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TECHNICZNE WYROBY WŁÓKIENNICZE

Czasopismo poświecone jest zagadnieniom technologii , stosowania i oceny technicznych wyrobów włókienniczych i kompozytów, szczególnie z zakresu ochrony zdrowia i życia (środki opatrunkowe, specjalistyczna odzież ochronna dla hutników, górników, strażaków, marynarzy, sprzęt ratunkowy – tratwy, pasy, liny spadochrony, kamizelki kuloodporne, itp.), ochrony środowiska (tkaniny i włókniny do filtracji powietrza, wody, ścieków, gorących gazów, itp.), budownictwa, budowy statków i okrętów, samochodów, samolotów, helikopterów, jachtów, łodzi, wagonów kolejowych, taśm transportowych, przemysłu zbrojeniowego.
Zamieszczone w czasopiśmie publikacje (artykuły naukowo-techniczne i informacje) omawiają tak osiągnięcia krajowe, jak i światowe. Czasopismo zalecane jest przede wszystkim dla zakładów wytwórczych i wszystkich użytkowników technicznych wyrobów włókienniczych.

TECHNICAL TEXTILES

The journal is devoted to the problems of technology, application and evaluation of technical textiles and composites, especially those concerning: protection of human health and life (dressing materials, specialist clothing for metallurgists, miners, firemen, seamen, rescue equipment – rafts, belts, ropes, parachutes, bulletproof vests, etc.); environment protection (woven and nonwoven fabrics for the filtration of air, water, sewage, hot gases, etc.); civil engineering, construction of ships and warships, cars, aeroplanes, helicopters, yachts and boats, railway wagons, conveyor belts and for armament industry.
The materials published in the journal (scientific and technical papers and information) discuss both Polish and world developments. The journal is recommended first of all for manufacturers and all users of technical textiles.

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ABSTRACTS

V. A. Grigoryan, I. F. Kobylkin, V. M. Marinin, I. A. Bespalov – JSC „NII STALI", Moscow, Russia: **Ballistic Resistance of Textile Armor Impregnated with Shear Thickening Fluid**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 12

In the systematized form a number of problems is discussed related to ballistic resistance of textile armor impregnated with shear thickening fluid (STF); as STF high-concentrated suspensions of sub-micron particles and nano-particles were used. Physical models of high-speed interaction of bullets and fragments with STF-impregnated textile armor are presented; where possible quantitative relationship and computational techniques for the "liquid armor" ballistic properties evaluation are described.
Based on notions of different mechanisms of the impactor energy absorption by textile armor packs under high-speed and low-speed interaction the conclusion was made about the highest efficiency of STF-impregnated textile armor when used against such threats as spike and as a back layer of combined fragmentation- and bullet-resistant textile armor packages

A. Bartczak, K. Fortuniak, E. Maklewska, E. Obersztyn, M. Olejnik, G. Redlich: **Camouflage as the Additional Form of Protection During Special Operations**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 15

Despite the increasing dominance of electronic detection devices, one of the most efficient ways to ensure safety and protection of people and equipment are activities associated with camouflage aimed at hiding these „objects" from the sight and the equipment of the opponent.
The paper presents a definition of camouflage and its types. It also discusses the requirements for various groups of camouflaging products gathered on the basis of the applicable standards in force and other regulations in this regard. The paper contains examples of state-of-the-art solutions for multidimensional products, which ensure camouflage against detection devices within the range of visibility, near infrared, thermal and radiolocation. It also presents the newest achievements in the field of camouflage patterns, as well as methods of attaining camouflage effects applied by global manufacturers of military products.

Jadwiga Polak, Iwona Kucinska, Grazyna Grabowska, Joanna Blaszczyk, Marcin H. Struszczyk: **Bullet-Proof Vests with the Ballistic Inserts Based On Fibrous Composites**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 95

Several design solutions of bullet-proof vests featuring improved ballistic resistance within area of hard inserts based on fibrous composites, recently developed by the „MORATEX" Institute were presented. They are mainly dedicated for the officers of services subordinated to the Ministry of Interior and Administration. They consider latest world-wide trends of developing, regarding started works within the development PO IG (Innovative Economy National Cohesion Strategy) project No.01.03.01-10-005/08 "Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites". The composite insert for the vests and some vest designs are one of product groups being developed within the project.
Their modern designs were presented and discussed, along with the results of metrological tests of physical and mechanical parameters of materials as well as the ballistic tests results. The initial presumptions for developing Polish inserts based on the fibrous composites were stated.

A. P. Antipov, V. A. Grigoryan, A. I. Egorov, A. V. Potapov – JSC "NII STALI", Moscow, Russia: **Improvement of Soldier Survivability by Signature Management**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 25

R&D in the field of ballistic protection of an individual soldier have led to creation of personal protection equipment. Modern body armor allows substantial reduction of personnel losses from small arms.
Unfortunately, it is not possible to ensure complete protection of the soldier by only those technical solutions which reduce threat penetration into the body armor, since the power of weapons is constantly increa-

sing and non-lethal ammunition has appeared; but the acceptable weight of body armor is limited.
The paper presents the results of development of such components of soldier's equipment which improve his protection by reducing his signature for visual, night vision, thermal and radar reconnaissance.

W. Blaszczyk: **Composite Ballistic Shields**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 28

Institute of Security Technology "MORATEX", as a unit subordinated to the Polish Ministry of Interior and Administration, carries on the works related to developing of products that provide security to the Ministry Services, such as Police, Border Guard, Government Protection Bureau and Fire Brigades.
One of such products is composite ballistic shield – the equipment dedicated for direct protection of health and life of the officers taking part in operational actions.
The presentation will present the ballistic shields designs from worldwide manufacturers. The design assumptions for the ballistic shield have been prepared in „MORATEX" Institute within the frame of research project "Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".
The aspects of: ballistic shield design, ballistic resistance levels, methods of their assaying, screening of materials for designing of the ballistic jacket and the additional equipment parts shall be discussed. The presentation will present important parameters of manufacturing the fibrous composites – a material particularly preferred for applications in making-up.
Keywords: ballistic shields, fibrous composites, ballistic tests

Project No POIG.01.03.01-10-005/08: Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites, realized in the range of the Innovative Economy Operational Programme (IE OP): Priority Axe 1. Research and developing of modern technologies, Activity 1.3. Supporting the R&D projects dedicated to enterprises, accomplished by scientific bodies , Sub-activity 1.3.1. Development projects

V. A. Grigoryan, A. I. Egorov, V. A. Khromushin, A. V. Sherbakov, V. P. Yankov – JSC „NII STALI", Moscow, Russia: **Improvement of Personal Protection Systems by Using New Materials**

The paper describes application of new materials in personal protection systems, i.e. ballistic helmets.
The materials are:
- Aramid fabric with improved ballistic properties;
- Light aluminium alloys;
- High-modulus polyethylene;
- B_4C-based ceramics made with nano-powders.

The values of weight reduction and ballistic resistance increase are obtained.

A. Wisniewski, L. Tomaszewski – Military Institute of Armament Technology, Zielonka, Poland: **Computer Simulation of AP Projectile Penetration Into RHA**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 32

The process of penetration of B-32 type 12.7 mm armour piercing bullet into one-layered and two-layered of 20 mm thickness RHA armour, is presented. Analysis was carried out with AUTODYN 5 programme and with the use of the SPH method. Projectile and armour strains occurring in the subsequent time period for seven variants with different material parameters of projectile and dimensions of armour, are shown. The influence of different material parameters of the projectile on its capability of armour penetration is presented here. It was proved that two times higher yield stress of projectile material causes almost three-fold improvement of depth of penetration and the bulging of the armour. In its initial phase of the projectile penetration into armour (0÷0.04 ms) the kinetic energy of the projectile rises together with the decrease of yield stress of its material. Computer simulation showed that capability of protection of one-layered RHA armour is higher than in case of two-layered RHA armour.

V. M. Marinin, I. F. Kobylkin, M. E. Bulanova – JSC „NII STALI", MGTU named after N. E. Bauman, JSC KShF „PeredovayaTextilshitsa": **Specific Features of Fragment Simulator Interaction With Different-Size Textile Armor Packages**

Textile armor is subjected to different types of ballistic tests: for bullet and fragment resistance and for energy capacity [1-6]. Difference in ballistic resistance values was observed in tests on different backing materials [1, 7]. The experiment was aimed at evaluation of the difference in ballistic resistance of loosely hanging textile packages of different sizes. The sizes differed from 4x4 cm to standard ballistic test target size of 24x24 cm. The best suited test method was evaluation of energy capacity, i.e. the impactor energy which is used for penetration of different-size targets at given interaction conditions. As a result of the experiment the quantitative characteristics of the energy capacity of different-size textile packages were evaluated and differences were revealed in the fragment simulator (a steel ball with weight of 1.03 grams and diameter of 6.35 mm) energy consumption mechanism of relatively small-size packages (4÷10 cm) and larger-size packages (>12 cm).

B. M. Makhov, A. A. Artsruni, S. A. Gladyshev, L. A. Tsurgozen, V. P. Yankov – JSC „NII STALI", Moscow, Russia: **Main Structural Armor Component – Metal – from the Point of View Latest Scientific Concepts**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 42

The paper presents general characteristics of the main title metals of iron, titanium and aluminium alloying systems. The nature of their comparative metal characteristics is shown against the background of latest concepts of the periodic system of elements. Examples of particular cases of using the above metals in armored vehicle hulls and body armor are provided.

A. L. Gavze, E. N. Petrova, S. Y. Chusov, V. P. Yankov – JSC „NII STALI", Moscow, Russia: **Investigation of Properties of Titanium Alloys with Mechanically Stable Beta-Structure for Body Armor Application**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 54

The paper presents the results of investigation of mechanical properties of titanium alloys with meta-stable beta-structure under static and dynamic loading after different thermal treatment modes. The thermal treatment modes were selected which ensure optimal combination of the toughness and strength characteristics of the material. The technological characteristics of sheet alloy semis and their armor resistance were estimated.
The obtained results show that the investigated alloys can be considered as the promising materials for application in those body armor components which are produced by cold sheet stamping.

V. A. Grigoryan, I. F. Kobylkin, I. A. Bespalov – JSC "NII STALI", Moscow, Russia: **Comparative Evaluation of Ballistic Resistance of Textile Armor Packages Against Steel and Lead Bullets**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 58

The paper contains physical models of high-speed interaction of non-deformable and deformable impactors with textile armor. The effect of the impactor deformability and of the method of the armor pack fixation on its ballistic characteristics is analyzed. Computational techniques are described for evaluation of textile armor ballistic resistance against steel- and lead-core bullets; quantitative dependences for evaluation of different grades of Russian armor textiles for different ways of fixation are presented.

A. I. Egorov, V. M. Kuznetsov, S. M. Logatkin, V. A. Khromushin – JSC "NII STALI", Moscow, Russia: **Investigation of Anti-Ricochet Properties of Bulletproof Vests with Steel Panels**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 63

The paper describes the ballistic experiment on counter-ricochet structures of armor vests with steel panels of protection levels 2, 3 and 5. A method of experimental evaluation of ballistic characteristics of such counter-ricochet structures was developed with substantiation of the target conditions. As a result of experimental ballistic and medical/biological research the parameters of witness plates were determined and justified. In the experimental research ballistic resistance of commercially-available vest counter-ricochet structures was investigated by methods of energy consumption and V_{50} evaluation.
Special technical requirements were worked-out for counter-ricochet structures of bulletproof vests with steel panels.

M. H. Struszczyk – The Institute of Security Technology „MORATEX", Lodz: **Risk Analysis in Designing of Body Armour**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 66

Risk analysis is helpful tools in design of body armor, such as: bullet, fragments proof vests. The proper design process requires the knowledge for all aspects connected with construction, selection of raw-materials, consumer needs as well as the performance and safety during the use and storage.

The paper will be present the application of risk analysis in designing of modern contractions of body armors. Several aspects should be taken into account for best performance and safety of body armors. The hazards resulted from technological process, selection of raw materials, comfort-ability, the lost of performance and safety during the standard use and storage will be presented and evaluated.

A. Palka: **Introducing Ballistic Innovations Based on DuPont™ Kevlar®**

The need for protection in the market place has increased due to arising levels of different threats. The market is requiring more sophisticated and modern armor capable of protecting the wearer from multiple hazards.

DuPont™ Kevlar® is a durable, innovative, lightweight and exceptionally strong fiber that has proven invaluable in ballistic protective helmets, vests, military vehicles and many other applications in Police, Army, Navy and Air Force.

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Vehicle armor systems made with DuPont™ Kevlar® meet the demand for lightweight reliability in automobiles, airplanes, helicopters, boats and military vehicles. They provide the best combination of ballistic performance, low bulk, extreme temperature resistance and low weight, without compromising vehicle performance.

<u>Kevlar® technology for body armor:</u>

DuPont™ Kevlar® XP™ is a new patented technology from DuPont that provides ballistic and trauma protection in a more comfortable body armor solution.

DuPont™ Kevlar® MTP Multi-Threat Protection is an advanced soft body armor technology introduced by DuPont in response to the rise in multiple threat levels. DuPont™ Kevlar® MTP allows to combine both ballistic, stab and blunt trauma protection into one solution.

A. I. Egorov, V. A. Khromushin, V. M. Marinin, O. B. Dashevskaya, M. E. Bulanova – JSC „NII STALI", Moscow, Russia, JSC KShF „PeredovayaTextilshitsa": **Test Conditions Dependence of Fragmentation Resistance of Protective Structures Consisting of Different Aramid Fabrics**

The earlier studies performed by JSC "NII STALI" evaluated dependence of fragmentation resistance of standard ballistic packages of the main aramid fabrics of 29.4 and 58.8 tex on test conditions. In the tests the type of backing materials was used as the variable (felt+wood/plasticine). Such backing materials are used in different standard test techniques.

The present paper is aimed at evaluation of the dependence of fragmentation resistance of a wider range of aramid fabrics with different weave types and areal density (from 14 tex to 100 tex) on different types of backing materials used in the tests. Effect of the standard test conditions on fragmentation resistance values of main aramid fabric types is determined.

Hans Meulman – DSM Dyneema, The Netherlands: **Lightweight High Performce Vests and Inserts with Dyneema® UD**

„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 81

For many years Dyneema fabric and Dyneema Uni-Directional composite are used in personal and vehicle armour. Dyneema Uni-Directional composite has proven to be very effective against small arms ammunition, both in soft and hard armour.

Vest and inserts with Dyneema® UD has the lowest weight, leading to a high comfort feeling of the user.

In this presentation the newest technology developments will be presented on body armour, based on Dyneema® UD. Not only ballistic resistance will be addressed, showing the light concepts, also other properties like fire resistance will be presented.

W. Steplewski, D. Wawro, J. Kazimierczak, Institute of Biopolymers and Chemical Fibres, Lodz, Poland: **New Ecological Preparation Method for Fireproof Cellulose/Silicate Fibres**

Research results on new ecological preparation method for cellulose/silicate fibres based on modified cellulose directly soluble in aqueous sodium hydroxide will be presented. The fibres are characterised by relatively high value of limiting oxygen index LOI which is retained even after repeated cycles of washing/drying. The advantages of the elaborated method over the other ones known in the literature are: lack of harmful substances emissions, minimized amounts of by-products (salts) and simplification of technological process. Relationship between silicate content in the fibres and some mechanical parameters of cellulose/silicate fibres such as titre, tenacity, elongation and friction coefficient will be presented for selected fibre-forming process conditions. Results of fireproofness tests (LOI), resistance to repeated washing as well as SEM and TGA analyses will be discussed.

E. Solinska, J. Wawrzyniak – The Institute of Security Technology „MORATEX", Lodz: **Assessment of Compliance of Products Serving the Purposes of the National Security**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 83

The paper presents principles of assessment of compliance to be observed by the suppliers of products serving the purposes of the national security and ordered by organisational units subject to or supervised by the competent minister of interior, arising from the act of November 17th, 2006. The authors also discussed the certification procedures and reference documents applied in the certification process carried out by the Product Certification Department (ZCW) of ITB MORATEX, a body accredited by the Ministry of Interior and Administration (MSWiA) in respect of OIB.

J. Blaszczyk, G. Grabowska, I. Kucinska – The Institute of Security Technology „MORATEX", Lodz: **Resistance to Bullets, Knives, Stabs and Needles According to Current Standards, Procedures and Users' Expectations**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 90

The paper presents the testing results analysis of the bullet-, knife-, stab- and needle-proofness in the aspect of material applied into the inserts for the body armour, manufactured according to the needs of Police officers as well as an individual orders.
The PN-V-87000:1999 Polish Standard does not include the stab resistance tests. Therefore the following documents have been used as the basis of this type of tests:

- NIJ 0115.00 US Standard;
- PBB-08 test procedure of the MORATEX Institute – "Stab resistance of personal body armour", comparable with the NIJ 0115.00 Standard;
- PBB-06 test procedure of the MORATEX Institute – "Samples' resistance against military knife type 92" developed on a basis of the Standard Body Armour – Part 2: Stab resistant vests (ISO/DIS 14876-2:1996).

The summary of presentation shows:

- the projectile impact energy;
- the depth of projectile penetration

for the samples of protective inserts for the tests used.

P. Komunski – Teching Hospital of Neurosurgery of Medical University of Lodz, T. Kubiak – Technical University of Lodz, M. Landwijt – Institute of Security Technology "MORATEX", R. Romek – Institute of Security Technology „MORATEX": **Transmission of a Bullet Impact Energy Through a Ballistic Helmet into a Head and Neck – Measurement and Analysis**

Nowadays the structures of ballistic helmets are quite different than in the past. The differences are results of development in material engineering. Ballistic helmet consists of two main parts: ballistic shell and internal equipment. Materials applied into helmets allow for obtaining higher protection level. But even if ballistic shell stops the bullet, there is still a risk of serious or lethal injury.
An important problem of protecting with a helmet is the kinetic energy, which is getting passed to the body of an user (the head and the neck) during penetration of the striking elements (bullets or fragments) into the ballistic protection (ballistic helmet). Transmission of great amount of energy to the head can cause crack of the skull, with injuries to the brain and the spine. The mechanism of such injuries is connected with action of acceleration and/or deceleration causing the relative movement of brain against the skull.
The stand equipped with the mannequin (a head-neck model) called Hybrid III is used to determine the transmitted energy. Its mechanical properties and structure correspond to the human head and the human neck. The measured results will be useful for increasing the protection level and for optimizing the structures of helmets.

M. Leonowicz, J. Kozlowska, L. Wierzbicki – Faculty of Materials Science and Engineering, Warsaw University of Technology: **Smart Passive Armours with Application of Nanostructured Rheological Fluids**

Advanced, passive, personal armours in the form of safety vests (bullet and knife-proved), blankets and shields for vehicles and steady objects are elabora-

ted. For this purpose nanostructured colloidal, as well as magnetorheological fluids will be used. The fluids will be applied for impregnation of fabrics made of high strength paraarmid or polyethylene fibres. As a result of this method elastic, light-weight, enabling movement, composite structures will be fabricated. Such materials, under action of strong hit (knife, bullet) or magnetic field, will undergo transformation from liquid to solid body.
Colloidal fluid is composed from nanoparticles of solid body dispersed in a liquid carrier. An important technological problem is proper choice of nanoparticles and liquid, and volume fraction of the components. The colloidal fluid, together with several layers of the impregnated with it textile material, are to form pockets, which will become parts of safety vests. The module form of the ballistic product will enable movement of soldier's limbs. When the composite structure is hit by the bullet or knife the fluid transfers to solid phase, blocking penetration.
The second type of the composite material is based on impregnation of textile materials with magnetorheological fluid. Under the application of magnetic field this fluid transfers to solid body and dispersed in the liquid carrier ferromagnetic particles form stiff fibres, which retard penetration of the hitting element. In this case the change of the armour properties is realized by switching on the electrical current in magnetizing circuit, by a soldier.

J. Sek – W. L. Gore & Associates Polska Sp.zo.o.: **Gore – a Globally Operating Technological Company With an Unusual Philosophy**

The American founder of the company, Dr. Wilbert L. Gore, left Du Pont in 1958 with the vision of setting up a company in which each associate would have the chance to develop and grow within the company in the best way possible. The achievements of his innovative technology company are something to be proud of today: the company has a turnover of some US$ 2,5 billion and employs 9,000 associates in 45 plants and sales offices all over the world. In Europe alone there are now some 2,500 associates working in eight different countries. The philosophy of its founder has certainly proved successful. Flat hierarchies, in which a culture of commitment, personal responsibility and direct communication is fostered, are the key to success. In recent years Gore has repeatedly been chosen as one of the 'best companies to work for', both in the USA and in Europe.
In its Fabrics Division Gore develops and produces its functional textile brands, GORE-TEX® and WINDSTOPPER®, well-known for their use in clothing systems and accessories in the sports and leisure markets. Today, in addition to this, Gore offers specially engineered functional fabrics and technologies to the professional and workwear markets. These clothing systems offer reliable protection and comfort to fire-fighters, rescue services, security staff, police, and people working in road construction, traffic services, logistics, industry, energy supply and waste disposal services. Together with its licensed partners, Gore has established an effective quality assurance system encompassing development, manufacturing and distribution so as to ensure that functional fabrics from Gore continue to deliver superior performance.
However, this is not all that Gore has to offer: experts in its electronic products, medical products and industrial products divisions are also working on high performance products and innovative plastics technologies for the benefit of the customer. These include medical implants for heart and vascular surgery, special cable assemblies, environmental technologies and filters for industry.
All of these products are based on PTFE (polytetrafluoroethylene), a highly versatile material and one of the most chemically and heat resistant plastics. PTFE permanently withstands temperatures ranging from –250 to +260° C, is water repellent and resistant to acids, alkaline solutions and most solvents. The different GORE-TEX® membranes and fibres are produced by a special PTFE expansion technology - Bob Gore's pioneering discovery in 1969.

A. Derewonko, P. Szurgott, T. Niezgoda – Military University of Technology: **Modeling of the Shock Wave Impact on the Flexible Shell**
„Techniczne Wyroby Włókiennicze" 2009, no. 2-3, page 108

An underwater explosion is one of the possible threat which can occure during military operations and/or civilian usage. The ballistic protection systems are the method to reduce the impact of the high explosive (HE) charge blast wave. The aim of this paper is to present the influence of the shock wave on the flexible shell. The simulation of the underwater detonation is provided with use of the Finite Element Method (FEM). The influence of the distance between the HE charge and the flexible shell on its deformation was estimated. The results of the conducted analysis including explosion were compared with those obtained for the basic model with no explosion.

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TECHNICAL TEXTILES

TECHNISCHE TEXTILEN

Ballistic Performance of Textile Armor Treated with Shear Thickening Fluid

V. A. Grigoryan, I. F. Kobylkin,
V. M. Marinin, I. A. Bespalov

JSC „NII STALI", Moscow, Russia

Laminated textile armor packages made of high -strength ballistic fabrics are widely used as armor panels in body armor to stop bullets of short-barrel small arms and fragments of artillery ammunition and mines [1].

One of recently most-widely discussed ways of increasing the ballistic resistance of textile armor is its impregnation with shear thickening fluid (STF). Newspapermen named the STF-treated textile armor "liquid armor", and the name stuck.

The main idea of upgrading the ballistic performance of the textile armor package by impregnating it with high-dispersive suspension is based on the following: at standard conditions the STF-impregnated textile armor package remains soft and flexible and does not impede movement; but when hit by a bullet or a fragment, the armor STF-content hardens thus improving the protective performance of the textile package.

Most often in ballistic applications such suspensions are used for STF as high-concentrated sub-micron suspension of inexpensive SiO_2 in ethylene glycol or in polyethylene glycol [1–4].

An important special feature of shear flow of the suspension is that the particles which are moving at an average speed of the carrying gradient flow of the dispersion medium rotate, which is caused by the difference of the flow speeds in the direction perpendicular to its direction. The rotating particles entrain the dispersion medium adjoining their surface, thus generating so-called adjoint mass.

As the concentration of the suspension increases, the layers of fluid adjoined to the particles begin to overlap, and their interaction becomes more significant. At some critical shear rate the rotation of individual particles decelerates to such extent that they adhere to each other and form a kind of undeformed clusters confining a portion of dispersion medium, and the rotation of particles is transferred to the clusters.

When the shear strain rate reaches some extremal value, the interaction forces among the clusters lead to their rupture which shows itself as reduction of effective viscosity and shear stress reaching the horizontal asymptote – it does not depend any more on the shear strain rate. On the contrary, reduction of the shear strain rate results in rupture of clusters due to Brownian movement of the dispersed phase particles; the effective viscosity of the mixture decreases, it shifts to the initial state of homogeneous dispersed medium in the form of suspension.

Particular dependences of viscosity factors of sub -micron suspensions of SiO_2 in ethylene glycol on the shear rate are presented in Fig. 1 [11].

For proper understanding of the mechanisms of STF effect on ballistic resistance of textile armor an adequate model of bullet/textile armor interaction is required in the first place. We succeeded in developing such a model which is described in papers [1, 5]. According to this model, at high-velocity impact the ballistic resistance of the textile armor package is determined mainly by its ability to transform the kinetic energy of the bullet into work for yarn stretching without their breaking. The analytical dependence of the ultimate penetration velocity of a laminated textile armor package v_{ult} on its structural characteristics and physical-and-mechanical properties of the textile,

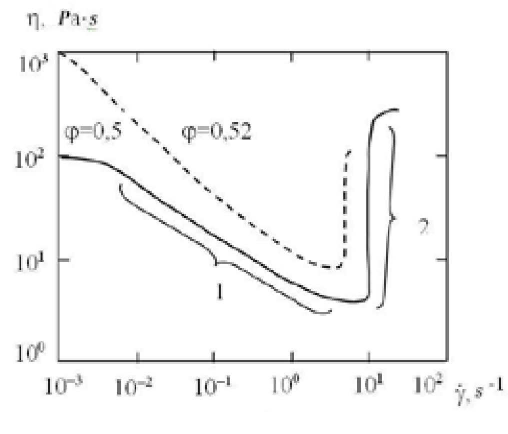


Fig. 1: Viscosity dependence of suspension of SiO_2 – particles with an average diameter of 446nm in ethylene glycol (φ - volume fraction of particles in the suspension, η - viscosity factor, γ - shear rate); 1- viscosity decrease branch; 2 – drastic viscosity increase branch

obtained on the basis of this concept, looks as follows [1, 5]:

$$v_{ult} = Kc_y\varepsilon_p\sqrt[3]{\frac{m_m d_b^2}{m}} \quad (1)$$

where K is the factor depending on the textile type; c_y is the rate of elastic wave spreading in the textile yarns; ε_p is the ultimate deformation of yarn elongation; d_b and m are bullet diameter and weight.

Dissipating mechanisms of energy absorption (friction work at yarn displacement) belong to "slow" mechanisms of energy absorption which are effective at the final phase of bullet deceleration or at low-velocity impacts of penetrators.

As treatment of textiles with STF reduces yarn mobility due to increase of resistance to yarn displacement, the energy portion absorbed in the processes related to yarn displacement inside the textile, increases. Hence we can expect increase of resistance of textile armor packages to penetrators which usually perforate textile armor due to stretching and separating the yarns in the fabric (like it takes place at puncturing laminated textile armor packages with a needle or an awl).

At the same time the presence of STF in inter-yarn and inter-filament space of the yarns (Fig. 2) increases their linear density ρ_y

$$\rho_y = \rho(1+\xi)$$

where ρ is the density of the dry yarn, ξ is a mass fraction of STF (with respect to the mass of the dry yarn). As the modulus of elasticity of SVM ballistic fabric yarns is much higher than that of STF we can assume that impregnation of the yarn with STF actually doesn't affect its modulus of elasticity. As a result of increase of the yarn inertia, the velocity of elastic wave propagation c_y in STF-impregnated yarn decreases according to relation (2).

$$c_y = \sqrt{\frac{E}{\rho_y}} = \sqrt{\frac{E}{\rho(1+\xi)}} = \frac{c}{\sqrt{1+\xi}} \quad (2)$$

where $c = \sqrt{E/\rho}$ is the velocity of longitudinal elastic wave propagation in a dry yarn.

Decrease of c_y results in reduction of the deformed volume, and consequently, in reduction of the energy

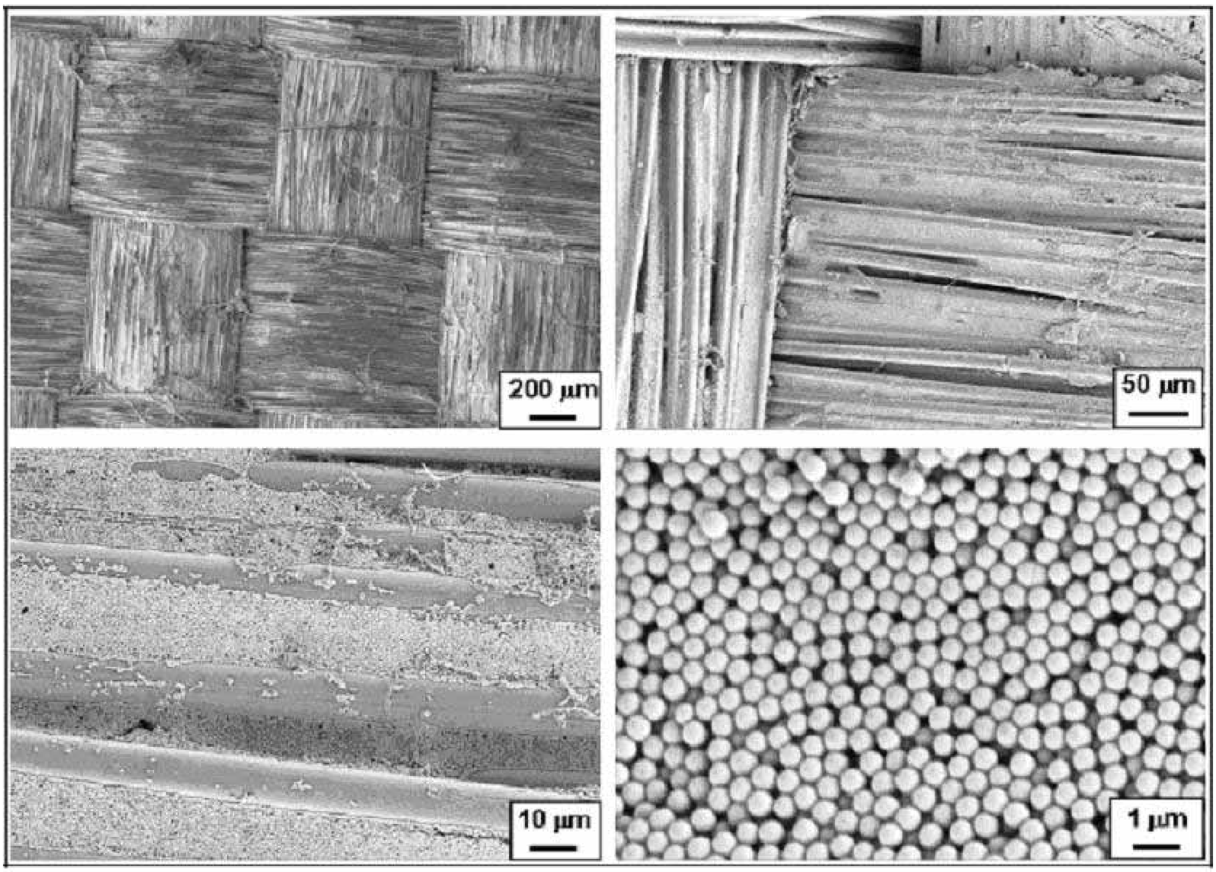


Fig.2 Microphotographs of Kevlar 706 fabric treated with STF based on polyethylene glycol and sub-micron SiO_2 particles. The particles are present both between the yarns and between the filaments [9].

absorbed by the armor package due to elastic stretching at their ultimate elongation. Thus, the ultimate velocity of STF-treated textile armor package perforation is reduced as in (3),

$$v_{perf}^{STF} = \frac{v_{perf}}{\sqrt{1+\xi}} \quad (3)$$

where v_{perf}, v_{perf}^{STF} are ultimate perforation velocities of the dry and STF-treated textile armor packages accordingly. The resulted formula qualitatively corresponds to the well-known facts: ballistic performance of textile armor decreases with introduction of any fillers, water (when armor packages get wet) or a polymer binder when making organic plastics.

In paper [7] the ballistic limits of perforation of single layers of ballistic fabric made of Kevlar yarns with linear density of 600 den (67 tex) and density of 34x34 yarns per inch were determined. The armor was tested with 5.59mm-diameter steel balls weighing 0.63g. For the dry fabric 50% ballistic limit was 100 m/s, and for the impregnated one it was 240 m/s.

In paper [6] the ballistic performance of Twaron CT615 textile armor packages impregnated with water suspension of SiO_2 particles with different concentrations was investigated. The target consisting of two layers of STF-treated fabric showed almost 100% increase of the specific ballistic energy capacity. However, this index of ballistic efficiency for STF-impregnated textile armor packages consisting of four and six fabric layers turned out to be much lower than for the dry fabric.

We also conducted a number of experiments for evaluation of the ballistic limit of 4-layer armor packages of Russian ballistic fabric Grade 56319A backed with plasticine. In these tests V_{50} of STF-treated armor packages was 20% higher as compared to dry packages.

These facts which look contradictory at first sight, can be explained as follows: it is known from experience that perforation of one- and two-layer textile targets is mainly caused not by yarn breaking in the deformation cupola, but by their separation and stretching. Prevention of yarn separation and stretching thanks to STF impregnation increases the ballistic limit due to changing the penetration mechanism. Such increase is limited by the breaking strength of the yarns correlated with the maximum velocity of the bullet or fragment v_p, which equals to [1]

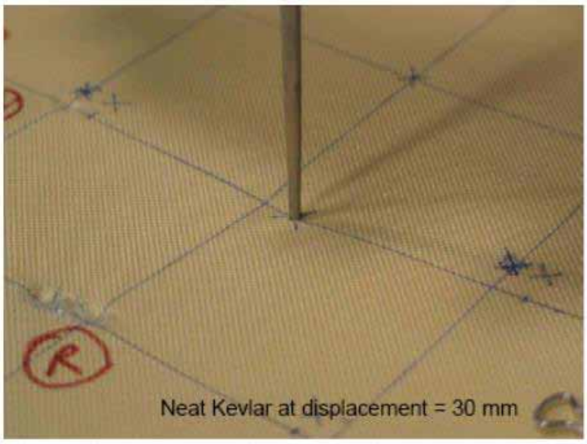
$$v_p \approx 1.41 c_y \varepsilon_p$$

For a wide range of dry para-aramid yarns v_p = 300-380 m/s. Impregnation of the yarns with STF reduces the rate of longitudinal waves propagation c_y (2) in them, and, consequently, according to relation (3), also the ultimate perforation velocity v_p to 250-300 m/s.

Another challenge for body armor designers is providing protection against different kinds of piercing weapons.

The results of an icepick impact on dry and STF-impregnated Kevlar packages with a backing plate of foamed elastomer are presented in Fig. 3 [10]. The dry 15-layer Kevlar package can be easily punctured by the icepick, whereas in the 12-layer STF-impregnated package even the outer layers cannot be pierced.

We also conducted a number of experiments on the effects of cold steel (bayonet and icepick) on dry and SiO_2-based STF-treated packages made of Russian ballistic fabric Article 56319A. The bayonet tests were conducted on a pendulous dynamic stand with the impact energy of 22.3 J. The acceptable outgoing depth of the bayonet behind the rear surface



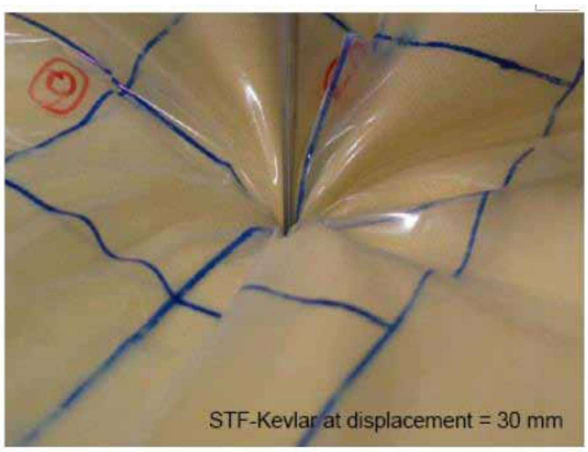


Fig.3 Impact effect of an icepick on 15-layer dry Kevlar package and 12-layer STF-treated Kevlar package [10]

of the target (5mm) was obtained on 16 layers of dry fabric and on 8 layers of fabric impregnated with SiO_2 water suspension. At the same time the weight of the impregnated armor package increased by a factor of 1.5, i.e. total gain by areal density was 25%. Fig. 3shows the photos of rear surfaces of the dry and impregnated 8-layer armor packages impacted by a bayonet.

A similar experiment was conducted with an icepick impacting dry and STF-treated armor packages made of Article 56319A ballistic fabric with the impact energy of 31 J. In this case non-perforation of the dry package was obtained on 32 layers, and of the STF-treated package – on 16 layers. Thus, in this case the gain by the areal density was also 25%. Fig.5 presents the photos of the rear surfaces of the dry and STF-treated 16-layer armor packages impacted by an ice-pick.

Camouflage as the Additional Form of Protection during Special Operations

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The Institute of Security Technology "Moratex"

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Key Project No. POIG 01.03.01-00-006/08 entitled: „New generation barrier materials, protecting humans against the harmful environmental impact".

INTRODUCTION

The camouflaging materials used at present warrant a wide range of masking possibilities. They are found in two forms: as masking covers ensuring optical and radiolocation camouflage and anti-thermal sets. These sets are presently used for large objects, such as vessels, vehicles etc. It seems interesting to attempt designing materials that ensure the widest scope of camouflage possible. They should be made of raw materials of the newest generation and they should meet the requirements of the European standards.

A significant issue is introduction of camouflaging material in a wide range of personal protection devices, such as ponchos, tents, etc. and objects, such as curtains, tarpaulins etc. It is particularly significant due to the fact that at present, products of this kind are made of imported and very expensive raw materials.

THE OBJECTIVE OF CAMOUFLAGE

Ensuring of safety of soldiers and officers of services subordinate to the Ministry of Interior and Administration and the Ministry of Defense influences greatly their emotional shape during various operating activities and peacekeeping missions. The priority of the commanding officers must be to ensure protection of their staff throughout all stages of the operations carried out, which should be ensured thanks to the following undertakings: hiding, camouflage, dispersal of the forces, assets and activities and fortification development. Performance of the specific scope of camouflaging activities ensures such benefits as:

- Preventing recognition and identification of objects and people by the opponent;
- Limitation of own loss of life and equipment, and thus strengthening of the „fighting spirit" among the soldiers and officers;
- Ensuring of the proper conditions for effective use of the combat assets.

Camouflage and protection against detection are treated as components of threat prevention, which require substantially less financial expenditures than purchase of expensive equipment in the field of advanced technology.

CAMOUFLAGE TYPES

According to the scope of the tasks and objectives and the nature of organizational and executive undertakings, camouflage can be divided as follows:

1. Operational camouflage – activities coordinated with regard to organizational and technical aspects, aimed at [1]:

- hiding of preparations for performance of an operation,
- misinformation of the opponent with regard to the operation plans,
- hiding of the valuable targets against nuclear attacks (e.g. the command systems developed throughout the territory of the country),
- hiding of the nature of the activities of the national defense military forces,
- drawing the opponent's attention to targets of secondary importance and fake targets.

Fig. 1. Direct camouflage for the soldiers [3]

2. Direct camouflage – hiding or modification of appearance of detached or modular objects, devices, equipment, armament and people using the available means and masking materials and masking assets while securing the operations [2].

According to the type of devices used, direct camouflage can be divided into: disinformation, simulation and concealment.

Disinformation is intentional preparation and distribution or direct delivery to the reconnaissance forces of the opponent of misinformation concerning the military forces numbers and military plans using the press, agencies and radio-electronic devices [1].

Simulation is devising of fake objects and provoking of fake situations using mock-ups of equipment and armament, smoke-generating, pyrotechnical, sound and other devices [2].

Concealment is elimination or limitation of exposing signs that are typical for military forces, military objects and their operation [2].

