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Research of protective multilayer titanium and aluminum system for cumulative jet

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EXPLOSIVE CLADDING OF METALS

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Introduction

This paper is the result of cooperation between research teams :

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   Department in Krupski Młyn, Zawadzkiego 1 str., 42-693 Krupski Młyn, PL

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Introduction

Research task :

1) **Ballistic tests**

The work presents the results of ballistic tests of protective capacity a layer system of titanium and aluminum (7 layers with a total thickness of 28 mm) of explosive charge influence.

The tested multilayer system was made by explosive welding in a single technological cycle appropriately with of alternating layers: Ti10mm + Al3mm + Ti3mm + Al3mm + Ti3mm + Al3mm + Ti3mm (manufacturer: ***Explomet***)

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Introduction

Research task:

The tests of Ti/Al - 28 mm type laminar system were done in two versions: (1)The material was perforated both from the side, which first layer was made of 10 mm thick titanium layer, and (2)from the side where titanium plate of 3 mm thickness constituted the first layer.

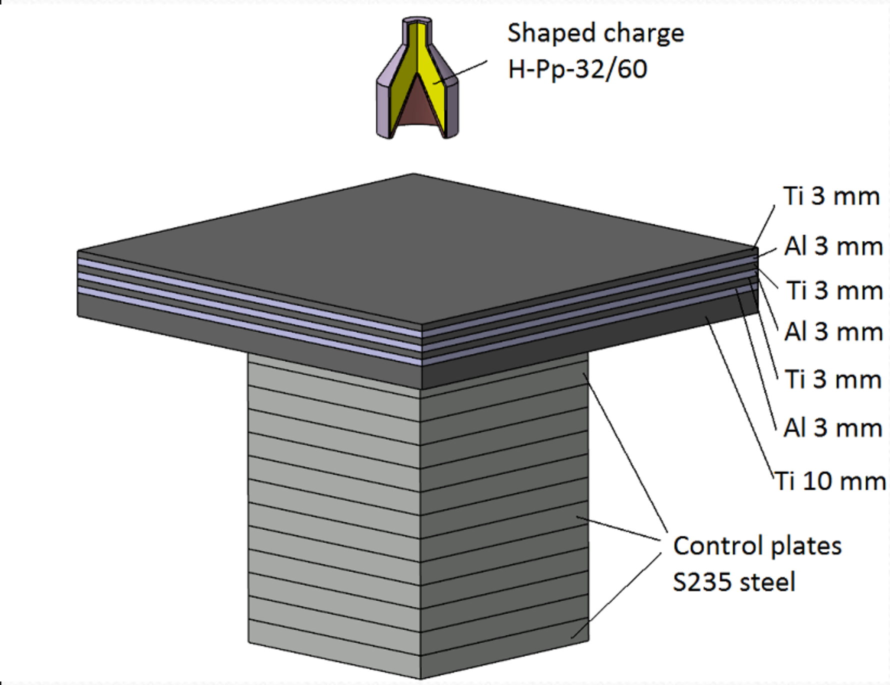
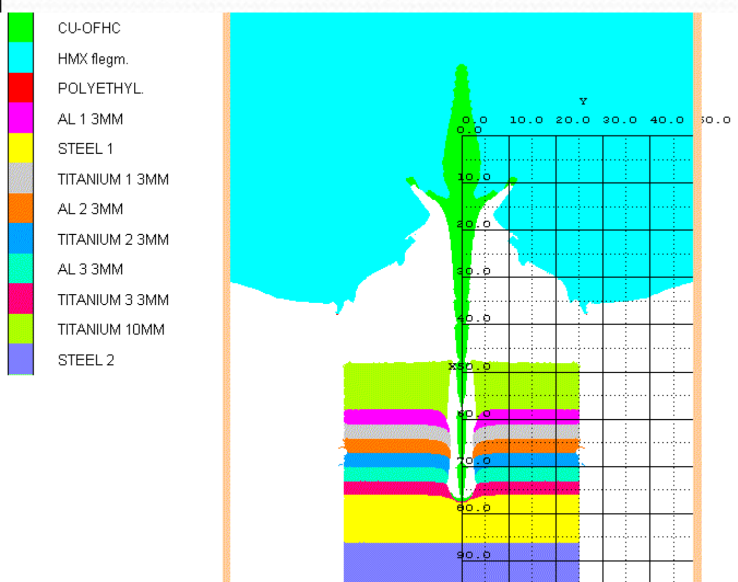


Fig. 1. Testing setup of multilayer Ti/Al.-28 mm system protective capacity

Introduction

Research task:

2) Construction and verification of the computer model
- for simulation and analysis of selected parameters of the test. The modeling was performed with use of specialized Autodyn 2D Academic Research software program.



