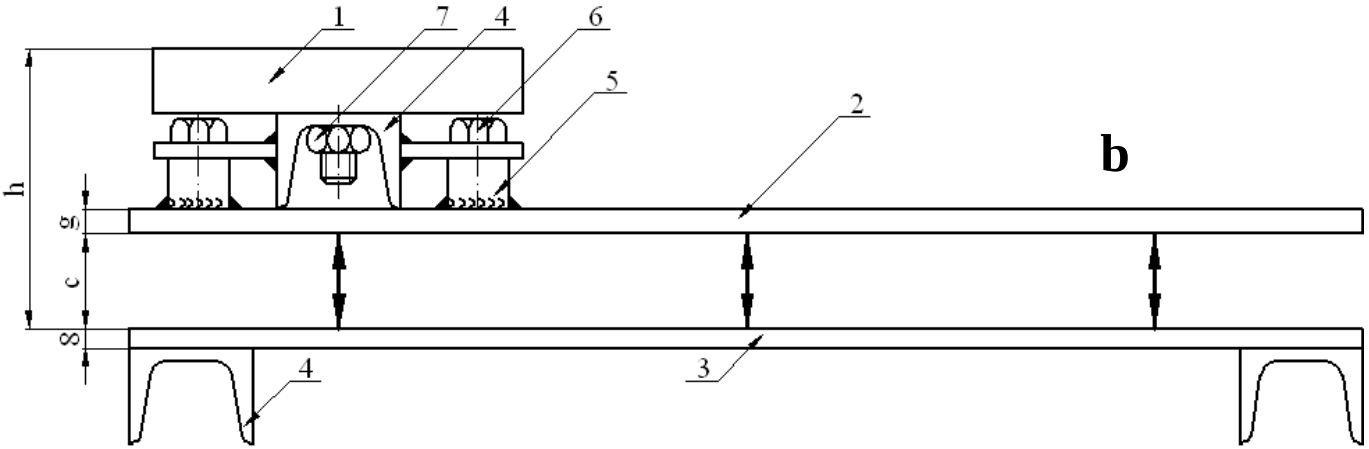
HEAT: PG-7, FAGOT + ERAWA



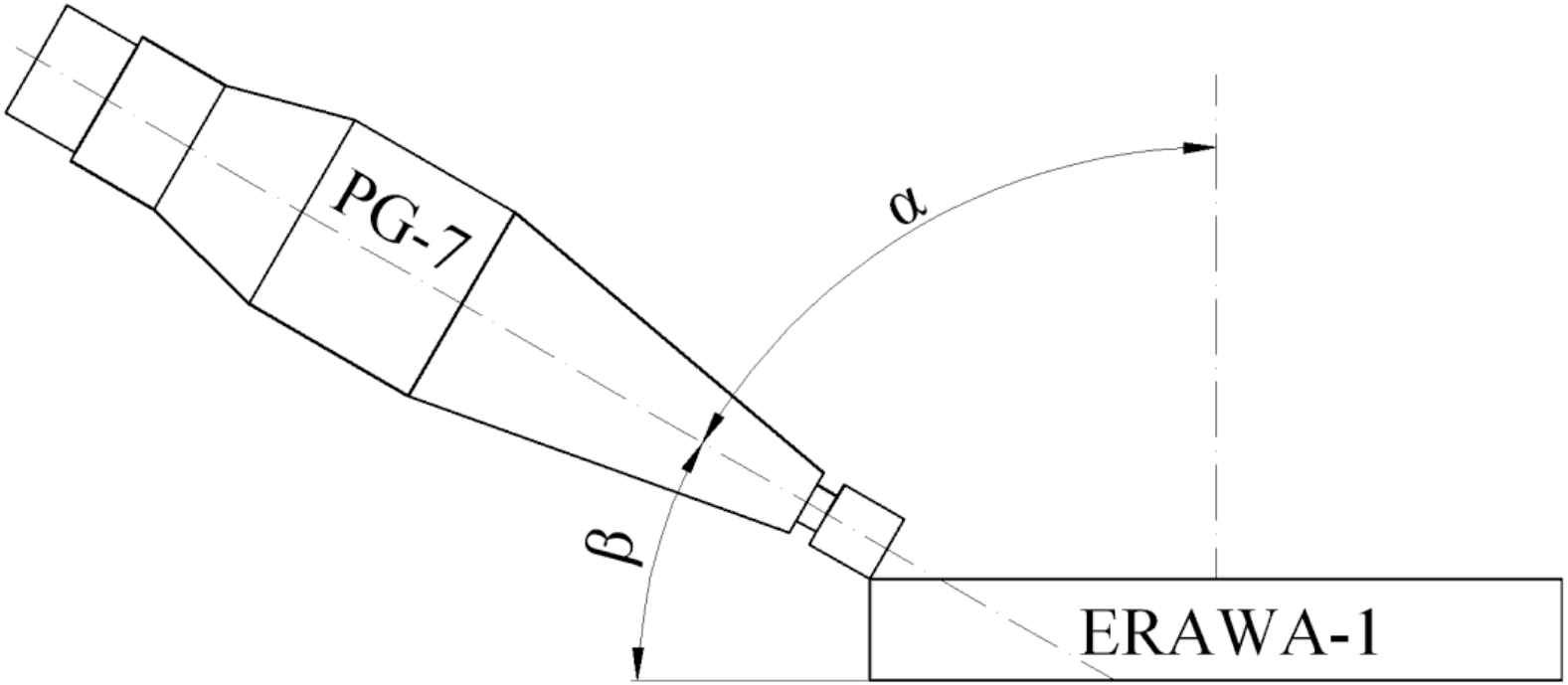
Penetration depth (*hw*) of the RHA protected with the ERAWA cassettes in the function of the impact angle (∝- in relation to normal to surface of cassette) of different jets of shaped charge projectiles