This type of camouflage can be divided into [2]:

- camouflage within visibility range – making it difficult for the opponent to recognize objects visually with or without application of optical devices, within the range of visibility, wavelength range λ = (from 0.38×10^{-6} to 0.78×10^{-6})m,
- anti infrared camouflage – making it difficult for the opponent to detect objects using noctovision, infrared photography and thermovision, wavelength range λ = (from 0.78×10^{-6} to 14.00×10^{-6})m,

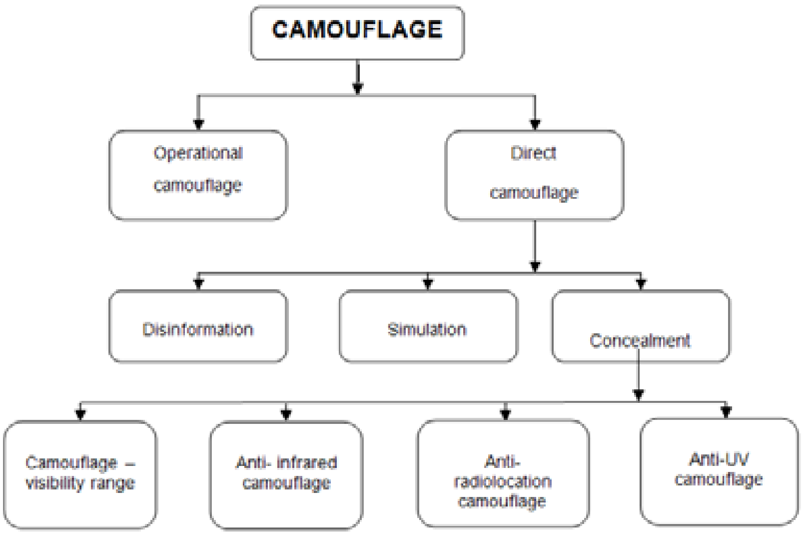


Fig. 2. Camouflage types

- anti-radiolocation camouflage - making it difficult for the opponent to detect objects using radiolocation devices within the microwave range of wavelength λ = (from 3.00×10^{-6} to 1.00)m,
- anti-UV camouflage - making it difficult for the opponent to detect objects using devices operating within the wavelength range of λ = (from 0.01×10^{-6} to 0.38×10^{-6})m.

The leading armies of the world have at their disposal an impressive selection of camouflage devices for a wide range of electromagnetic radiation from UV to microwave radiation. These include:

- *deforming camouflage paints,*
- *camouflage covers,*
- *radar radiation absorbing materials (RAM),*
- *anti-thermal camouflage devices,*
- *active camouflage kits.*

The possibilities of camouflaging our armed forces had, until recently, been limited to the visibility range, which was definitely inconsistent with the demands of the modern battlefield. In the nineties, research work on models for concealment of tanks, trucks and anti-radar paints was concluded [4]. In the recent years, a complex set for concealment of T-72 tanks was devised, as well as a modern broadband camouflage cover BERBEFIG.

The ZMK-Cz set is designated for direct concealment of T-72 tank against reconnaissance devices working within the optical, thermal and radiolocation range and it consists of:

- the anti-thermal multi-layer unit, made of materials characterized by a low emission index to conceal the hottest tank components,
- the anti-radiolocation unit, made of an anti-radiolocation cover, which is sewn onto the carrying material.

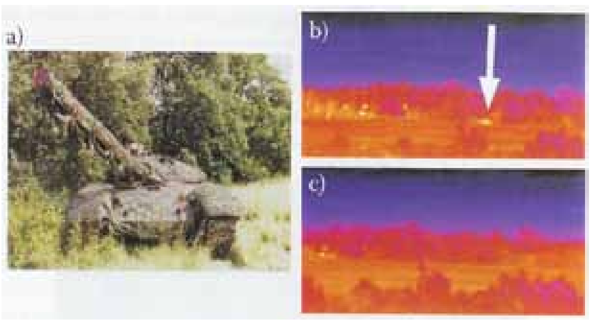


Fig. 3. A complex tank camouflaging set and the research results:
a) the set,
b) a tank without a set,
c) a tank with the set [4]

The broadband camouflage cover BERBERYS has been devised in cooperation with the Military Institute of Technical Engineering and „MIRANDA" Sp. z o.o.[5,6]. It is designated for camouflaging, in the period from the spring until the autumn and snowless winter, of deployed combat and technical equipment, material storage facilities, fortifications and other facilities. Each set consists of a cover and additional equipment (stakes, spikes, mounting brackets, guys and ropes), used to cover the camouflaged object. BERBERYS camouflage cover allows for masking of equipment and objects during ground and air observations falling into the following categories:

- Naked eye,
- Using visible light optical devices,
- Within the radiolocation range,
- Within the thermal range,
- Using noctovision optical devices.

Use of these covers eliminates the army masking defects only within the visibility range.

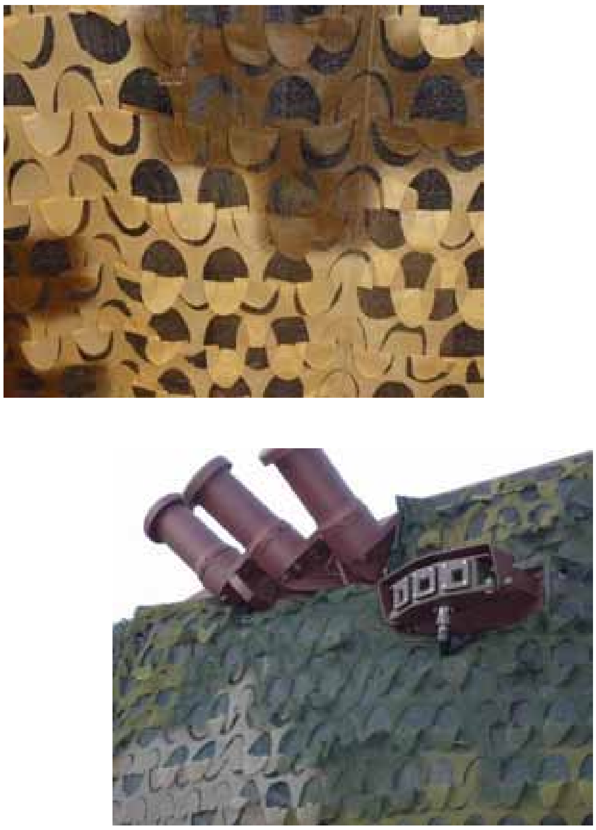


Fig. 4. BERBERYS camouflage cover [7]

Another issue, which is of great significance for protection of people during extraordinary operations, is the uniform and other equipment (including tents, groundsheets etc.) that are used for camouflage purposes.

The basic form of camouflage in products of this type is mimetic camouflage. In its simplest form, it constitutes of a product made of material of uniform color, which corresponds with the dominant color in the surrounding area.

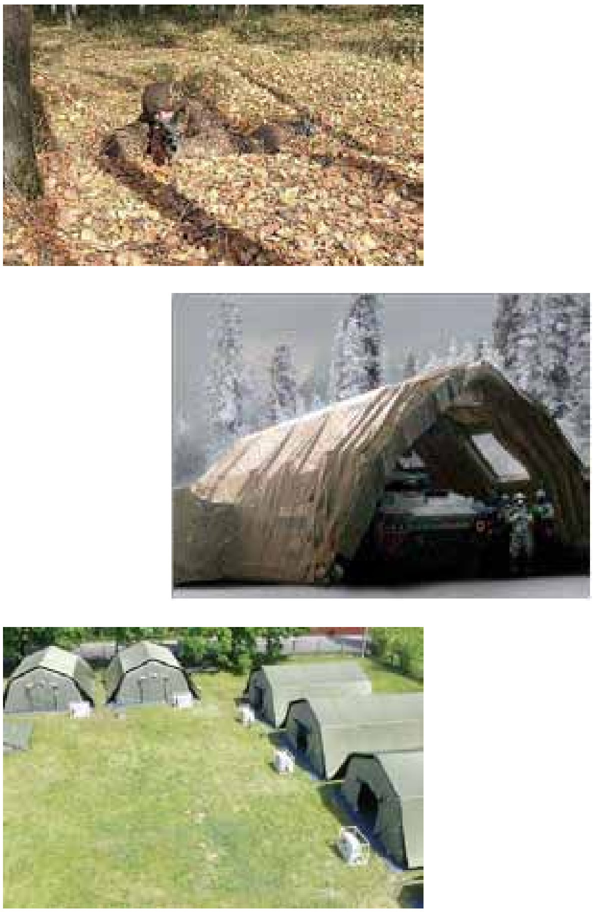


Fig. 5. Examples of mimetic camouflage
a) uniform [8]
b) Technical Pneumatic Tent TNP/2008 [9]

The defects of these patterns include their low efficiency of camouflage at medium and small distances.

This problem has been solved by creation of camouflage patterns, which consist of polychromic patches of the size and shape similar to the natural elements of the environment, such as tree branches, leaves, grass tussocks or small stones.

Presented below are the most popular camouflage types and their short descriptions and exemplary application [11].

WOODLAND camouflage – excellent for operations in forested areas (four color). It is officially used by the US army [11].

There are several types of camouflage of this kind, which differ only with regard to the colors used (the shape and distribution of the pattern remains the same). The most popular ones include:

- METRO camouflage – used mainly for operations in urbanized areas,
- REDCAMO camouflage – civil camouflage,
- SKYBLUE camouflage – used mainly for operations in urbanized areas.

FLECKTRAN camouflage – used for operations in forested areas (five colors). Used by the German army since 1991 [11].

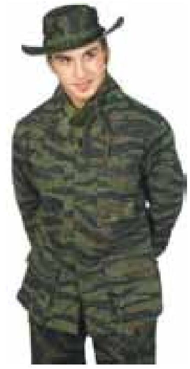
DESERT 3 (Three Color Desert) camouflage – excellent for operations in desert and sandy areas. Used by the US army (e.g. in Iraq) [11].

DESERT 6 (Six Color Desert) camouflage – used by the US army during desert exercises in the eighties and later during the "Desert Storm" operation. At present, it has been replaced by Three Color Desert camouflage [11].

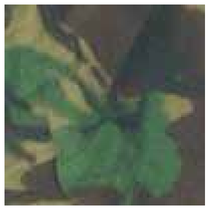

TROPENTARN camouflage (Tropical FLECKTARN) – very similar to typical FLECKTARN (slightly darker). The difference, however, is crucial, as a different type of material has been used, which is more sheer and lighter. Originally, it has been used by the German soldiers during their military missions in forested areas and tropical geographic zones [11].


WUSTENTARN camouflage – currently used by the German armed forces. Excellent for operations in desert areas (three color)) [11].


TIGER STRIPE camouflage – created by Filipino armed forces, also used by the US special forces. Excellent for operations in forested areas [11].

DPM (Disruptive Pattern Material) camouflage – presently used by the British armed forces [11].

DANISH camouflage M84 – this camouflage consists of small, overlapping, round spots (pixels) in three colors – it is based on FLECKTARN camouflage. At present, used by the Danish armed forces [11].


CCE camouflage – presently used by the French armed forces. Very similar to the American WOODLAND (four color) [11].

THE NEW TRENDS IN CAMOUFLAGING TECHNOLOGY

In the late nineties of the 20th century, camouflages performed using modern techniques emerged. These were the so-called "pixel" camouflages. The first states to introduce these were Canada (CADPAT pattern – Fig. 6a) and the United States (MARPAT pattern – Fig. 6b).

The first generation of „pixel" camouflages was characterized by very small print. Masking of this type was particularly efficient mainly at small distances, but it was less effective at medium distances, while at great distances (>100 m) its efficiency differed little from that of uniform color camouflage.

Fig. 6a. Examples of „pixel" camouflage: CADPAT

Fig. 6b. Examples of „pixel" camouflage: MARPAT [8]

State-of-the-art achievements in the field of mimetic camouflage, produced using digital techniques, have been introduced in 2005 in the uniforms of the Finnish army (pattern M/05).

Individual spots, even the smallest ones, are not square- or rectangle-shaped „pixels", known from the earlier „digital" camouflage patterns, but irregular shapes with developed edges. Apart from chaotically scattered small spots, pattern M/05 includes larger spots as well (Fig. 7).

Fig. 7. The Finnish „pixel" camouflage pattern [12]

As a result of the proper selection of the spot size, the effectiveness of masking has increased in comparison with CADPAT pattern. At the same time, the new material has better mimetic characteristics than the classical WOODLAND type camouflage.

The typical modern field uniforms and equipment used by soldiers, although they use camouflage within the visible light range, does not make it possible to avoid detection in other radiation ranges. Therefore, works have been commenced to design multispectral camouflage uniforms. An example of such uniform is the Warrior field uniform (Fig. 8), designed by Saab Barracuda (in cooperation with the Norwegian company NFM Caseb). It ensures multispectral camouflage for such ranges as visible light, near infrared and the so-called thermal infrared (VIS, NIR, TIR). All components of the uniform are covered with sewn-in stripes made of a special synthetic material.

Fig. 8. Soldiers wearing Warrior uniforms during the night exercises in the urbanized areas(a) and in the forested area (b) [13]

DESIGNING OF REQUIREMENTS AND A RESEARCH PROGRAMME FOR MATERIALS DESIGNATED FOR MASKING PEOPLE OR EQUIPMENT

Topic V, analyzed by ITB „MORATEX", entitled „Barrier masking materials for VIS, IR and microwave radiation" for the Key Project „New generation barrier materials, protecting humans against the harmful environmental impact (No. POIG.01.03.01-00-006/08) is aimed at devising and production of a material or a set of materials used for: masking, passive and active concealment, disturbances and imitations for the broad wavelength range (VIS, IR, microwave, thermal radiation).

Within the framework of Task 1 for Topic V, among other things, the general requirements for the newly devised masking materials depending upon their designation have been prepared on the basis of the standards of the Polish Committee for Standardization and the Military Standardization Center.

The newly devised material/ set of materials should ensure:

- Masking in visible light (VIS) and near infrared (IR) for the wavelength range of λ = 0.4 x 10^{-6} to 1.1 x 10^{-6}m,
- Masking against radiolocation devices for wavelength range from λ = 3 x 10^{-3} to 0.15 m for equipment masking materials and from λ = 3 x 10^{-3} to 3.75 x 10^{-2} m for personal camouflage materials,
- Anti-thermal masking for the wavelength range from λ = 3 x 10^{-6} to 14 x 10^{-6} m,
- Protection against naked eye visibility under field conditions during ground and air observation from the distance or height of 1000 m or greater and on photographs taken at a scale of 1:5000 and lower while the linear resolution of photographs is 20 lines/mm,
- Decreasing of the index of reflection of radiation by the masked object so that the distance of its detection by the radars is decreased by at least 50% while decreasing the maximum reflection of electromagnetic waves by the masked object by at least 12 dB,
- Limiting of effectiveness of thermal detection thanks to deformation of thermal imaging of the masked object, changes in the spatial characteristics of radiation and decreasing of the thermal contrast between the masked object and the background to the value of k = 0.05 at a temperature difference up to 6 K.
- Meeting of requirements specified in the Regulation of the Council of Ministers of 6.04.2004, concerning the safety and marking of textile products, as amended.

It is forecasted that the newly devised material/set of materials is to be subjected to upgrading processing in accordance with the final designation of the product. The possible finishing techniques are: coloring and the following finishes: water-resistant, hydrophobic, oleophobic etc.

Literature

1. *K. Wieczorek „Maskowanie wojsk – cele i zadania"; materials from WITI seminar, Warsaw 10.1994*
2. *PN-V-01005:2000, Maskowanie bezpośrednie wojsk lądowych. Maskowanie ludzi, sprzętu i obiektów. Terminologia*
3. *http://pl.wikipedia.org/wiki/Maskowanie_taktyczne*
4. *Nowoczesne technologie systemów uzbrojenia, Collective work edited by Zygmunt Mierczyk, WAT, Warsaw 2008*
5. *Information materials of „MIRANDA" company - www.miranda.com.pl*
6. *Report MSPO 2/2008 – www.altair.com.pl*
7. *http://www.altair.com.pl/nsp-spec-98*

8. http://militaria.wp.pl/kat,27395,wid,8759944,wiadomosc.html?ticaid=18634
9. http://www.lubawa.com.pl/indexw.php?pid=60
10. http://www.lubawa.com.pl/indexw.php?pid=61
11. http://www.militaryarea.pl/Rodzaje-kamuflazu-chelp-pol-17.html
12. http://militaria.wp.pl/kat,27395,wid,8898584,wiadomosc.html
13. http://www.specops.com.pl/technika/wachowski/Saab_warrior/Saab_warrior.htm

Assault High Protection Level Armor Helmets Based on Ceramics and Organic Fiber-Reinforced Composites

Ye. F. Kharchenko, V. A. Aniskovich,
I. S. Gavrikov

Statistics of combat losses in local military conflicts and anti-terrorist operations witnesses the considerable increase of the number of gunshot head wounds connected with features of combat action fighting.

In particular, the results of studying the gunshot wound structure that were obtained in the course of anti-terrorist operations in the Caucasus, show that the overwhelming majority of gunshot wounds among the killed are bullet wounds - 67%. This exceeds the similar indices of the Second World War by 1.5-2 times.

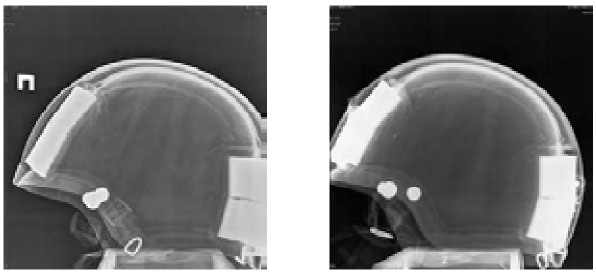
Characteristically that among the killed in the result of bullet wounds, 56% of hitting cases falls at a head and a chest. It is necessary also to note that such wounds in a head are in most cases undoubtedly fatal [1].

Optimum characteristics of armor helmets over the bullet resistance - weight range can be reached only using modern materials in their structure. Organic ceramics consisting of a screen based of ceramic elements and organic fiber-reinforced composite backing is one of these materials.

The especially hard ceramic screen provides breaking up the bullet core and simultaneously is failed, and the backing absorbs a flow of bullet and screen fragments. The power-consuming backing is a layered composite material on the basis of high-strength aramid fabric and elastic binder.

After choosing a protective structure for the strengthened assault helmet, the development of underlining device of the helmet is an important question when designing. The structure of the helmet underlining device should provide reliable fixing the helmet on a head and good shock-absorption, as well as prevent a contact impact by the helmet rear surface in the head.

On the basis of the above technical decisions and conducted work on the optimization of the organic fiber-reinforced plastic backing, we have developed experimental armor helmets with the increased protective level. At the first stage, strengthened organic-ceramic inserts were placed in frontal and rare parts of helmets. X-ray photographs of armor helmets are presented in Figure 1.



a b

Figure 1. X-ray photographs of increased protection level helmet with strengthened frontal and rear areas: a - before submachine-gun fire; b - after the fire.

The armor helmets were fired heat-strengthened core bullets of the long-barrel submachine weapon at the distance of 5 m. To evaluate the bullet resistance, the shots were fired into a frontal part of the helmet. The distance between two next hittings were 30 mm. Through piercings were absent.

At the second stage, we have developed a technology of manufacturing semi-closed ceramic shells based on silicon carbide and consisting of 5 sections with subsequent molding the energy-absorbing organic composite insert inside them.

Medical and biological tests of armor helmets have been conducted on the base of the St. Petersburg Military-Medical Academy. After fire testing, a state of the cervical vertebrae, brain, skull vault bones, etc. has been evaluated. As a result of medical and biological tests, it was determined that internal structures of the brain and spinal cord (jugular section) had no any visual damage; osseous structures of skull vault and base bones, as well as jugular section of spinal column were without injuries. The volume and expressness of the biological object injuries are not in excess of surface injuries of the skin epidermis and are not subject to the forensic medical estimation of health injury severity.

The residual beyond-armor projection did not exceed 3-4 mm even when hitting a bullet at the distance of 20 mm from the edge of the helmet, Figure 2.

Using a method of high-speed filming for this type

Figure 2. General view of organic-ceramic armor helmet after testing:
a - front view;
b - rear view;
c - inner surface of helmet after firing;
d - X-ray photograph of failed fragment of helmet (unpiercing).

of organic ceramics, we determined that the residual beyond-barrier projection is considerably less than the strain that is brought about at instant of bullet impact and ceramics failure. Figure 3 shows that the maximum strain is developed during the first 120 ms of the bullet-armor interaction and reaches 14 to 15 mm, then we see the back (negative) strain. The finite strain is found by 2 - 2.5 times less than the momentary strain.

Nevertheless, it is obvious that just a maximal value of the beyond-armor projection is of the most danger and when designing organic-ceramic helmets it is necessary to allow a gap at least 15 mm between inner surface of the helmet and a head. The structure of the underlining device material also plays a particular part. Through numerous experiments, we found an optimum combination of materials and a structural shape of the helmet underlining device protecting against high-energy bullets.

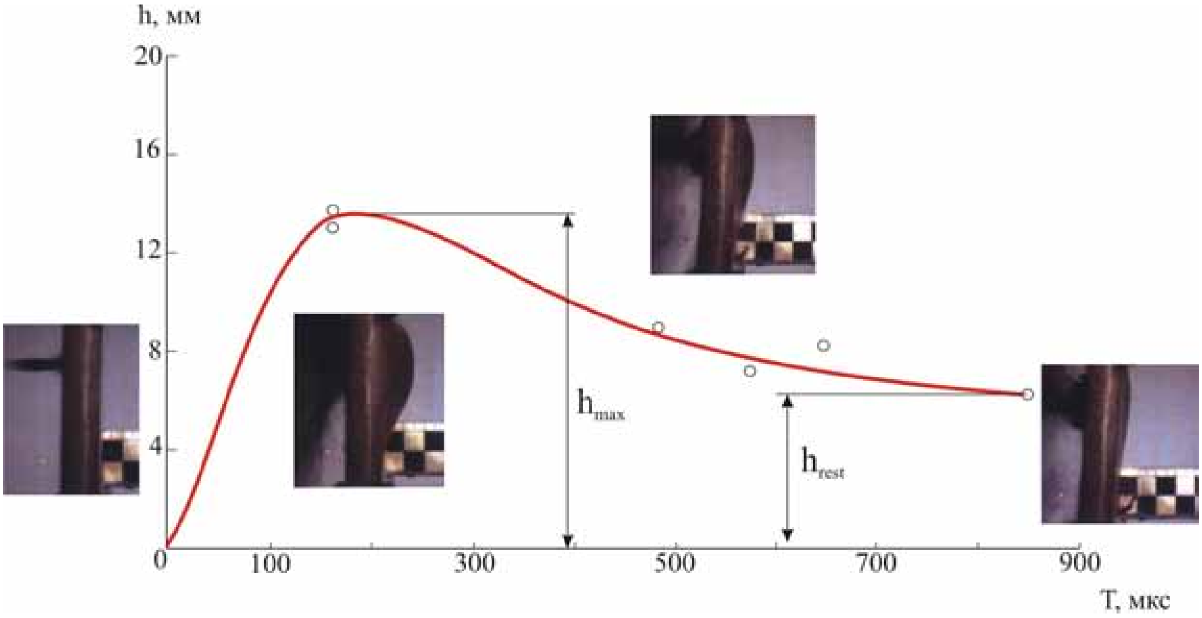


Figure 3. Changing the value of beyond-armor projection (h) as a function of time (t) when interacting bullet and armor.

Thus we have an assault helmet, first produced and passing comprehensive tests, with a weight less than 4.5 kg and a protection area over 13 dm^2, which protects servicemen against increased piercibility bullets of the hand long-barrel weapon with shots fired from minimally near distance of 5 m.

In comparison with steel counterparts having more low protection level, the helmet developed by us ensures:

- considerable decrease of battle losses of personnel in special sub-units when carrying out assault operations;
- lack of a ricochet and possible secondary fragment hitting in organic-ceramics armor helmet;
- much lesser thermal conductivity of composite shell that improves ergonomic characteristics of the organic-ceramic helmet, especially in a hot climate.

Literature

1. *L.B. Ozeretskovsky, Ye.K. Gumanenko and V.V. Boyarintsev. Wound ballistics. History and state-of-the -art of fire-arms and body armors, St. Petersburg, 2006.*

Improvement of Soldier Survivability by Signature Management

V. A. Grigoryan, A. P. Antipov, A. V. Potapov, A. I. Egorov

Personal protection of a warrior has always been the focus of attention. Development of weapons and ammunition has been going on hand in hand with improvement of protection equipment. If in ancient world protection was offered by leather shields which saved human life against arrows, nowadays we enjoy ballistic helmets and vests saving human lives against small arms, grenade fragments and other types of modern ammunition. Such protection equipment makes us feel proud for our protection designers, but unfortunately cannot make us feel completely satisfied with the offered protection level.

The necessity to improve the soldier's survivability is caused in the first turn by the fact that the possibilities of ballistic protection are limited by the acceptable mass of protective equipment. Even well-physically-trained person is not able to wear protective clothing weighing 6 to 8 kilos for a long time. It's quite a load, especially if one bears in mind that the soldier wearing such clothing while performing his combat mission must also carry his weapons, surmount obstacles, shoot and run in cross-country. Besides, further improvement of ballistic protection can be achieved only by stronger and stronger efforts and expenses, and the results are less and less impressive.

At the same time the weapon threatening the modern warrior is constantly improving. While small arms improvement rate has also decelerated, high-explosive ammunition is rapidly developing. We've seen the use of volume effects ammunition against infantry In Afghanistan, and no body armor can protect against such threat. In many countries uncommon anti-personnel weapons are under development, including non-lethal ones.

The above facts show the urgency of finding the ways to protect the warrior against all modernx threats. And such comprehensive way of protection does exist but is undeservingly little used, and this is personal signature management which offers concealment against all known and future surveillance and tracking equipment. The theoretical basis of such conclusion is the soldier disabling probability equation in the following form:

$$P_{disabl.} = P_{det.} \cdot P_{recogn.} \cdot P^{i}_{hit} \cdot P^{i}_{guar.disabl.} \qquad (1)$$

where $P_{det.}$ is the probability of soldier detection;

$P_{recogn.}$ is the probability of detected soldier recognition, P^{i}_{hit} is the hit probability in i-zone of the soldier; $P^{i}_{guar.disabl.}$ is the probability of guaranteed disabling of the soldier.

From equation (1) analysis it follows that P_{hit} completely depends on the enemy's capabilities. The values of probabilities can be affected by changing the soldier's equipment features.

It must note that while $P^{i}_{guar.disabl.}$ is an attribute which is selective to different threats and is a conditional probability (i.e. depending on other multipliers), the detection probability is an unconditional probability and manifests itself to a greater extent, preventing from using the weapon.

Thus, the challenge of making the warrior more concealed in the modern warfare is critical and solvable.

To determine the methods and means of signature management and to develop particular technical solutions for signature reduction it's first necessary to consider the capabilities of detection devices.

In the optical wavelength range most widely used is visual surveillance and detection by such optical equipment as binoculars, field glasses and sights, often with image intensifiers.

Possibilities of optical concealment of the warrior are rather limited by a great variety of detection conditions and their versatility during day and night and during different seasons of the year. Backgrounds are also very different (Fig.1). The amount, direction and spectral composition of daylight and artificial light vary in a wide range. The capabilities of viewing devices also differ greatly. The conditions of optical contrast formation when using night vision devices with or without lighting require application of low-reflective materials in the warrior's uniform in the first case and of high-reflective materials in the second case which is mutually exclusive.

It is impossible to provide concealment in all these

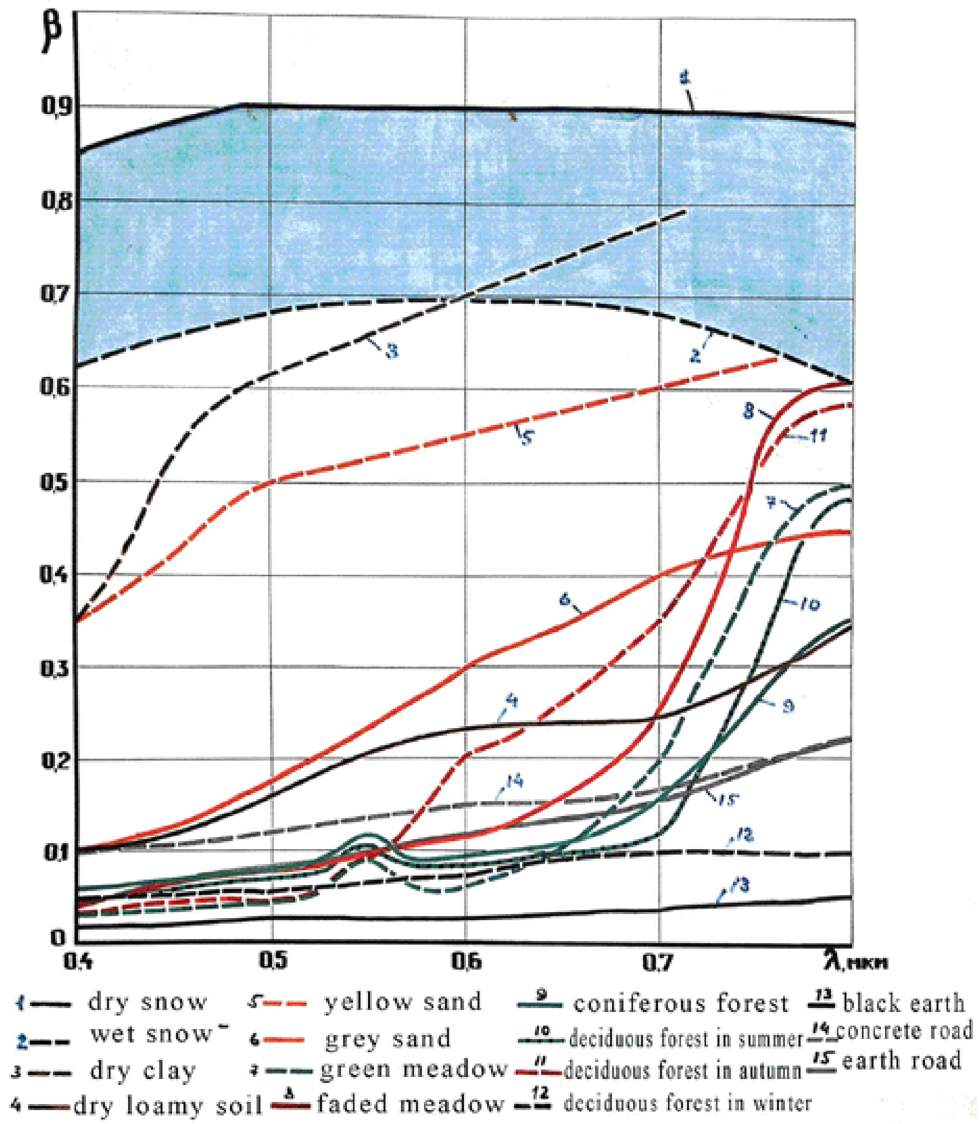


Fig. 1 Background spectral characteristics

conditions with the same materials. Data on signature reduction materials should be checked experimentally for the whole range of optical surveillance conditions. Spots typical for body armor camouflage painting, with linear size of less than 30-50mm, are not visible from more than 30 meters and, subsequently, lose their camouflage effect. The color pattern of camouflage painting often includes also different shades of red and blue which are not typical for nature and do not conceal but rather discover the soldier.

To reduce optical signature of the warrior's personal equipment (not only body armor) it is necessary to use camouflage spots of such sizes which are optically resoluble at the most probable distances of small arms fire, i.e. 300-500 meters. It is recommended to use combinations of spots with brightness coefficients of 5-10% and 25-30%. The color pattern should contain the colors typical for the particular geographical zone and season. Spectral characteristics of color spots shall be normalizable characteristics of camouflage materials.

The spectral characteristics of green spots shall feature increased reflectivity at the wavelength of 550 nanometers, matching the natural vegetation because of chlorophyll. For winter patterns it's preferable to use the materials and paints with reflectivity matching that of snow in UV region. Most white-color textiles and films do not meet this requirement and when viewed through filters can be seen as dark against white snow. Besides, the spot pattern is also necessary for winter camouflage. The idea of monotonous snow surface on the battlefield is erroneous.

It's important that with the advent of thermal imagers and radars optical surveillance lost its unique role. Optical surveillance cannot be used or is very difficult to use at night, in fog, from behind the smoke screens, in low forest. But thermal systems can detect warriors in all these conditions with high probability. Experimentally we have confirmed the possibility of detecting a warrior in standard uniform in summer via a thermal sight at the ranges of up to 4 km. It's very important that neither the night-time nor aerosols can conceal a person from thermal detection which makes the issue of soldier's thermal signature management even more critical.

Radar surveillance of warriors is not used so widely. Just some cases of using AN/TPS-15 radar in the role of rifle sight are known. However, radar surveillance of combat units is an important method of target designation for mortar and artillery batteries.

"NII STALI" JSC has designed a range of personal equipment for optical, thermal and radar signature management.

Fig.2a shows a general view of an armor vest with metal ballistic panels; the vest reduces the radar reflection of the soldier in centimeter wavelength range by one order. Fig.2b presents a general view of a polymer ballistic helmet with low radar reflection and concealing the thermal image of the soldier's face. Signature reduction is gained with the help of special materials, and the weight increase is only 30-60 grams.

a b

Fig.2 Body armor with reduced radar reflection
a - armor vest
b - ballistic helmet

Fig.3 Warrior wearing a camouflage cape and a ballistic helmet made by "NII STALI" JSC

a b

Fig.4 Thermal image of warriors, one of whom is wearing a standard Army camouflage uniform (left) and the other - a camouflage cape made by "NII STALI" JSC (right)
a – front view
b – back view

For combined reduction of optical, thermal and radar signature "NII STALI" JSC has designed a camouflage cape (see Fig.3). Fig.4 presents a close-distance thermal image of soldiers wearing a standard camouflage uniform and a camouflage cape made by "NII STALI" JSC. The new soldier's signature reduction means impede the use of any type of weapons by the enemy and in combination with body armor can greatly improve survivability of warriors, even against such types of weapons which cannot be stopped by ballistic protection.

Composite Ballistic Shields

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M. Landwijt

The Institute of Security Technology "Moratex"

INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN REGIONAL
DEVELOPMENT FUND

Key Project No. POIG 01.03.01-10-005/08 entitled: „Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".

Preface

No composite ballistic shields are manufactured in Poland. It still isn't a well-known matter, especially regarding specific, textile ballistic products. In this case the method of making the fibrous composite structural cohesion and homogeneity while providing its protective features calls for study. Consequently, the research towards designing and developing the objective composite product is essential.

The Institute of Security Technology „MORATEX", a body incorporated into hierarchy of the Ministry of Interior and Administration, executes currently the Key Project within the frame of Operational Programme Innovative Economy No.POIG01.03.01-10-005/08entitled:„Modernballisticbody armours and covers for transportation means as well as for buildings made on a basis of textile composites". The goal of the Project is development of innovative products, that provide security to the officers of: Police, Border Guard, Government Protection Bureau and Fire Brigades. One of the product is the range of composite ballistic shields – the equipment for direct protection of health and life of officers who take parts in operational actions..

Bibliography says, that all of currently leading worldwide manufacturers make individual ballistic protectors, including the shields, of the fibrous composites on a basis of para-aramide or PE fibres. Such products feature unhesitatingly lower areal density then those of traditional materials i.e. armour steel, while providing the same level of protection. Yet they don't need maintenance and are corrosion-proof. Moreover, they are resistant to abrasion, strokes, chemical agents and water, UV radiation as well as to variable atmospheric conditions. In some cases they also act as effective cover against radar and thermovision [1, 2].

PE composite is of remarkable importance – it's the only available fibrous composite, which provides effective protection against standard carbine bullets 7.62x39 model 43 PS and against 7.62x51 NATO BALL. Other fibrous composites (e.g. aramide-phenolic or aramide-rubber) require reinforcing with a layer of ceramics or steel in order to reach similar class of protection. Among the materials resistant to the projectiles mentioned above (table 1), the PE composite allows for remarkable reduction of the product weight, thus increasing the usage comfort as well as improving the officer's mobility.

Table 1. Areal densities of selected materials [3].

item	Material	Areal density [kg/m^2]
1.	PE composite	21
2.	Composite of aramid + Al_2O_3 ceramics	38
3.	Ballistic steel	45
4.	Composite of glass + Al_2O_3 ceramics	54
5.	Aluminium	70

The information available across the Internet as well as the review and analysis of brochures form ballistic shields' worldwide manufacturers [6-8, 10-12] leads to conclusion, that the Police units in many countries are equipped with such a kind of product. The covers differ mainly with their level of protection, dimensions, design of handle, and extra accessories.

From the review one could conclude that the ballistic resistance of the shields is mainly defined by the requirements of NIJ Standard 0108.01 [4]. Concerning the ballistic resistance the shields might be divided into two groups i.e.: resistant to small arms (level III-A) and carbine bullets (level III, IV).

No matter what is the ballistic protection level, the shields consist of the following design elements:

- ballistic jacket,
- edge band,
- cushioning insert,
- handle,

and extra equipment.

The dimensions of ballistic jacket vary. However typical dimensions are:

- shields resistant to bullets shot from small arms: ~ 45 x 80 cm,
- shields resistant to bullets shot from carbine or rifle: ~ 50 x 100 cm.

The shield's jacket may feature flat profile, flat profile with bent margin or cylindrical profile. Mostly often applied radius of the cylindrical shield's jacket is 800 mm. The shields of various jacket's profile are presented on the Figure 1.

Fig. 1. View of shields featuring flat profile [5], flat profile with bent margin [6] and cylindrical profile [7].

Fig. 2. View of shield „Kent Shield" featuring special profile of jacket [8].

The edge band protects edge of shield's jacket against mechanical damage and against access of humidity. Mostly often it is made of rubber profile or other polymer.

The cushioning insert is designed for attenuating the stroke energy. It is made of foamed plastic. No information on kind of the plastic neither it's energy attenuation capabilities is published.

A handle is handy for transportation and allows for usage during operations. Mostly often it's made of metal bent pipes, or textile technical bands. Typical handle design allows for using the shield both by right -handed and left-handed individuals.

Fig. 3. Views of shield handles made as profiles of metal pipes [9]

Extra equipment for the shields allows for improving operational advantages of such product. It may be e.g. bullet-proof visor, light source, a support for keeping the shield in stable vertical position, or a carriage (Fig. 4).

Fig. 4. Views of typical extra equipment for ballistic shields [10-12].

Developing the innovative model of ballistic shield made with composite technology, and resistant to the carbine bullets, in compliance with the requirements of level III according to NIJ Standard 0108.01 is expected within a frame of the currently realized key project.

Preliminary works of project assume, that the model of shield shall be developed without extra equipment. Nevertheless along the latest worldwide technology trends, our developers introduce design solutions, which allow for applying the extra equipment e.g. bullet-proof visor, light source or carriage, thus inducing optimum adjusting the product to the users needs. Novelty of the ballistic shield aims to provide its usage properties of the level higher than those in use so far among our officers.

The elements of design of composite ballistic shield under development are shown on figure 5.

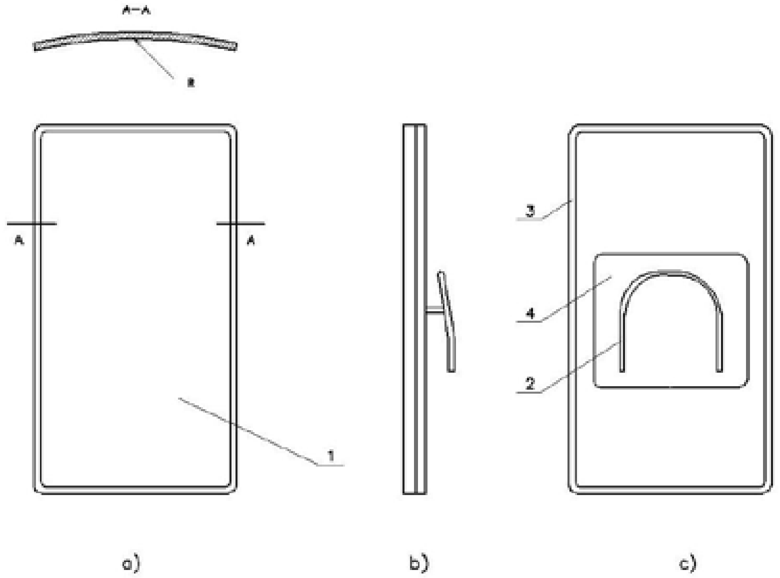

Fig. 5. Composite ballistic shield (no accessories):
a) front view; b) side view; c) rear view.

Moreover, the following assumptions have been defined during R&D works:

- ballistic jacket shall be made of PE composite.
- edge band made of suitably shaped polymer material would allow for securing the edge of shield against mechanical damage and humidity access.
- cushioning insert made on a basis of foamed plastic shall provide adequate level of stroke energy attenuation.
- handle made of ergonomic system of metal pipes will allow the user for using the shield by both right-handed and left-handed individuals. Properly designed handle structure will not need incorporating any system for adjusting the angle between handle and the axe of shield's jacket.

Advanced technologies of preparing the composites [13] of thermoplastic warp offer wide possibilities of optimum development of product's properties. With the support from latest science achievements, the technology of manufacturing the composite dedicated for making the ballistic shield shall be based on the process of thermal pressure joining the unwoven sheets of polyethylene. Figure 6 [14] presents key technology parameters of the process.

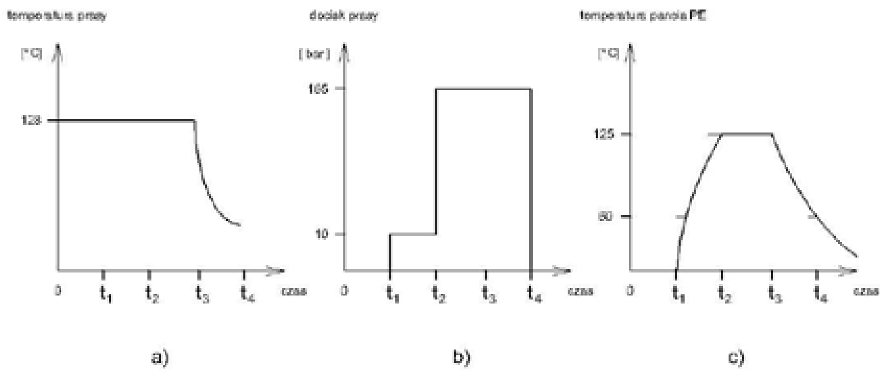

Fig. 6. Schema of the thermal pressure process of manufacturing the polyethylene composite; (a) changes of press temperature, (b) changes of moulding pressure, (c) changes of polyethylene panel's temperature, times t1 – t4 parameter determined experimentally dependent on the PE sheet type and on thickness of composite being manufactured.