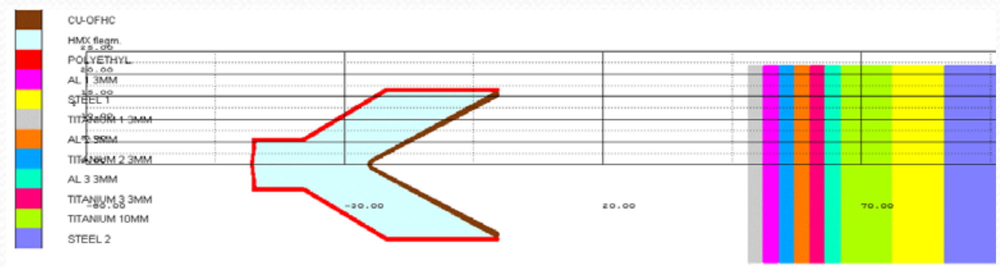
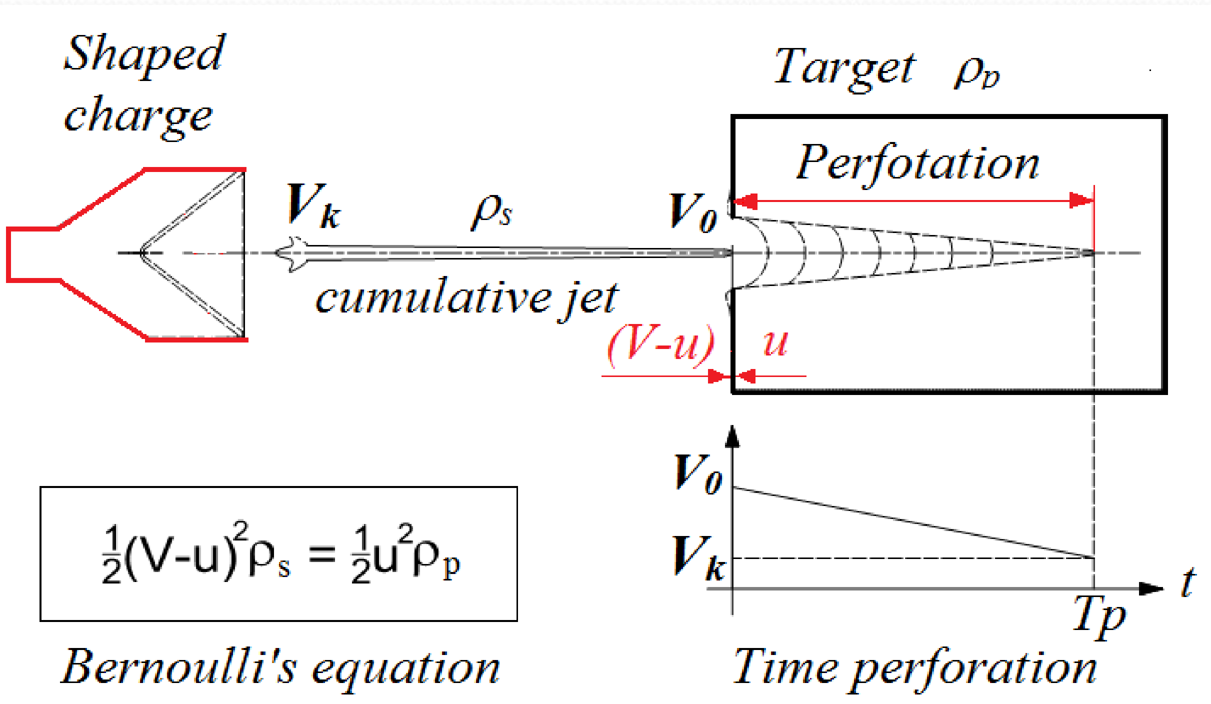