Reactive-passive panels supported in: two (a - version 1 and 2) and three (b - version 3) places



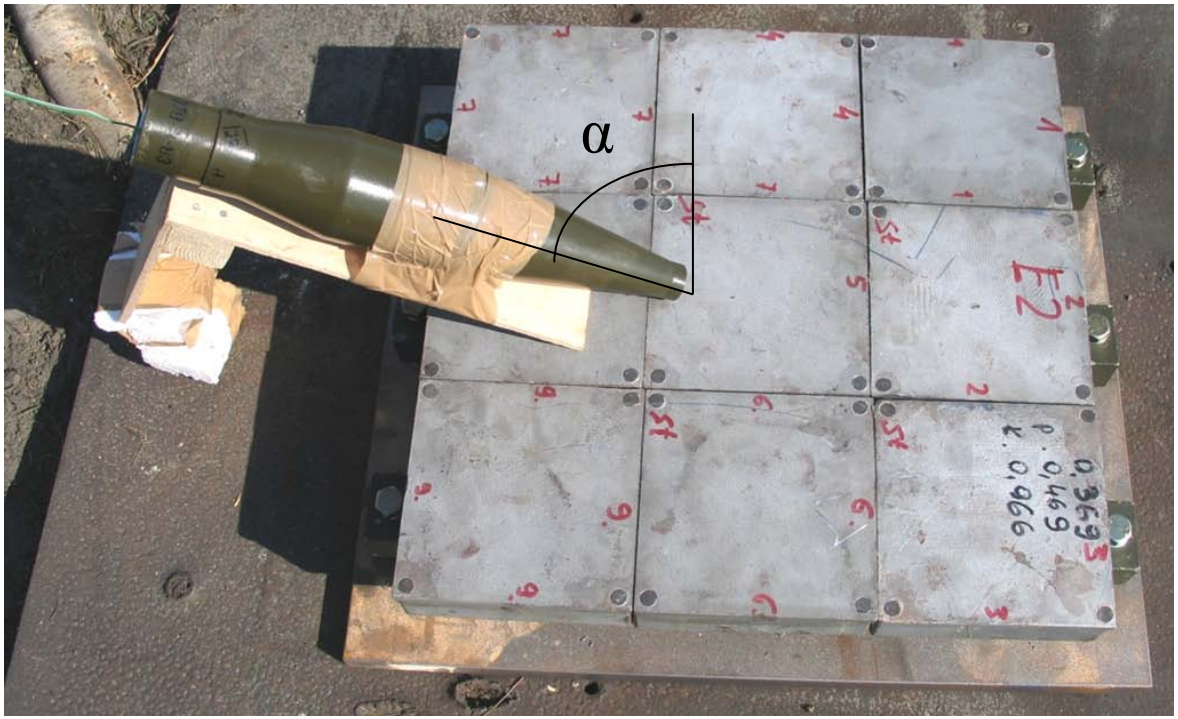


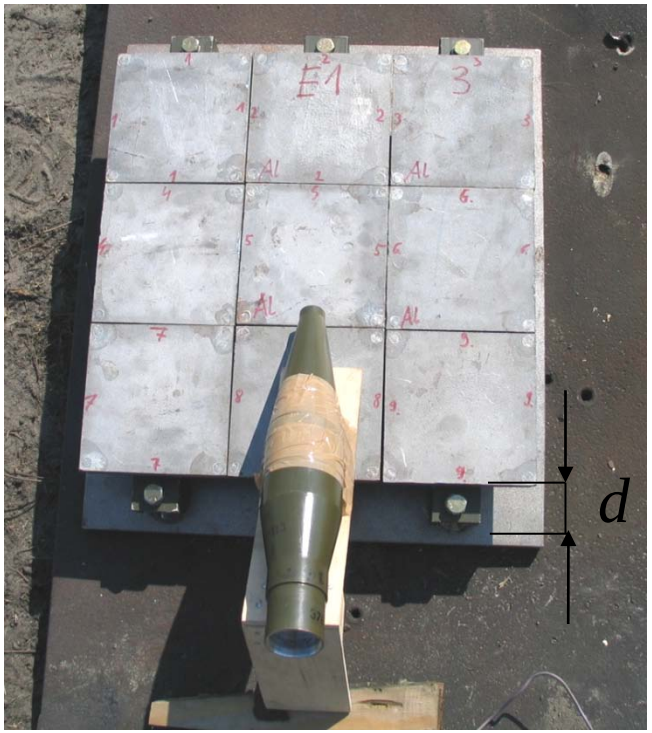
1 - ERAWA-1 cassette,
2 - steel plate 1,
3 - RHA witness plate 2,
4 - steel channel section,
5 - sleeve,
6 - screw,
7 - nut



The arrangement of the PG-7 shaped charge projectile in relation to the ERAWA-1 reactive cassette

Testing of the reaction of the ERAWA cassettes to the shaped charge jet of the PG-7WM projectile





Nine-element aluminium panel ERAWA-1 cassettes before initiation with the PG-7WM shaped charge projectile

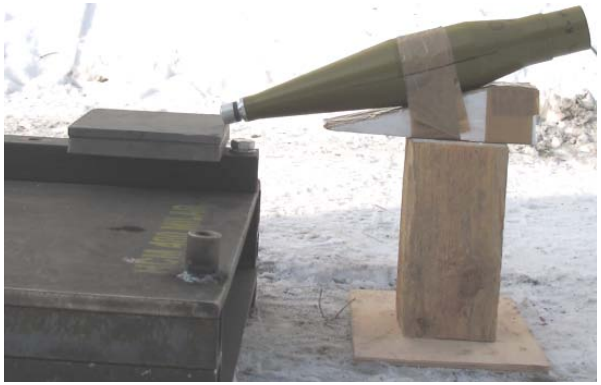
Reactive-passive panel - version 1

Parameters of panels of passive-reactive armors

No of panel / No of variant	Setting angle of PG-7 projectile in relation to normal to the surface of ERAWA-1 cassette, deg	Material of plate 1	Surface mass of panel, *m*, kg/m^2
1/1	72	RHA	227
2/1	60	RHA	227
3/2	72	St3	211
4/2	60	St3	211
5/3	72	RHA	221
6/3	60	RHA	221

Panels with the ERAWA-1 cassettes from aluminium alloy before and after the initiation of the PG-7 projectile

The PG-7 projectile at angles of α from normal to the cassettes:



a

a - panel 1, α=72

b

lack of copper trace on witness plate 2 (panel 1)

c

panel 2, α=60

d

DP=1 and copper trace on witness plate 2 (panel 2)

Panels with the ERAWA-1 cassettes from aluminium alloy before and after the initiation of the PG-7 projectile