In order to gain objective product, the research shall be supported with series of experiments concerning effects of pressure, high temperatures, time etc. on the presumed designs of composites. The experiments shall be executed i.a. with using a special press and moulds, which allow for manufacturing the fibrous composites featuring multi-layer, cohesive structure and precisely defined, modifiable ballistic properties.

Summary

Completing the project shall allow for delivery of new and innovative solution for manufacturing the ballistic shields. Until now, no composite ballistic shields were offered by domestic manufacturers. The new product will be based on the newest fibrous ballistic materials, which arise in recent years on the worldwide market, and benefit from latest technologies. Developing the product will take execution of multi-directional research, results of which shall allow for optimization models made-up. Reduction of shield's weight and diversification of extra equipment will lead to optimum matching to the needs of the officers of special units subordinated to Ministry of Interior and Administration.

Moreover the commercialization of the research results will happen. The preliminary technical and technological documentation regarding practical applications ready to use/implement will be made. Grant of patent protection is expected for the results of project.

Literature

1. *A. Wilczyński; „Polimerowe kompozyty włókniste"; Wydawnictwa Naukowo-Techniczne 1996 Warszawa.*
2. *W. Jabłoński, J. Wnuk; „Włókno aramidowe bazą produktów innowacyjnych"; BIT; 2000 Bielsko-Biała.*
3. *W. Błaszczyk, M. Łandwijt; Zeszyty Naukowe Akademii Marynarki Wojennej Rok XLIX Nr 172 K/2; 2008 str. 15.*
4. *NIJ Standard 0108.01:1985 „Ballistic Resistant Protective Materials".*
5. *Tencate Advanced Armour Francja, materiały reklamowe; Warunki Techniczne WT-364/ ITWW/2003, ITWW „MORATEX", unpublished.*
6. *http://www.thefind.com/sports/browse-ballistic-shield-level*
7. *http://www.specops.com.pl/taktyka_czarna/wyposazenie/tarcze_balistyczne/tarcze_balistyczne.htm*
8. *K. Suddes "The Kent Shield revolutionizes ballistic protection", internet publication (13.02.2007), The One Resource for Police and Law Enforcement (http://www.policeone.com).*
9. *Warunki Techniczne WT-347/ITWW/2003, ITWW „MORATEX", unpublished.*
10. *http://www.protechtactical.com/bshields.aspx*
11. *http://www.global-security-solutions.com/BallisticShield.htm*
12. *http://www.securityprousa.com/bashleiiiwig.html*
13. *JEC Composites Magazine, nr 8 str. 26, 2006.*
14. *„Manual for Dyneema® ballistic panels" – information brochure by DSM.*

Computer Simulation of AP Projectile Penetration into RHA

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1. Introduction

Four stages can be noted in the process of the projectile penetration into armour [1]. In the first stage a wave is created, propagating from the top of the projectile toward its back and generating stresses many times bigger than strength of projectile material, causing plastic strain at its top. The same occurs in the armour, where the stresses cause local transition of armour material in liquid state and, in effect, create a crater.

In the second stage the projectile penetrates into the armour with a constant velocity, and in the third one – the projectile sheds successively the velocity as the result of disappearance of high pressure space. At the last stage a contraction of the crater occurs under the influence of recrystallization and annealing of the armour material.

The above-mentioned process of projectile penetration into armour was analysed with the use of AUTODYN 5 programme. The numerical simulations which were obtained in this way, show changes occurring in the projectile and armour at every moment from the beginning of their contact with the use of discretization, sharing such a complicated effect onto a finite number of simplistic elements. Linear variables of time and space are subjected to discretization. The values of the variables (the displacements, stress, strain, et cetera.) in the function of time, are calculated as a result of the integration of function of entry variables (for example: velocity of projectile) over time, considering values these variables from a previous time step. The discretization of space relies on its division into smaller elements – cells or particles, which interact each other. Then a system of equations is solved, which describes static and dynamic material properties of the projectile and armour. AUTODYN 5 programme contains database of such parameters for different kinds of materials. There exist several methods of computer physics to model phenomena occurring during the collision of the projectile with armour (for example: Lagrange's method, Euler's method, SPH method, etc.).

In AUTODYN 5 programme, the SPH (Smooth Particle Hydrodynamic) method was used, according to it the considered area was covered with particles moving with deforming object. There is calculated sum of interactions for a selected particle of all its adjacent particles. In the every time step of the SPH method, basic stages of calculations are carried out, relying on that, for given initial and boundary conditions, the equations of state, constitutive relations, etc., there are calculated new parameters, such as velocity, stress, force, displacement, etc. in every following cycle and at every point. The main advantage of this method against any other is the lack of mesh on the analysed object. In other methods the mesh covering the examined object can procure significant deformations which sometimes make impossible further calculations. Another advantage of this method is the possibility of the modeling of the cracking effects and the scattering of elements formed from the collision of the projectile and armour.

2. Numerical analysis of projectile penetration into armour

Numerical simulations of the projectile penetration into armour using different dimensions of armour and different physical and mechanical properties of 12.7 mm AP (armour piercing) material were carried out here. In realistic conditions this bullet pierces 20 mm thick steel RHA armour (rolled homogeneous armour) [2]. The goal of computer simulations was to choose optimum parameters of the projectile to obtain the result of projectile penetration into armour closest to reality.

In the all numerical variants RHA steel was used as a homogenous rolled armour which is accessible in the AUTODYN database under the same name. The values of the RHA parameters are shown in Table 1.

In the process of armour penetration the main role is played by the core of the AP projectile, however its remaining elements (coat and pyrotechnical material) have a insignificant influence on the depth of penetration. From this reason only the dimensions and shape of the core of this projectile were considered in subsequent computer simulations.

The material parameters of the projectile were taken from the work [3], where the author explored the capacity of the projectile to pierce ceramic armours. Steel of the 4340 type was used as projectile material with correction of its three parameters. The values of the bulk modulus, specific heat and shear modulus were modified. The 4340a symbol was used for this steel. The parameters of 4340 and 4340a steel were shown in Table 2.

Table 1. The parameters of RHA steel

Steel	RHA	Unit
Equation of state	Shock	
Reference density	7.86	g/cm^3
Gruneisen Coefficient	1.67E+00	-
Parameter C1	4.61E+03	m/s
Parameter S1	1.73E+00	-
Parameter Quadratic S2	0.00E+00	s/m
Relative Volume, VE	0.00E+00	-
Relative Volume, VB	0.00E+00	-
Parameter C2	0.00E+00	m/s
Parameter S2	0.00E+00	-
Reference Temperature	0.00E+00	K
Specific Heat	0.00E+00	J/kgK
Strength	von Mises	
Shear Modulus	6.41E+07	kPa
Yield Stress	1.50E+06	kPa
Maximum Expansion	1.00E-01	-
Minimum Density Factor (Euler)	1.00E-04	-
Minimum Density Factor (SPH)	2.00E-01	-
Maximum Density Factor (SPH)	3.00E+00	-
Minimum Soundspeed	1.00E-06	m/s
Maximum Soundspeed	1.01E+20	m/s

Table 2. The parameters of 4340 and 4340a steel

Steel	**4340**	**4340a**	**Unit**
Equation of state	Linear	Linear	
Reference density	7.83	7.83	g/cm^3
Bulk Modulus	1.59E+08	**1.30E+08**	kPa
Reference Temperature	3.00E+02	3.00E+02	K
Specific Heat	4.77E+02	**5.00E+02**	J/kgK
Strength	Johnson Cook	Johnson Cook	
Shear Modulus	8.18E+07	**7.20E+07**	kPa
Yield Stress	7.92E+05	7.92E+05	kPa
Hardening Constant	5.10E+05	5.10E+05	kPa
Hardening Exponent	2.60E-01	2.60E-01	-
Strain Rate Constant	1.40E-02	1.40E-02	-
Thermal Softening Exponent	1.03E+00	1.03E+00	-
Melting Temperature	1.79E+03	1.79E+03	K
Strain Rate Correction	1st order	1st order	
Maximum Expansion	1.00E-01	1.00E-01	-
Minimum Density Factor (Euler)	1.00E-04	1.00E-04	-
Minimum Density Factor (SPH)	2.00E-01	2.00E-01	-
Maximum Density Factor (SPH)	3.00E+00	3.00E+00	-
Minimum Soundspeed	1.00E-06	1.00E-06	m/s
Maximum Soundspeed	1.01E+20	1.01E+20	m/s
Maximum Temperature	1.01E+20	1.01E+20	-

The measured velocity of the projectile [3] at the moment of collision with the armour (845 m/s) was taken as the entry variable in numerical simulations.

In the first variant of computer simulation the projectile penetrated armour only 8 mm of depth and the armour bulging was 4.5 mm. For this reason a correction of projectile parameters was necessary.

In the next variant 2 of computer simulations, using 4340 steel parameters, the armour was also not pierced.

In the successive variant 3 the projectile was made from RHA steel. In this case the bulging was the same as in the previous variants, however the depth of penetration increased by about 3% in comparison with the first and second variants. Significant differences in the degree of plastic strain were observed. The decrease of dimension along the axis of projectile in variants 1 and 2 was about 20% higher than in variant 3. The differences in the values of the diameters of so called "projectile mushrooms" were also observed. The projectile mushroom diameter in the variant 3 was about 10% smaller than in variants 1 and 2. The results of simulations for variants 1÷3 are shown in Tables 3 and 4.

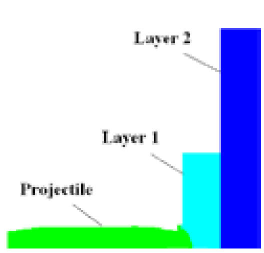
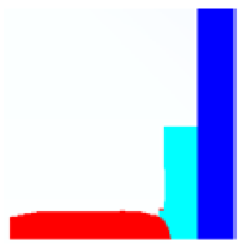
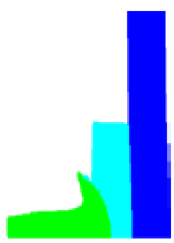
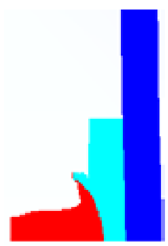
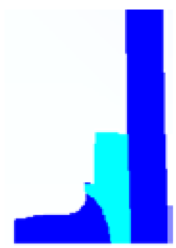
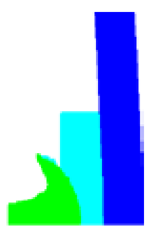
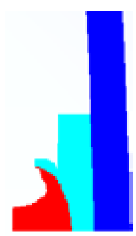
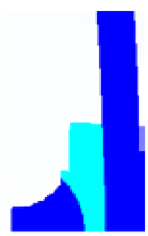
Table 3. Results of simulations of penetration of 12.7 mm projectile into RHA layers for variants 1÷3

Variant	Material of projectile	Diameter (Ø) and thickness (a) of armour layers, Ø x a, mm	Depth of penetration, DP, mm	Armour bulging d, mm	Final length of projectile, L, mm	Mushroom diameter, D, mm
1	4340a	layer 1: Ø50x10/ layer 2: Ø500x10	8	4.5	18	29
2	4340	layer 1: Ø50x10/ layer 2: Ø500x10	7.9	4.5	18.3	28
3	RHA	layer 1: Ø50x10/ layer 2: Ø500x10	8.2	4.5	22.5	26

In successive calculations the thickness of armour was the same (20 mm), but only one layer of armour was used (Tables 5 and 6).

In regards to the fact that in hitherto simulations the RHA projectile had the best parameters (smaller plastic strain of projectile, bigger depth of armour penetration), the basic (output) projectile material was RHA steel with increased yield stress Re (2500 MPa in variant 4 in relation to 1500 MPa in variant 3). In every next variant, the Re parameter was successively increased (Table 5) to the value of 5000 MPa (variant 7). Results of numerical simulations for variants 4÷7 are shown in Tables 6 and 7.

Table 4. The simulations of penetration of 12.7 mm projectile into RHA layers for variant 1÷3

Variant 1	Variant 2	Variant 3
Projectile: 4340a	Projectile: 4340	Projectile: RHA
Layer 1: Ø50x10; layer 2: Ø500x10		
		
Cycle 532 Time 0.01 ms	Cycle 537 Time 0.01 ms	Cycle 557 Time 0.01 ms
		
Cycle 2037 Time 0.04 ms	Cycle 2200 Time 0.04 ms	Cycle 2156 Time 0.04 ms
		
Cycle 6628 Time 0.14 ms	Cycle 7200 Time 0.14 ms	Cycle 7245 Time 0.14 ms

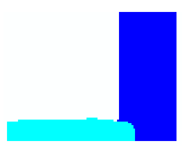
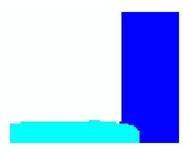
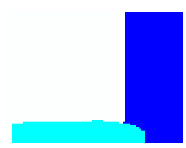
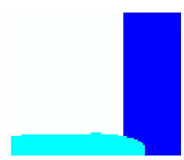
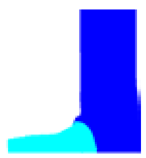
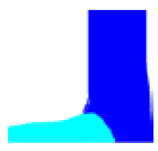
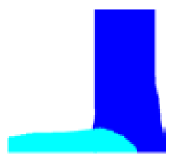
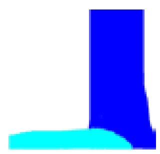
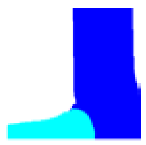
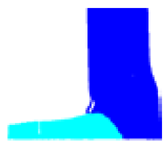
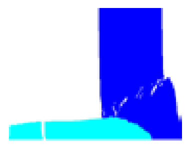
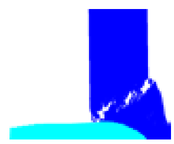
Variant	Symbol of RHA	Yield stress, R_e, MPa
4	RHAa	2500
5	RHAb	3500
6	RHAc	4500
7	RHAd	5000

Table 5. The yield stress of RHA projectile for variants 4÷7

Table 6. The results of simulations of penetration of 12.7 mm projectile into RHA layers for variants 4÷7

Variant	Material of projectile	Diameter (Ø) and thickness (a) of RHA armour layer 1, Ø x a, mm	Depth of penetration, DP, mm	Armour bulging d, mm	Final lenght of projectile, L, mm	Mushroom diameter, D, mm
4	RHAa	Ø500x20	7.3	3.2	29.6	19
5	RHAb	Ø500x20	11.9	4.9	fragmentation of projectile	16
6	RHAc	Ø500x20	17.3	6.7	fragmentation of projectile	13
7	RHAd	Ø500x20	20.7	9.1	fragmentation of projectile	12.5

Table 7. The simulations of penetration of 12.7 mm projectile into RHA for variants 4÷7

Variant 4	Variant 5	Variant 6	Variant 7
Projectile: RHAa	Projectile: RHAb	Projectile: RHAc	Projectile: RHAd
			
Cycle 557 Time 0.01 ms	Cycle 557 Time 0.01 ms	Cycle 557 Time 0.01 ms	Cycle 557 Time 0.01 ms
			
Cycle 2127 Time 0.04 ms	Cycle 2121 Time 0.04 ms	Cycle 2121 Time 0.04 ms	Cycle 2125 Time 0.04 ms
			
Cycle 4564 Time 0.09 ms	Cycle 4561 Time 0.09 ms	Cycle 4596 Time 0.09 ms	Cycle 4588 Time 0.09 ms

In the Figure 1 armour bulging is shown, as well as the depth of penetration of the armour and the mushroom diameter in function of yield stress for variants 4÷7. Together with the increase of yield stress of the projectile material, its capability of armour penetration also increased. Whereas the mushroom diameter decreases together with the increase of Re. In variant 7 the projectile penetrated 20.7 mm depth of armour, but without piercing it and it was stopped in the armour. The material of the armour underwent large plastic strains, but it retained its cohesion (Table 7). The effect of fragmentation of the projectile into two parts was observed for variants 5÷7.

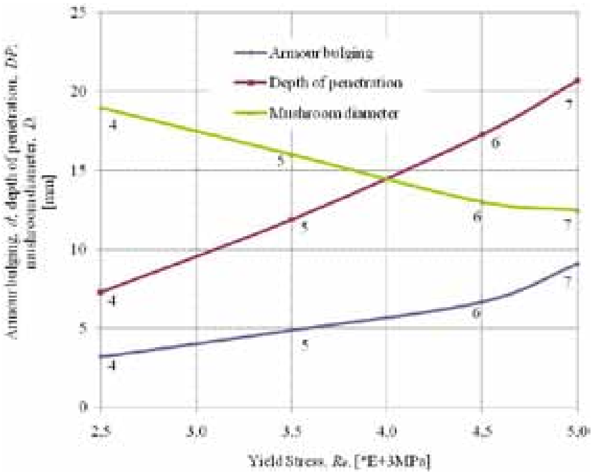
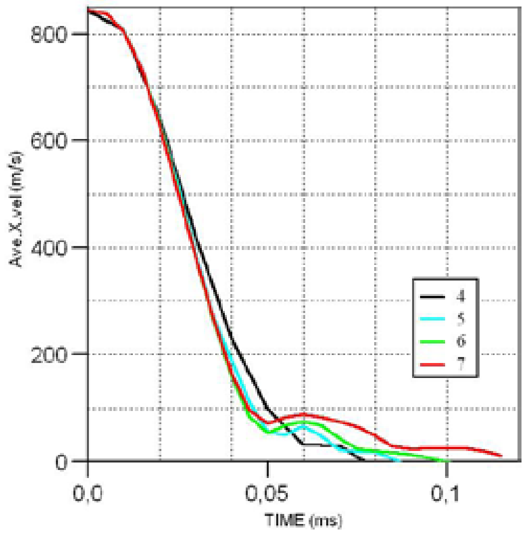


Fig. 1. The changes of armour bulging, the depth of penetration and projectile mushrooming in the function of Re yield stress of projectile material for variant 4÷7

In Figure 2a graphs of projectile velocity along its axis in the function of time for variants 4÷7 are shown. In the 0.02÷0.05 ms time interval, value of the vector of projectile velocity along its axis was the largest during the penetration of armour in variant 4, but at time above 0.05 ms this projectile wasted velocity violently and got stuck in the armour. The projectile in variant 7 kept the value of its velocity above zero for the longest time.

In the Figure 2b graphs of vectors of projectile velocity in orthogonal direction to its axis in the function of time for variants 4÷7 can be observed. The projectile penetrating into armour 4 had the highest velocity. The lowest values of the vectors of projectile velocity were held by the projectile with the highest yield stress (5000 MPa, variant 7).



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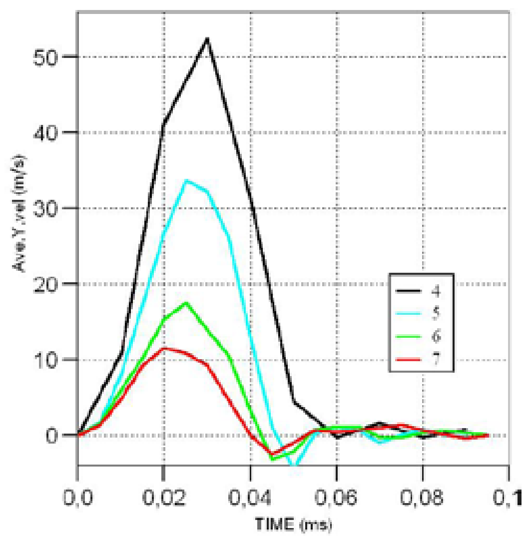
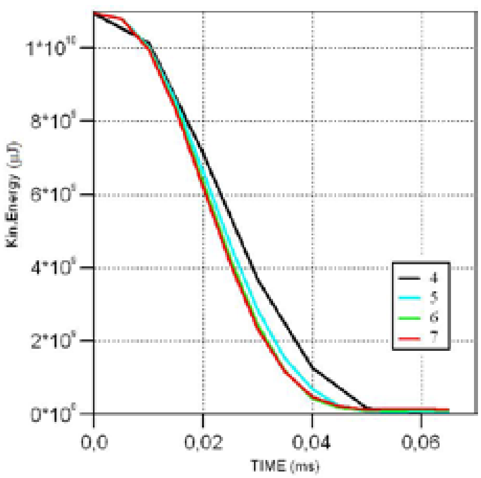


b

Fig. 2. Average velocity of projectile in the function of time for variants 4÷7:
a - along its axis,
b - in orthogonal direction to its axis

In the Figure 3 changes of kinetic energy of the projectile in the function of time are shown. In the 0.02÷0.05 ms time interval, the greatest kinetic energy belonged to the projectile with the smallest yield stress (variant 4). This is related to the greatest strains of the projectile in this variant. At the moment of collision of the projectile and armour the top of the projectile brakes violently, and rear fragments of it move with a velocity similar to its initial value (845 m/s), as a result of plastic strains of the projectile material. The greater these strains are, the lower the yield stress of the projectile material is.

There is also an effect of the projectile mushrooming at the beginning of the penetration process of the armour in variant 4. The lowest yield stress (1500 MPa) and, connected to it, the most substantial ductility, caused a dissipation of projectile elements in an orthogonal direction to its axis of penetration. This is disadvantageous effect because of the fact that its big portion of kinetic energy is dissipated not along axis of armour penetration, but in a transverse way. In variant 4 at the time above 0.05 ms a sudden drop of the projectile's kinetic energy followed as a result of its velocity drop (Fig. 2a and 2b).



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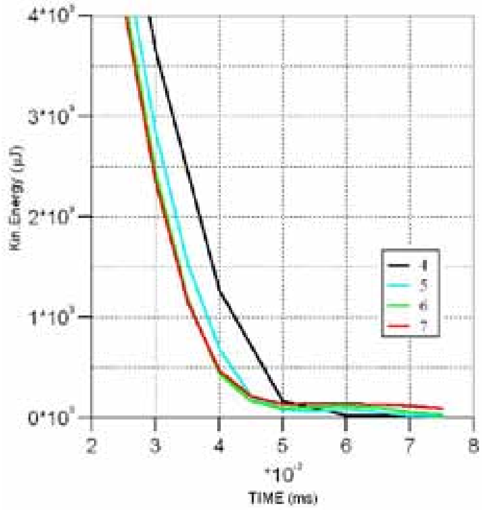

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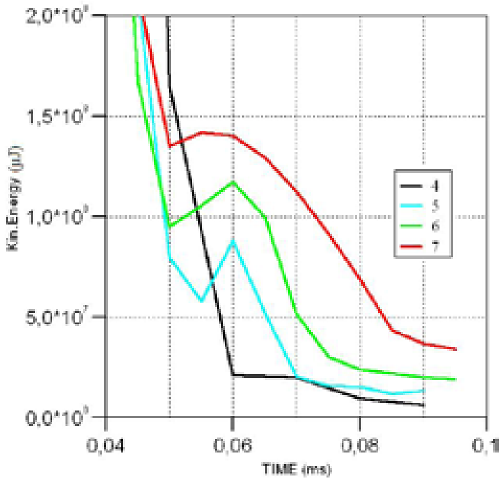

c

Fig. 3. The kinetic energy of projectilein the function of several interval times for variants 4÷7:
a - 0÷0.06 ms,
b - 0.2÷0.08 ms,
c - 0.04÷0.1 ms

3. Conclusions

On the base of above simulations the following conclusions can be presented:

1. The value of time t at which a projectile is stopped in armour rises together with the yield stress of the projectile material (the time of penetration was 60% longer in case of using projectile made from steel with two times higher yield stress).
2. At the initial phase of projectile penetration into armour (0÷0.04 ms) kinetic energy of the projectile is inversely proportional to the yield stress of its material. Above 0.06 ms the higher kinetic energy of projectile is, the higher the yield stress of its material is (Table 8).
3. The lower yield stress of projectile material is, the shorter time of losing kinetic energy during penetrating of RHA armour is (Table 8):

- in the 0.03÷0.06 ms time interval, the projectile in variant 4 (Re =2500 MPa) lost 99% of its kinetic energy in comparison with 94% of kinetic energy loss for projectile in variant 7 (Re =5000 MPa).
- in the 0.06 ms time, the projectile in variant 4 had only 14% value of kinetic energy of the projectile in variant

Table 8. Kinetic energy of projectile in its successive stages of penetration process into RHA for variants 4÷7

Variant	Yield stress, R_e, MPa	Kinetic energy of projectile, E_{kin}, for time, t		Decrease of energy, ΔE_{kin}, % t = 0.03÷0.06 ms	Kinetic energy relations between respective variants 4÷7, %	
		0.03 ms	0.06 ms		t = 0.03 ms	t = 0.06 ms
4	2500	3.7E9 μJ	2.0E7 μJ	99	E_{kin4} / E_{kin4}= 100	E_{kin4} / E_{kin7}= 14
5	3500	2.9E9 μJ	8.0E7 μJ	97	E_{kin5} / E_{kin4}= 78	E_{kin5} / E_{kin7}= 57
6	4500	2.4E9 μJ	1.2E8 μJ	95	E_{kin6} / E_{kin4}= 65	E_{kin6} / E_{kin7}= 86
7	5000	2.2E9 μJ	1.4E8 μJ	94	E_{kin7} / E_{kin4}= 60	E_{kin7} / E_{kin7}= 100

Table 9. The influence of the yield stress of projectile material on its plastic strains and on capability of armour penetration in initial phase (t=0.04 ms) of penetration

Variant	Yield stress, R_e, MPa	Depth of penetration, DP, mm	Length of the rest of projectile, L, mm	Mushroom diameter, D, mm
4	2500	5.7	31.7	19
5	3500	9.3	37.1	15.6
6	4500	13.8	43.1	13
7	5000	15.7	45.6	12.5

4. Projectile made from material with lower yield stress (Re =2500 MPa, on the assumption Ekin=100%) causes the following (Table 9):
   - the highest kinetic energy of projectile (in the 0÷0.04 ms time interval) is used mainly for plastic strains of projectile;
   - armour penetration is less deeply in the axis of the projectile because it undergoes more plastic strains.
5. Two times higher yield stress of projectile material, i.e. Re =5000 MPa - variant 7 in comparison with projectile material, i.e. Re =2500 MPa - variant 4 causes (in the 0÷0.04 ms time interval) that (Table 9):
   - the mushroom diameter is 35% smaller,
   - the depth of penetration is 2.75 times bigger.
   - the length of the rest of projectile is 43.8% bigger.
6. In variant 3 greater depth of penetration (DP=8.2 mm) and more substantial armour bulging (d=4.5 mm) was obtained than in variant 4 (one-layered armour - DP=7.3 mm, d=3.2 mm) despite the fact that the projectile material in variant 4 had a higher yield stress (2500 MPa in variant 4 in the comparison to 1500 MPa in variant 3). The resulting conclusion is that the protection capability of one-layered steel armours is higher than two-layered steel armours made from the same material.

Literature

1. *Magier M.: Methods to estimate the armour penetration depth by kinetic projectiles. Problemy Techniki Uzbrojenia i Radiolokacji (Problems of Armament Technology and Radiolocation), Wojskowy Instytut Techniczny Uzbrojenia (Military Institute of Armament Technology), Zielonka, 103, 2007.*
2. *Wiśniewski A.: Pancerze - budowa, projektowanie i badanie (Armours - construction, designing and testing). Wydawnictwa Naukowo Techniczne (Scientific-Technology Publisher), Warsaw, 2001.*
3. *Łukasik W.: Protection capabilities of large-sized corundum ceramics. Doctor's thesis. Akademia Górniczo-Hutnicza (Coal-Metallurgy University), Cracow, 2005.*

This work was financially supported by European Fund for Regional Development in Poland (Project "Technology of production of superhard nanostructural Fe-based alloys and their application in passive and passive-reactive armours" under contract No. UDA-POIG.01.03.01-00-042/08-00) and carried out within consortium between Instytut Metalurgii Żelaza (Institute for Ferrous Metallurgy) and Wojskowy Instytut Techniczny Uzbrojenia (Military Institute of Armanent Technology).

Development and Study of Laminated Aluminum-Ceramic Armor Materials

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TSNIISM JSC

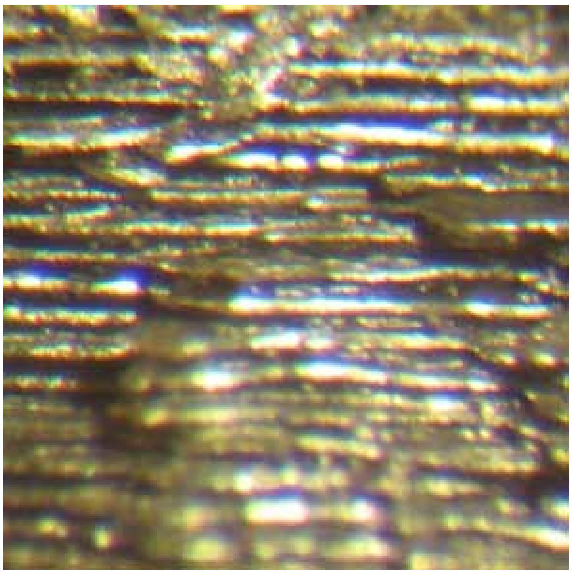
At present ceramic materials found a wide application in body armors. Physical and mechanical properties of ceramics are determined by chemical-bond character and crystalline structure. Chemical bond in ceramics is ionic or mixed ionic-covalent that explains its low plasticity, high rigidity and hardness and relatively high level of compression strength [1]. In particular, ceramics obtained by traditional hot pressure (powder baking) method has Vickers hardness of ~2000 MPa.

There are methods for obtaining ceramics by electrochemical anodization of aluminum in salt or acid solutions, for example, in sulfuric acid with concentration of 170 to 200 g/liter at current density of 1 to 2 A/dm^2 with a thickness up to 70 μm. In some other types of electrolytes and anodization methods, the thickness of anodic layer can reach 300 μm. The aluminum oxide films obtained by this method represent porous ceramic structure with high mechanical impact strength: its hardness reaches from 5000 MPa to 6500 MPa.

In this work, oxide films were obtained using aluminum foil up to 100 μm thick. A plate obtained as a result of anodization process is a sandwich with plastic aluminum as inner layer and two outer ceramic layers of aluminum oxide (Figure 1).

At the first stage of work, the plates in the number from 18 to 28 pcs were connected using film polymeric adhesive 220 μm thick.

To evaluate ballistic efficiency of plates obtained, tests for determining the dependence of ballistic efficiency parameter upon initial rate of an indenter were conducted. A steel ball 6.3 mm in diameter and 1.06 g in weight was used as the indenter. About 20 shots were fired at each sample. Maximums of obtained curves determine values of speeds for which protection of this type of armor is the most effective (Figure 2), i.e. this armor should show the most efficiency at speeds of ~430 m/s.



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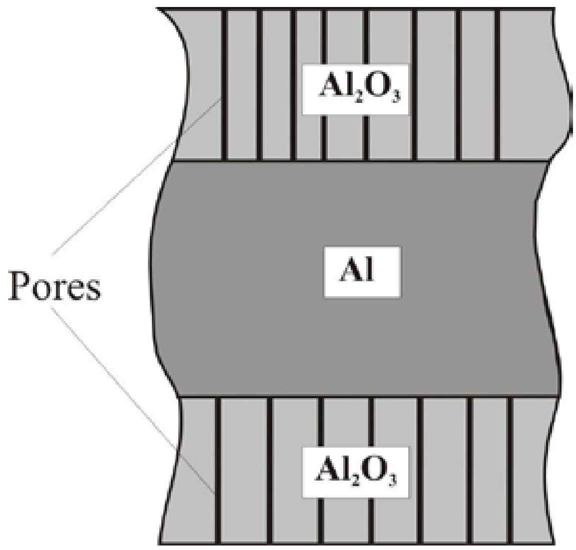

b

Figure 1. Multilayered anodized plate:
a - photograph of plate surface;
b - schematic of one layer of anodized plate.

A failure pattern of armor under study is of a particular interest. Around the opening there are concentric circles, their diameter near the opening (fragment entrance place) grows with increasing the fragment speed, and the opening diameter (fragment exit place), on the contrary, decreases with increasing the fragment speed (Figure 2). The tested sample remains plane practically until speed of 700 m/s that testifies to its vitality. At speeds of 650 to 700 m/s, the ballistic efficiency curve increases that gives preconditions for using the developed plate in making hybrid armor with aramid fabrics, ceramics and others. Value V_{50} for the sample with a backing of aramid fabric was 694 m/s.

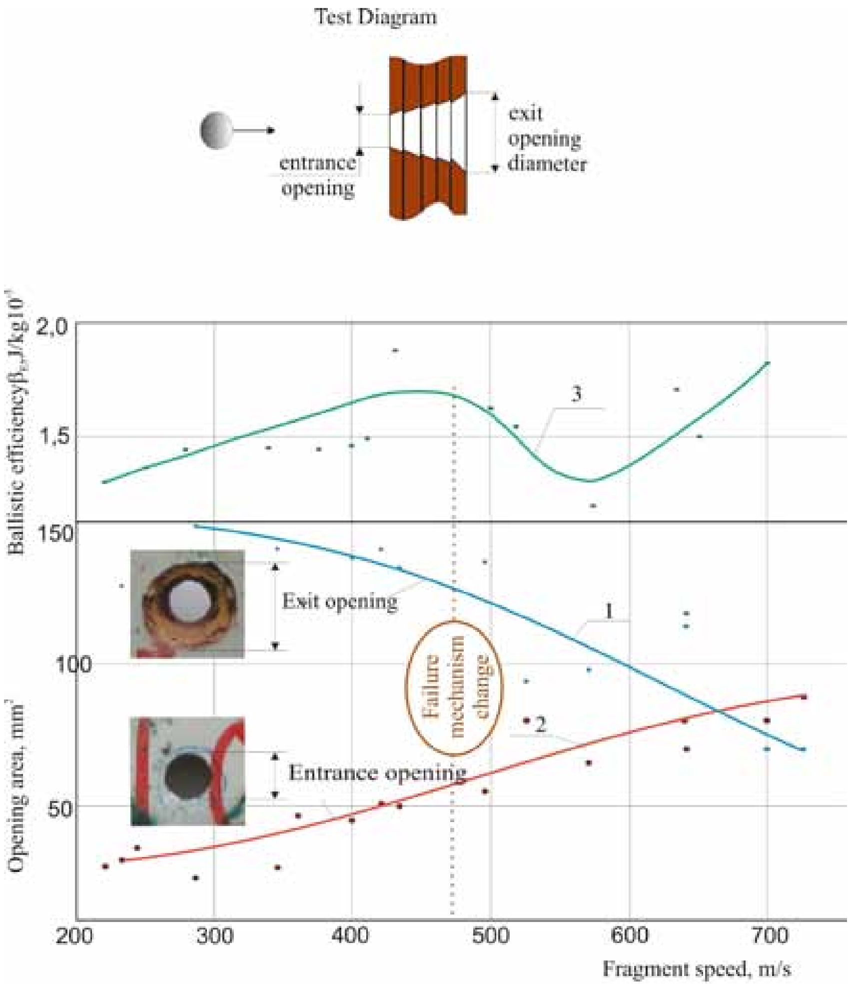

Figure 2. Failure area (1, 2) and ballistic efficiency BE (3) of the sample made of 18 layers of oxidized aluminum foil (surface density of ~6.9 kg/m2) cemented with polymer film as a function of fragment speed.

The test results show that the presence of ceramic layer on aluminum substantially increases the armor plate vitality: a sample measuring 10 cm x 15 cm remains practically plane after 18 shots, although in the indenter entrance and exit place there are concentric "funnels". The developed armor plate was found effective over the range of speeds corresponding to the second (II) protection level according to GOST R 50744-95 that creates the preconditions for developing more lightweight II-level armor. Also, the aluminum-ceramic armor with surface density of 7 kg/m^2 showed a result similar to steel armor with surface density of 17 kg/m^2. Furthermore, there is a possibility of further decrease of the armor plate weight and thickness at the expense of selection of more thin film-forming adhesives.

Literature

1. *1. A.Yu. Letnikov, I.F. Kobylkin and I.V. Kulakov State and development outlooks of protective armor-clothes structures // Double Technologies, 1998, № 2. C. 81-82.*

Main Structural Armor Component - Metal - from the Point of View of Latest Scientific Concepts

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S. A. Gladyshev, L. A. Tsurgozen,
V. P. Yankov

Armor is one of the oldest inventions of mankind which appeared and has been improving together with weapons (stones, arrows, darts, spears, swords, sabers, bullets and shells). Quite different materials were used as armor – wood, woven rods, clay, leather, sand and even moistened and solidified salt, and of course metals. Metals may and must be named as the dominating material for armor and armored structures. First of all, we should note a wide range of metals used in armor, and a great variety of their structural application - from single structural elements (cover plates and badges) through whole products (helmets, cuirasses, hauberks) to large-sized structural armor (ships, tanks, trains, cars etc.).

"Metal" is the name of a dominating group consisting of at least 80 chemical elements which corresponds to almost 80% of all presently known chemical elements. Traditionally metals are characterized by a particular solid-state crystal structure and by a number of specific features such as thermal conduction, electric conduction, strength, hardness, glitter, permanent melting temperature. Metals with density up to 5 g/cm^3 are called "light metals", the rest are called "heavy metals". Also such metal categories are known as "noble metals" (gold, silver, platinum etc.), "rare (rare earth) metals", "alkali metals", "transition metals" etc. The number of alloys of metals with other metals or with other chemical elements and compounds is past one thousand and is constantly increasing. The role of metals in the history of mankind does not need any special discussion; it's enough to remember the names of subsequent historical epochs such as "Stone age", "Copper age", "Bronze age", "Iron age".

It is interesting to note the placement of metals in the modern periodical system of elements. As we know, the Periodical Law and periodical system of elements were invented by the Russian scientist Dmitry Mendeleev in 1869. The invention brought Russian science to the front line of international science and still constitutes the pride of our country. However, Dmitry Mendeleev could not explain the underlying cause of periodicity and said frankly: "We don't know the cause of periodicity". Mendeleev's periodic system of elements in its today's form features a whole system of evident faults: insufficiently clear distinction between metals and nonmetals; the place of hydrogen, the problem of Group 8 (when well-known iron found itself in the same group as noble gases); lack of the place for lantanoids and actinoids etc.

Our paper focuses on new suggestions aimed at improvement, or rather, at creation of a new Periodic system which is caused by the necessity to eliminate the faults of the existing system. The new suggestions are based on the use of all four quantum numbers. The place of each element is clearly and definitely determined by its own combination of four quantum numbers (a kind of personal passport) which is responsible for the quantum equilibrium of the atom as a whole. The system is based on the results of investigation of linear optical spectrums and related to them Pauli exclusion principle, V.M.Klechkovsky and D.N.Trifonov rules and on radical reconsideration of the customary model of atom. The system is called "Symmetric quantum periodic system of neutral atoms", or "Makhov's Tree" by the name of its inventor Boris F. Makhov (Fig.1). The essence of the system is as follows:

The sequence of elements (Mendeleev's row) is maintained, but a new division for periods is introduced on the basis of distinct and clear parameters (quantum numbers).

All periods presented by horizontal rows form dyads with successively increasing number of superstructing horizontal rows (successive one-row, two-row, three-row and four-row pairs of periods, i.e. all in all eight periods).

Length and composition of the periods increase along with increase of the dyad number, forming a kind of "tree".

The new system retains all vertical groups.

In the new system metals and nonmetals are distinctly separated.

In the new system there's a proper place for lantanoids and actinoids.

The problem of Group 8 of Mendeleev's system has been solved.

The new system is a continuous sequence of elements (each element which finishes the previous row, starts the next row, which means that the system can be presented in the form of a 3D model) (Fig.2-7).

Development of the new system required consideration of the neutral atom model and has led to development of a radically new model of atom structure which has been called "Oscillatory resonance model of neutral atom" (Fig.8). In contrast to the existing model of atom, the new model treats the nucleus as pulsing and generating around itself an alternating electromagnetic field which spreads in the surrounding medium to a depth, strictly typical for each atom, and in this way generating a standing (elastic, coherent) electromagnetic wave. The new model does not imply the notion of a negatively charged particle (electron). At interaction of neutral atoms (chemical interaction) their electromagnetic fields overlap and they transfer to some degree of excitation. In this process selection of partners and particular physical conditions of interaction are very important.

According to the new Periodic system and the new atom model each element is characterized by the radius of propagation of the alternating electromagnetic field, generated by the nucleus, or of the standing electromagnetic wave (atom radius).

The characteristics of atom radius values of the elements in the new Periodic system are presented in Fig. 9, from which we can see that the metal atom radiuses are significantly larger than the radiuses of non-metal atoms. It also explains the nature of high-strength of metal bonds.

Another fact is as interesting: in the new System the main alloying components of steel – carbon and nitrogen – are situated next to each other, at the top and in the centre of the new Table. They are p-elements which feature high bond energy (especially nitrogen; that's why it is present also in all such vital organic matters as proteins, and in all explosives.