Fig. 2. Selected sequence of cumulative jet forming and 28 mm Ti/Al laminar barrier penetration, for the two arrangement of layers: Ti10Al3Ti3Al3Ti3Al3Ti3

Analytical model of penetrating barrier by cumulative jet



$$U = \frac{Vs}{1+\sqrt{\rho_P/\rho_S}}$$

$$U_{min} = \sqrt{\frac{2Rm}{\rho p}}$$

$$V_k = U\min * (1+\sqrt{\rho p/\rho s})$$

Fig. 3. Schematic representation of homogeneous barrier perforation by a classical cumulative jet - hydrodynamical model of the jet penetration

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Analytical model of penetrating barrier by cumulative jet

Tab. 1. Characteristics of barrier material

Material name	Density ρ_P [g/cm³]	Strength R_m [MPa]	Specific energy E_S * [J/cm3]
4140 steel	7.86	1030	4000
Water	1.00	-	20
L80 steel	7.86	620	3100
Concrete	2.20	37	800
S235 steel (standard control material)	7.8	300	2600

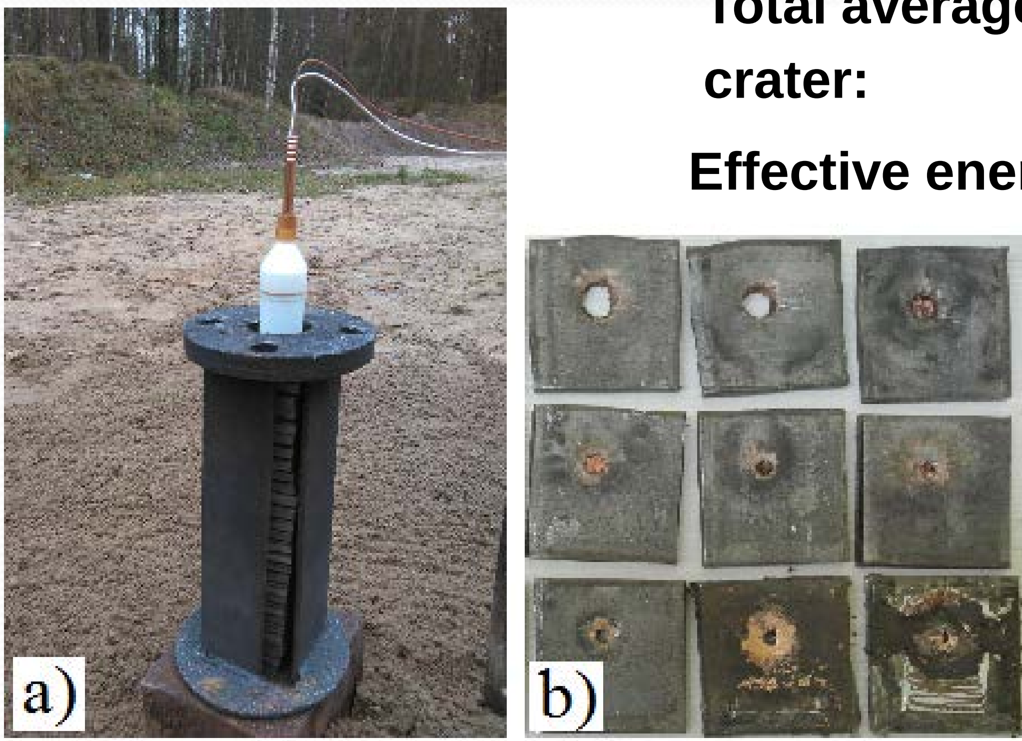
**Note:* *Specific energy for copper cumulative jet.*

It is possible to determine the effective jet energy E_{SK} by means of measuring crater volume V_{KR} in the material which we know of specific energy for barrier material E_s:

$$E_{SK} = V_{KR} * E_S$$

Experimental research

Control test of H-Pp-32/60 shaped charges



Total average volume of created crater: $V_{KR} = 2.605\ cm^3$

Effective energy of cumulative jet:

$$E_{SK} = E_S * V_{KR}$$

2600 [J/ cm³]* 2,605 [cm³] =

6773 [J]

E_S = 2600 J/cm³ is the specific energy for mild steel (S235 – in table 1)

Fig. 4. View of prepared setup for control test of shaped charge (a) and view of plates after control test (b).