The PG-7 projectile at angles of α from normal to the cassette:

a

panel 3,
α=72
DP =4.5 mm
copper trace on
witness plate 2

b

panel 4,
α=60
DP=8 mm
perforation
of witness plate 2

c

panel 5,
α=72
copper trace
on witness plate 2

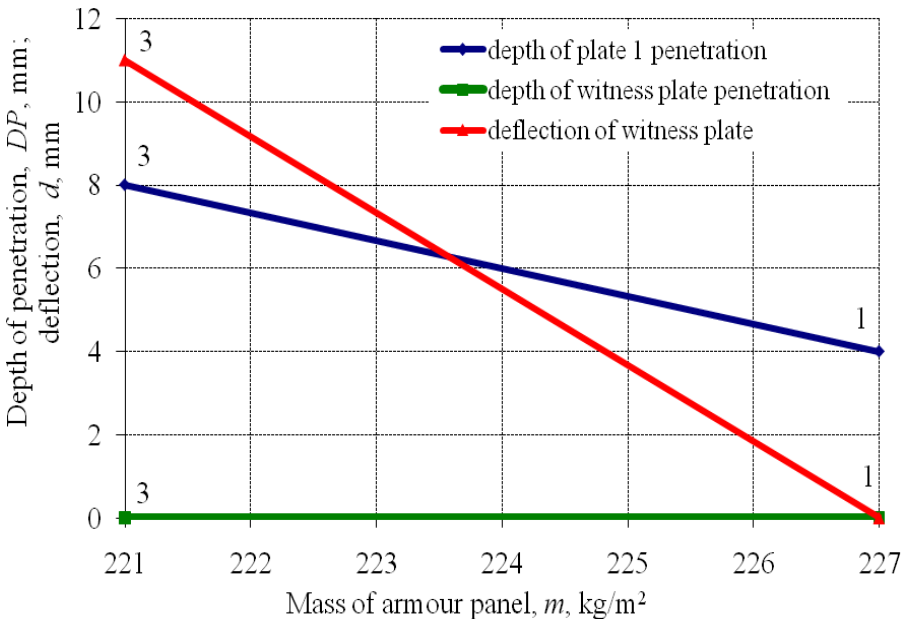
d

panel 6,
α=60
DP=2 mm and
copper trace on
witness plate 2

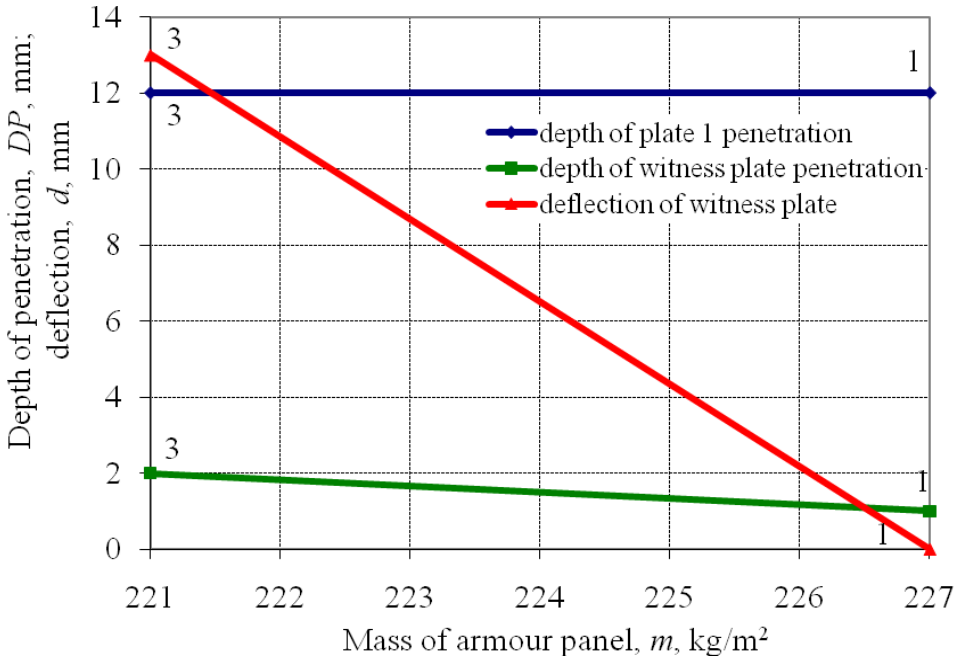
Results of firing of panels of passive-reactive armors with the use of the PG-7 projectiles