As applied to one of the main "title" metals – iron – it can be seen that iron itself as well as the main alloying elements are d-elements (Cr, Ni, Mo, V etc.) which belong to the 7-th horizontal row of the new System.

Going back to the problems of armor materials science, and comparing the properties of most accepted "title" metals of alloying systems – iron (steel), titanium and aluminium – we must specially emphasize the efficiency of using aluminium as the armored hull material (Fig.10) and also note the higher efficiency of composing new aluminium-based alloys as compared to composing iron-, copper- and titanium-based alloys. For example, strength improvement ratio in the comparison "pure aluminium – aluminium alloys" can be in the range of 15-20 whereas it is only 10 in the pair "iron-steel", and only 8 in the pairs "pure copper-copper alloys" and "pure titanium-titanium alloys". Thus, aluminium alloys are worth being considered as very efficient and promising armor materials.

Presently good results has been achieved in both two-component and more complex alloys of aluminium with Mg Si Cu Zn (recently attention has been attracted also to Li Ag) which can be explained by better and varying solubility of these metals in aluminium. Maximum solubility of the element in the solid solution is 17.4 1.65 5.7 82% accordingly. It is known that variable solubility provides thermal hardening (tempering) effect. It can be explained by the metallophysical similarity of the above alloying materials with aluminium which expresses itself in closeness of their atom radiuses to the atom radius of aluminium. In Fig.11 the authors present the forecast of development of aluminium-based high-strength armor materials.

The authors are absolutely sure that the new system of periodization of elements and the new atom structure model offer great potentialities and can serve as the basis for further development of fundamental research in natural sciences and in particular in armor material science.

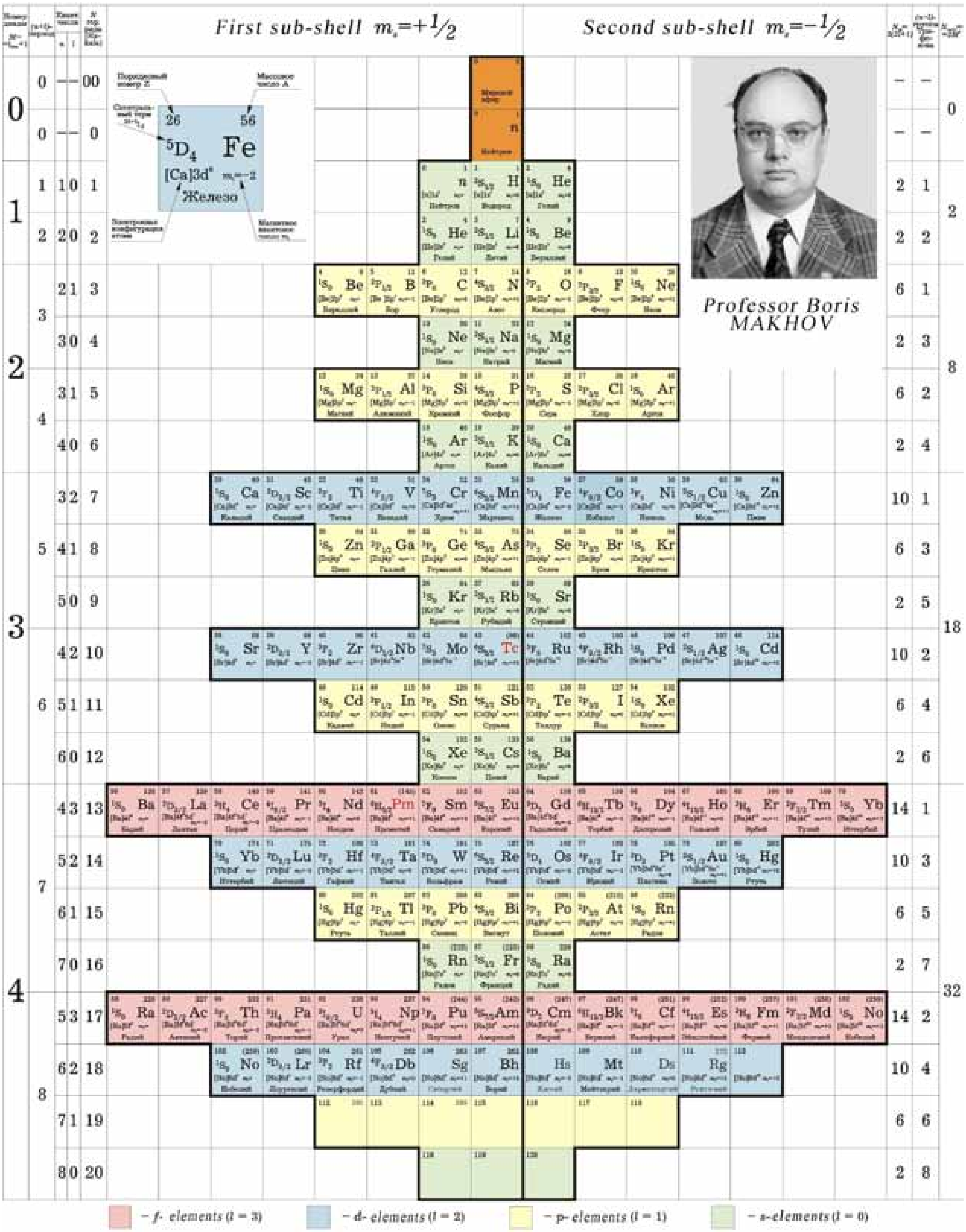

Fig. 1 Symmetrical quantum version of Mendeleev's periodic system of elements ("Makhov's Tree")

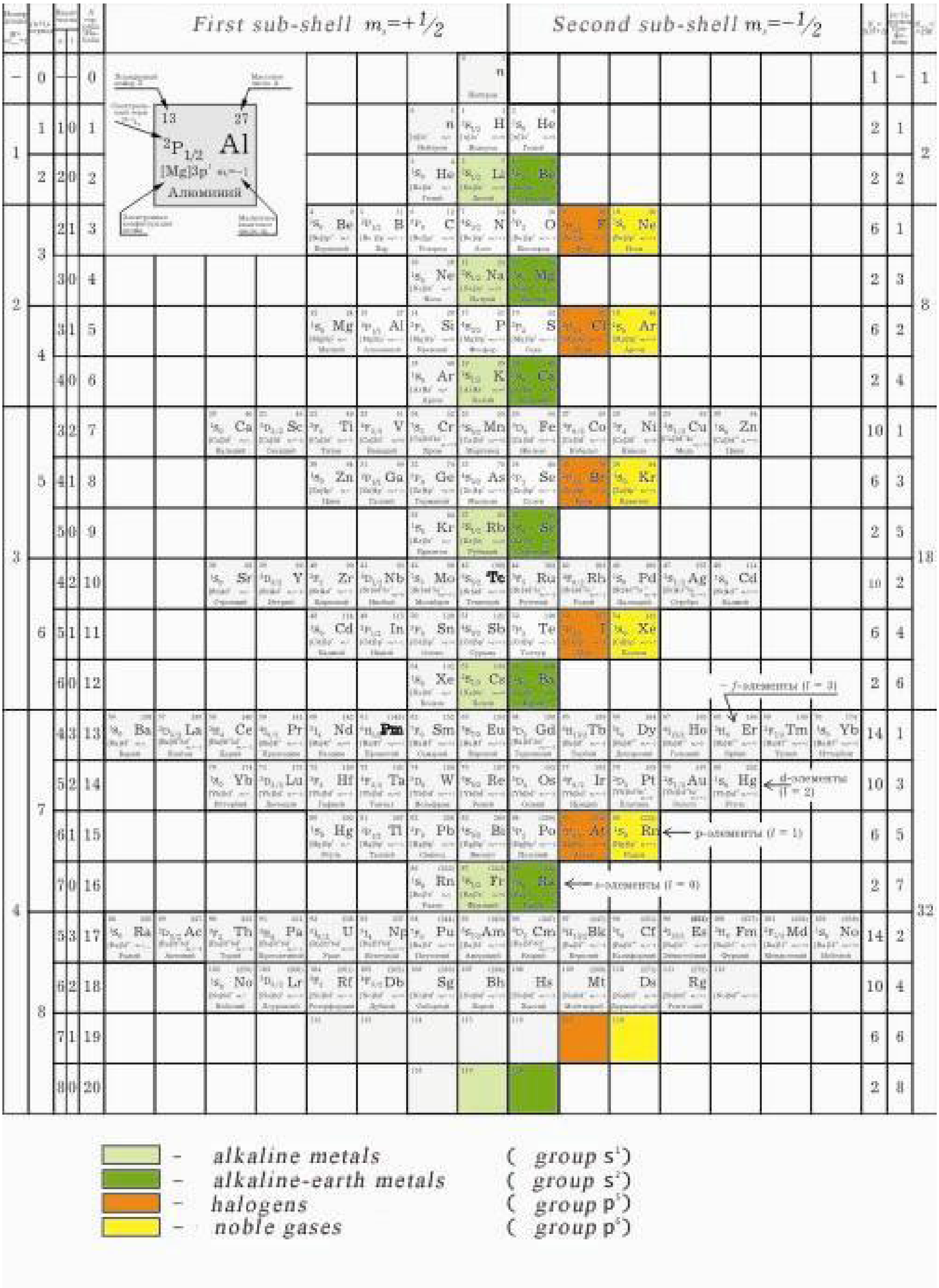

Fig. 2 Distribution of groups of elements in "Symmetric quantum periodic system of neutral atoms"

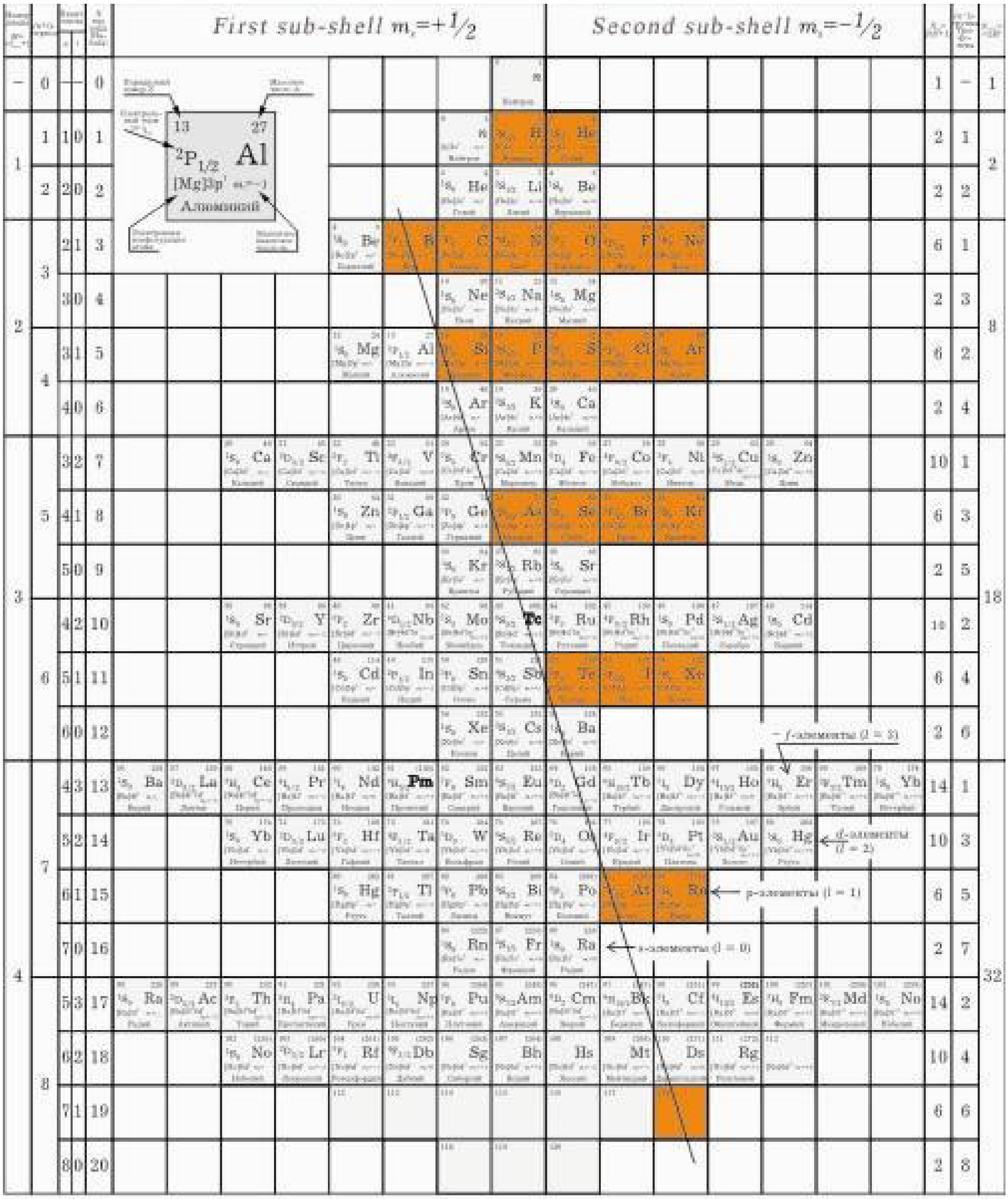

Fig.3 Distribution of metals and nonmetals in "Symmetric quantum periodic system of neutral atoms"

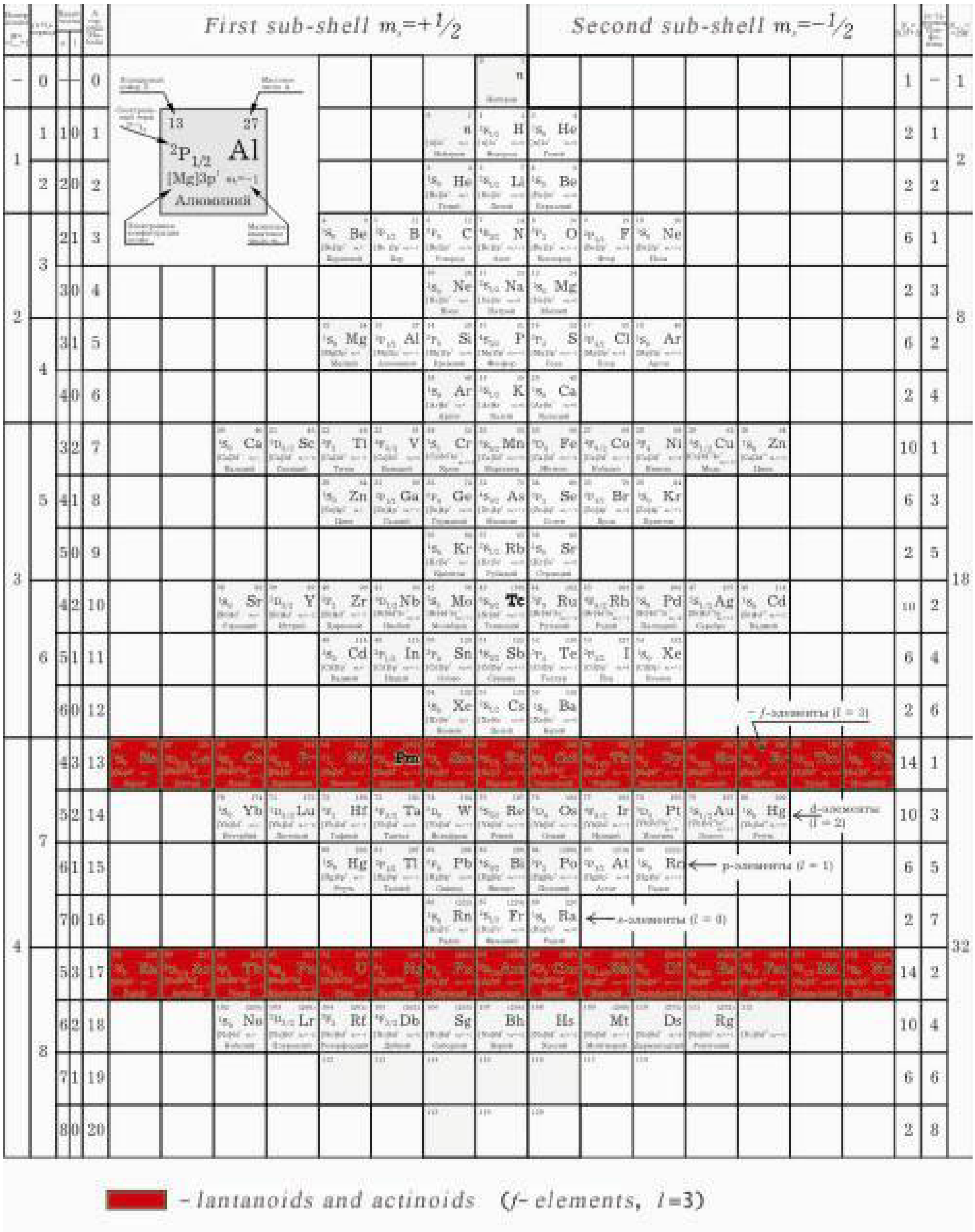

Fig.4 Distribution of lantanoids and actinoids in "Symmetric quantum periodic system of neutral atoms"

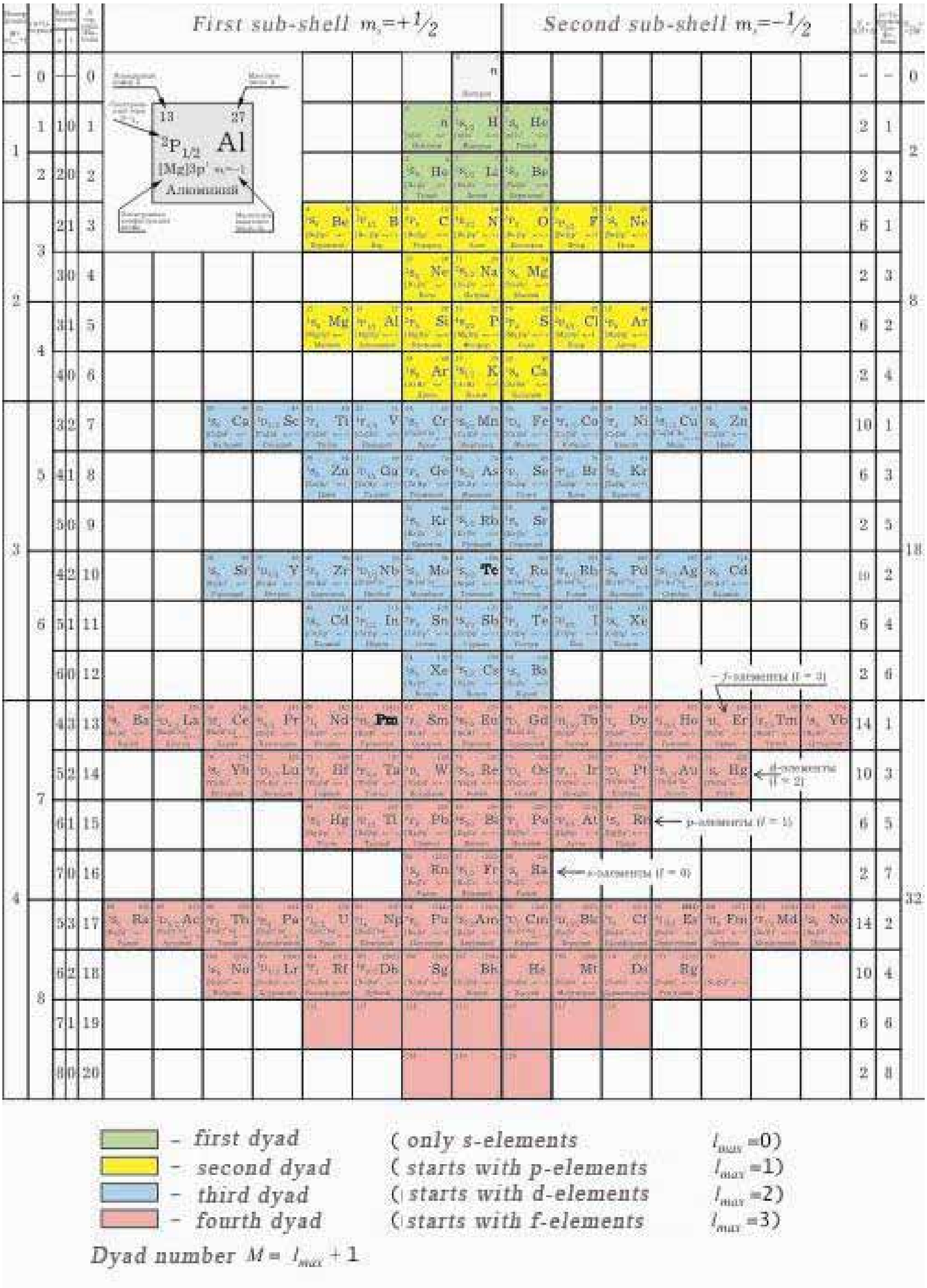

Fig. 5 Distribution of dyads in "Symmetric quantum periodic system of neutral atoms"

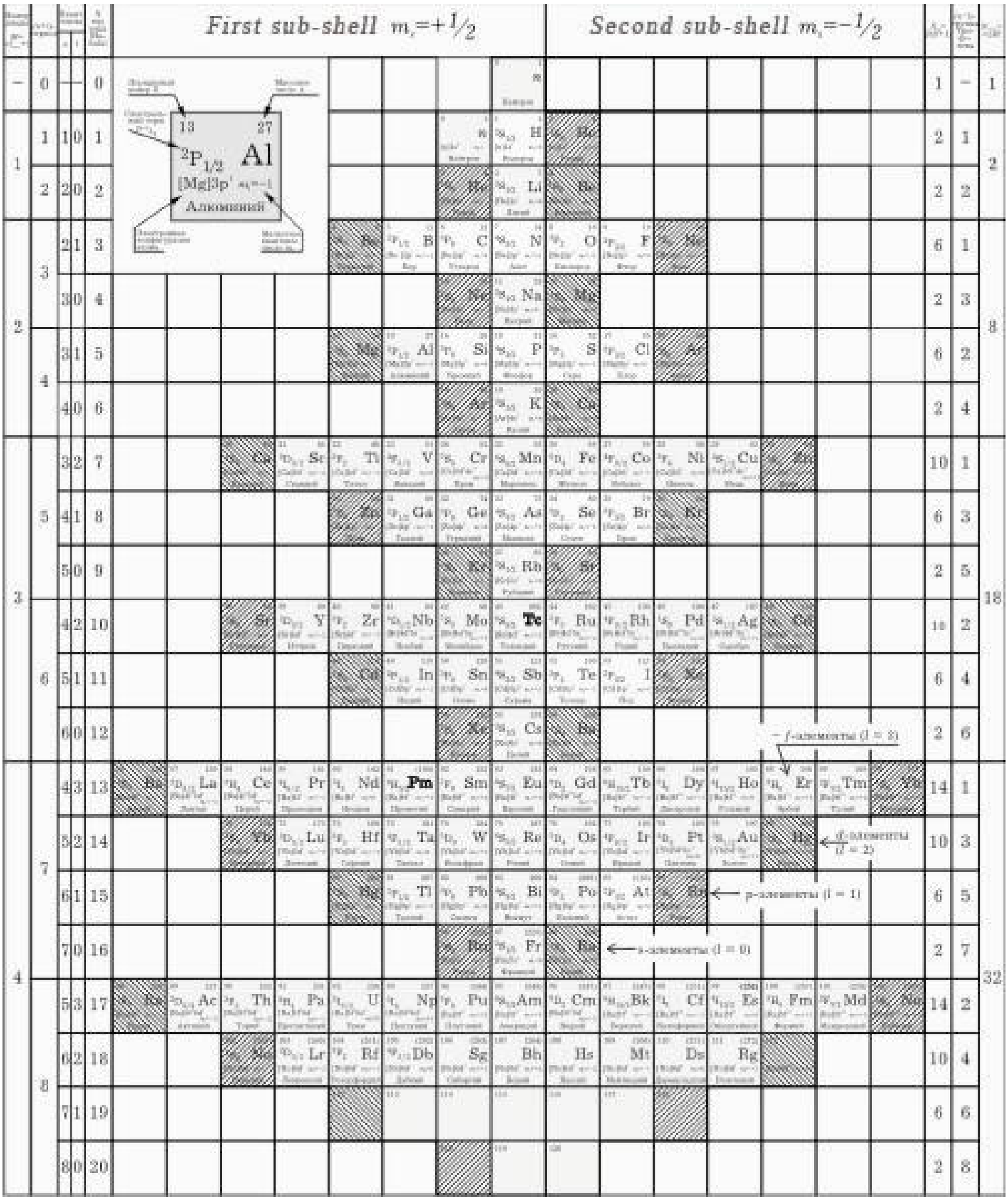

Fig.6 Diagram of relation and continuity of the successive row of elements (each horizontal row starts and finishes with spectral term 1S0)

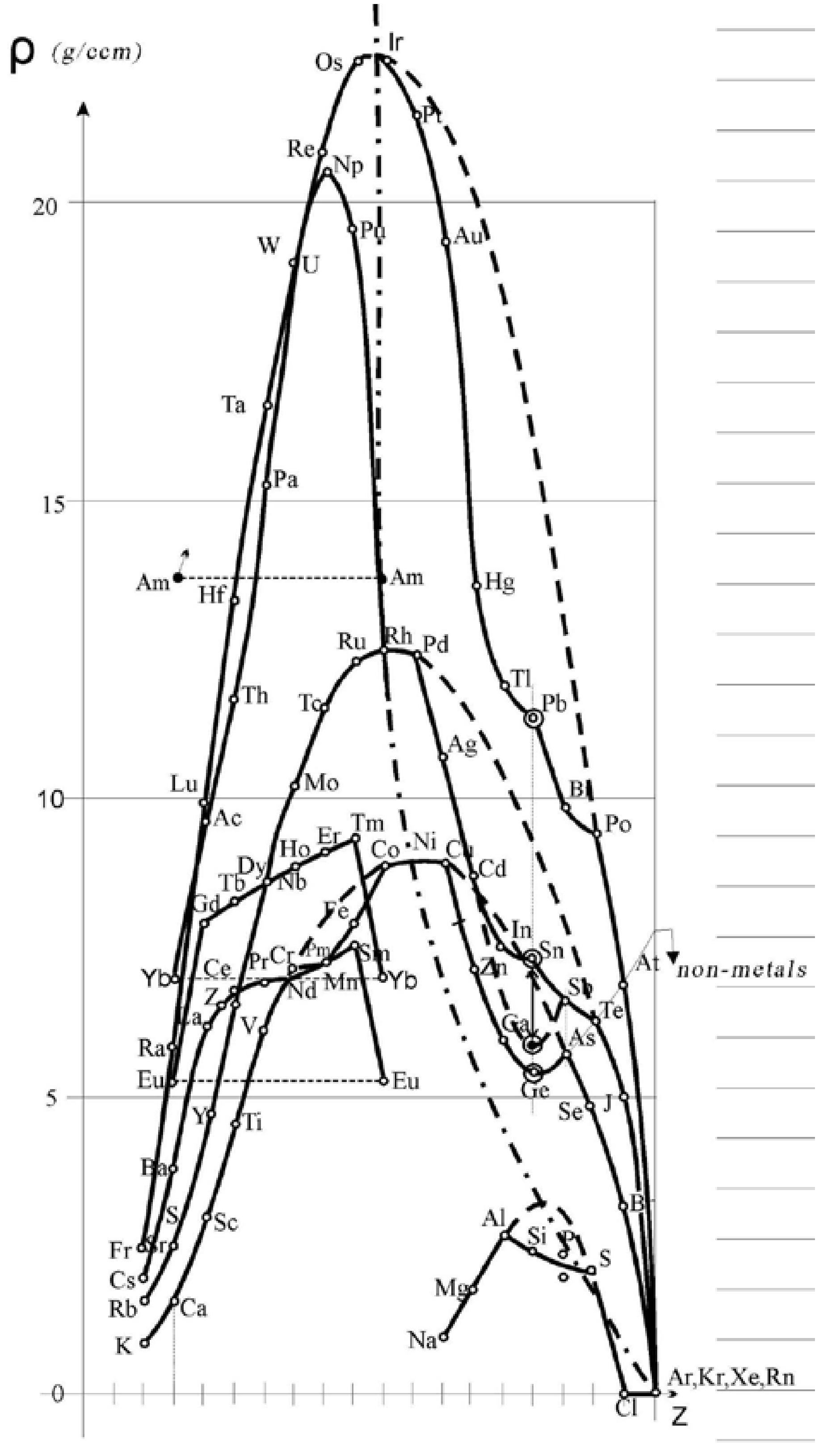

Fig.7 Specific weights of elementary substances formed by particular elements

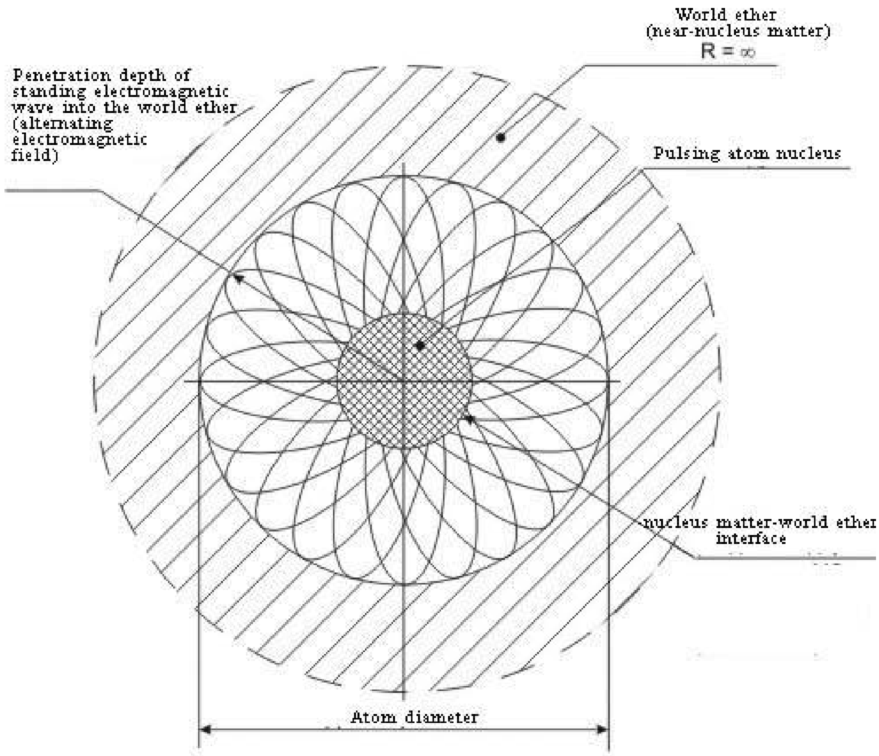

Fig.8 Makhov's oscillatory resonance model of neutral atom

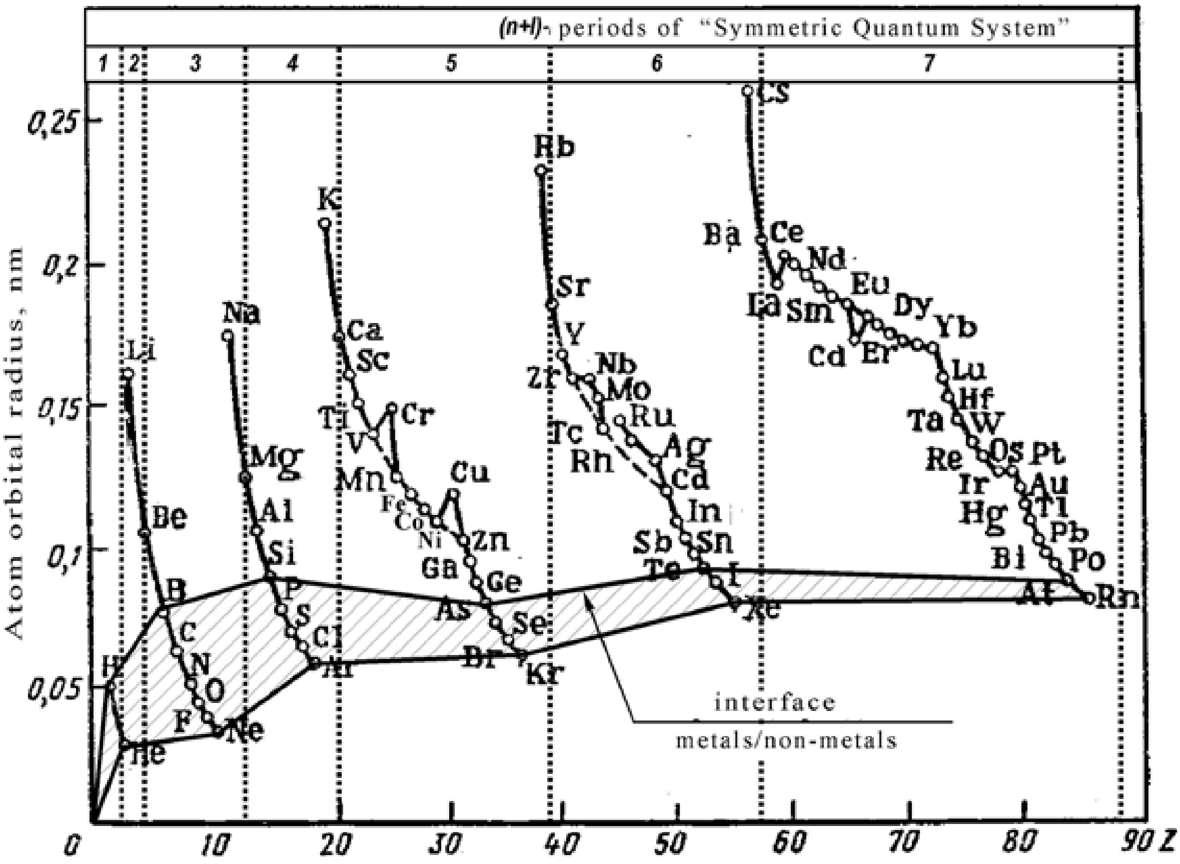

Fig.9 Dependence of the atom orbital radius on the element serial number. The upper line is the interface between metals (above) and non-metals (below).

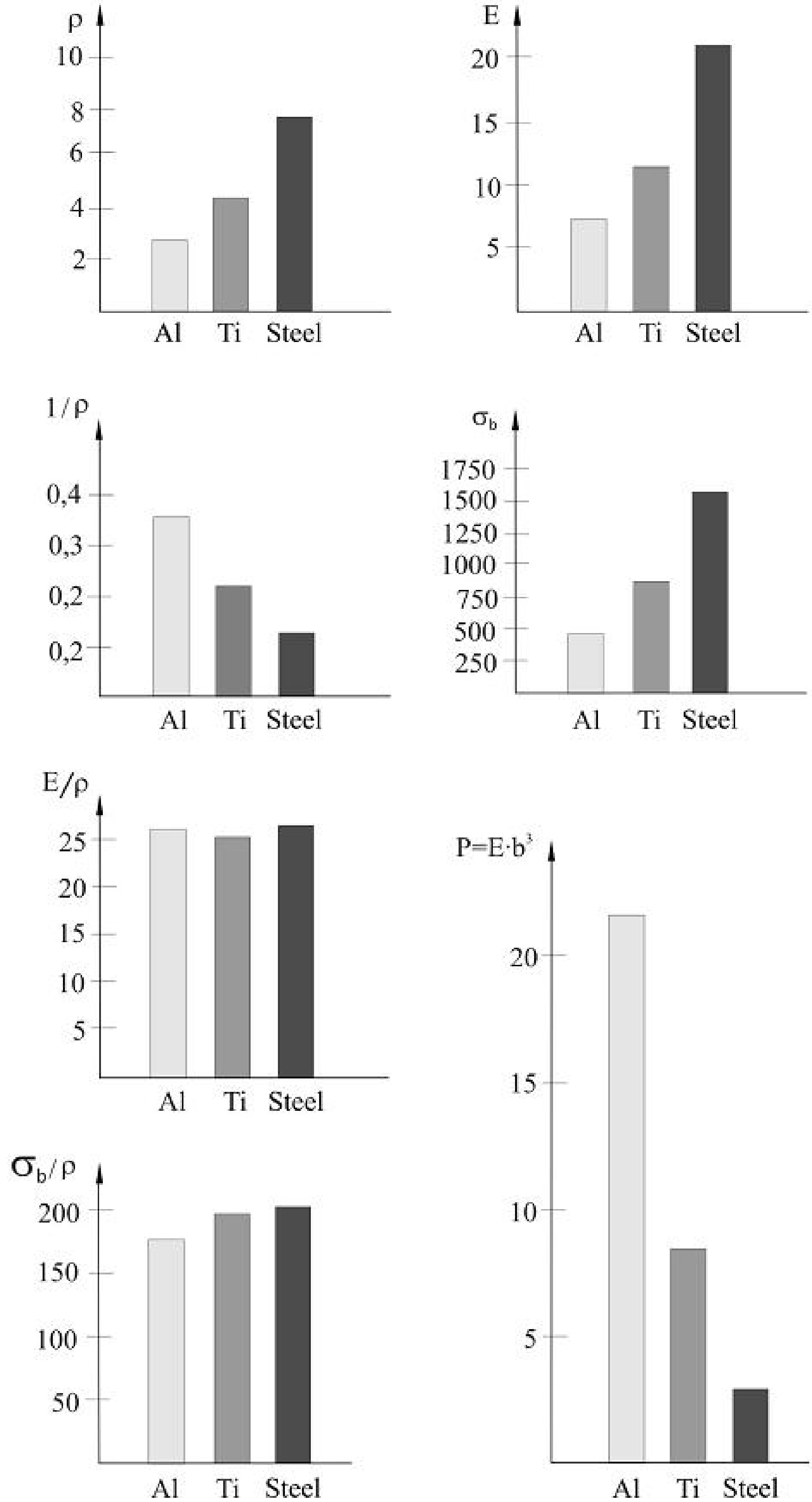

Fig.10 Comparative evaluation of the efficiency of "title metals" application (Fe, Ti, Al) for hull armoring

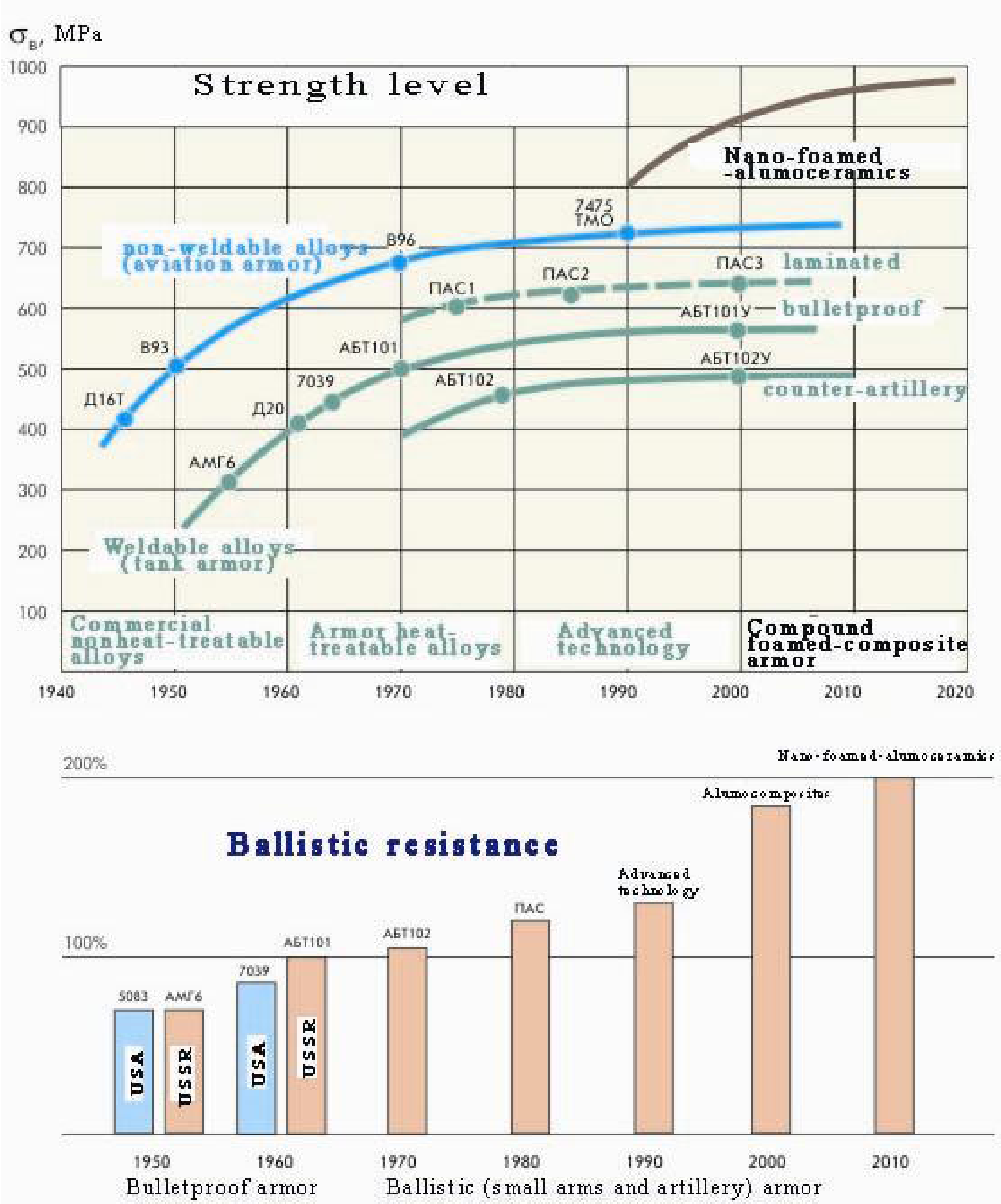

Fig.11 Development of aluminium alloy-based light armor materials

Investigation of Properties of Titanium Alloys with Mechanically Stable Beta-Structure for Body Armor Application

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Systematic research of protective performance of titanium alloys has been conducted in NII STALI since 1958 in order to evaluate the potentials of their application as materials which provide reliable operation of components and assembly units of transport facilities and special-purpose vehicles under intense impact loading. The properties of actually all existing structural titanium alloys with different structure types were investigated both as a mono-material and in compound structures or in combination with high-strength steels, aluminium alloys, ceramics and high-modulus polymers. The conclusion has been made that for different titanium alloy applications the requirements concerning physical, mechanical and technological performance can vary to a great extent, but what remains invariable is the requirement of using alloys with highest possible hardness (which also means highest possible strength) with maintaining or increasing ductility and reserve toughness of alloys at ambient temperatures.