Experimental research

Control test of H-Pp-32/60 shaped charges

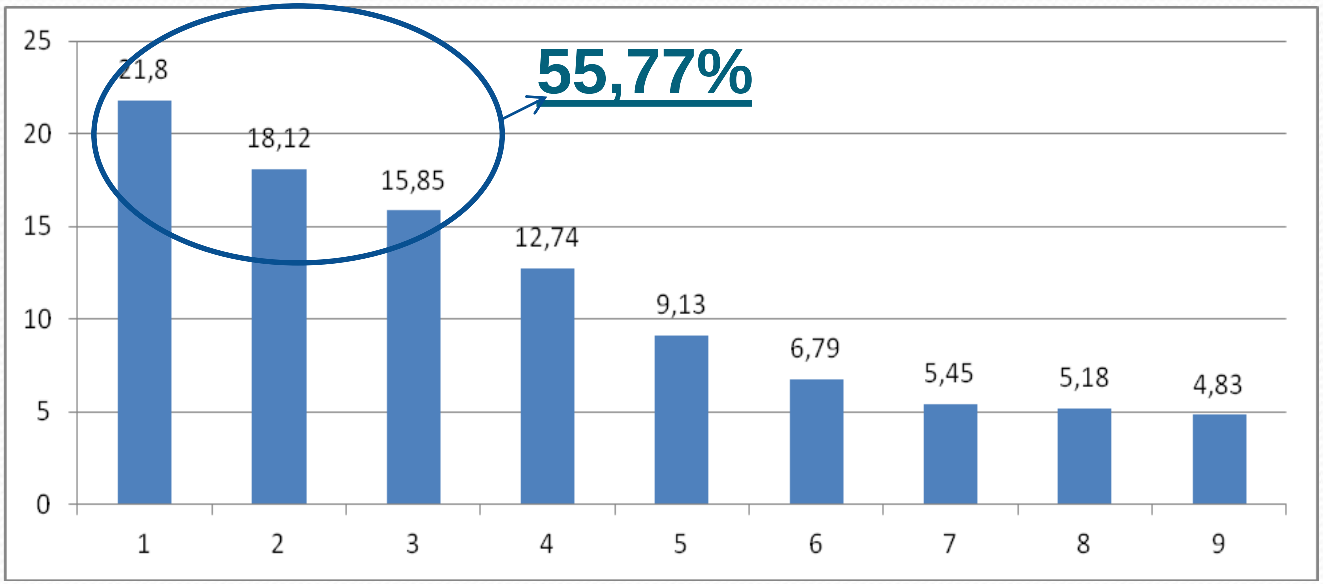


Fig. 5. Percentage distribution of energy cumulative jet in stack control (steel S235),

Classic cumulative jet largest flow of energy has in its front part.

More than half of their energy (approx. 55%) loss in the first stage of the three plates (30 mm).

Experimental research

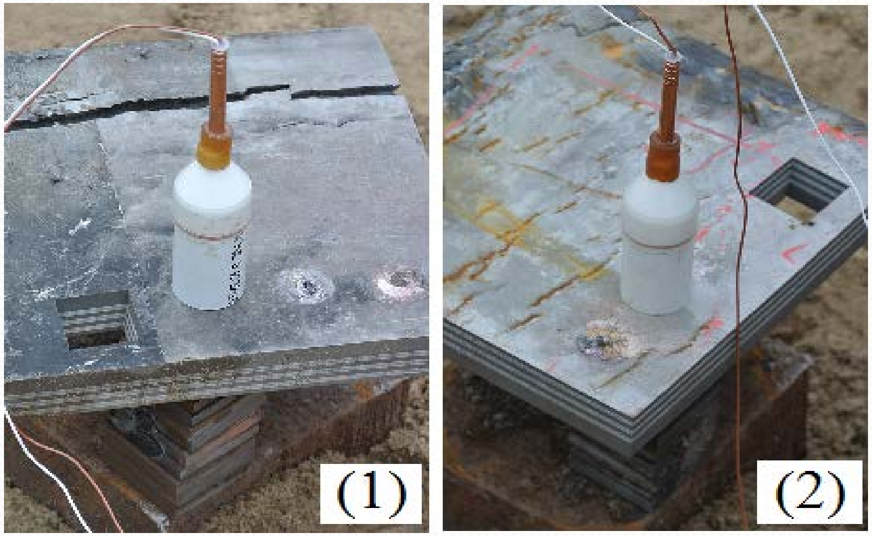


Fig. 6. General view of experimental setup

(1) Arrangement of the layers: Ti10Al3Ti3Al3Ti3Al3Ti3

(2) Arrangement of the layers: Ti3Al3Ti3Al3Ti3Al3Ti10

Multilayer protective system under testing was placed on the stack of control plates, 10 mm thick each, made of S235 steel.