No of panel / No of variant / setting angle of PG-7, α, º	Material of steel plate 1 / penetration depth of RHA plate 2 (witness), *DP*, mm	Sizes of holes in RHA plate 2 (witness), *a* x *b*, mm		Deflection of RHA plate 2 (witness), *d*, mm
		inlet	outlet	
1 / 1 / 72	RHA / -	-	-	-
2 / 1 / 60	RHA / 1	~3x3	-	-
3 / 2 / 72	St3 / 4,5	51x13	-	8
4 / 2 / 60	St3 / 8	34x17	10x6	27
5 / 3 / 72	RHA / -	-	-	11
6 / 3 / 60	RHA / 2	~3x3	-	13

The depth of penetration



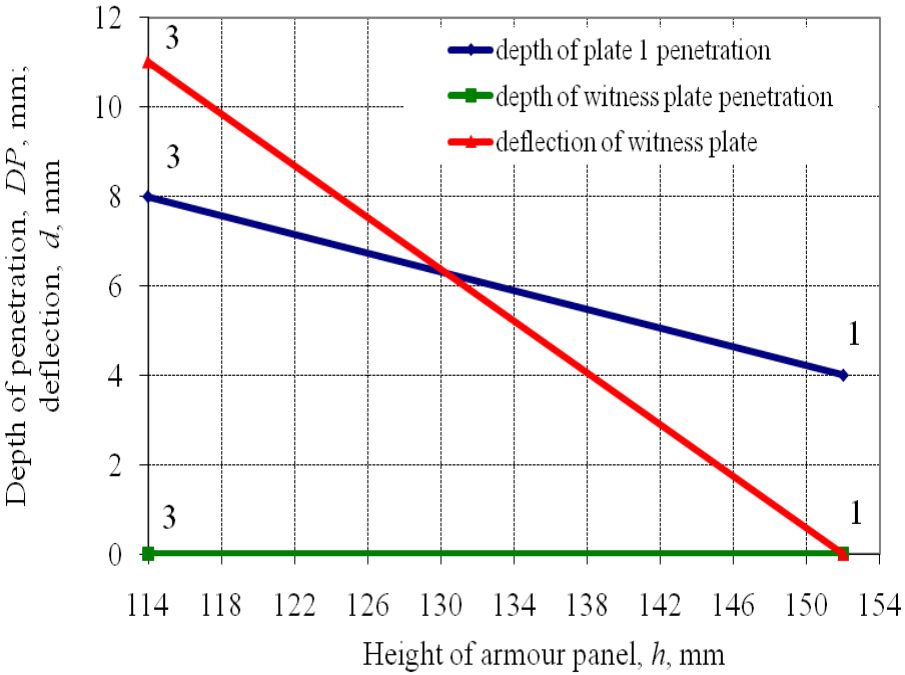
α=72



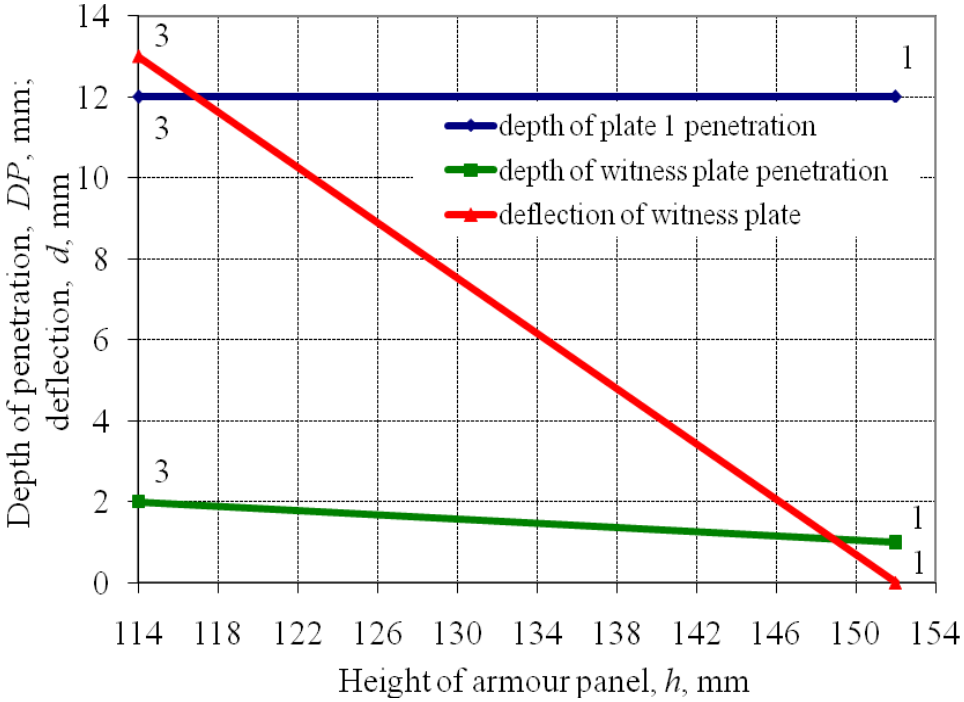
α=60

The depth of penetration of the steel plate 1, the RHA plate 2 (witness) and the deflection of the RHA plate 2 (witness): in the function of the mass of the armor panel for the angles of α=72 and α=60

The depth of penetration



α=72



α=60

The depth of penetration of the steel plate 1, the RHA plate 2 (witness) and the deflection of the RHA plate 2 (witness): in the function of the height of the armor panel for the angles of α=72 and α=60

Conclusions

The CERAWA-1 composite-reactive armor

1. The CERAWA-1 composite-reactive armor cassettes are the first solution of this type in the world. These cassettes are characterized by little thickness in relation to similar foreign cassettes and can be used on infantry fighting vehicle BWP-1 or on other light armored vehicles. As a result of firing tests of CERAWA-1 cassettes it can be stated that:

- Passive layer with ceramics in cassette of CERAWA-1 composite-reactive armor does not diminish the protection capacity of explosive of this cassette.
- CERAWA-1 cassettes protect RHA with thickness of b = 10 mm against perforation with 12.7 mm bullets of B-32 type with penetration capacity of RHA h = 20 mm and against PG-7 shaped charge projectiles with penetration capacity of RHA h = 300 mm.