It has been stated that for relatively simple-shape armor components exposed to impact loading most efficient alloys are VT6 and VT23. These alloys with $\alpha+\beta$ - structure are used mainly in annealed state which provides optimal combination of strength characteristics (σ_B about 900-1200 MPa) and toughness (about 40-60 J/cm^2). Multiple experiments have revealed inexpediency of volume heat hardening of titanium alloy components with tempering and aging, as it results in lower endurance and drastically low survivability (formation of brittle fractures and back spalls) of the components. At the same time, use of speeding electrothermic surface treatment with varying-hardness structure formation throughout the component depth resulted in considerable positive effect on components made of VT23 alloy.

Complex-shaped components made by deep cold stamping nowadays are produced of low-strength (σ_B~600-700 MPa) high-ductile "pseudo-α-alloys" grades OT4-1 or PT3-V. Because of higher requirements to endurance and weight characteristics of complex-shaped components there's a problem of selection or development of a titanium alloy with high technological ductility which would reduce the component weight by 15-20% due to better strength characteristics.

To solve the problem we think it expedient to investigate titanium alloys with meta-stable β - structure, or so called "pseudo- β - alloys".

To "pseudo- β - alloys" class belong titanium high alloys with β- stabilizing elements (K_β =1.6-2.8). Because of high stability the structure of β - phase of these alloys is retained not only after tempering but also after annealing at temperatures higher than $\alpha+\beta \leftrightarrow \beta$ - transformation and subsequent cooling in air in cross-sections up to 100mm. Meta-stable β - phase in the alloys of this class is mechanically stable, i.e. does not disintegrate in the process of plastic deformation and changes only at heating. A specific feature of β- alloys processed for the solid solution is a small difference between ultimate strength and yield strength values and a very low uniform elongation value. However, it does not mean (as one could think) that β- alloys feature little strain hardening. As it can be seen from comparison of true tensile stress - deformation diagrams of titanium alloys with different structure types, β - alloys feature significant hardening even at the stage of concentrated deformation. It results in formation of a wide zone of concentrated deformation along the sample length. Even after neck formation, as loading further increases, deformation takes place not only in the neck but also in adjacent zones; as a result β - alloys with minimal content of additions acquire high characteristics of ductility, toughness and straining ability at different types of loading which are close to those of unalloyed titanium. Alloys with β - structure can effectively harden after tempering and aging, though to achieve such hardening some technological restrictions are to overcome; such restrictions are caused by irregular decomposition of solid solution which results in embrittlement of the material if the half-finished product has coarse-grained structure. The following alloys belong to the group of alloys with pseudo-β-structure with mechanically stable β- phase: B-120VCA (USA), VT15, TS6 etc.

Titanium alloys with mechanically stable β-phase feature the following disadvantages:

- higher density and price as compared to other titanium alloys because of considerable number of alloying elements;
- sensitivity to effect of interstitial impurities. Higher content of interstitial impurities (O, N, C) introduced with burden materials can result (as typical for other metals with volume-centered lattice) in drastic drop of operational temperature.

Almost all alloys of this type are experimental or small-scale production ones.

The present paper discusses the results of investigation of alloys with Kb>2,0 containing Al, Cr, Mo, V, Zr and Fe. The composition of experimental alloys is presented in Table 1.

Ingots of the experimental alloys were subjected to plastic deformation in order to obtain half-finished products in the form of sheets and plates.

The subjects of investigation were mechanical properties of the alloys at static and dynamic loading, technological characteristics of sheet stock and ballistic resistance of the material.

Tensile properties of experimental alloys were determined according to GOST 1497-84 standard on quintuple samples Type II No.6. Impact bending test was arranged according to GOST 9454-78 standard on samples Type 1.

Effect of hardening temperature on mechanical properties of one of the experimental alloys is shown in Fig.1. The test results have revealed that impact strength is most sensitive to hardening temperature. The tests of other alloys yielded the same results. Optimal hardening temperature range for the investigated compositions was 850-950°C which corresponded to formation of one-phase polyhedral structure of β- solid solution in the experimental alloys.

Table 1 The composition of experimental alloys

Alloy Designation	Chemical composition of alloy, mass %								
	Al	Cr	V	Mo	Zr	Fe	O_2	N_2	H_2
415	3.00	10.20	-	7.80	0.62	0.32	0.03	0.04	0.004
421	2.95	10.30	9.90	2.80	1.60	0.25	0.02	0.03	0.001
462	2.87	15.94	-	-	1.93	0.30	0.02	0.05	0.001
464	2.87	16.89	-	-	-	0.30	0.05	0.05	0.002
466	2.83	15.87	-	3.00	-	0.30	0.04	0.05	0.001
468	2.85	17.15	-	3.10	1.96	0.30	0.03	0.05	0.002
470	2.65	16.00	-	1.70	1.00	0.30	0.09	0.05	0.005
472	2.65	14.81	-	2.20	0.97	0.64	0.05	0.05	0.002
406	3.11	10.64	7.08	3.78	1.10	0.09	0.13	0.014	0.004

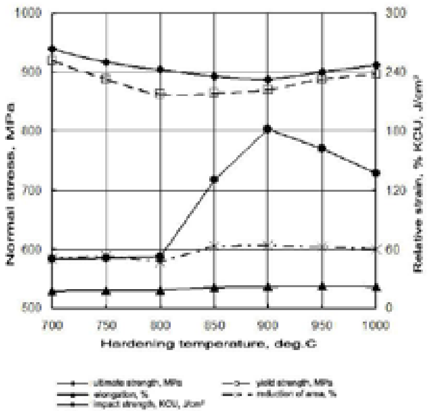


Fig.1 Hardening temperature effect on mechanical properties of samples made of Alloy 415

All subsequent tests were conducted on samples hardened from temperature ~850-900°C in water or in the air. In these tests the ultimate strength of the alloys was in the range of σ_B~850-950 MPa, and impact strength KCU>150J/cm².

The resistance of the alloys to penetration was compared by such characteristic as an average penetration resistance (dynamic hardness – H_D), which was determined by relating the kinetic energy of a 45°-tip-cone-impactor to the crater volume which was calculated via the penetration depth and averaged by the results of several tests. The penetration depth was measured from the face of the sample. The tests were conducted on samples made of medium-hardness armor steel and of some titanium alloys, including the experimental alloys with β-structure.

Despite lower static hardness, dynamic hardness values of titanium alloys come very close to those of steel, and by specific dynamic hardness titanium alloys are superior to steel. The highest values of dynamic hardness and especially of specific dynamic hardness were demonstrated by experimental alloys with meta-stable β-structure S415 and S421 (Figs.2, 3). These results can imply that at normal ballistic tests the alloys with β-structure should demonstrate high resistance characteristics.

To check this assumption we conducted comparative ballistic tests of the experimental alloy with meta-stable β-structure and OT 4-1 alloy (by TT pistol, 7.62mm cartridge 57-N-134S with PST bullet) at normal impact from 5m. The test results are presented in Table 2.

Besides, we empirically selected and tested same-ballistic-resistance protective structures made of commercial alloy OT 4-1 and experimental β-alloy with high-modulus textile/polymer backing. The test results are presented in Table 3.

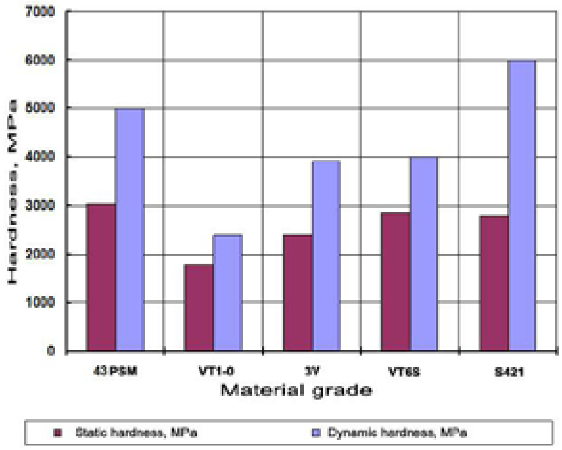


Fig. 2 Static and dynamic hardness of titanium alloys and 4PSM steel

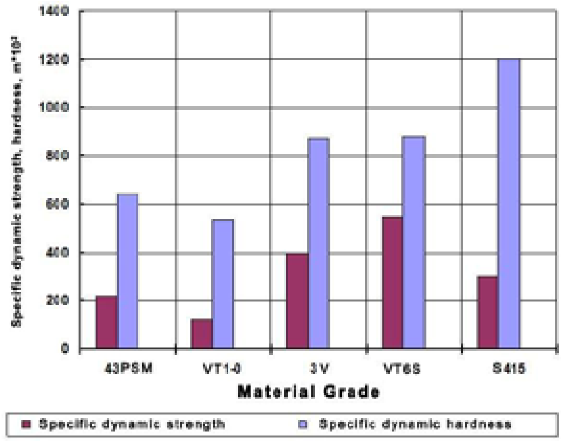


Fig.3 Specific dynamic characteristics of titanium alloys and 43PSM steel

Table 2 ballistic tests of the experimental alloy with meta-stable b-structure and OT 4-1 alloy

Titanium alloy	Areal density of the protective structure, g/dm²	Titanium target hardness HB, kg/mm²	Remarks
OT 4-1	157.5	217	=
S406	127	255	Weight saving ~ 20%

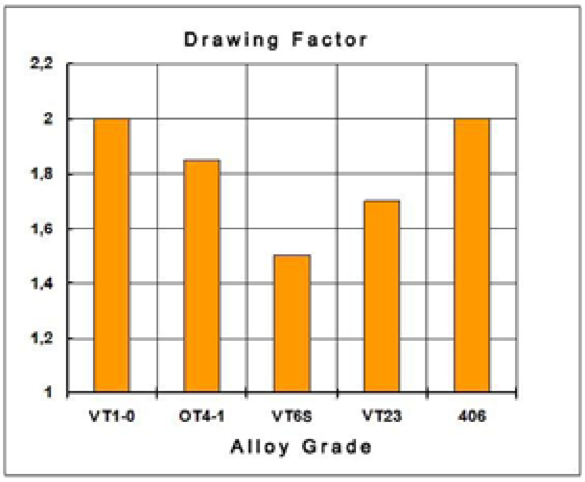
Table 3 Commercial alloy OT 4-1 and experimental b-alloy test results

Titanium alloy	Backing No.	Areal density of the polymer backing, g/cm²	Remarks
OT 4-1	1	30	
S406	1	20	Saving of textile materials ~33%
OT 4-1	2	52	
S406	2	44	Saving of textile materials ~ 15%

Fig.4 presents technological properties of titanium alloys with different structures at room temperature. The results of evaluation of technological characteristics of the alloys, represented in this figure, show that only the alloys with β-structure approach by their technological properties the unalloyed titanium and alloys with pseudo- α-structure OT4-1 and 3V, which can be deep-drawn in cold state.

Conclusion

The results of our investigation point at good prospects of using titanium alloys with meta-stable β-structure for producing complex-shaped body armor components. We think it expedient to undertake a search for sparingly-alloyed β-alloys containing minimal concentrations of molybdenum, vanadium and zirconium.



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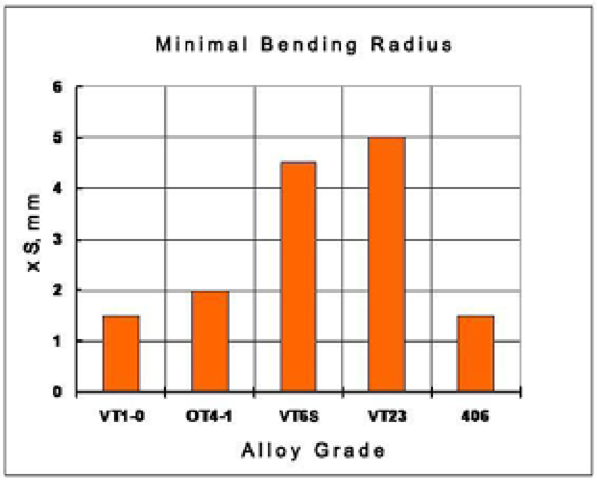

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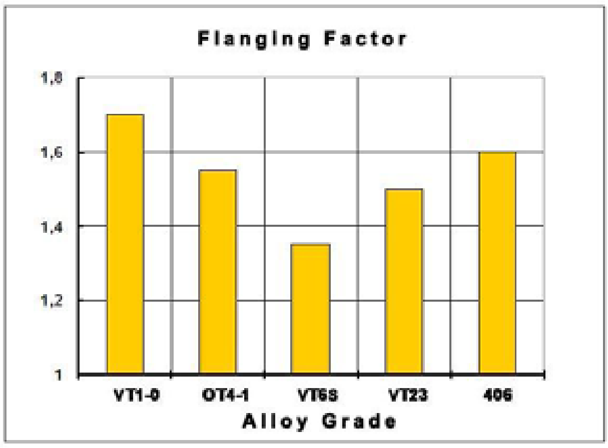

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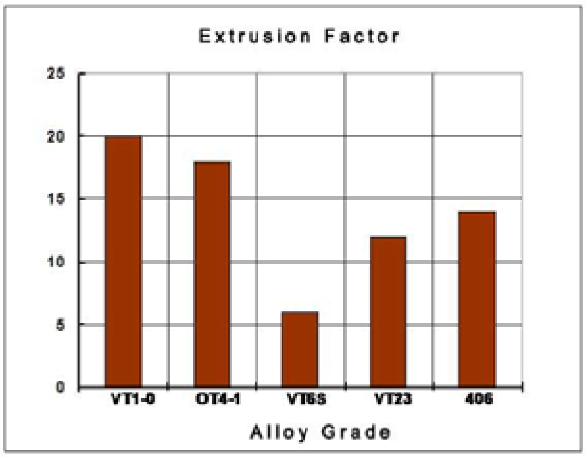

d

Fig.4 Technological properties of titanium alloys

Comparative Evaluation of Ballistic Resistance of Textile Armor Packages Against Steel and Lead Bullets

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Textile armor materials are widely used for protection against pistol and revolver bullets. In Russian practice the optimal number of layers and the type of ballistic fabric are usually selected empirically. However, the use of even simplest engineering models could reduce the number of required experiments and expenses for such experiments.

Russian pistol bullets feature a steel core whereas foreign short-barrel bullets use mainly lead cores. Therefore, for comparative evaluation of ballistic performance of textile packages against steel and lead-core bullets it is important to have techniques for evaluation of textile armor resistance to non-deformable and deformable impactors and to understand specifics of their interaction with textile armor.

Non-deformable impactors

Paper [1] presents an engineering model of interaction of a non-deformable penetrator with a textile armor package; the model is based on energy approach. The kinetic energy of the penetrator equates with the elastic deformation energy of the armor package yarns. It means that only the first interaction stage is considered. The second stage (i.e. dissipation of the potential deformation energy due to friction at stretching and separation of the yarns) is not considered.

From the pulse and energy conservation laws at inelastic collision it follows that after the initial (wave) interaction stage the velocity of the penetrator and the adjoint mass of the textile armor package v_1 and the kinetic energy of the penetrator and the adjoint mass W_1 will be:

$$v_1 = \frac{mv_0}{m + M_{TP}}$$

$$W_1 = \frac{(m + M_{TP})v_1^2}{2}$$

where v_0 is the initial velocity of the penetrator, m is the penetrator mass, M_{TP} is the adjoint mass of the textile package.

Energy conservation law for the penetrator and armor package after the impact-wave stage is written as follows:

$$W_1 = W_{el} + A_{fr} + A_b$$

where W_{el} is the elastic energy of yarn stretching; A_{fr} is the work of friction at yarn stretching and separating; A_b is the work of bullet deformation.

If we consider only the stage of yarn elastic stretching and take into account the fact that the penetrators are non-deformable, the energy balance is reduced to the following form:

$$W_1 = W_{el}$$

or

$$\frac{(m + M_{TP})v_1^2}{2} = \frac{E\varepsilon_p^2}{2}\frac{M}{\rho} \tag{1}$$

where E is the yarn elasticity module, ε_p is the ultimate elongation of the yarns, M is the mass of the textile deforming volume, ρ is the yarn material density.

The mass of the textile deforming volume (Fig. 1) is found from the model of equivalent yarns [1]

$$M = 4\beta d c_T t_T m_{TP}$$

where $\beta = 1\ldots2$ is an enlargement coefficient of the package area involved into movement as compared to the bullet cross-section area; d is the penetrator caliber; $c_T = \alpha c$ is the longitudinal wave velocity in equivalent yarns, c is the sound velocity in the yarns; $\alpha = 0.75\ldots1$ is the coefficient of sound velocity reduction due to yarn winding; t_T is a typical time of the penetrator braking; m_{TP} is the areal density of the textile armor package.

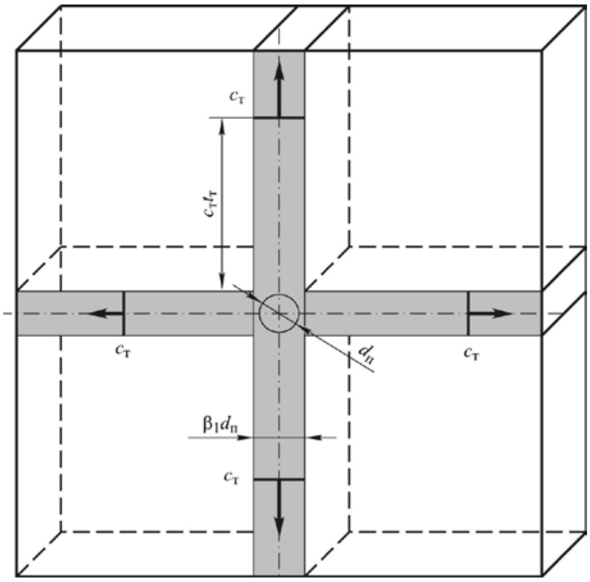

Fig.1: Diagram of deformed textile package covmputation at $t = t_T$

$$t_T = \frac{w_{\max}}{v_0}$$

where $w_{\max}$ is the maximum achievable deflection at the package perforation threshold at the stage of transformation of the penetrator kinetic energy to elastic energy of yarn stretching. Such deflection is by an order less than that which is formed after termination of the process of textile package yarn stretching and which can be measured, for example, on a plasticine block. We assume that the maximum achievable deflection is proportional to the yarn ultimate strain: $w_{\max} = \gamma\varepsilon_p d$, where γ is the coefficient of proportionality which depends on the textile properties.

The term

$$X = \frac{\pi d^2}{4}\frac{m_{TP}}{m}$$

is introduced which is the ratio of the mass of the textile package area directly under the penetrator to the penetrator mass.

Now, substituting all the above expressions into (1), we can obtain the expression for the textile package perforation threshold velocity v_{th}:

$$v_{th} = c\varepsilon_p \sqrt[3]{4\alpha\beta\gamma(1+\beta X)\frac{d^2 m_{TP}}{m}} \qquad (2)$$

If we denote $K = \sqrt[3]{4\alpha\beta\gamma}$ and take into account that $\sqrt[3]{1+\beta X} \approx 1$, we can obtain:

$$v_{th} = Kc\varepsilon_p \sqrt[3]{\frac{d^2 m_{TP}}{m}}$$

Coefficient K is determined by the textile properties, backup structure, method of textile armor package fixation. It follows from the fact that the threshold velocity of penetration can be measured only in the experiment as a whole, but not separately at the first stage of penetrator/armor package interaction. That's why the backup structure which determines the interaction conditions at the second stage – stage of yarn stretching and separation – will have a great effect on v_{th} and K.

Table 1 contains values of coefficients K for some Russian ballistic fabrics, calculated with the help of expression (2) from experimental data. In these calculations it was assumed that the sound velocity c and ultimate elongation $_p$ in para-aramid fabrics were c=9600m/s, ε=0.04; coefficient β=1.5.

Analysis of the obtained results leads to the following conclusions:

1. Coefficient K (if we take into account a large spread of fabric properties) does not depend on the type of the weapon, at least the types against which textile armor is typically used.
2. However, this coefficient significantly depends on the back-up material or the supporting structure: $K_{\text{pasticine}} \sim 0.95K_{\text{felt}}$; $K_{\text{frame}} \sim 1.1K_{\text{felt}}$. Frame fixation results in increase of coefficient K, and the plasticine back-up – in its reduction, as it reduces the height of deformation cupola and impedes formation of elastic strain (energy absorption at the elastic stage).

Deformable penetrators

Lead bullets deform heavily in the process of interaction with textile armor (Fig.1). The deformation extent depends on the bullet structure. From experimental data we can state that lead bullets take the form close to a spherical segment with the basis diameter equaling to 1.6 to 2 of the bullet caliber. The lesser number corresponds to FMJ bullets, the larger – to SWC.

Two significant amendments shall be introduced into the above model: taking into account energy consumption for bullet deformation, and increase of the bullet diameter in the process of interaction with the textile armor package.

Thus, the energy balance for deformable bullets will look as follows:

$$W_1 = W_{el} + A_b$$

Table 1.

Designations: PM– PM pistol bullet, SB – steel ball, fragment simulator
Note: Table 1 contains the average values of areal densities and threshold velocities of textile armor package perforation from many tests.
** – data from one test.*

Fabric Article/ Number of layers	**Areal density, kg/m²**	**Backup material or supporting structure**	**Threat**			**V_{th}, m/s**	**K**
			Type	**Mass, g**	**Caliber, mm**		
56319A 18	2.3	Plasticine	PM	5.9	9	340	**2.78**
56319A 18	2.3	Plasticine	SB	1.05	6.35	492*	**2.86**
56319A 18	2.3	Felt	SB	1.05	6.35	521	**3.03**
56319A 30	3.84	Felt	SB	1.05	6.35	632	**3.1**
56319A 30	3.92	Fixed in the frame by clamp straps	SB	1.05	6.35	680*	**3.31**
86-204-07BO 16	3.66	Plasticine	PM	5.9	9	340	**2.38**
86-204-07BO 25	5.24	Felt	SB	1.05	6.35	562	**2.48**
86-204-07BO 18	3.77	Felt	SB	1.05	6.35	510*	**2.51**
86-294-05 20	3.24	Felt	SB	1.05	6.35	565	**2.93**
84127 20	2.97	Felt	SB	1.05	6.35	578	**3.09**
84127 20	2.97	Fixed in the frame by clamp straps	SB	1.05	6.35	620*	**3.31**

To estimate the energy consumed for bullet deformation, let's approximately define the bullet deformation as uniaxial compression deformation (Fig.3)

$$\varepsilon_b = \frac{l_b - h}{l_b}$$

For lead bullets $\varepsilon_b = 0.6 \div 0.7$

The work of upsetting of the cylindrical blank will be as follows:

$$A_b = \iint\limits_{V\ \varepsilon} \sigma_i d\varepsilon_i \approx \sigma_{fr}\varepsilon_b V_b = \sigma_{fr}\varepsilon_b \frac{m}{\rho_b}$$

where σ_T is the yield strength of the bullet material.

Let's find the fraction of the work of bullet deformation from its initial kinetic energy:

$$\frac{A_b}{W_0} = \frac{\sigma_{fr}\varepsilon_b \dfrac{m}{\rho_b}}{m\dfrac{v_0^2}{2}} = \frac{2\sigma_T\varepsilon_b}{\rho_b v_0^2} \qquad (3)$$

After substituting the values of actual bullet characteristics into expression (3) we can see that the deformation work constitutes a very small portion as compared to the initial kinetic energy of the bullet. For example, for JHP bullets of 0.44 Magnum revolver the bullet deformation work is about 1.5% of the initial kinetic energy (lead density ρ_b=11300 kg/m³, ε_p=0.6, σ_T=50 MPa, v_0=436 m/s). Therefore, it can be ignored.

When lead bullets interact with textile armor, an important factor is an increase of the penetrator diameter in the process of its deformation. That's why it would be expedient to multiply parameter *d* in the model for a non-deformable bullet by coefficient *f* which takes into account the penetrator diameter increase.

a

b

Fig.2: Lead bullets after interaction with textile armor
a) [top] FMJ 9mm Parabellum
b) [bottom] JHP 0.44 Magnum

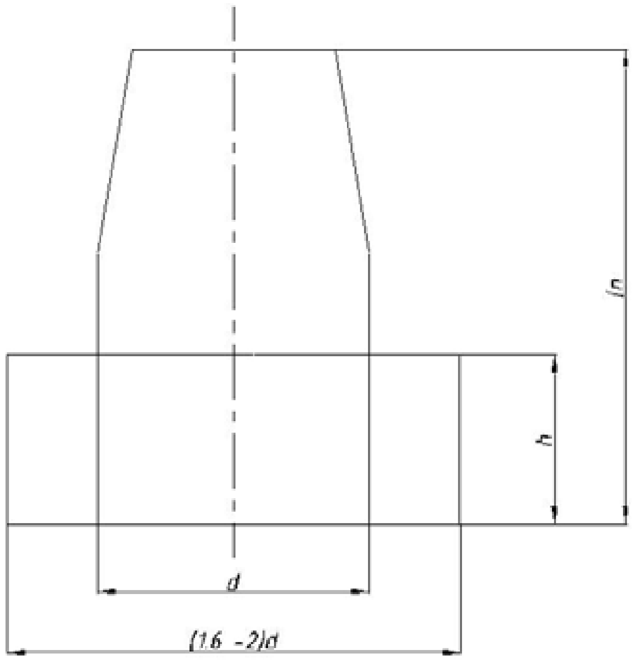

Fig.3: Diagram of bullet deformation estimation

Table 2.

** NP – non-perforation; P – perforation.*

*** re-calculated coefficient: $K_{plasticine} \sim 0.95K_{felt}$*

Fabric Article / Number of layers	Areal density, kg/m²	Threat	Velocity, m/s	Result	Assumed coef. K	Rated V_{th}, m/s
56319A 36	4.6	0.44 Magnum m=15.6g, d=11mm	432 449 442	NP NP NP	2.82	**512**
56319A 24	3.1	0.44Magnum m=15.6g, d=11mm	448 443 442	NP NP NP	2.82	**444**
56319A 30	3.8	Parabellum m=8г d=9мм	461 467 475	NP NP NP	2.82	**514**
86-204-07BO 18	3.7	0.44 Magnum m=15,6г, d=11мм	447	P	2.38	**400**
86-204-07BO 22	4.52	0.44 Magnum m=15,6г, d=11мм	425 442 430	NP NP NP	2.38	**431**
86-294-05 20	3.24	0.44 Magnum m=15,6г, d=11мм	422 442 442	NP P P	2.78**	**440**
86-294-05 25	4.1	0.44 Magnum m=15,6г, d=11мм	438 438 435	NP NP P	2.78**	**480**

As we emphasized above, from our experimental data it follows that coefficient $f = 1.6\ldots2$. Assuming such approximation, from (2) we'll obtain the following equation:

$$v_{th} = Kc\varepsilon_p \sqrt[3]{\frac{(fd)^2 m_{TP}}{m}} \tag{4}$$

Table 2 contains test data for textile armor packages with plasticine back-up and values of vth calculated on the described model with the use of coefficients *K* from Table 1. The sound velocity in para-aramid yarns, the ultimate elongation and coefficient β we assumed to be the same as above. Coefficient *f*=1.8.

As we can see from Table 2, the calculated data correlate well with the experimental one.

Comparative evaluation of textile armor packages to steel and lead bullets

To compare the threshold penetration velocities (v_{th}) of deformable and non-deformable bullets for the same armor package we can divide (2) by (4):

$$\eta = \frac{v_{th}^{st}}{v_{th}^{lead}} = \sqrt[3]{\frac{d_{st}^2 m_{lead}}{f^2 d_{lead}^2 m_{st}}} \tag{5}$$

where subindexes *st* and *lead* refer accordingly to steel and lead penetrators.

Thus, η is the parameter for recalculation of the armor package ballistic performance against different bullets. If we assume *f=1.8* and substitute the values of masses and calibers of steel and lead bullets into (5), we can obtain, for example, the following:

$$\begin{aligned} v_{th}^{PM} &= 0{,}75 v_{th}^{Parabellum} \\ v_{th}^{TT} &= 0{,}68 v_{th}^{Parabellum} \\ v_{th}^{PM} &= 0{,}82 v_{th}^{0.44 Magnum} \end{aligned} \tag{6}$$

These relations shall be understood as follows: if the textile package has v_{th} = *436 m/s* when impacted by 0.44 Magnum revolver bullet, then it will have v_{th} = *0.82 . 436 m/s = 356 m/s* when impacted by PM pistol bullet. This value is much higher that the standard velocity of PM pistol bullet (315±10 m/s), therefore the armor package which belongs to Ballistic Level IIIA of NIJ 0101.04 (USA) will correspond to Level 1 of the Russian standard GOST 50744-95. And vice versa, if the armor package has v_{th} = *445 m/s* when impacted by TT pistol bullet, it will have v_{th} = *445 m/s* ÷ *0.68* = *652 m/s* when hit by Parabellum bullet, therefore the armor package belonging to Ballistic Level IIIA of NIJ 0101.04 (USA) will not correspond to Level 2 of the Russian standard GOST 50744-95. From the above it follows that armor structures with Level 2 of the Russian standard GOST 50744-95 are superior by their ballistic performance to similar structures with Level IIIA of NIJ 0101.04.

Thus, we managed to expand the range of tasks performed with the help of computational model of penetrator/textile armor interaction. We obtained the values of coefficient K for most widely used para-aramid fabrics manufactured in Russia. We established the correlation parameter of perforation ability of steel and lead bullets against textile armor packages; the parameter can be used to compare the ballistic resistance of armor structures belonging to different classes of Russian and foreign standards.

References

1. *Materials and protective structures for local and personal armouring (text) / V.A. Grigoryan, I.F. Kobylkin, V.M. Marinin, E.N. Chistyakov. – Moscow. Radiosoft Publishing House, 2008*

Investigation of Anti-Ricochet Properties of Body Armor with Steel Armor Panels

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Exploitation of body armor with steel armor panels has shown, that fragments formed in interaction of destructive elements (bullets or high -velocity fragments) with high hardness steel surface are ricocheting and can lead to arm, face or neck injuries. In that case in front of steel armor panels anti -ricochet structure (ARS) is mounted as protective element, providing partial or full localization of secondary fragments.

The aim of the investigation, that included study of the structure of witness plates, their damage criteria, target conditions and real body armor tests, was creation of ARS evaluation procedure and working out of recommendations on ARS composition for body armor with steel armor panels.

0.5 mm-thick aluminum sheet of AMG6 alloy was selected as the witness plate. For confirmation of the right choice of the witness plate, values of V_{50}, energy intensity (ΔE), and energy density E_{den} were determined. Possible effect of test conditions, and in particular of the characteristics of test means – weight

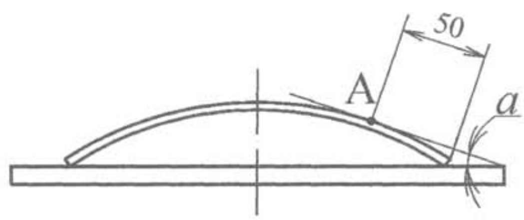

Fig. 1

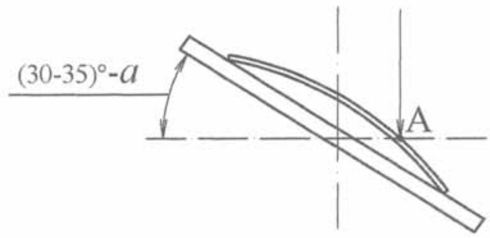

Fig. 2

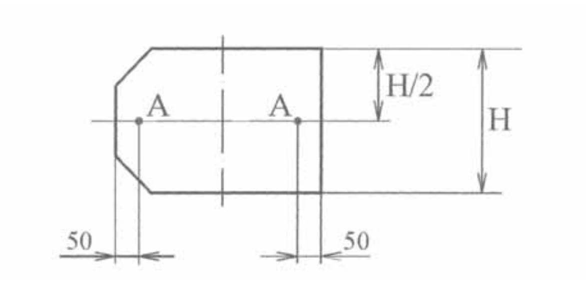

Fig. 3

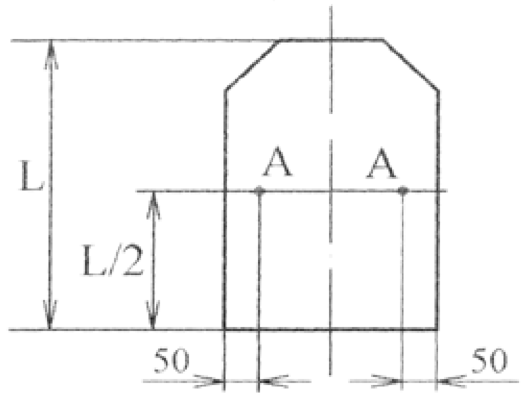

Fig. 4

and material of fragment simulators - on the obtained values of $V_{50,}$ ΔE, E_{den} was evaluated.

The following tests were conducted:

- steel ball, diameter 6.35 mm, weight 1.05 g;
- steel ball, diameter 5.0 mm, weight 0.514 g;
- steel ball, diameter 6.3 mm, weight 1.56 g;

During experimental investigations real body armor was tested. The test item was fixed tightly to a hard flat support with a technical band. A wooden panel made from 50mm-thick softwood boards was used as a support.

To provide the required impact angle of the bullet with the protective structure, the support with fixed test item could rotate around the vertical axis either to the right (clockwise), or to the left (anticlockwise), and also rotate to 90 degrees in vertical plane, perpendicularly to the line of sight.

The test item was fixed to the support with a shift to the left edge of the support (when the support turned to the right) or to the right edge of the support (when it turned to the left). The distance from the edge of the support to the edge of steel armor panel along the central line, on which the impact point was supposed to be, did not exceed 20 mm.

To provide the required impact angle of the bullet with the protective structure of the body armor, the correction angle a was determined which took into account the geometry of the steel armor panel surface curvature in the supposed impact point.

The correcting angle was calculated on the basis of nominal sizes, indicated in construction documentation. (Fig. 1)

Taking into account the correcting angle, the support with the attached test item was turned to the angle equal to {(30-35)°- *a* } (Fig. 2)

Protective characteristics of the anti-ricochet structure were evaluated by bullet impacts in four directions (from the left, right, above and beyond relating to the front surface of test item). Impacts were provided to the left and to the right with consistent turn of the support with the attached test item relating to the vertical axis. Then the support (test item) was turned to 90° in the vertical plane, perpendicular to the line of sight, and the impacts were provided again to the left and to the right with consistent turn of the support relating to the vertical axis.

The supposed impact point on the steel armor panel was to be situated on the horizontal central line of the steel armor panel (irrespectively of spatial position of the test item) at a distance of 50 mm from the steel armor panel left edge (when the support turns to the right) or from the right edge (when the support turns to the left) (Figs. 3 and 4)

The witness plate, by the integrity of which the type of anti-ricochet structure was determined, was made from AMG6 alloy with thickness 0.5 mm (Federal standard GOST 21631-76), height 500 mm, length 600 mm and was mounted into a hard skeleton frame.

The witness plate was mounted vertically from the left (when the support turned clockwise) or from the right (when the support turned anticlockwise) side

Table 1. Values of energy density of aluminum witness plate depending on the test means

Fragment material	Fragment weight, g	V_{50}, m/s	E_{50}, J	E_{den}, J/sm^2
Steel	0.5	131.1	4.42	22.5
Steel	1.05	106.7	5.66	18.9
Lead	1.56	91.7	6.39	20.5

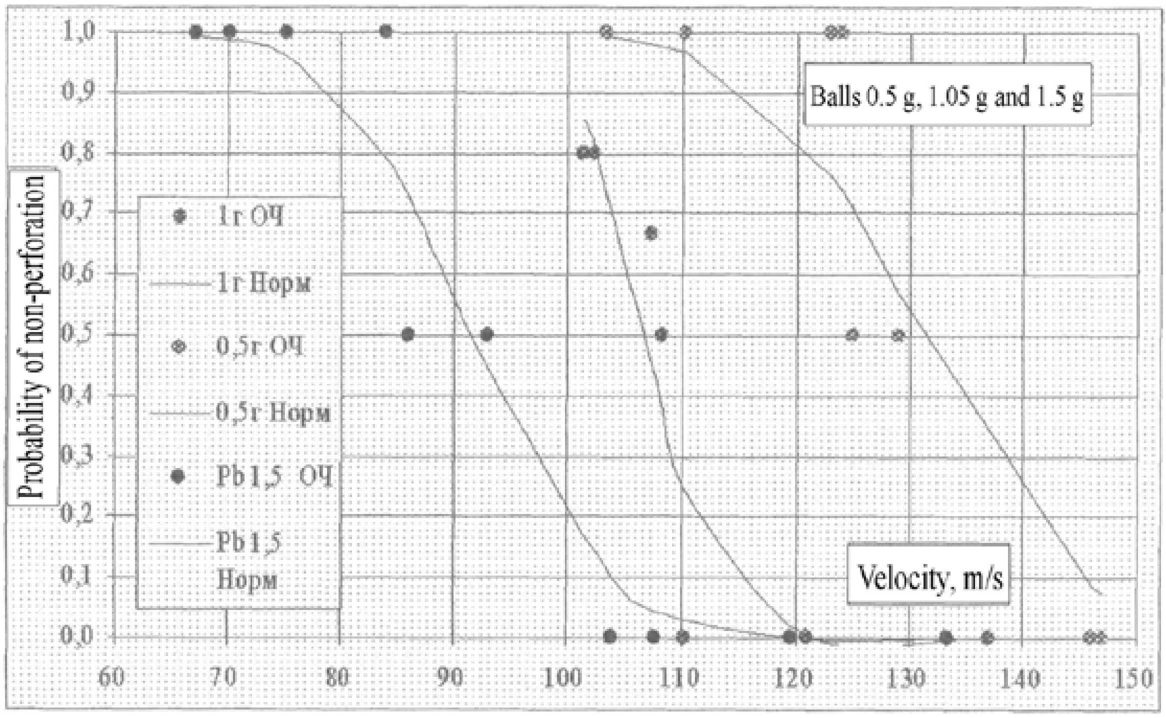

Fig. 5. Test-means-type dependant perforation/non-perforation frequency of the aluminum witness plate graphs.

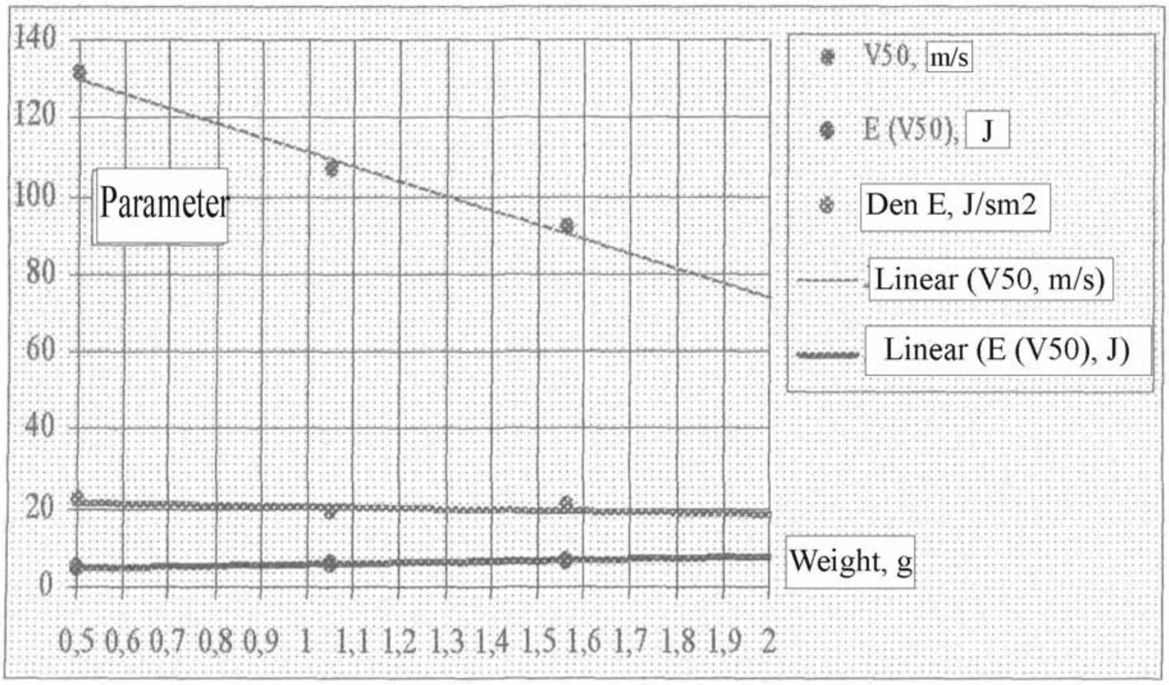

Fig. 6. Dependency of defense properties of the control aluminum screen parameter from splinter type (weight) diagram

of the support with the attached test item. Furthermore, the witness plate was mounted in the vertical plane, parallel to the line of sight, at a distance of 50-100 mm from the steel armor panel edge. The center of the witness plate was to be situated in the line of the expected slug and secondary damage fragments outlet.