In the static experiments, small caliber, H-Pp-32/60 type shaped charges were shot at 48 mm distance (that is, at distance equal to 1.5 of liner diameter).

Experimental research

Fire-ground testing of penetrating ability with cumulative jet of titanium/aluminum multilayer material (Ti/Al - 28mm type)

Fig. 7. Cumulative jet action towards 10 mm Ti layer

Fig. 8. Cumulative jet action towards 3 mm Ti layer

Protective effectiveness of Ti/Al.-28 mm plater, for cumulative jet corresponds to protective effectiveness of 6 steel plates (60 mm).

Protective effectiveness of Ti/Al.-28 mm plater, for cumulative jet corresponds to protective effectiveness of 4 steel plates (40 mm).

Experimental research

Fire-ground testing of penetrating ability with cumulative jet of titanium/aluminum multilayer material (Ti/Al - 28mm type)

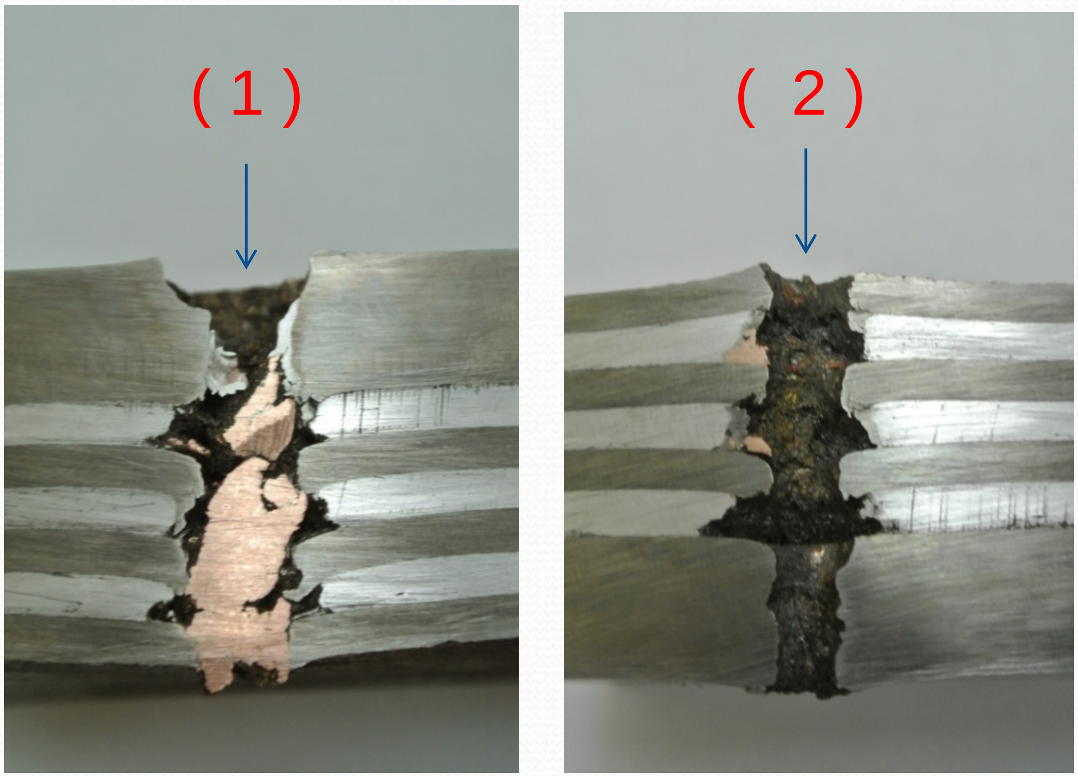


Fig. 9. Metallographic holes shown in one scale.