- After the perforation of the reactive-passive armor on the surface of the hull of protected vehicle small craters with the depth of several millimeters and traces of dispersed copper of shaped charge jet of PG-7 can occur.

Conclusions

Reactive-passive armor with ERAWA-1 cassettes from aluminium alloy

2. The panel of the reactive-passive armor with ERAWA-1 cassettes from aluminium alloy can protect light armored fighting vehicles against the perforation of PG-7 projectiles hitting this armor at the angle of $60^o \leq \alpha \leq 72^o$ from normal to this armor.

3. After the perforation of the reactive-passive armor on the surface of the hull of the protected vehicle, some small craters with a depth of several millimeters and some traces of dispersed copper from the shaped charge jet of the PG-7WM can occur.

4. The best protection was provided by the reactive-passive armor in the version 1. The shaped charge jet did not pierce the plate 1 with the size of 500×500 mm, both for the angle of $\alpha = 72°$ and $\alpha = 60°$. There was also no deflection of the steel armor witness plate with the size of 600×500×8 mm as a result of the initiation of the explosive of the shaped charge jet projectile and the ERAWA-1 cassette.

Conclusions

Reactive-passive armor with ERAWA-1 cassettes from aluminium alloy

5. The protection against the perforation of the shaped charge jet was also provided by the reactive-passive armor in the variant 3. The deflections of the RHA witness plates (of 11 mm for the panel 5 and 13 mm for the panel 6) occurred for the $\alpha = 60$ and $\alpha = 72$ setting angles of the shaped charge jet PG-7WM projectile in relation to the normal external surface of the cassette. They were caused by:
   - smaller distances between the plates 1 and 2,
   - greater stiffness of the plate 1 due to its support in three places on the plate 2 (the witness one),
   - distances between the plates 1 and 2 in the variant 3 smaller than in the variants 1 and the variants 1 and 2.