Quantity of test items has been determined in dependence on the surface of steel armor panels. If the steel armor panel surface didn't exceed 0.02 m^2, one impact was produced. When the steel armor panel surface exceeded 0.02 m^2, two impacts were produced.

During the tests perforation or non-perforation of the body armor protective structure was determined and also the integrity or quantity of perforations in the witness plate.

The impact is considered fair, if numerical values of bullet velocity and shooting range are equal to the values set in Federal standard GOST R 50744, the body armor protective structure is not perforated, and the achieved impact point is spaced not more than 10 mm from the supposed impact point.

On the basis of processing of the received data on perforation (non-perforation) velocities (speeds) of the witness screen by different test weapons, the following data were determined and created:

- probabilities of normal distribution (frequency curves) of impact on the aluminum witness plate
- parameter of protective properties of the aluminum witness plate vs splinter type (weight) diagram

On the basis of the obtained data the values of velocity for 50% non-perforation (V_{50}, m/s), energy intensity (E_{50}, J) and energy density (E_{den}, J/cm^2) were determined, rated on the basis of obtained value of 50% non-perforation (V_{50}, m/s).

The obtained data is represented in Table 1. From the obtained data it follows:

- the energy intensity of the aluminum witness plate in the investigated range of velocities and weights of the selected fragments does not practically depend on the type (weight) of the fragment and at the average is equal to$E_{den\ 50}$ (20.5±2) J/sm^2;
- the obtained value of the aluminum witness plate energy density sufficiently correlates with biomedical tests data on injurious effect of fragments formed when bullets ricochet from the steel armor panel of body armor (safe criteria – 10-11 J/cm^2, fatal – 100 J/cm^2 and more) (Projects of S.M. Kirov Military medical academy and N.N. Priorov Central institute for scientific research of traumatology and orthopedics)

In accordance with experimental findings evaluation of ARS has been proposed by three-type qualitative assessment of witness plates.

Anti-ricochet structure is classified as Type 1 if there are no perforations recorded in witness plates after all impacts on test items from the types of weapons declared in technical documentation.

Anti-ricochet structure is classified as Type 2 if there is no more than one perforation in each witness plate.

Anti-ricochet structure is classified as Type 3 if there is more than one perforation in each witness plate.

During the investigation it was found out, that for armor steel protective panels the following amount of material in body armor ARS basically solves the problem of localization of secondary fragments: 6 layers of art. 56319 for Protection Class 2, 16 layers for Protection Class 3 and 18 layers for Protection Class 5, mainly for secondary fragments localization task.

Risk Analysis in Designing of Body Armour

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INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN REGIONAL
DEVELOPMENT FUND

Key Project No. POIG 01.03.01-10-005/08 entitled: „Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".

Introduction

The risk analysis and an ocean of potential threats arising from the process of designing, manufacture as well the experience resulting from post-manufacture stage of ballistic body armours' life cycle are helpful tools for providing the functionality of the products, and the adequate, acceptable security level to their users.

The risk management has been approved and implemented i.a. as basic requirement for the medical products according to the provisions of European Directive 93/42/EWG [1] and defined in the standard PN-EN ISO 14971:2007 [2] and PN-EN ISO 22442-1:2008 [3]. The tool is versatile so much, that there are possibilities of applying it directly to the designing, manufacture and marketing.

General rules concerning applying the risk analysis

At the stage of designing the modern ballistic body armour the selection of most suitable and optimum technical, technological and design solutions for pro-

Table 1. Definitions of concepts related to the risk analysis [2]

Concept	Definition
Harm	• physical injury, health impairment of individuals or damage to a property or environment
Threat	• potential source of harm
Threatening Situation	• a circumstance, under which some individuals, property or environment are exposed to one or more threats
Expected Usage	• usage, for which a product, process or service is dedicated according to the specifications, instructions and information provided by the manufacturer
Residual Risk	• a risk that remains after applying the means of risk controlling
Risk	• combination of probability of harm occurrence and its severity
Risk Analysis	• systematic applying the available information for identification of threats and for estimation of risk
Risk Assessment	• full process including the risk analysis and assessment of risk acceptability
Risk Controlling	• process, within which the decisions are taken and means of risk reduction to certain levels or to keep it at a certain level are implemented
Estimation of Risk	• process being applied in order to assign a magnitude to the probability of harm occurrence as well as to the severity of the harm
Assessment of Risk Acceptability	• process of comparing the estimated risk with given criteria of risk in order to find the risk acceptability
Risk Management	• systematic applying the management policy, procedures and practices to the tasks of risk analysis, assessment of risk acceptability, risk controlling and monitoring
Severity	• measure of possible consequences of threat
Security	• lack of inacceptable risk

ducts is presumed, so the solutions were before all compliant to the security rules while taking into account state of the art of knowledge and technology. The goal is to eliminate or partially reduce the risk to an acceptable level, applying the adequate protective factors to the risk, which isn't fully eradicable as well as full information to the users on the residual risks resulting from the adopted security means [2].

Using the body armour is always connected to some risk level, which varies depending on the product, its wearer, usage time and other factors, mainly external ones.

According to the provisions in [2] the definition of risk includes two elements:

- the probability of occurrence of a harm,
- consequences of the harm, i.e. how severe the harm could be.

The acceptability of risk is depending on the above elements and the awareness of the risk occurrence both at the manufacturers and the user. The assessment of the risk level should take into account the expected application, functional properties and the risks related with the protective product, as well as the risks and benefits related to the procedure or circumstances of usage.

Definitions and process of risk management for the ballistic protection products

The concept of risk is a junction of two phenomena: probability of harm occurrence an the consequences of the harm i.e., its severity. When estimating the risk for the protective products, the following should be considered:

- the initiating occurrence or circumstances,
- the sequence of events, which could lead to a threatening situation,
- probability of occurrence of such a situation,
- probability of the situation leads to a harm,
- kind of harm, which could arise [2].

According to [2] it is indispensable to define the concepts supporting the analysis of threats arising from design, manufacture and usage of the protective products.

The process of risk management for ballistic protective products is presented on Fig. 1.

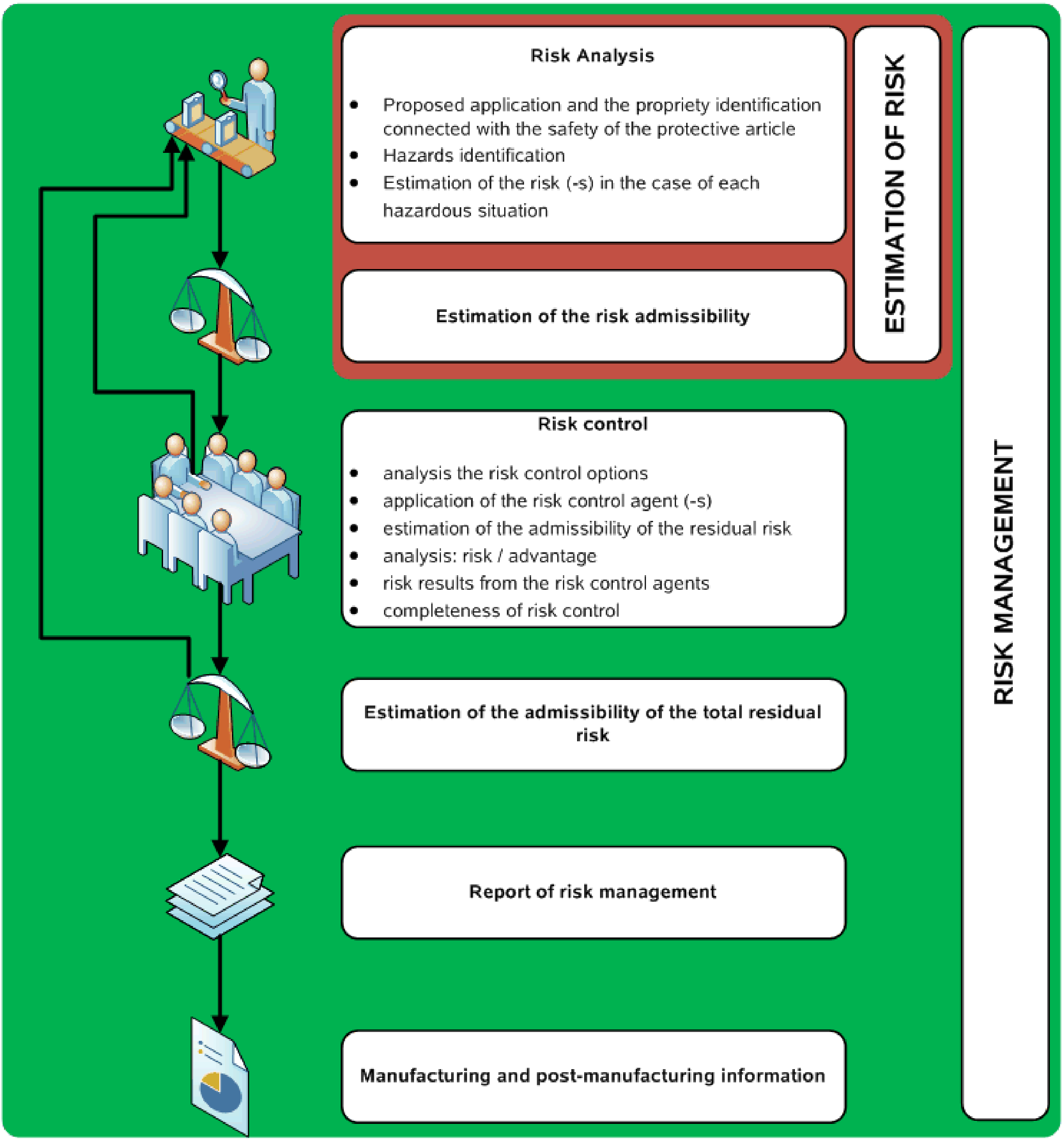


Figure 1. Proposed process of risk management for ballistic protective products [2]

The activities related to the risk management for protective products should be planned with special carefulness. A plan of risk management should include:

- the scope of planned activities related to risk management, identifying and describing a protective product and its life cycle stage (i.e. designing, manufacture, post-production phases, etc.), where each element of plan applies,
- assigning the responsibility and authorizations,
- requirements regarding review of activities related to risk management,
- criteria of risk acceptability, including also the criteria of the risks' acceptability, where the probability of harm occurrence isn't possible to estimate,
- the verifying activities necessary in order to reduce the risk to the acceptable level,
- the activities related to collecting and reviewing the adequate information concerning the design, manufacture and post-manufacturing [2].

The risk management documentation prepared in the above manner will allow for providing the traceability of each detected threat and shall ensure implementation as well as verification of the means affecting the reduction of risk level to the acceptable value [2]. The documentation is helpful at assessment of acceptability of each occurring residual risk. A remark should be made, that there is no such situation, to reduce a risk to 0, i.e. eliminate existing risk. Every time, despite prevention activities and/or correcting ones, some risks exist at a residual level. Question is, whether the level is equally acceptable for both the manufacturer, and for the users of the protective product.

An important element in a process of risk reduction (risk management) is foreseeing all of the factors appearing at the expected application and full identification of the protective product's properties related to the security guaranteed by the product. Any rationally predictable improper use of the protective product should be assumed with connection to potential threats resulting from such an use. One should also weigh, whether the protective product can be in use by an unprofessional (untrained) user as well as whether the protective products may be used in situations other, than the manufacturer intended and in situations other than expected at the stage of designing the product [2]. The manufacturer should „look into future", perceiving the threats caused by potential applying their product, effect of external conditions on the operational properties. He should look ahead, on an „event tree" basis (expectable damage as a result of sequence or combination of incidents), occurrences, that may appear, in case of product's damage as well as in it's impracticability states ie. damage, long-term exposition to sunlight or getting the ballistic insert wet. In case of threats, when estimation of damage probability is impossible, a list of potential consequences arising from given threat or threats accumulation should be made.

The information immensely important at estimation of risk may be aquired from published Standards or other standardizing documents (ie. NIJ [4] standardizing documents), scientific and technical information (including technical and technological documentation), the operating data concerning equivalent protective products in use, published reports concerning unwanted events and/or incidents (i.e. related to bullet- and fragment-proof vests made of Zylon® [6] or Dragon Skin [7] bullet- and fragment-proof vest), tests of usage among typical users and organizations dealing with verification of usage safety and ballistic performance of protective products (ie. [5]), usage data, results of laboratory tests, opinions from experts, data published in peer-review publications etc. It is important to realize, that the risk may only be assessed and managed, (meaning introduction of preventive measures and/or corrective in order to decrease level of risk to an acceptable one), if the threatening situation is identified. This shall enable reasonable predicting the event sequences that convert a threat into an incident or unwanted happening. The process of estimating the probability of threat conversion into an incident or unwanted happening includes a situation and event sequence from trigger reason to the damage occurrence. The mentioned above damage probability is directly and inseparably linked with human exposition to an unwanted effect of protective product. Thus, the level or scope of threat should be considered, i.e. assessing the aspects related to:

- threat situation occurrence without impracticability,
- threat situation occurrence with impracticability,
- threat situation occurrence only with multiple impracticability and
- probability (quantitative and qualitative) of threatening situation to lead to a damage [2].

As a practical aspect the following approaches to probability estimation are being applied, which are also applicable for ballistic protective products [2]:

- applying relevant historical data,
- probability forecasting with analytical or simulation techniques,
- applying experimental data,
- reliability estimation,
- production data,
- post-production information,
- applying the experts' opinion.

One should be also aware, that the probability of damage occurrence as a consequence of threatening situation depends on:

- what lifecycle stage is the protective product at (i.e. is it a recently-developed product, or is it rather a product already present on the market for many years),
- estimated quantity of products on the market.

A decision whether the reduction of risk is required, should be taken for each identified threatening situation, certainly having the mentioned criteria applied. The minimum requirement is to apply the screening test of risk acceptability of threat related to the protective product. In case of necessity to reduce the risk level, the factor (or factors) should be identified, which applied properly contribute to decreasing risk to an acceptable level both for manufacturer and the user. It may be accomplished by:

- introducing the rule of full safety at the research & development stage as well as the implementation works, for each product, by eliminating particular threats, decreasing probability of damage occurrence and/or reducing the severity of damage,
- assuring adequate, acceptable level of safety to the protective product itself and during the process of its manufacture (i.e. suitable selection of quality check techniques, placing the warnings

into the product marking, limiting the application or application conditions, giving the information on improper use, on threats, which may occur, or other information, that may support risk reduction, including the information about methods of reducing the damage, providing training for manufacturer's employees in order to improve their activities or their possibilities of errors detection at the stage of manufacture and control processes),
- adequate, widest possible range of information dedicated for user, including verification of training scope on using given ballistic protective product.

In order to assess the operative efficiency of applied element, introduction of mentioned risk reducing factors should be verified, under conditions which simulate usage or under conditions of regular using the ballistic protective product.

Reducing the risk to an acceptable level always relates to leaving a residual risk, the permissibility of which should be each time assayed as well as the possibility and reasonableness of applying the risk reducing factors. For the residual risks, level of which has been considered acceptable, the manufacturer should decide what residual risks to disclose and what information is necessary to include, i.e. in the product's user manual [2]. On the other hand, when the residual risk is not considered acceptable and there's no way to decrease risk level by applying additional factors, the manufacturer should censoriously review the data (usage, expertises, market feedback etc.) and publications (preferably peer-review periodicals) in order to determine whether benefits of expected application outweigh residual risk.

If such an analysis yields no conclusions proving domination usage and protection benefits over existing residual risk, then such a risk must remain inacceptable. Otherwise, i.e. in cases of risks, overweighed by benefits, a decision is necessary, which information are indispensable for safety and usefulness of protective product, to disclose the residual risk [2]. For protective products it is recommended to determine acceptable risk level reasonably and censoriously.

Applying the risk level decreasing factors brings two-fold threats:
- probability of introducing new threats or threatening situations and
- changes of risk levels of threats that have been previously identified, described and proving previously (i.e. before introduction of the factors) risk at an acceptable level.

In such a situation, the effect of the factor on the levels of all identified risks related to safety and usefulness of ballistic protection product should be weighted. It is especially important for complex protective products with numerous risks.

To recapitulate, the final stage of risk management process should yield the conclusions of accepting the total residual risk and introducing for practical applications the procedures aiming to gain the manufacture and post-manufacture information, which may be helpful at new threats identifying, or reducing the residual risk. For this reason a system of collecting and reviewing information on the product or equivalent products present on the market should be implemented and maintained. The information should be assessed for possible link to safety and usefulness, especially:
- if any unrecognized before threats or threatening situations occur, or
- if estimated risk resulting from threatening situation is not acceptable anymore [2].

Table 2 shows sample criteria of threats identifications and their description for the ballistic protection products.

Table 2. Threats identifications criteria and their description for the ballistic protection products [2].

What it anticipated use and how the protective product should be used ?	Factors, which are recommended to be weighted, include a) functions of the protective product (i.a. protection of torso, head or other body parts), b) the way of protection applied, c) application recommendations, d) any special intervention in case of product incapacity necessary?
Is the protective product intended for direct contact with the user ?	Factors to be weighted include kind of presumed contact, i.e. area of contact and possibility of emission of potentially toxic substances during usage, considering most extreme usage conditions

Is the protective product intended for regular cleaning and disinfection by the user ?	Factors, which are recommended to be weighted, include kinds of cleaning or disinfecting agents, which are to be applied, as well as any limitations of cleaning cycles' number. The product's design may also impact the effectiveness of regular cleaning and disinfection. Moreover, the effect of cleaning and disinfecting agents on safety and functionality of product is recommended to be weighted.
Do the protective product's properties alter during storing and using ?	Factors, which are recommended to be weighted, include: • temperature, • humidity, • atmospheric air composition, • pressure, • sunlight and its spectrum.
Is the protective product intended for usage with a link to other products or other techniques ?	Factors, which are recommended to be weighted, include identification of any other products or other techniques, which might be concerned, and potential problems related to such mutual interactions.
Is there any unwanted substance emission from the protective product ?	Substance related factors, which are recommended to be weighted, include emission of substances being used in process of manufacture, cleaning or testing, which have unwanted physiological effect, if they remain in the product. The impact of materials of which the protective product has been made of on the natural environment should be weighted [8].
Is the protective product sensitive to impact of environment ?	Factors, which are recommended to be weighted, include environment of using, transportation and storage. They include light, temperature, humidity, vibrations, flooding, variable climatic conditions, exposing to sunlight and variations of its spectrum.
Are any necessary consumables or equipment linked with the protective product ?	Factors, which are recommended to be weighted, include specifications regarding consumables or equipment and any limitations of choice, layed upon users.
Does the protective product feature limited period of usability or storage ?	Factors, which are recommended to be weighted, include marking or indicators and disposal of the products, when the usability period expires. The usability period should be weighted as well as the storage period, which does not deteriorate presumed usability properties (including the protective ones).
Are there any results of delayed or long-term usage of the protective product ?	Factors, which are recommended to be weighted, include ergonomic and cumulative results. Examples could include mechanical fatigue, loose straps and fastenings, effects of vibrations, labels which get attrited or lost, long-term degradation of material as a result of environmental factors, bad maintenance of product, bad way of storing them, etc.
What mechanical forces will be the protective product subject to ?	Factors, which are recommended to be weighted, include for example the force necessary to keep a protective vest integral (of the Quick Release type) and the force necessary to release it, force necessary to pull a wounded user with safety belts, etc.
What determines the lifetime of the protective product ?	Factors, which are recommended to be weighted, include those, which affect degradation of materials directly responsible for functionality and safety of protective product. Factors, which are recommended to be weighted, include environment of use, transportation and storage. They are light, temperature, humidity, vibrations, flooding, dynamic climatic conditions, exposure to sunlight as well as its spectrum variations,
Is a safe recycling of the protective product necessary ?	Factors, which are recommended to be weighted, include waste products, arising during recycling of used or damaged protective product. For example, does it contain toxic or dangerous materials or whether the material is suitable for recycling?

Does the transport, storing, using or maintenance of the protective product require any special training or special skills ?	Factors, which are recommended to be weighted, include novelty of protective product as well as probable skills and training of personnel responsible for transportation, storage, using the product and its maintenance.
How the information will be delivered in order to allow for safe usage of the protective product ?	Factors, which are recommended to be weighted, include: a) if the information shall be delivered directly to the end-user by the manufacturer, or a third party shall be committed, such as distributors, whether a training will be a result of that and whether performing such a training is necessary, b) whether it might be required, on a base of expected usage period of the product, to re-verify the safety and functionality of protective product.
Will it be necessary to establish or introduce new manufacturing processes ?	Factors, which are recommended to be weighted, include new technology or new manufacturing scale necessary to introduce for given protective product.
Is the protective product being used In the environment, or under conditions, where distraction may result with a threat towards health or life of user or others ?	Factors, which are recommended to be weighted, include: a) effect of the protective product's ergonomics on frequency of threat occurrence, b) consequences of usage fault, c) is the distraction a common occurrence or not, d) are the user's perception or focusing exposed to rare interference resulting from design of the protective product.
Does the product include attachable parts or additional equipment ?	Factors, which are recommended to be weighted, include possibility of bad fastening, similarity to other solutions applied into other products strength of fastening, feedback regarding join integrity and too strong or too weak joining, linking properties, etc.
Is the product to be used by individuals of special needs ?	Factors, which are recommended to be weighted, include the user, his mental and physical capabilities, skills and training, ergonomic matters, usage environment, users' abilities to affect the use of the protective product. Special attention is recommended to the fact, that the protective product may be in use among individuals of various skills level and cultural origin.
How the product could be improperly used, on purpose or unintentionally ?	Factors, which are recommended to be weighted, are improper use of joints, which obstruct safety elements, neglecting the maintenance recommended by the manufacturer.
Is the product planned to be mobile or portable ?	Factors, which are recommended to be weighted, are necessary handles, grips, ties, mechanical stability, physical integrity during transportation and storage, as well as the durability. Attention should be paid to intuitive and easy set-up after transporting or storing the protective product.
Does the protective product's usage depend on its basic applicative properties ?	Factors, which are recommended to be weighted, are adequacy of ergonomic solutions, assumed minimum protective area, ballistic class of the product, etc. [9-10]

Findings

The risk analysis as well as the risk management process proposed in the paper is based on the verified procedure described in international standards and applied for assessment of risk on the medical products area. Implementation of such a kind of process shall be helpful at providing the safety of using the protective products, including ballistic ones and ensuring their long-term functionality.

A benefit of risk management process entails directly economical results of manufacturers, who have implemented such a procedure within their factories. It is linked to a fact, that full analysis of threats for a given kind of protective product gives also the data related to manufacturing process optimisation, marketing data regarding the product and equivalent ones, thus enables improving the product as well, as easy identification of competition's weak points.

Bibliography

1. *Dyrektywy Europejskiej 93/42/EWG „Wyroby medyczne"*
2. *PN-EN ISO 14971:2007 „Wyroby medyczne. Zastosowanie zarządzania ryzykiem do wyrobów medycznych"*
3. *PN-EN ISO 22442-1:2008 „Wyroby medyczne wykorzystujące tkanki zwierzęce i ich pochodne -- Część 1: Zastosowanie zarządzania ryzykiem"*
4. *Ballistic Resistance of Personal Body Armor (NIJ Standard—0101.04)*
5. *Solicitation: Body Armor for Law Enforcement and Corrections, http://www.ncjrs.gov/pdffiles1/nij/sl000764.pdf*
6. *NIJ Body Armor Research and Evaluation Results, http://www.ojp.usdoj.gov/bvpbasi/docs/SupplementII_08_12_05.pdf*
7. *NIJ Body Armor Research and Evaluation Results, http://www.ojp.usdoj.gov/newsroom/pressreleases/2007/NIJ07057.htm*
8. *Alim A. Fatah, Richard D. Arcilesi Jr., Kenneth J. Ewing, Charlotte H. Lattin, Michael S. Helinski, NCJ 184449, June 2000, NIJ Guide, Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders NIJ Guide 100-00, Volume I,*
9. *Selection and Application Guide to Personal Body Armor, NIJ Guide 100-01 (Update to NIJ Guide 100-98), NCJ 189633, November 2001, NIJ Guide, by National Law Enforcement and Corrections Technology Center*
10. *Selection and Application Guide to Police Body Armor, NCJ 169587, October 1998*

On Non-Stationary Energy Absorption when Interacting High-Speed Striker with Textile Armor Materials

Ye. F. Kharchenko, A. F. Yermolenko

Last years, questions of energy absorption when interacting strikers with various ballistic materials are of all greater interest. This interest is based on the attempt to find a scientific approach to the problem of designing optimum armor materials and protection systems on their basis.

Assume a ballistic efficiency as a parameter for evaluating the ability of material (a sample) to absorb kinetic energy of a hitting element falling at effective contact area S_0.

In our experiments, the ballistic efficiency was determined from the expression (1),

$$\beta_t = \frac{\Delta E}{m} \text{ (J/kg)} \qquad (1)$$

where ΔE is energy absorbed by a barrier, $\Delta E = E_1 - E_2$ and E_2 are the striker kinetic energy values before and after the barrier respectively, m is material weight on the contact site (sample weight).

Taking into account changing kinetic energy of the striker when piercing each layer, it must not be used too many layers to characterize materials under study. At the same time, energy absorption is effected by not only the single layer properties but and the interaction of layers with each other, for example, the frictional interaction which always takes place in the actual armor protection system.

In this connection, we have selected for our experiments a packet of 4 layers of fabrics with surface density from 130 to 240 g/m2 and measuring 20 cm x 20 cm in a plane. Figure 1 presents energy absorption of 4 different types of textile armor materials as a function of striker speed over the range of 250 m/s to 750 m/s.

It is seen that over the studied range of fragment speeds, we deal, in reality, with the energy absorption spec-

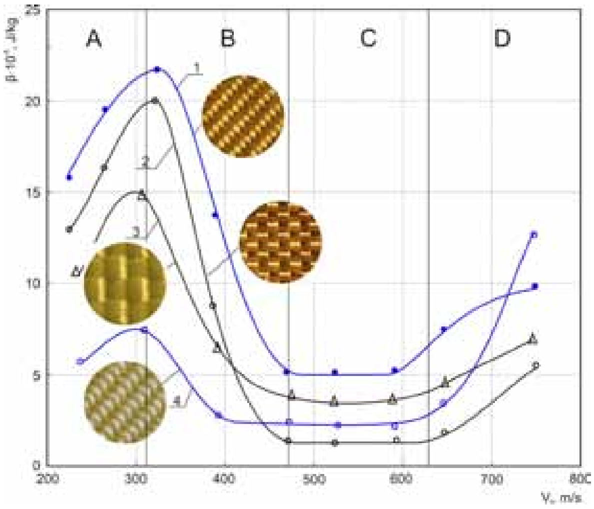


Figure 1. Ballistic efficiency (b) of 4-layer packet of fabrics as a function of fragment speed:
1 - twill fabric of Arus filament, 29 tex;
2 - linen fabric of Arus filament, 58 tex;
3 - linen fabric of Twaron filament, 110 tex;
4 - twill fabric of polyethylene filaments, 40 tex.

trum which is changed almost on a order. The most efficiency of studied materials takes place over the speed range from 250 to 320 m/s. The extremely low energy absorption is typical for the range of 500 to 600 m/s, where only about 10-20 % from the maximum energy absorption level remains.

This is a very negative circumstance because the majority of fragmentation protective systems are planned precisely for this fragment speed range.

As a whole, as we can see in Figure 1, the twill textile armor of Rusar filaments with minimum linear density of 29 tex has the best protective properties at any speed (curve 1).

The decrease of efficiency of armor materials accompanies the increase of linear density of filaments from which the fabric was made (curves 2 & 3). The least energy absorption over the range of 250 to 600 m/s were shown by fabric of polyethylene filaments (curve 4).

It is highly notable that all curves in Figure 1 have a general trend. It witnesses the presence of common failure regularities for studied materials expressed

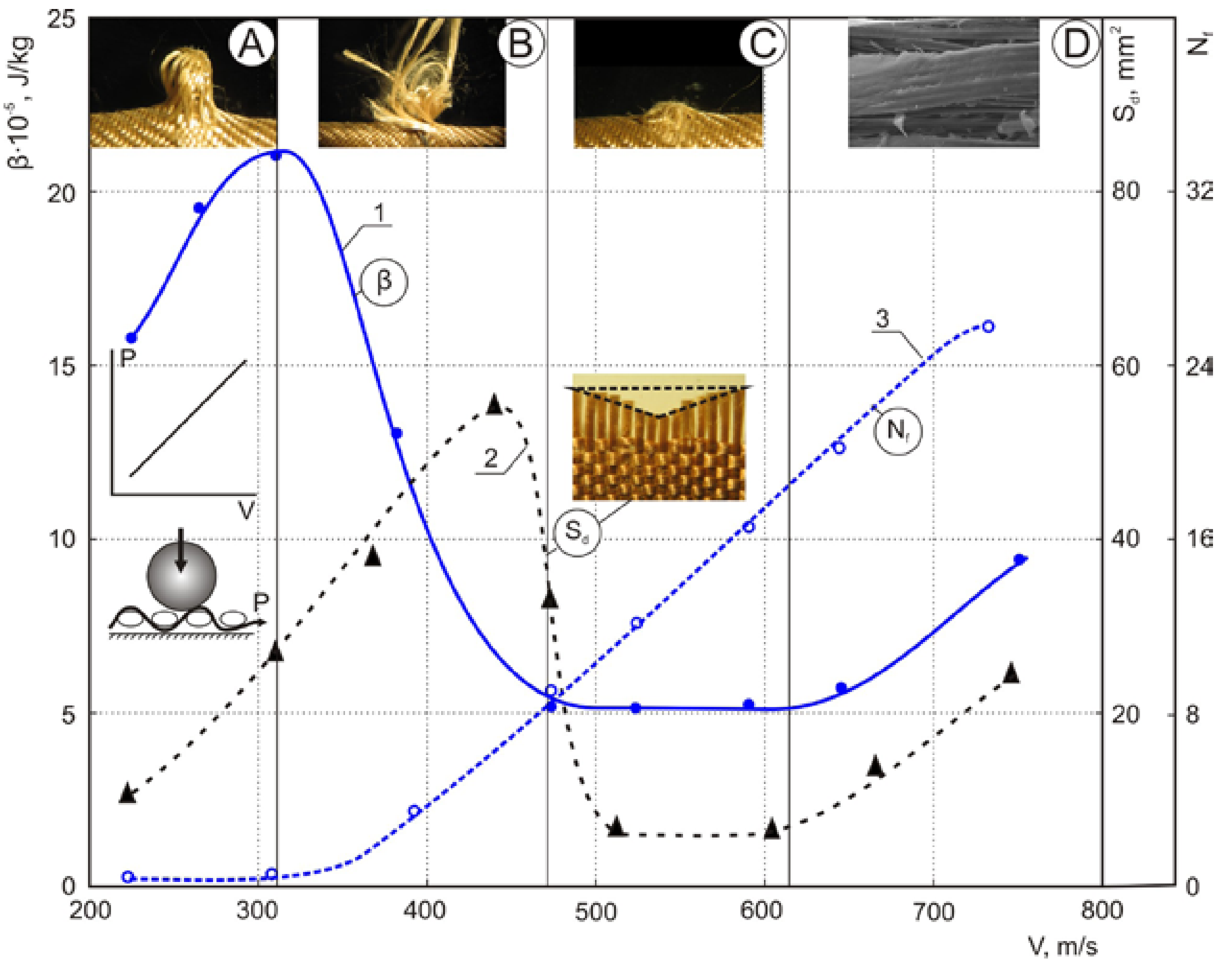
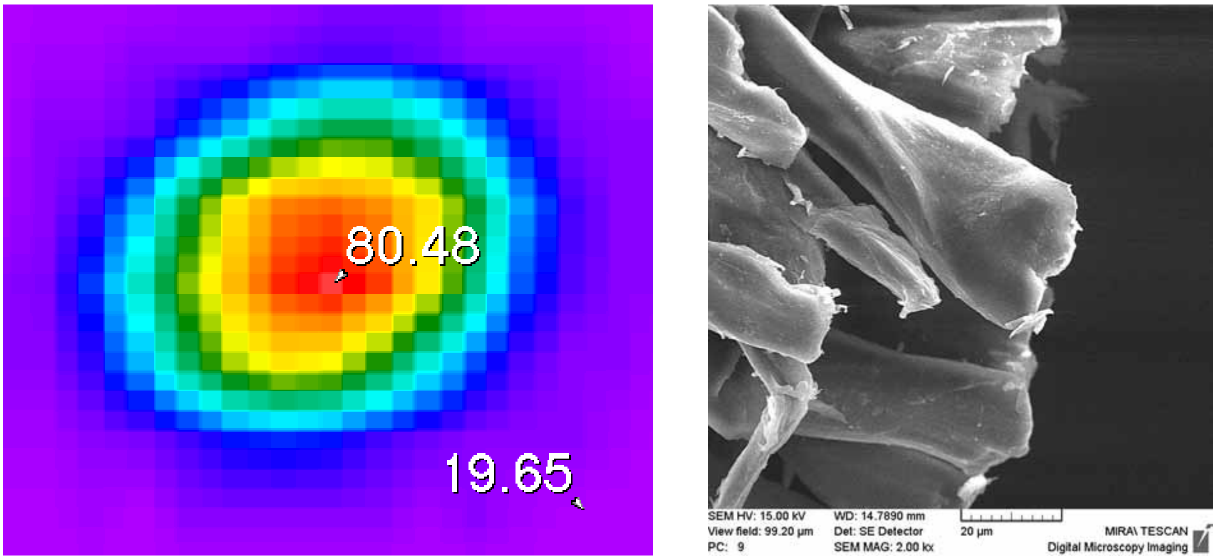


Figure 2. Change of ballistic efficiency of the 29-tex filament twill aramid fabric (1), movement area - filament pulling (2) and broken filament number (3).



a b

Figure 3. Termal imaged pattern in a zone of fragment impact with a speed of about 500 m/s into aramid textile material (a), fiber failure section in impact zone (b).

to a different extent. Apparently, there are 4 basic zones A - D, where one or another tendency is prevalent.

It is very important to understand what precisely has an influence on the material behavior over one or another speed range. Some answers can be received on the basis of data from Figure 2, using the 29-tex Arus filament fabric as an example.

The behavior of materials in zone A, where there is no yet through piercing the material, yields to explanation best of all. Here we have the primary operating of the friction components of interaction process, i.e. pulling filaments out of fabric. It is clear that the lateral pressure on the sample increases with increasing the striker fly-up speed (V), so and the force of pulling a filament out of structure, i.e. work to be performed, also increases.

This takes place until a speed about 320 m/s, beyond which the filaments begin to break (see a photo above). Stage B seems to be the most responsible not only that here there are the most visible changes - energy absorption decreases by 4 times - but and owing to the complex totality of several interaction mechanisms.

Curve 3 witnesses that the number of broken filaments continuously increases, beginning from a speed of 320 to 350 m/s. The trend of curve 2 shows that the filament pulling area in the major part of zone B increases that would have to increase energy absorption, however, parameter b, when approaching to a speed of 470 to 480 m/s, decreases to minimum.

Evidently at these speeds and over, other factors seem to be connected up. Firstly, it is the movement

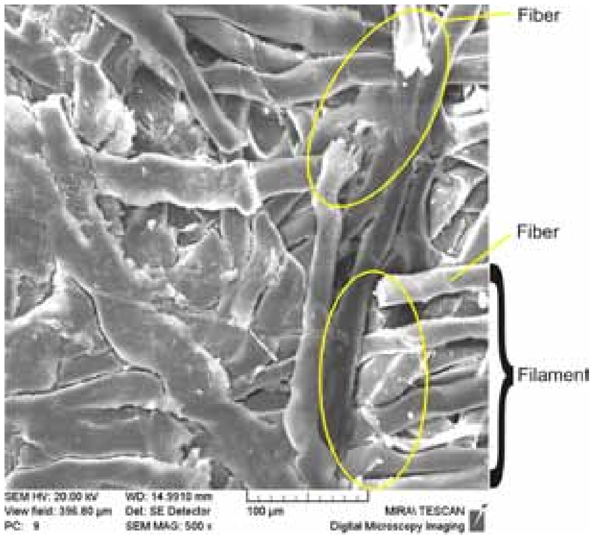


Figure 4. Scanned electronic photograph of fiber failure in filament intersection zones.

of filaments aside, i.e., their displacement perpendicularly to an axis. We showed long ago that the size of opening formed from broken filaments in fabric is by 3-4 times less than a striker diameter. So the unbroken filaments go to the side from the trajectory of fragment or bullet motion.

Secondly, at fragment speeds more than 400 m/s, heat effects also begin to play their negative part. Using the thermal imager, we established that the temperature in the moment of fragment impact against armor material substantially increases (by 60 to 70°C). In consequence of dynamic heat-mechanical action,

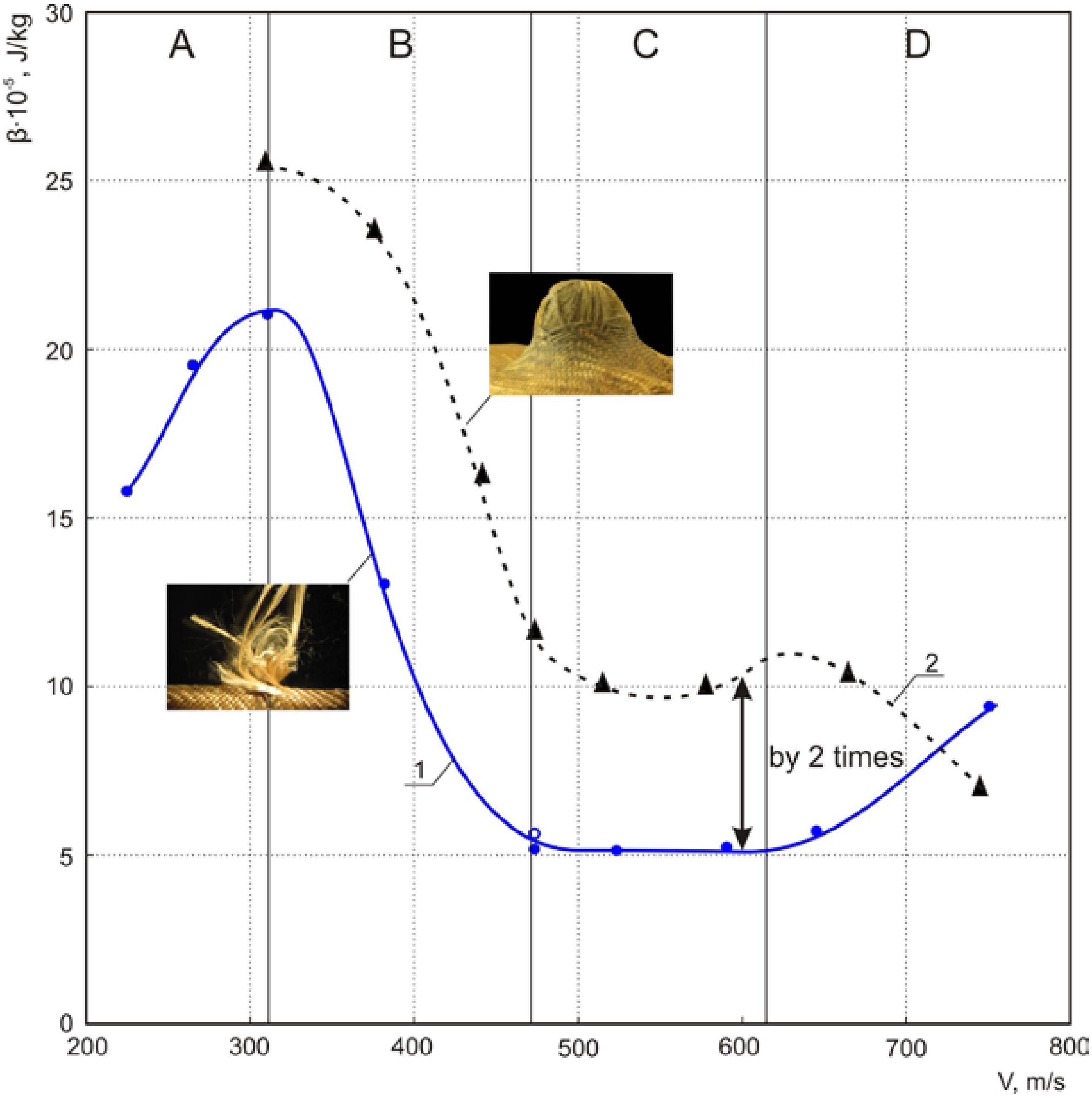


Figure 5. Ballistic efficiency of the 29-tex filament twill aramid fabric (1) and hybrid material based on the same fabric with isotropic aramid material gaskets (2).

fibers in filaments can be broken under considerably lesser stresses. The scanned electronic photographs in Figure 3b confirm a break in the impact zone untypical for fibers.