Visible copper is trapped cluster of inserts cumulative load in the hole test No. 1.

The diameters of the holes in the zone of aluminum are much higher than in titanium.

The volume of the hole is much greater for the test No. 1 (excluding the cooper insert residue).

(1) - Cumulative jet action towards 10 mm Ti layer

(2) - Cumulative jet action towards 3 mm Ti layer

Computer model of cumulative jet penetration through titanium / aluminum multilayer material

Selected examples of simulation and analysis (Ansys 2D)

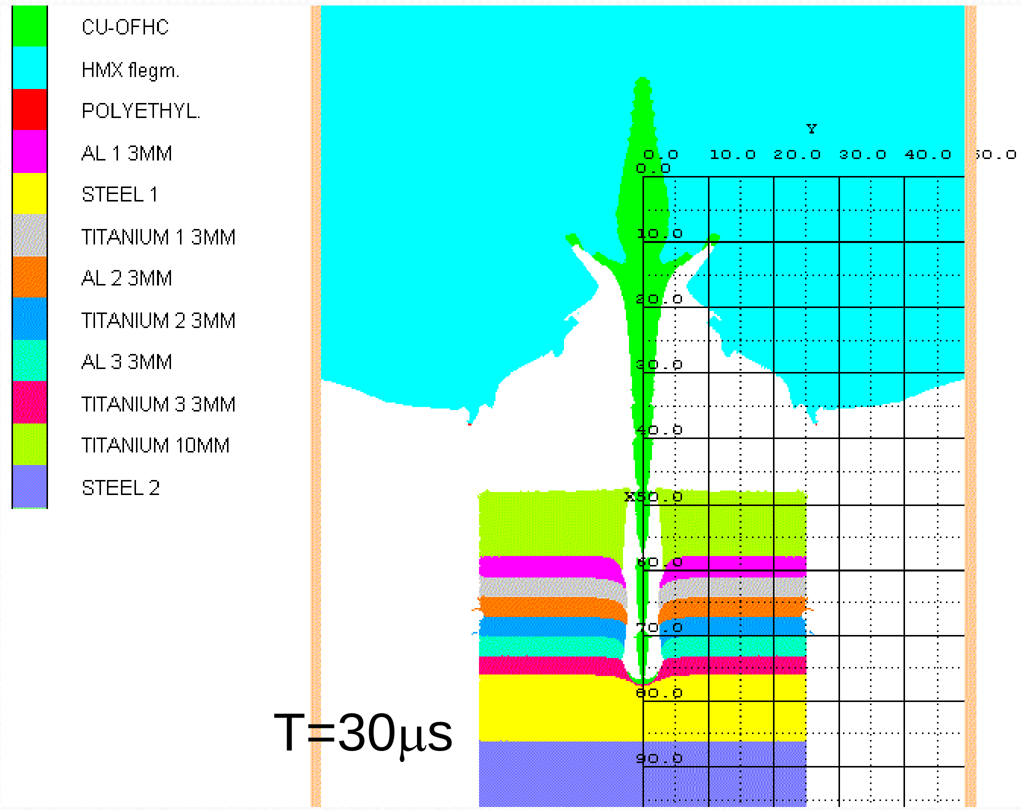


Fig.10.

Model 1. System layers: Ti10Al3Ti3Al3Ti3Al3Ti3.