Apparently because of strong heat-mechanical impact action, the armor material in zone C at speed of 500 to 600 m/s has a minimum fragment penetration resistance - the hole pattern in this zone sharply differs from zones A and B, i.e. pulling and volume break of filaments are absent and the failure zone is localized (see a photograph in Fig.2). Scanned electronic photographs in Figures 3b and 4 witness a peculiar effect of «cutting into two» the fibes in zones of their weave.

One can suppose that if filaments and fibers in textile armor materials are mainly UD-oriented, without bending, as this takes place, for example, in unidirectional structures, the minimum energy absorption areas like zone C will be less.

The ascending branches of curves in area D, where evidently there is an effect of welding the fibers in their parallel lay-up zones, but not «cutting into two», are the indirect confirmation of this (see a photograph in zone D).

In any case, the presence of areas with very low ballistic efficiency leads to that a coefficient of using high potentialities of superstrong aramid and other fibers remains very low and according to our repeated estimations is not more than 0.7. And this is clear since the hitting element flying up to armor protection has a maximally possible speed (frequently 550 to 750 m/s).

The textile material in outer layers keeps only 10-20% from the maximally possible energy absorption (in zone A). And only when the striker speed reaches 300 to 350 m/s, the material, somewhere in the middle of the packet, reaches the ballistic efficiency maximum.

The main and practically important question remains: how to remove the so-called «transparency windows» at the hitting element speeds over 500 m/s?

There are several ways. Firstly, using non-woven UD-type materials and axially stitched structures. Secondly, placing other types of materials that are more effective over the high-speed range and «soften» the first and the most strong impact impulse, in outer (frontal) layers of aramid textile armor.

We succeeded in reducing the ballistic efficiency losses at speeds of 500 to 600 m/s almost by 2 times at the expense of introducing interlayer gaskets from other materials (see Figure 5).

Thirdly, perfecting the textile structure of aramid and polyethylene fibrous materials, including also at the expense of introducing the interfibre polymer additives into them.

Study of Wear Resistance of Aramid Fabrics with Various Textile Structures

Ye. F. Kharchenko, V. A. Aniskovich,
D. Yu. Kurmashova

During using armor vests and some other body armors, aramid fabrics included as their compound are subject to multiple abrasion .

Analysis of the state of vests after their long wearing showed that mechanical wear of ballistic fabric, in the main, its outer layers is the main factor of vest ageing.

This work presents the results of studying the influence of the type of weave in ballistic fabric, linear density and filamentarity of aramid thread in the fabric on its wear resistance. The study was carried out for linen- and twill-weave fabrics made of filaments with linear density of 100 tex, 58.8 tex and 29.4 tex. In addition, filaments with linear density of 58.8 tex and 29.4 tex consisted of different number of microfilaments.

The tests were conducted using the DIT-M unit under normal conditions. In these tests, the abrasion of fabric is made along a plane in the process of planetary motion of travellers. The stop of the unit is conducted automatically as soon as the fabric gets a wear-out. The load between an abrasive and fabric was 9.8 N

Table 1. Wear resistance of various ballistic fabrics (abrasive paper as an abrasive)

Sample №	Characteristic of Fabric			Number of Cycles under Loading, N	
	Type of Weave	Linear Density of Filament, tex	Filament	9.8 N	29.4 N
1	Twill	29.4	Standard	371	161
2	Twill	29.4	Microfilament	531	171
3	Linen	58.8	Standard	261	213
4	Linen	58.8	Microfilament	804	440
5	Twill	58.8	Microfilament	351	118
6	Linen	100	Standard	178	102

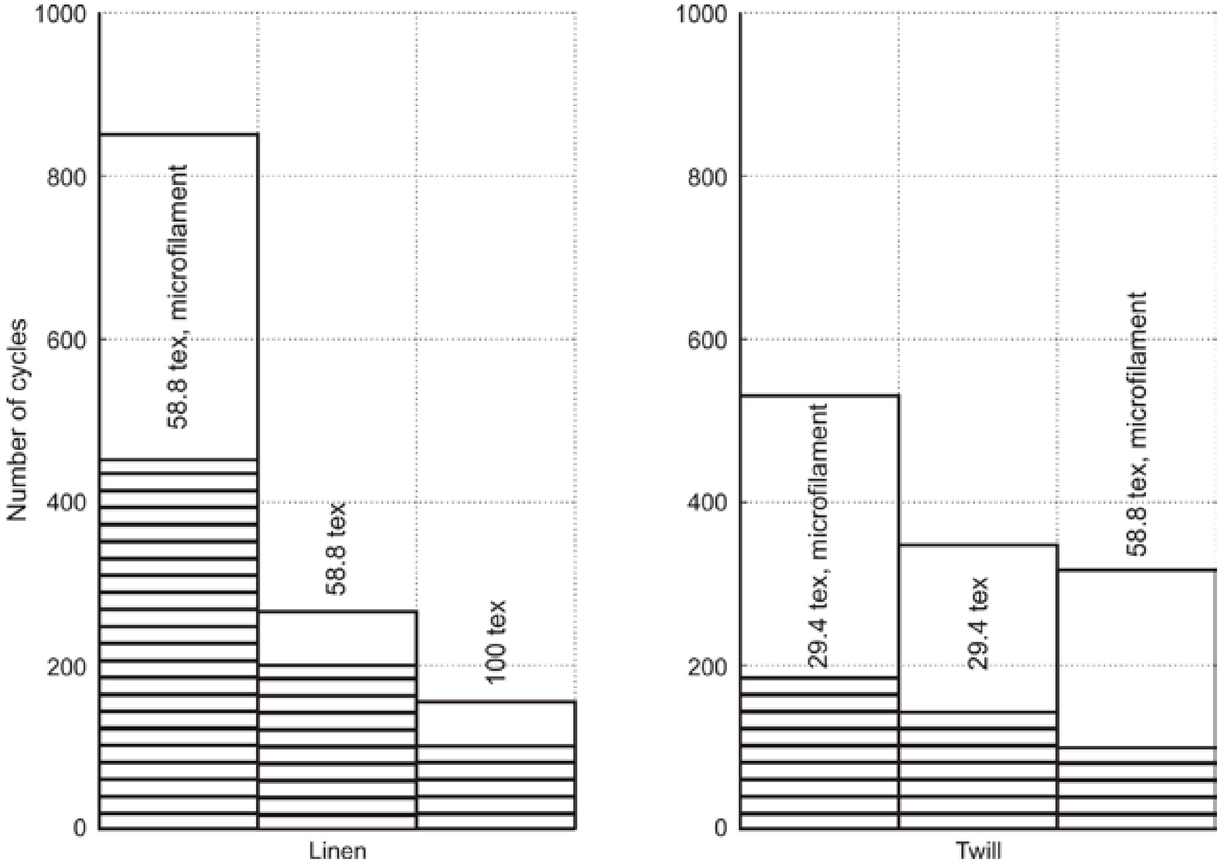


Figure 1. Number of abrasion cycles as a function of fabric textile structure, linear density and thread filamentarity:
- a load between abrasive and fabric of 9.8 N and 29.4 N respectively.

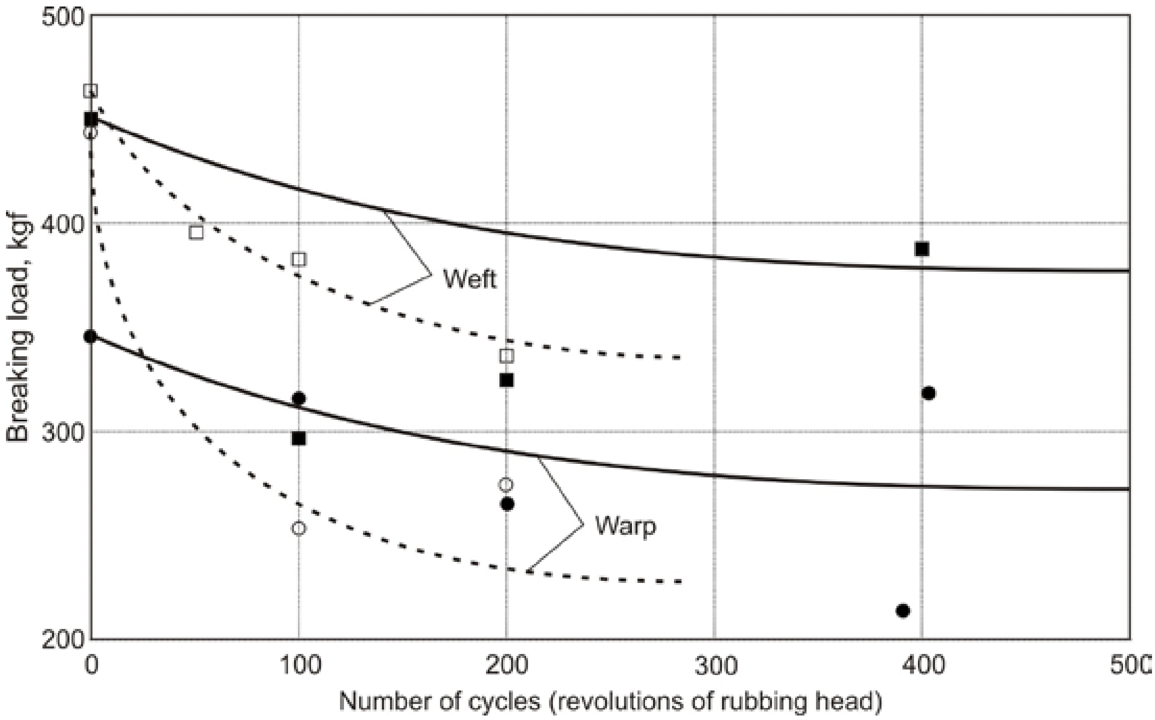


Figure 2. Breaking load along warp and weft as a function of number of abrasion cycles conducted for aramid fabric of filaments with linear density of 29.4 tex:
●, ■, — : microfilament (weight loss of 1.5%);
○, □, - - - : standard filament (weight loss of 0.9%)

or 29.4 N (1 or 3 kgf). A counter shows rotational speed (number of cycles) of the rubbing head to fabric failure (until a hole).

The abrasion of samples was conducted with rotational speed of rubbing heads equal to 200 minutes^{-1}. For each load (9.8 N and 29.4 N), 6 samples of every name of fabric were prepared. The abrasive paper No.600 was used as an abrasive for aramid fabrics.

During abrading, complex filaments are divided into individual filaments with subsequent their failure. Depending on weave, there are different failure mechanisms: for twill weave the structure of separate filaments is seen even after abrasion failure; for linen weave the failed fabric is a "non-weave linen". It is possibly bound up with that the mobility of separate filaments in linen weave is less than in twill one, therefore during abrading in the first case the fabric works, and in second case the filament works. The arithmetic mean of the number of cycles which samples withstand until full failure under given mode of operation is an wear resistance characteristic of fabric. Test results for aramid fabrics with various textile structures are presented in Table 1 and Figure 1.

All woven materials made of microfilaments have a considerable advantage in wear resistance compared with similar fabrics of usual filaments.

To evaluate the influence of abrasion process, that imitates the fabric operation under actual conditions, on strength properties of fabric, the following parameters have been measured:

- breaking load along fabric warp and weft after abrasion depending on number of cycles;
- weight loss depending on number of cycles.

The breaking load was measured for samples with a base of 8.5 cm and a width of 2.5 cm. It is bound up with dimensions of samples to be required for abrasion tests. Results of the study are presented in Fig. 2-4.

For all kinds of fabrics studied, the strength decrease along warp is more significant than along weft. It can be explained by features of textile structure of the fabric: warp filaments are more curved and therefore exposed to abrasion in the first instance.

On the basis of the results obtained, the following conclusions can be made:

1. All woven materials made of microfilaments are more resistant to abrasion than similar fabrics of usual aramid filaments.

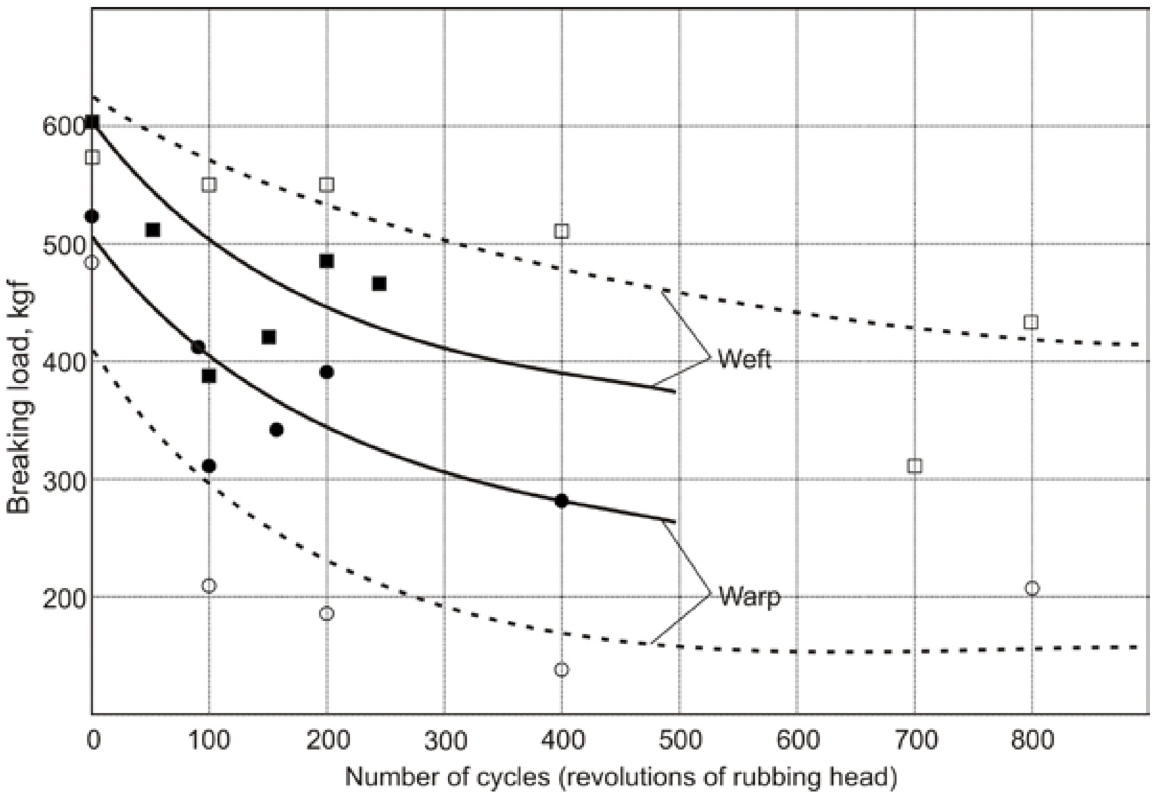


Figure 3. Breaking load along warp and weft as a function of number of abrasion cycles conducted for aramid fabric of microfilaments with linear density of 58.8 tex:
●, ■, — *: twill weave (weight loss of 0.9%);*
○, □, - - - *: linen weave (weight loss of 2.0%)*

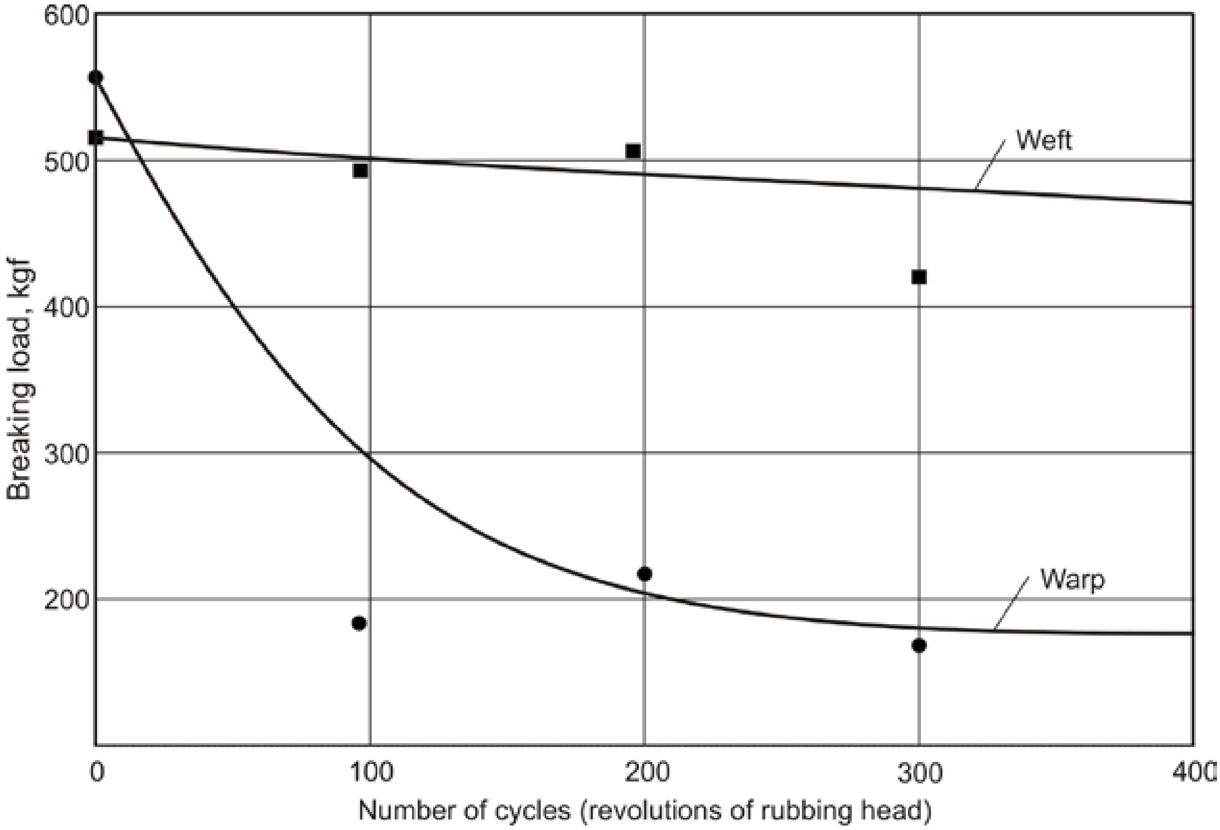


Figure 4. Breaking load along warp and weft as a function of number of abrasion cycles conducted for aramid fabric of filaments with linear density of 100 tex (weight loss of 1.9%).

2. With decreasing linear density of filaments (100 tex, 58.8 tex, 29.4 tex) used for manufacturing the fabric, its wear resistance is increased. Thus, for example, the fabric based on filament with linear density of 100 tex withstands not more than 300 cycles.
3. In twill-weave fabrics, the number of individual filaments in a filament and linear density affect the wear resistance not so substantially as in linen-weave fabrics. It is obvious that here we have an influence of degree of fastening filaments in fabric structure: in twill, the filaments have more freedom (mobility) and therefore are less subject to traumatizing (can deviate from the rubbing head).
4. For linen-weave fabrics of usual filaments, the influence of load value on wearability is slight compared with twill-weave fabrics.
5. Among fabrics studied, the linen-weave fabric of microfilament with linear density of 58.8 tex has the most wear resistance.
6. For all kinds of fabrics studied, the strength decrease is more significant along warp than along weft. It can be explained by features of textile processing the filament (warp filaments are more curved and therefore subject to abrasion in the first instance). It is possible, this feature would be taken into account when designing soft armor systems.

Lightweight High Performance Vests and Inserts with Dyneema® UD

H. Meulman

DSM Dyneema, The Netherlands

Introduction

DSM is the producer Dyneema®, the world's strongest fiber™. This fiber is 15 times stronger than steel (on same weight basis) and still floats on water. As this fiber is made of polyethylene it is very stable and does not react with most chemicals. This combination of properties makes this fiber extremely interesting for various applications.Hereby two examples which show these strong qualities:

- Dyneema® fiber is used as a suture (stitching yarn) in human bodies, for example to connect a broken tendon to a bone. This suture can stay inside the human body for many years as there is no rejection response due to the chemical inertia of polyethylene. Also the water content in the human body does not affect the yarn's strength as polyethylene does not react with water.
- Dyneema® fiber is also used in harbors to tow large vessels. Dyneema® has excellent resistance against the environmental conditions like (sea-)water, UVlight and high/low temperatures. This results in cables which can be used for a long time in a demanding environment and are so light that they can be lifted by hand.

Dyneema® in Body Armour

Since the early 1990's Dyneema® fiber is also used in bullet resistant applications, mostly using our Dyneema® UD product line. With Dyneema® UD vests are made which have the lowest weight for standards as the US Police NIJ 0101.04. Additionally Dyneema® UD is one of the few materials that can be used to produce inserts to give resistance against 7.62x39 mm AK47 MSC and 7.62x51 mm NATO ball without using a separate strike face. Those inserts are the lightest that can be found in the market resisting these threats.

These properties are recognized by many users within the military and police forces allover the world.

This is accompanied with a high quality assurance program, that amongst others include ballistic tests on every batch Dyneema® UD, visual inspection of every linear meter produced and the capability to trace all raw materials per batch. The batch number is always printed on a roll of Dyneema® UD, see Figure 1 for an example.

Key properties of vests with Dyneema®

Some other aspects that show the excellent performance which Dyneema® UD gives in vests and inserts:

Angle impact. Many specifications only test bullets with a normal impact on the vests. With Dyneema® UD the vest wearer has even better protection against bullets under an angle which can be considered as a more realistic scenario.

Dyneema® SB21 has been tested many times for the HOSDB standard or Royal Netherlands Army, both standards have extra test requirements on angle impact. The requested impact angles are 45° and 65° between line of fire and normal to the surface of the sample. In these tests the bullet was stopped and kept in the package.

Edge impact. Tests on samples with Dyneema® SB21 have shown that it can stop 9 mm parabellum bullets that impact only 3 cm from the edge. This results in a very high area of protection.

Multiple impact. Dyneema® UD had been tested with multiple impacts many times, capable

Figure 1: Print on Dyneema® UD with type and batch number

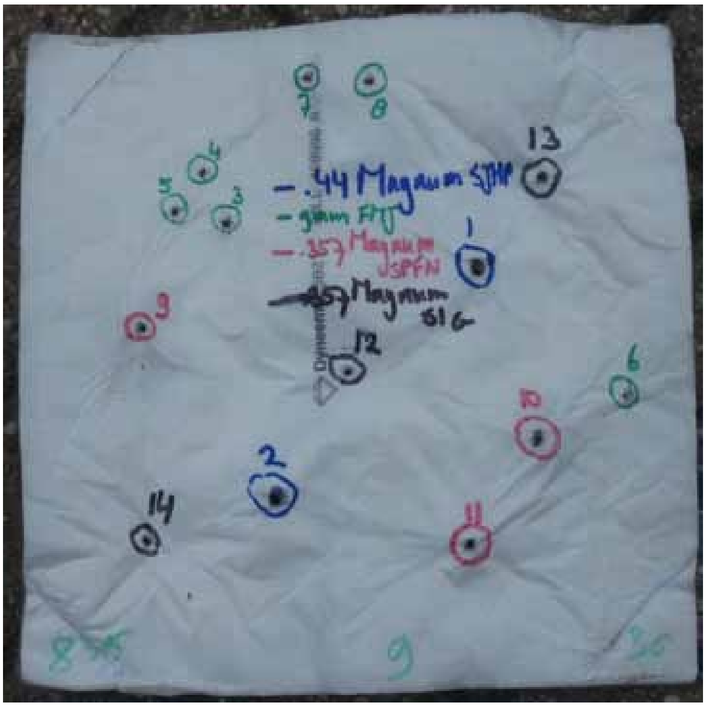


Figure 2: A package of Dyneema® SB21 with multiple impacts from various bullets, including close to the edge and close to other impacts

to stop 9 mm impacts with a shot-to-shot distance of only 3 cm. An example is shown in Figure 2.

High temperatures. Vests with Dyneema® UD have been conditioned at temperatures up to 75°C for 8 weeks and still no difference in performance have been observed in comparison to new vests.

Further a vests has been conditioned for 6 hours at 80°C and then for 6 hours 70°C (as prescribed in the German Schutzklasse) and then passed tests according to NIJ 0101.04 level 3A.

Fire resistance. For police officers it is important that a vest still keeps its properties, also in difficult circumstances. Resistance to a short fire is one of these conditions. In a test, prescribed by a Finnish end-user, a vest is put for 30 seconds in a fire. Then immediately a 9 mm parabellum should be stopped. A vest of Dyneema® passed this test without a problem.

In addition keep note that in a real situation a person with vest burning for 30 seconds, for example due to a Molotov cocktail, would have 3rd degree burning wounds around his head.

Life time performance. A customer returned to DSM a set of vests which have been used intensively for 24 hrs per day for 3 years. Tests showed that the Dyneema® UD still the same performance against 9 mm parabellum bullets as when the Dyneema® was produced.

Vests of Dyneema® SB21 has been conditioned in the tumbler according to NIJ 0101.06 level 3A and passed these tests.

Key properties of inserts with Dyneema® UD

Dyneema® UD is an excellent choice for inserts, both for stand-alone as for used as backing behind a strike face of ceramics. The UD is pressed into an hard armour in a specific cycle, using high temperature and pressure levels.

With Dyneema® inserts can be made that can stop AK47 MSC and NATO ball and Dragunov LPS ammunition. Such inserts are the lightest inserts available on the market.

For threats with a hard steel core like armour piercing ammunition Dyneema® UD is an excellent material for backing the ceramic strike face. It results again in inserts with the lowest weight and the best performance for multiple impacts, and still stopping the lower threats like NATO Ball.

Conclusion

We think that based on the list as shown above that Dyneema® UD is an excellent material for the production of ballistic resistant vests. We hope that this overview gives you further support in selecting Dyneema® UD as basic ballistic for resistance vests and inserts.

Assessment of Compliance of Products Serving the Purposes of the National Security

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The Institute of Security Technology "Moratex"

Introduction

In order to protect the interest of the Polish state in respect of defence and security, in the years 2006-2007 a number of legal regulations determining the principles of assessment of compliance of products ordered by the organisational units subject to or supervised by the Minister of National Defence and the competent minister of interior were implemented.

- The compliance assessment system in respect of products serving the purpose of the national security is governed by the following regulations:
- Act on compliance assessment system in respect of products serving the purpose of the national defence and security of November 17th, 2006 (Journal of Laws No. 235, item 1700),
- Ordinance of the Minister of Interior and Administration on organisational units empowered to assess the compliance of products serving the purposes of the national security of August 17th, 2007 (Journal of Laws No. 172, item 1216),
- Ordinance of the Minister of Interior and Administration on the method of determination of fees for activities involving examinations and certification of products serving the purposes of the national security of August 17th, 2007 (Journal of Laws No. 155, item 1094),
- Ordinance of the Minister of Interior and Administration on the method of supervision of inspection bodies and certification bodies of August 27th, 2007 (Journal of Laws No. 168, item 1183),
- Ordinance of the Minister of Interior and Administration on detailed method of supervision of the activities involving the product to be used in organisational and business units subject to or supervised by the competent minister of interior of August 29th, 2007 (Journal of Laws No. 170, item 1201),
- Ordinance of the Minister of Interior and Administration on detailed method of assessment of compliance of products serving the purposes of the national security and their list of September 25th, 2007 (Journal of Laws No. 188, item 1351),
- Ordinance of the Minister of Interior and Administration amending the ordinance on detailed method of assessment of compliance of products serving the purposes of the national security and their list of September 10th,2008 (Journal of Laws No. 169, item 1047).

The act on the compliance assessment system and the related ordinances determine:

- the principles of the compliance assessment of products serving the purposes of the national defence and security along with technical specifications,
- principles of detailed compliance assessment of products prior to introduction in organizational and business units subject to or supervised by the competent minister of interior,
- detailed lists of products subject of the compliance assessment to be used at organizational and business units subject to or supervised by the competent minister of interior,
- conditions to be fulfilled by the entities participating in the process of compliance assessment of products serving the purposes of the national defence and security,
- principles of supervision of functioning the compliance assessment system of products serving the purposes of the national defence and security.

The goals of introduction of legal regulations involving the compliance assessment of products serving the purposes of the national defence and security include:

- protection of the state interest in respect of defence and security by means of determination of principles of compliance assessment;
- providing conditions for competent and independent entities to carry out the product compliance assessment in respect of fulfilment of requirements contained in technical specifications;
- providing conditions to eliminate threats posed by the products to users' life and health and to the environment.

In accordance with the act, the system of compliance assessment of products serving the purposes of the national defence and security is created by:

- technical specifications
- regulations determining the method of compliance assessment
- regulations determining the operations of entities participating in the compliance assessment process.

At the same time, suppliers, inspection and certification bodies participate in the process of compliance assessment of products serving the purposes of the national defence and security.

The suppliers include enterprises supplying products to organizational and business units subject to or supervised by the Minster of National Defence and bodies, organizational and business units subject to or supervise by the competent minister of interior, including producers, distributors and importers.

Inspection bodies include organizational units with OIB accreditation assessing the compliance of a product on the basis of examinations and measurements to determine the compliance of the product with the technical specification.

Certification bodies include independent organizational units with OIB accreditation performing certification.

The assessment of compliance means activities of the supplier and the inspection body or the certification body to determine whether a product complies with the requirements specified in the technical specification. The assessment of compliance is carried out before a product is used. Irrespective of the assessment of compliance with the requirements determined in the technical specification, a voluntary assessment of compliance may be carried out according to the terms and conditions of the contract concluded by the parties concerned.

Depending on the features and technical parameters and threats the products may pose to users, the assessment of compliance of products to serve the purposes of the national security is carried out on three stages.

At stage one the supplier may carry out the assessment of compliance on its own. Stage two require participation of a research laboratory and stage three, which concerns products that may pose the greatest threat to the users, require participation of a certification body.

A positive result of the assessment of compliance of the product with the technical specification allows the supplier to issue an OIB declaration of compliance.

Activities of the Product Certification Department

The Product Certification Department, having the accreditation of the Polish Centre for Accreditation **AC 097**, has been operating at ITB „MORATEX" since 2000.

The certification included voluntary certification of commonly used products, including class I medical products, working clothes, protective clothes, protective equipment, etc.

The department has implemented and maintain the quality system compliant with the requirements of PN-EN 45011:2000 standard "General requirements regarding bodies implementing product certification systems" and PKN-ISO/IEC Guide 67:2007 "Assessment of compliance. Product certification basics.", which guarantees professional certification processes.

The certification of compliance is carried out on the basis of national and foreign standards, directives and other normative documents specified by the supplier.

ITB "MORATEX" is also a notified body No. 1475 in respect of the Directive.

Currently, the priori thy of the Department's activities is the assessment of compliance of products to serve the purposes of the national security used at organizational units subject to and/or supervised by the Minister of Interior and Administration, i.e. the Police Headquarters, Border Guards, and the Government Protection Bureau in accordance with the act of November 17th, 2006 on the system of assessment of compliance of products to serve the purposes of the national defence and security.

In 2008, the Product Certification Department was accredited by the Ministry of Interior and Administration, accreditation no. CA-OiB-004.01/2008.


CERTYFIKAT
Zakład Certyfikacji Wyrobów

The OiB certification includes the following product groups:

- skin protection devices (filtration and barrier protective clothes),
- ballistic protection equipment and measures (protective bulletproof vests, fragment-proof vests, knife-proof vests, needle-proof vests and others, protective helmets, protective covers, impact-proof covers),
- firework equipment,
- uniform equipment objects.

The Product Certification Department issues voluntary certificates for the materials used in the aforementioned products.

Certification programmes and systems

The certification activities are carried out on the basis of certification programme and systems.

The certification systems determine the principles and procedures and management used in the compliance assessment system.

The certification programs determine the principles of conduct referring to specific products to which the same specialized requirements, specific principles and procedures apply.

The Product Certification Department performs certification of compliance of products according to the certification systems 1b, 3, 5, 7 (in accordance with PKN-ISO/IEC Guide 67:2007).

Certification system 1b involves only the assessment of product type, including:

- taking samples,
- determination of features on the basis of sample examination,
- assessment of examination reports,
- decisions,
- issue of compliance certificates.

Certification system 3 involves certification of compliance of products manufactured in series, including:

- taking samples;
- determination of features on the basis of sample examination;
- initial assessment of the production process or the quality system, if applicable;
- assessment of examination reports;
- decisions;
- issue of compliance certificates;
- supervision in the certificate validity period, including periodical controls of the production process quality system of the supplier and examination of assessment of quality of samples taken from the supplier.

Certification system 5 involves certification of products manufactured or supplied in series and includes quality system examination and assessment. With respect to supervision, the certification body supervises the maintenance of the quality system and continuity of compliance of products by means of examination of samples taken from the market or the place of production or from both of them.

The system includes:

- taking samples;
- determination of features on the basis of sample examination;
- assessment of the supplier's quality system or technical and organisational conditions and its effectiveness;
- assessment of examination reports;
- decisions;
- issue of compliance certificates;
- supervision of the organization of the production process or the quality system or both of them;
- continuous supervision of the product by means of examination or inspection of samples from the factory or market or from both of them.

Certification system 7 involves certification of clearly specified batches of products and includes:

- taking samples;
- sample examination;
- assessment of compliance of a batch of product with the requirements;
- decisions;
- issue of a certificate of compliance with clearly determined requirements for duly identified product batch;
- supervision of correct use of the certificate.

Programmes

The Product Certification Department has prepared 5 certification programmes including the principles of procedure regarding products to which the same specialized requirements, determined principles and procedures apply.

PC OiB-01 Certification Programme includes certification of clothes, including:

- skin protection equipment and measures
- firework equipment
- uniform equipment objects.

PC OiB-02 Certification Programme includes certification of protective vests.
PC OiB-03 Certification Programme includes certification of protective helmets.
PC OiB-04 Certification Programme includes certification of protective covers.
PC OiB-05 Certification Programme includes certification of impact-proof covers

The certification system is chosen on the basis of the product type and supplier's nature. The certification systems have been determined in the basis of PKN-ISO/IEC Guide 67:2007 "Assessment of compliance. Product certification basics." Depending on the certification system applied, the certification process stages have been presented in the table below:

Table 1 Certification process stages

	Certification process stages	**Certification system**			
		1b	**3**	**5**	**7**
1.	Submission of an application including: – full Supplier's data – producer's data of the supplier is an importer or distributor – full product data – declaration on covering costs of the certification process	X	X	X	X
2.	Appendices to the application:				
	• documentation of the product containing identification of materials, description of production processes, tables of measurements, technological and utility parameters, application of the standard, marking method, maintenance principles, packing method, description of the quality control method	X	X	X	X
	• questionnaire of the Supplier	-	X	X	-
	• product model	X	X	X	X
	• results of laboratory research	X	X	X	-
3.	Application registration	X	X	X	X
4.	Formal assessment of the documentation submitted	X	X	X	X
5.	Initial fee for review of the application	X	X	X	X
6.	Conclusion of contract for certification process	X	X	X	X
7.	Taking samples by the body from the product batch	-	-	-	X
8.	Laboratory examination of the products taken from a batch	-	-	-	X
9.	Assessment of the quality system or technical and organisational conditions	-	-	X	-
10.	Assessment of documentation of the product certified	X	X	X	X
11.	Assessment of results of laboratory examination	X	X	X	X
12.	Decision of the Technical Committee	X	X	X	X
13.	Decision on whether the certificate is given or not	X	X	X	X
14.	Free for the certification process (irrespective of the result)	X	X	X	X
15.	Contract for issue and supervision of the certificate	X*)	X	X	X
16.	Issue of the certificate	X	X	X	X
17.	Supervision:				
	• examination of samples taken from the recipient	-	-	X	X
	• examination of samples from the plant	-	X	X	X
	• quality system audits connected with random examinations	-	-	X	-
	• production process assessment	-	X	X	-
*) The contract regards issue of the certificate only					

Certification process stage

Preparatory procedure

Prior to submission of the application for certification of a product, the supplier will agree the following with the PCD in an explicit and clear way:

- certification scope and system,
- requirements to be met by the product introduced to trading, i.e. standards and normative documents determining requirements and examination methods,
- principles of taking samples to examinations,
- type and scope of the documentation identifying the product,
- certification process costs and examination costs.

Submission of an application

After the stage of arrangements, the supplier submits the application for certification along with:

- technical documentation necessary to perform the compliance assessment,
- appropriate number of product items,
- manual describing safe use,
- information about maintenance,
- for products manufactured in series, information regarding the quality management system.

Formal assessment of the application

Prior to registration, the application is subject to formal assessment. In the case of a positive result, the application is registered. If the application requires supplementation, the Product Certification Department provides the supplier with a list of irregularities.

After supplementation of the application with lacking information, the application is registered.

Product examinations for the purposes of the certification

Product examinations the results of which are used in the certification process are carried out by any testing laboratory independent of the supplier and accredited within appropriate scope.

The PCD maintains and regularly updates a list of testing laboratories accredited by the PCA the scope of which includes examinations required to the product certification.

Taking products for examinations

Products for examinations for the purposes of certification should be taken by the supplier randomly, in accordance with the requirements of the standard in question. The products for examinations should be representative for the whole supply. In the case of certification of a batch of products, the PCD takes a blind sample from a clearly identified batch of products with numerousness depending on the number of items in the batch. The samples are taken from different places of the batch. Each time, a report is prepared on taking samples.

Examination report

The PCD admits examination reports prepared by national or foreign accredited testing laboratories.

Assessment of the quality assurance system or technical and organisational conditions of the supplier

If the supplier maintains a certified quality assurance system, the PCD may admit the system certified and resign from performing control at the supplier's place after making sure that the certificate is valid and has appropriate scope.

In the case the applicant did not submit a declaration on the quality assurance system applied. The PCD assesses technical and organisational conditions necessary to ensure repeatable and good supply.

Review and assessment of materials collected during the product certification process

After confirmation of paying the initial fee, the application along with the documents attached is analyzed by an employee of the PCD. The result of the analysis in the form of assessment of the documentation of the applicant for issue of the certificate for a product are presented and discussed at the meeting of the Certification Technical Committee.

The opinion of the Committee is conveyed to the Manager of the PCD.

Decision on whether the certificate is issued or not

The Product Certification Department issues a certificate of compliance if it finds that the product complies with the documentation necessary to perform the compliance assessment and in the case of a product manufactured in series, also that the quality management system of the supplier complies with the required standards. The certificate validity is three years as of the issue date.

In the case of refusal of issue of the certificate, the supplier receives a written justification of the refusal, settlement of costs of the certification process along with information about the method of appeal from the decision.

Interruption of the certification process

It is permitted to interrupt the certification process of a product if the supplier submits a letter to the PCD on interruption of the certification process, fails to comply with the terms and conditions of the contract for certification process, or fails to adhere to the financial liabilities towards the PCD.

Information confidentiality

The PCD ensures confidentiality of the information obtained in the certification process, except for special cases provided for by legal regulations. All employees of the PCD and employees of units providing services related to the certification process are obliged to maintain confidentiality.

Supervision of the certificate issued

The certificate may be used solely by the owner in accordance with the contract for the issue and supervision of the certificate.

The holder of the certificate issued by the PCD is obliged, in particular, to:

- apply the certificate solely to the products meeting the determined requirements and for which it was issued;
- not to lend it for use by another natural or legal person;
- inform the PCD about any and all intended changes regarding the product certified, its production process and quality assurance system.

The PCD supervises the certificates issued by it by means of:

- supervision of the way of use of the certificate by the supplier;
- control of results of examinations of uncompleted products covered by the certificate, taken from the supplier and / or purchased in the market, performer in the accredited or authorized laboratories;
- supervision of technical and organizational conditions at the supplier's place during the certificate validity;
- assessment of the supplier in respect of correct functioning of its quality system.

Suspension, invalidation or cancellation of the certificate

Incorrect reference to the certificate issued or its incorrect application results in suspension or cancellation of the certificate. The principles and conditions regarding suspension, invalidation and cancellation of the certificate have been contained in the contract for issue and supervision of the certificate.

The PCD may suspend the certificate if:

- it finds that the product fails to conform with the requirements of the normative document determined in the certificate;
- negative results of controls or examinations of products conducted within the confines of supervision of the certificate are obtained;
- the supplier (applicant) renders it impossible for the PCD to conduct inspection or control of the product;
- the supplier (applicant) fails to comply with the terms and conditions specified in the contract with the PCD;
- the supplier (applicant) applied for suspension of the certificate on account of temporary production stoppage.

When suspending the validity of the certificate, the PCD determines the conditions pursuant to which the certificate may be resorted and the date of their fulfilment. If the safety requirements are not met, the suspension takes place with immediate effect.

The certificate is invalidated of the holder resigns from the certificate and submits a written application for its invalidation.