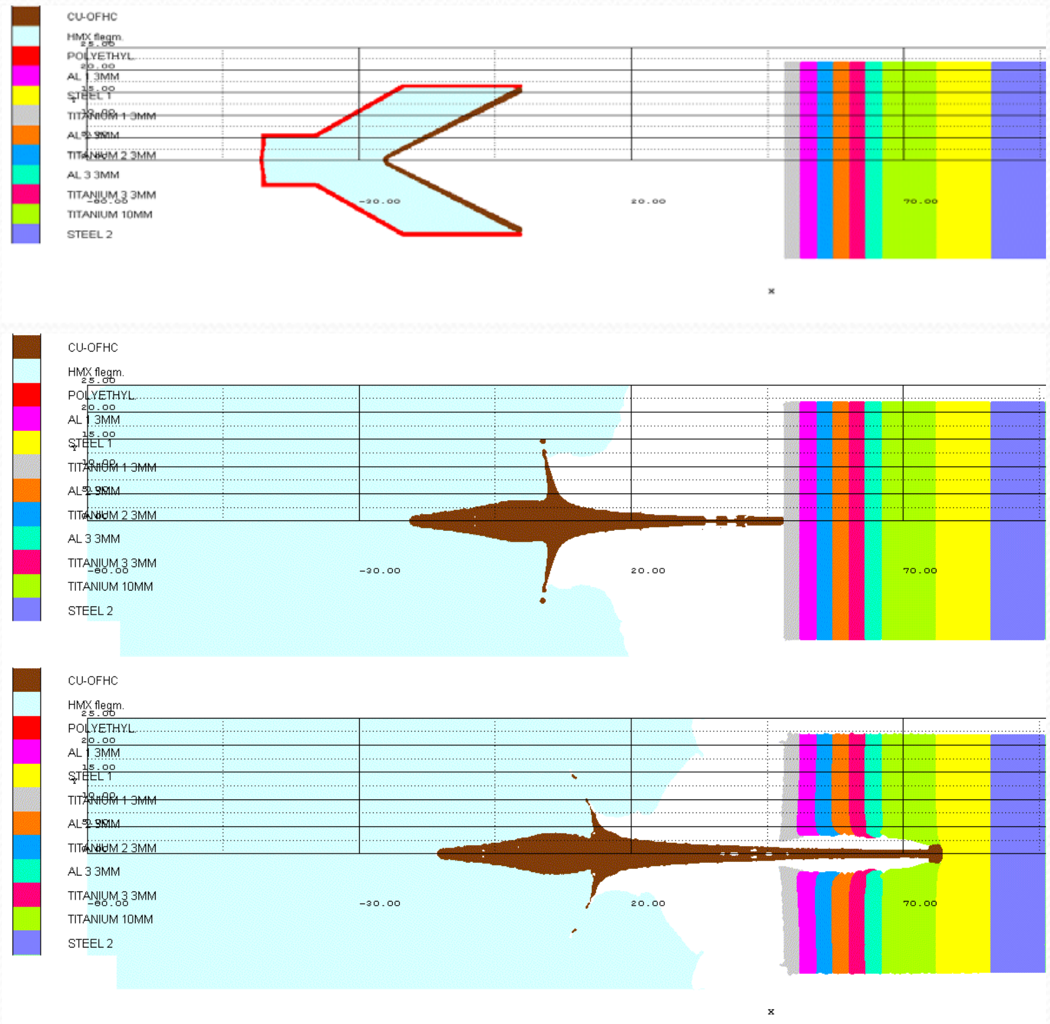
The selected sequence of formation of cumulative flow and septum piercing layered Ti / Al-28mm:

Breakthrough time of the multilayer of Ti/Al-28mm is:

Tp = approx. 12 µs.

Computer model of cumulative jet penetration through titanium / aluminum multilayer material

Selected examples of simulation and analysis (Ansys 2D)



T=0

T=18μs

T=30μs

Fig. 11.

Model 2. System layers: Ti3Al3Ti3Al3Ti3Al3Ti10

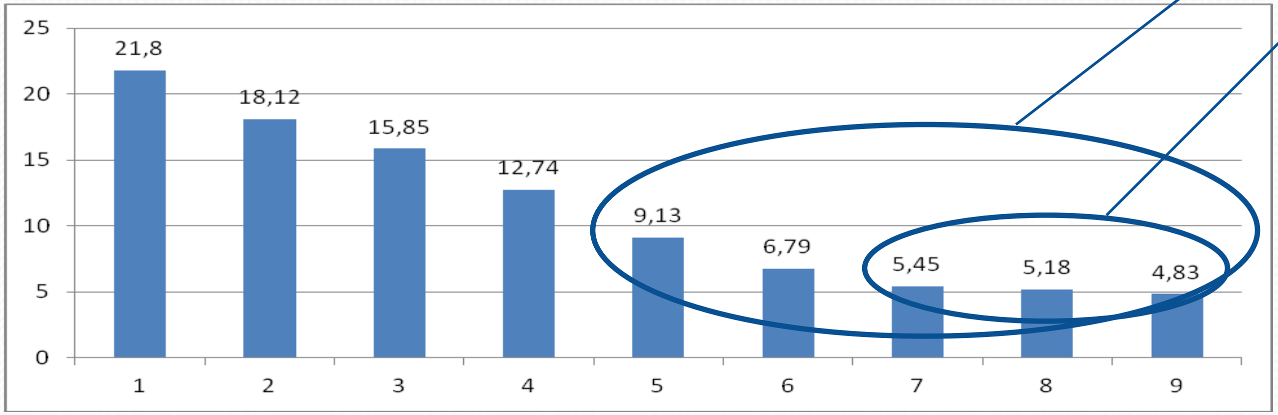
Breakthrough time of the multilayer of Ti/Al-28mm is:

Tp = approx. 12μs.

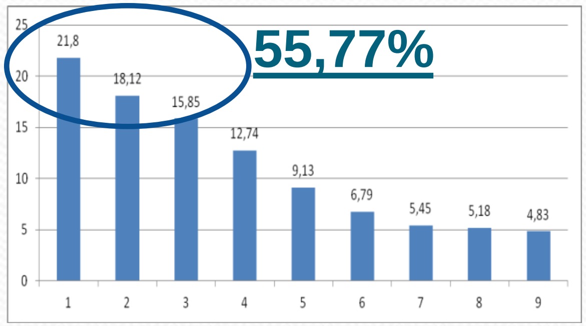
ANALYSIS OF RESULTS

Tab. 2. . A summary distribution of energy in the tests of penetration cumulative jet in composite material Ti / Al-28mm

Designation test material / test system	Distribution cumulative jet energy [%]	
	Tested composite Ti/Al-28mm	Standard control material - S235 steel
Test 2: Ti3Al3Ti3Al3Ti3Al3Ti10	68,62	31,38
Test 1 : Ti10Al3Ti3Al3Ti3Al3Ti3	84,54	15,46



SUMMARY



Analysing the distribution of the energy wasted by the flow of cumulative jet from shaped charge H-Pp-32/60 in the stack control (plate 10 mm S235), it was found that the highest levels of energy contained in the forehead stream. Eg. approx. 56% of its energy flux is losing to beat the first three plates (30 mm) from 9 pcs. of the stack control.

The tests gave the mass ratios protective test unsymmetrical a multi-layer of Ti / Al thickness of 28 mm at 50% or 70% of the protective control material (steel S235).

More effective protection against jet cumulative shows a system under fire from the side of the layer of Ti 10mm.

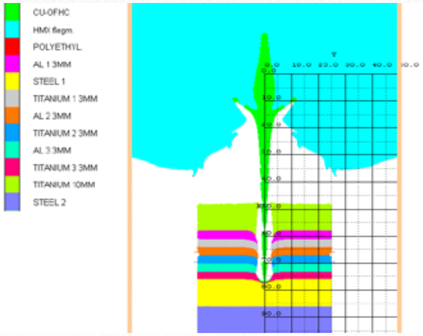
Breakthrough time of the layer of Ti / Al 28 mm is approx. 12 μs.

SUMMARY

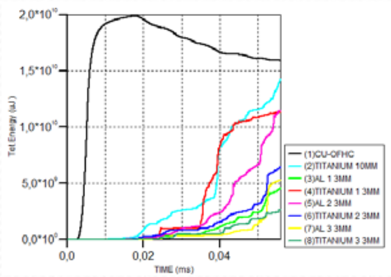
The use layer structures of protective systems (eg. such as studied in this work light layered structure of Ti / Al) allows to increase the degree of protection and reduce their weight (relative to the steel system).

The first protective layer systems before the cumulative flow should provide the highest energy absorption capability rapid flow front (passive systems), or result in strong disturbance of the head part stream in the active systems.

SUMMARY



For the adopted methodology of protective systems layered on the cumulative effect of the stream has been built and experimentally verified computer model



Verified computer model allows you to perform a series of analyzes of issues, eg. for a variety of other materials and layer systems or other geometric arrangement of shooting (eg. at a different angle of attack stream cumulative).

Acknowledgements

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Narodowe Centrum Badań i Rozwoju

Project nr PBS2/A5/35/2013 titled:

”New, advanced Al-Ti layered materials with enhanced ballistic resistance for aviation and space constructions”;

Realization period 2013-2016.

Thank you for your attention

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