The certificate is cancelled if:

- the supplier (applicant) intentionally abuses rights resulting from the certificate;
- the supplier (applicant) fails to meet the requirements of the PCD within the determined period when suspending the validity of the certificate and the change of the period is not agreed earlier;
- the supplier (applicant) suspended at its own request and failed to take activities aimed at restoration of the certificate.

Extension and limitation of the scope of the certificate

The extension regards a product that has already received a certificate and which the producer wants to introduce tiny changes to, e.g. in the product structure or use of additional resources. Introduction of changes may not influence the requirements for the product contained in the certificate issued.

The PCD provides a possibility to extend the scope of the certificate after simplified certification process (without assessment of the supplier's quality system). The scope of the process and the documentation required is determined by the PCD.

The extension is made in the form of an annexe to the certificate for the basic product with the same validity period.

The limitation of the scope of the certificate may take place at the request of the holder if it ceased the production of a determined product version included in a certified type of products.

Extension of validity of the certificate

The extension of validity of the certificate regards a certificate that becomes invalid and takes place at the request of the certificate holder on the basis of:

- positive results of examinations and controls carried out within the confines of the supervision of the certificate;
- positive results of additional examinations for the product required by the PCD at the moment of extension of the certificate validity;
- lack of objections as to observance of all provisions of the contract concluded between the PCD and the supplier;
- lack of users' complaints about the product;
- Lack of objections as to the correct use and application of the certificate held by the supplier;
- positive results of the simplified certification process;
- settlement of financial liabilities towards the PCD for extension of the certificate validity by the supplier.

In the case of extension of the certificate validity, the applicant submits an application for extension of the certificate validity one month prior to the expiry of the validity. The validity of the certificate may be extended by up to 5 years and regards the same product.

Transfer of ownership rights to the certificate

In the case of a change of the legal status of the certificate holder, it may apply for transfer of ownership rights to the certificate.

The applicant should attach the following documents to the application for transfer of ownership rights:

- confirmation of transfer of ownership rights,
- confirmation of change in the relevant register,
- declaration on assumption of the rights and obligations of the previous certificate holder.

The quality system or technical and organisational conditions of the applicant for transfer of ownership rights to the certificate will be assessed like in the case of the supplier.

Fees for certification and supervision of the certificate issued

Total costs related to the product certification process and costs related to supervision of the certificate issued are incurred by the applicant / holder of the certificate irrespective of the result of the certification process.

The costs of the certification process and supervision are determined individually and the value thereof is determined in the contract. The fees for the certification process are charged at two stages:

- on submission of the application for certification of a product by the supplier (initial fee),
- after completion of the certification process (full settlement of costs).

The costs of laboratory tests are not included in the costs of the certification process and comply with the price lists of the accredited laboratories making the tests.

Appeal from the decision of the PCD

If the supplier does not agree with the decision on refusal to issue, refusal to extend, suspension or cancellation of the certificate, it is entitled to appeal from the decision with the Institution Director within 30 days as of the notification.

If the appeal is not approved by the Director, the Customer may appeal to the Court having jurisdiction over the Institute of Security Technology "MORATEX".

The certificate of ITB „MORATEX" confirms the compliance of the product with the requirements, safety of the product for people and the environment and the reliability of producers. Furthermore, the certificate enhances the reliability and rang of the product, which is a priority in the case of elimination of threats posed by products serving the purposes of the country's defence and security.

The certificate allows the supplier to issue the OiB declaration of compliance and shortens the activities of the body supervising the activities related to introduction of a product for use.

Resistance to Bullets, Knives, Stabs and Needles According to Current Standards, Procedures and Users' Expectations

G. Grabowska, J. Blaszczyk,
I. Kucinska

The Institute of Security Technology "Moratex"

1. INTRODUCTION

Public security menace may be considered on many areas, however two of them certainly mould recognition among the society.

First area subject to social penetrating assessment are so called common crimes; linked with day-to-day threat i.a.: breaking and entering, carjacking, scrimmages and batteries or riots at sports events.

Second area of threat towards public security isn't visible everyday and the information are passed by media. They are violent stick-ups at banks and exchange offices, mafia old scores pay-offs, or most tragic – acts of terror. This group of threats is made by their executors – professionally trained individuals, determined, ready to die theirselves. Mortal casualties and wounded should be expected at such happenings, also among officers.

Protective activities are also implemented in the countries where virtually each clannish, criminal or terrorist fighting squad is armed with armour-piercing grenade launcher and machine guns, and bomb attacks are typical means of propaganda campaign.

2. THE GOAL

The response to threats getting deeper nowadays is elaborating more effective ballistic protection means including protective vests in both domestic and foreign research institutes.

Therefore in the recent years, when designing the protective vests, an aspect of increasing the wearer's body protected area i.a. has been considered. Thus contemporary vests often protect not only front and back of a body, but also sides, neck, inguinal arteries, crotch, arms from elbow to collar-bone, thighs etc.

Moreover, the bulletproof vests are often enriched with knife-, stab-, or needle-proofness, The functionalities are not defined in Polish Standards in due. Therefore inaccurate expressions are often included into tender specifications. This is why the present article attempts to put the matters in order, the test methods are specified as well as the requirements for bullet-, knife- and stab-proofness, and the guidelines for gaining the needle-proofness for protective vests too.

3. TEST METHODS

3.1 Ballistic covers

The matters of ballistic resistance is described i.a. in the following standardising documents:

- PN-V-87000:1999 Ballistic covers. Bullet- and fragment-proof vests. General requirements and tests.
- NIJ Standard 0101.04:2001 Ballistic Resistance of Personal Body Armor.

Contemporary ballistic covers usually feature maximum resistance available for soft ballistic inserts:

- class 3 according to PN-V-87000:1999, protection against 7,62mm lead core pistol 5.5g bullet at the impact velocity of 420^{+15} m/s, shot from 7,62mm Tokarev pistol model 33 TT,
- level IIIA according to NIJ Standard 0101.04, protection against 0,44" Magnum JHP 15.6g bullets at the impact velocity of 436^{+9} m/s and 9 mm Parabellum FMJ 8.2 g bullets at the impact velocity of 436^{+9} m/s.

In order to gain such resistance, one of the worldwide known ballistic materials is mostly applied i.e. based on para-aramide fibres woven or non-woven featuring very high strength (Goldflex®) or non-woven material based on polyethylene fibres featuring very high strength (Dyneema®). Sometimes some anti-trauma liner find appear applicable for decreasing the deflection of background down to 25 mm.

3.2 Knife-proof covers

Despite continuous development of firearms, there is a constant threat of unchanged intensity since the dawn of history; the threat from cold steel: knife, stab, needle.

So the question appeared:

- whether ballistic covers made conformable to class 2 or 3 according to PN-V-87000:1999 Standard and to the level IIIA according to NIJ Standard 0101.04 do protect against cold steel, and
- to what pitch and with what to enrich the ballistic covers of class 3 according to PN-V-87000:1999 Standard or level IIIA according to NIJ Standard 0101.04 in order to provide such protection, with no remarkable increase of their stiffness and mass.

To answer this question the test methods shall be invoked as well as the users' expectation level.

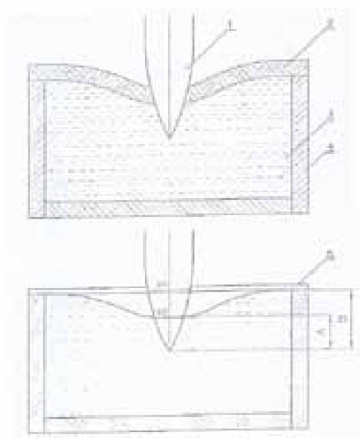
Unfortunately, the Polish Standard PN-V-87000:1999 does not include such tests, therefore the following test procedures have been formulated in the accredited Ballistic Laboratory of „MORATEX" Institute:

- **Procedure ITWW „Moratex" PBB-06:1996 "Impacting tests. Determining the resistance of set of samples to piercing with cold steel" developed on a basis of ISO/DIS 14876-2:1996 Standard "Body armour – Part 2: Stab resistant Vests".**

The compilation of object test conditions according to the above procedure is shown in Table 1.

Table 1. Tested objects' (panels) protection level depending on the number of hits with falling edge of military knife model 92, on angle and on impact energy

Protection level	Kind of test edge	Impact energy [J]	Number of hits at the angle of 0°
1	Military knife model 92	25,0 ± 0,50	6
2	Military knife model 92	35,0 ± 0,70	
3	Military knife model 92	45,0 ± 0,90	



1. edge — SG – upper imprint
2. tested sample — SD – lower imprint
3. basis — A – penetration
4. box — B – penetration and deformation
5. metal slat

Fig. 1.Knife hit – definitions of names and concepts

- **Procedure ITB „MORATEX" PBB – 08:2006 "Impacting tests. Determining the resistance of personal armour to an edge" – procedure compliant with NIJ STANDARD 0115.00**

The compilation of object test conditions according to the above procedure is shown in Table 2.

Table 2. Protection level of tested objects (panels) depending on energy of hit with P1 and S1 edges

Protection level	Energy of hit with E1 [J]	Energy of hit with E2 [J]
1	24 ± 0,50	36 ± 0,60
2	33 ± 0,60	50 ± 0,70
3	43 ± 0,60	65 ± 0,80

Table 3. Number of hits with falling edge P1 and S1 depending on angle and energy of hit (see Table 2)

Number of hits	Angle of hit	Test edge	Energy of hit
1	0°	P1	E1
1	0°	P1	E2
1	0°	S1	E1
1	0°	S1	E2
1	45°	P1	E1
1	45°	S1	E1

Table 4.Number of hits with falling edge (stab) for each of tested panels depending on angle and energy of hit (see Table 3)

Number of hits	Angle of hit	Test edge	Energy of hit
1	0°	Stab	E1
1	0°	Stab	E2
1	45°	Stab	E1

The criteria of assessment is the depth of penetration Gw of the testing edge – the following quantities are assumed acceptable:

For E1 - max Gw = 7 mm
For E2 - max Gw = 20 mm

4. MATERIALS

The tests were executed on the ballistic panels as well as the bullet-, knife- and needle-proof vests with soft inserts, made of:

- fabric based on para-aramid fibres featuring very high strength,
- non-woven material based on para-aramid fibres featuring very high strength - Goldflex®,
- non-woven material based on polyethylene fibres featuring very high strength - Dyneema®.

In some cases the anti-trauma poly-carbonate liners were additionally applied to gain decrease of deflection down to level of 20 mm. In some products were also applied the anti-trauma liners made of para-aramid fibres featuring very high strength and coated with silicon carbide - SRM® .

5. RESULTS AND DISCUSSION

5.1 Knife-proof covers

The comprehensive tests of resistance to piercing with military knife model 92, edge types P1, P2, S1 and S2 as well as with the stab have been done at the accredited Ballistic Laboratory on the ballistic armours of class 2 and 3 according to the PN-V-87000:1999 Standard and of level IIIA according to NIJ Standard 0115.00, following the procedures PBB-06 and PBB-08, respectively.

The results were collected of tests on samples compliant to class 2 according to PN-V- 87000:1999 Standard, made of non-woven polyethylene sheets Dyneema® with anti-trauma liner made of 0.75mm thick polycarbonate. The hit energy of 10 J was achieved for such an arrangement while providing the maximum depth of penetration as low as 3 mm (Fig.1).

The standalone GoldFlex® samples compliant with class 3 according to PN-V-87000:1999 Standard, as well as the samples compliant with class 2 according to PN-V-87000:1999 Standard made of GoldFlex® combined with several-ply liner of SRM® yielded the maximum depth of penetration 20 mm (Fig. 1) at the hit energy of 10 J

The tests above have given results below class 1 of knife-proofness according to the procedure ITWW „Moratex" PBB-06:1999, therefore they are only executed upon customer's explicit request.

Top results have been achieved from tests on the samples compliant with class 3 according to PN-V-87000:1999 Standard, made of non-woven polyethylene sheets Dyneema® pith 0.75mm or 05mm thick polycarbonate anti-trauma liner. The hit energy of 35 J was achieved for such an arrangement while providing the maximum depth of penetration as low as 4 mm (Fig.1) which means class 2 according to the procedure ITWW „MORATEX" PBB – 06:1996.

Samples compliant with class 3 of the PN-V-87000:1999 Standard, made of woven CT 714® aramide fibres were combined with several-ply liner SRM® have been also tested. The hit energy of 45 J was achieved for such an arrangement while providing the maximum depth of penetration as low as 4 mm (Fig.1) which means class 3 according to the procedure ITWW „MORATEX" PBB – 06:1996.

In order to gain resistance within class 1 of knife-proofness according to procedure ITB „MORATEX" PBB – 08:2006. the optimisation research has been done, which allowed for determining the number of plies in the SRM® liner for each sample made of various ballistic materials.

In the course of tests with P1, S1 edge and the stab and applied energy of 24 ± 0,50 J the maximum observed depth of penetration was 17 mm, which does not exceed the limit of 20 mm defined by the procedure. Applying the liner made of SRM® increases the vest's mass by about 1 kg.

The results discussed above have been gained on a basis of flexible textile materials, known at he turn of 2008/2009, further improvement of personal armour's resistance to knife is currently being achieved by applying steel chain mails.

5.2 Needle-proof covers

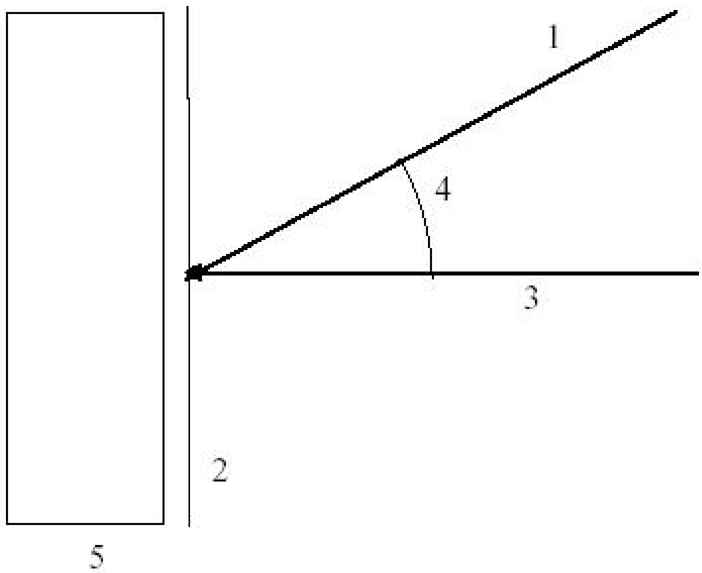
Gaining the resistance to needle is a separate problem.

In the correctional institutions a needle is a big threat, especially in the age of AIDS. The knife-, needle-, and bullet-proof covers are demanded, as well as just needle-proof ones.

World-wide known Standards do not cover the matter, therefore „MORATEX" Institute has elaborated innovative testing procedure, of extra-regional range - PBB-12:2008 Impacting tests. Determining the resistance to piercing with needle.

Table 5. List of conditions of testing the objects

Protection level	Kind of needle	Energy of impact [J]	Mass of carriage [kg]	Number of hits at the angle of 0°
1	- 21 G (0,8mm x 40mm)	2,5 ± 0,1	2,50 ± 0,5 kg	6 (3 on each needle)
2	- 18 G (1,2 mm x 40 mm)	25,0 ± 0,5		



The legend of figure:
1. the line of needle falling
2. the tangent surface
3. the perpendicular to tangent surface
4. the angle of hit
5. the tested sample

Fig. 2 Schematic sketch of angle of hitting a sample with an edge

The tests of needle-proofness executed with the energy of 25+0.5 J allow for the statements:

- only the ballistic insert made of Dyneema® compliant to class 3 of ballistic resistance according to PN-V-87000:1999 is resistant to needles and achieves class 2 of needle-proofness according to the procedure PBB -12:2008,
- for ballistic inserts resistant within class 3 according to PN-V-87000:1999, made of GoldFlex® aramide fibres woven or non-woven, to achieve the class 2 of needle-proofness according to procedure PBB-12, application of several-ply liner of SRM® is necessary,
- several-ply liner of SRM® applied into the ballistic cover of class 3 according to PN-V-87000:1999 makes them knife-proof respectively within class 2 and 3 according to procedure PBB–06 or knife-proofness within class 1 according to procedure PBB-08 and provides also needle-proofness at the hit energy of 25+0.5 J, while achieving class 2 of needle-proofness according to procedure PBB-12:2008 regardless of arrangement together with the ballistic insert or separate,
- applying a several-ply SRM® liner allows for achieving the class 2 of needle-proofness according to the procedure PBB-12 for each ballistic material, no matter which class according to PN-V-87000:1999.

6. SUMMARY

The article presents possibilities of designing various kinds of armour based on world-wide known flexible textile materials.

The following kinds of protection was discussed;

- ballistic,
- ballistic and knife-proof,
- ballistic, knife-proof and needle-proof,
- needle-proof ones.

7. SOURCES

The text makes use of reports of tests executed at the accredited ballistic laboratory of „MORATEX" Institute, which have been in-depth analyzed and discussed in the works done within a frame of statutory activity, entitled „Developing new commercial solutions of design, material and technology for new products of special dedication" – Institute of Security Technology „MORATEX", 2008.

Literature

1. *NIJ STANDARD 0101.04 Ballistic Resistance of Personal Body Armor.*
2. *NIJ STANDARD 0115.00 Stab Resistance of Personal Body Armor.*
3. *PN-V-87000:1999 Ballistic covers. Bullet- and fragment-proof vests. General requirements and tests.*
4. *Procedure ITWW „MORATEX" PBB-06:1996 Impacting tests. Determining the resistance of set of samples to piercing with cold steel.*
5. *Procedure ITB „MORATEX" PBB-08:2006 Impacting tests. Determining the resistance of personal armour to an edge – procedure compliant with NIJ STANDARD 0115.00.*
6. *Procedure ITB „MORATEX PBB-12:2008 Impacting tests. Determining the resistance to piercing with needle.*

Bullet – Proof Vests with the Ballistic Inserts Based on the Fibrous Composites

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The Institute of Security Technology "Moratex"

INNOVATIVE ECONOMY NATIONAL COHESION STRATEGY

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Key Project No. POIG 01.03.01-10-005/08 entitled: „Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".

Introduction

The Institute of Security Technology „MORATEX" for more than 15 years works the solutions of scientific and research matters as well as design and technology of individual ballistic armour, including torso armour. The Institute has developed a line of protective vests designs, within the frame of research projects as well as scientific and research works of the statutory activity, They were tested in the Institute's laboratories (metrological and ballistic one) accredited by Polish Centre for Accreditation. A big group of those designs are bullet-proof vests featuring enhanced ballistic resistance within the area of hard inserts based on the fibrous composites. A creative idea was behind virtually every aspect of the developed ballistic armour for torso excluding composite bullet-proof panels, which aren't manufactured in Poland yet. However it is necessary to emphasize, that the „MORATEX" Institute has a batch of test-experience of the design of composite ballistic products [1 - 2], including the panels for bullet-proof vests [2]. Thanks to that, among others, it is possible to continue the works within started project No.POIG.01.03.01-10-005/08 "Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites", where the composite inserts for vests with selected vest designs are one of the developed products' groups. The above-mentioned project is carried out in Priority Axe 1: Research and developing of modern technologies, 1.3 Activity: Supporting the R&D Projects dedicated to enterprises, accomplished by scientific bodies, 1.3.1 Sub-activity: Development Projects.

1. Recently developed bullet-proof vests with ballistic panels based on fibrous composites

In 2008 some modern solutions of bullet-proof vest designs have been developed and made-up at the „MORATEX" Institute, with ballistic inserts based on imported fibrous composites, which feature improved ballistic resistance within the area of such insert [3,4]. They consider latest worldwide trends of designing such products, and are dedicated mainly for officers of special services of Ministry of Interior and Administration as well as for various military units. Present article will present and discuss three kinds of vests, namely:

- bullet-proof vest featuring improved ballistic resistance „WARRIOR" (fig. 1),
- overt bullet-proof vest for special forces „FIGHTER" (fig. 2),
- special overt bullet-proof vest (fig. 3).

1.1 Basic materials and elements

The following materials and elements have been applied into all of the discussed vests:

- for external covering – Polyamide fabric, coated with PU, olive-green and locally-manufactured, green technical bands,
- for internal lining, to improve product wearing comfort – a 3D-material – polyester 3D distance--mesh,
- for soft ballistic inserts – sheets of thermoplastic foil reinforced with para-aramide fibres
- for the covering of ballistic inserts – watertight vapour-permeable material,
- additional component for reduction of dynamic deflection (trauma) upon bullet hit – anti-trauma polycarbonate plate,
- extra inserts to improve vest's ballistic resistance locally – imported lightweight polyethylene composite panels.

Applying modern materials for covering, anti-trauma and distance as well as the lightweight composite bullet-proof panels (instead of steel ones) for local increasing the ballistic resistance, into the design of discussed bullet-proof vests (fig. 1. – 3.), was aimed to improving their usability features, including comfort and ergonomics, plus providing maximum safety possible.

1.1.1 The results of basic materials' tests

The laboratory tests of basic materials have been completed at the accredited Metrology Laboratory of

Fig. 1. Bullet-proof vest featuring improved ballistic resistance „WARRIOR" [3]

Fig. 2. Overt bullet-proof vest for special forces „FIGHTER" [3]

Fig. 3. Special overt bullet-proof vest [3]

the „MORATEX" Institute in Lodz.

On the basis of completed metrological tests one can say, that the basic materials applied into bullet-proof vests (fig. 1 - 3) feature physical and mechanical properties of a approved level. Textile materials – ballistic one for the soft inserts and outer covering feature high values of tensile and tear strength. Favourable results of the tests were the base for making-up the presented bullet-proof vests of planned ballistic resistance, which was verified by completing appropriate tests.

1.2 Ballistic resistance of the vests and their basic design.

Planned ballistic resistance of the bullet-proof vest featuring improved ballistic resistance „WARRIOR" (fig. 1) is:

- within the area of soft ballistic inserts at front, at back and at the abdomen protector it should protect against 7.62 mm bullet at the hit velocity of 420^{+15} m/s shot from Tokarev pistol, model 33 TT – the 3rd class of the bulletproofness according to PN-V-87000:1999 Standard, as well as against 9 mm FMJ bullets and 0.44" Magnum bullets as for level IIIA of NIJ Standard 0101.04,
- within the area of ballistic extra insert – lightweight PE composite panel placed in the front pocket it should protect against 7.62 mm steel core PS bullets at the hit velocity of 710^{+20} m/s shot from 7.62 mm Kalashnikov AKM rifle – the 4th class of the bulletproofness according to PN-V-87000:1999 Standard.

The design of vest should provide protection to user in a following manner: at front – from midriff up to shoulders, also the abdomen, having the abdomen protector attached as well as at back – from kidneys up to the shoulders inclusively. It has been built of two separate parts – front and back plus the detachable abdomen protector which is ready to be alternatively attached to the front part of vest. The vest is designed to be fastened on shoulders and sides with velcro tapes.

Planned ballistic resistance of the overt bullet-proof vest for special forces „FIGHTER" (fig. 2) and special overt bullet-proof vest (fig. 3), are:

- within the area of soft ballistic inserts at front, at back and at the abdomen protector it should protect against 7.62 mm bullet at the hit velocity of 420^{+15} m/s, shot from Tokarev pistol model 33 TT – the 3rd class of the bulletproofness according to PN-V-87000:1999 Standard,
- within the area of ballistic extra insert – lightweight PE composite panel placed in the front pocket of special design it protect against 7.62 mm steel core PS bullets at the hit velocity of 710^{+20} m/s, shot from 7.62 mm Kalashnikov AKM rifle – the 4th class of the bulletproofness according to PN-V-87000:1999 Standard.

The fronts' length of both vests – down to the midriff shall provide usage comfort when sitting. The abdomen protector is attached to the front part of vest (fig. 2), contrary to the other vest (fig. 3) which has the abdomen protector fastened permanently to its front part. However the protector might get turned up and fastened to the inner side of each vest's front part. The product (fig. 2) has several pockets dedicated for special equipment.

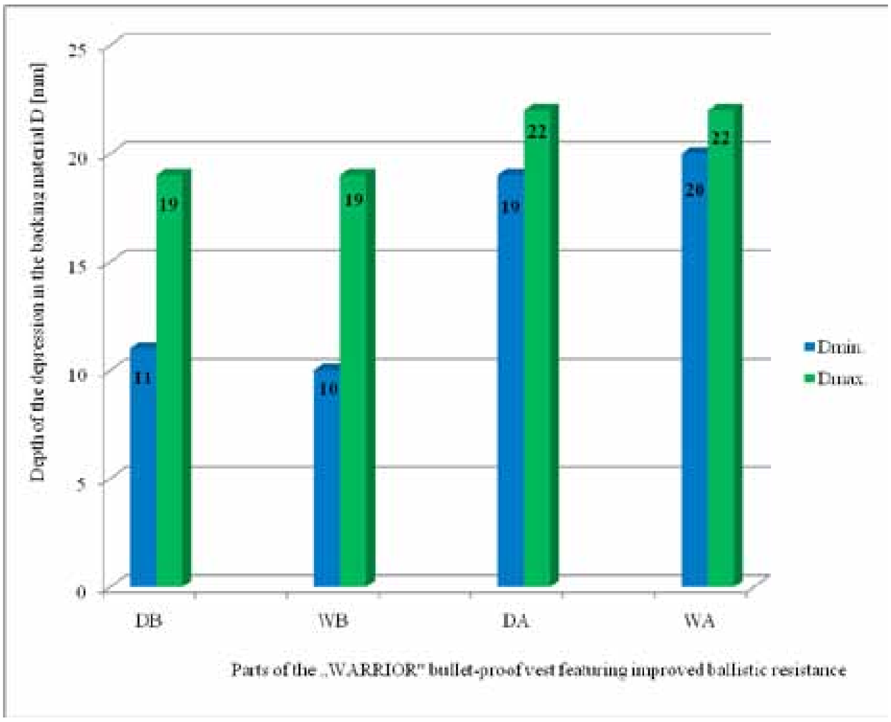
The vests above feature some common properties, namely:

- rescue handles which ease evacuation, fixed to the top of vests' back parts,
- horizontally stitched parallel straps on the external parts of vests' cover for preferred location of add-on pockets for equipment necessary under various battle and climatic conditions, ie. water container on desert, extra clips etc.,
- internal parts of covering made of polyester distance 3D-mesh,
- usefulness in various climatic zones within the temperature range of -40°C up to +50°C.

1.2.1. Tests of ballistic resistance of vests

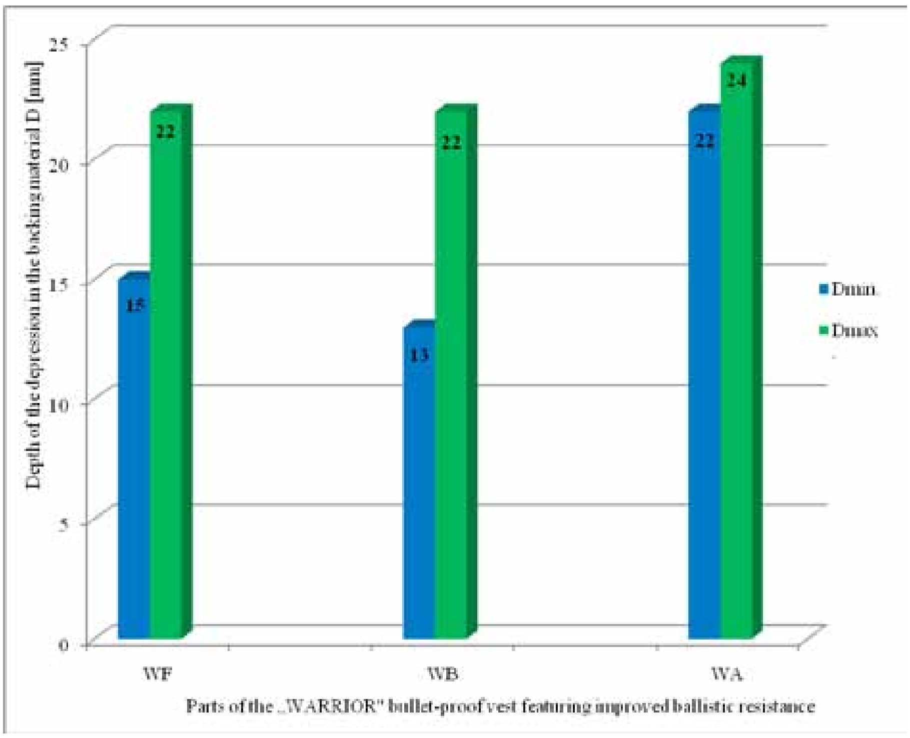
The lab tests of the ballistic resistance of the bullet-proof vests have been completed at the accredited Ballistics Laboratory of the „MORATEX" Institute. The results are presented as charts on the following figures:

- fig. 4 - 7 for the bullet-proof vest featuring improved ballistic resistance „WARRIOR",
- fig. 8 - 9 for the overt bullet-proof vest for special forces „FIGHTER",
- fig. 10 - 11 special overt bullet-proof vest.



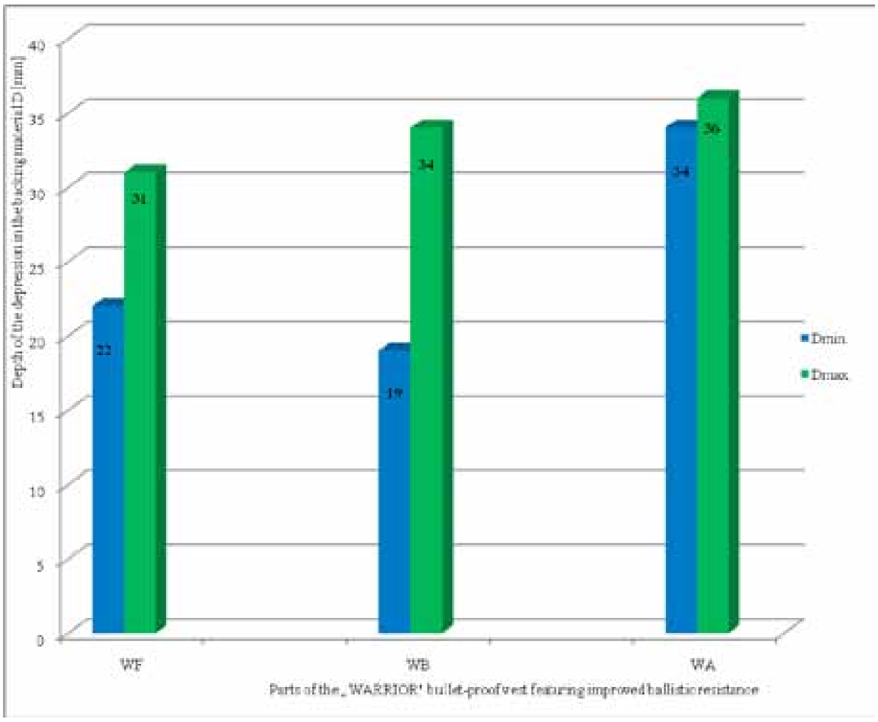
Legend: DB – dry back part, WB – wet conditioned back part, DA – dry abdomen protector, WA – wet conditioned abdomen protector

Fig.4. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the vest featuring improved ballistic resistance „WARRIOR"– shooting with lead core 7.62 mm bullets at the hit velocity of 420+15 m/s shot from Tokarev pistol 33 TT – the 3rd class of bulletproofness according to PN-V-87000:1999 Standard



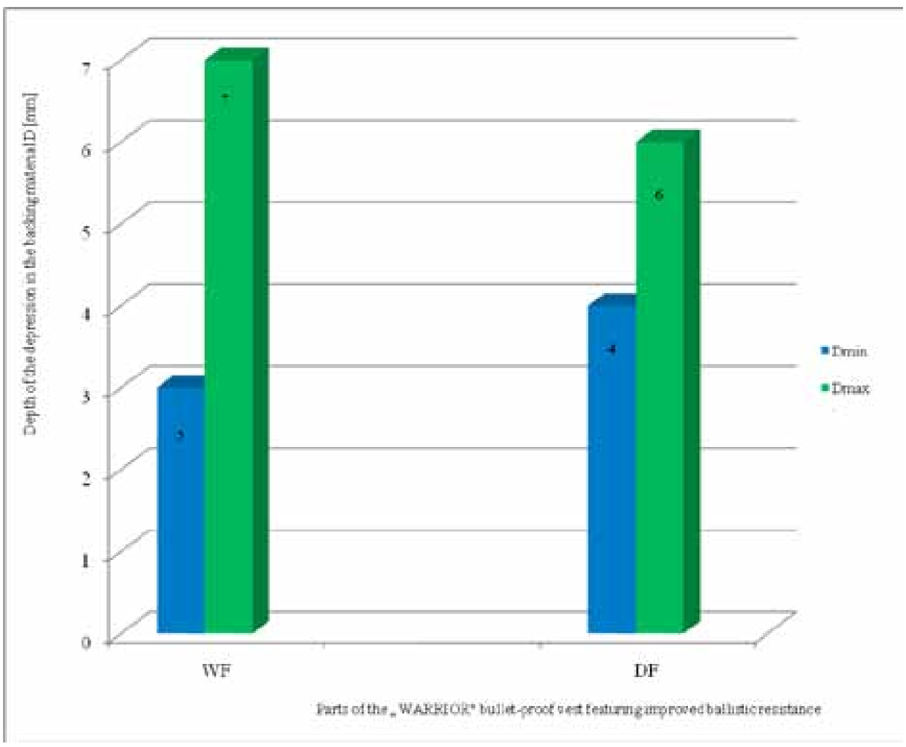
Legend: WF – wet conditioned front part, WB – wet conditioned back part, WA – wet conditioned abdomen protector

Fig. 5. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the vest featuring improved ballistic resistance „WARRIOR"– shooting with 9 mm FMJ bullets of the level III A of bulletproofness according to NIJ Standard 0101.04. Test method according to the PN-V-87000:1999 Standard



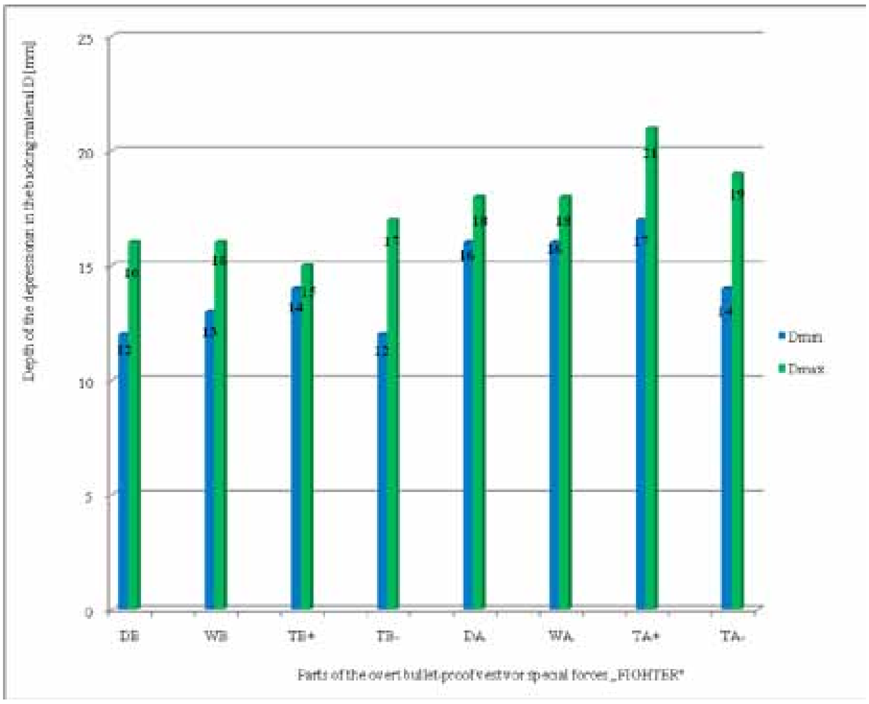
Legend: WF – wet conditioned front part, WB – wet conditioned back part,
WA – wet conditioned abdomen protector sprinkled

Fig. 6. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the vest featuring improved ballistic resistance „WARRIOR"– shooting with 0.44 in. Magnum bullets of the level III A of bulletproofness according to NIJ Standard 0101.04. Test method according to PN-V-87000:1999 Standard



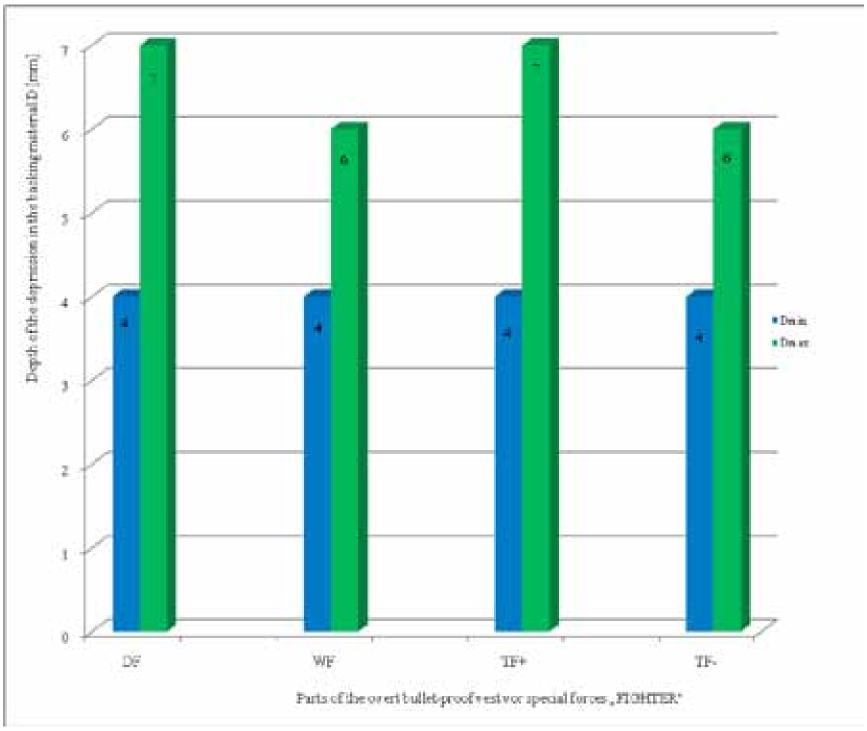
Legend: WF – wet conditioned front part , DF – dry front part

Fig. 7. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of front parts of the vest featuring improved ballistic resistance „WARRIOR" within the area of extra ballistic inserts – the lightweight PE composite panels – steel core 7.62 mm PS bullets at the hit velocity of 710+20 m/s shot from 7.62 mm AKM rifle – the 4th class of bulletproofness according to PN-V-87000:1999 Standard



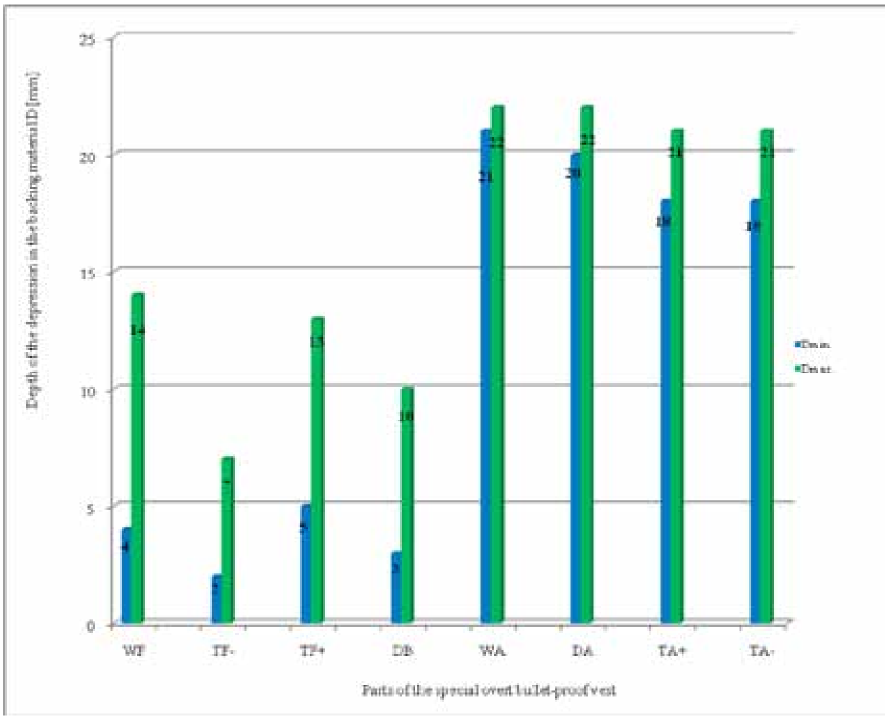
Legend: DB – dry back part, WB – wet conditioned back part, TB+ - back part stabilized thermally at +500C, TB- - back part stabilized thermally at -400C, DA – dry abdomen protector, WA – wet conditioned abdomen protector, TA+ - abdomen protector stabilized thermally at +500C, TA- abdomen protector stabilized thermally at -400C

Fig. 8. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the overt bullet-proof vest for special forces „FIGHTER" – lead core 7.62 mm bullets at the hit velocity of 420+15 m/s shot from Tokarev pistol 33 TT – the 3rd class of bulletproofness according to PN-V-87000:1999 Standard



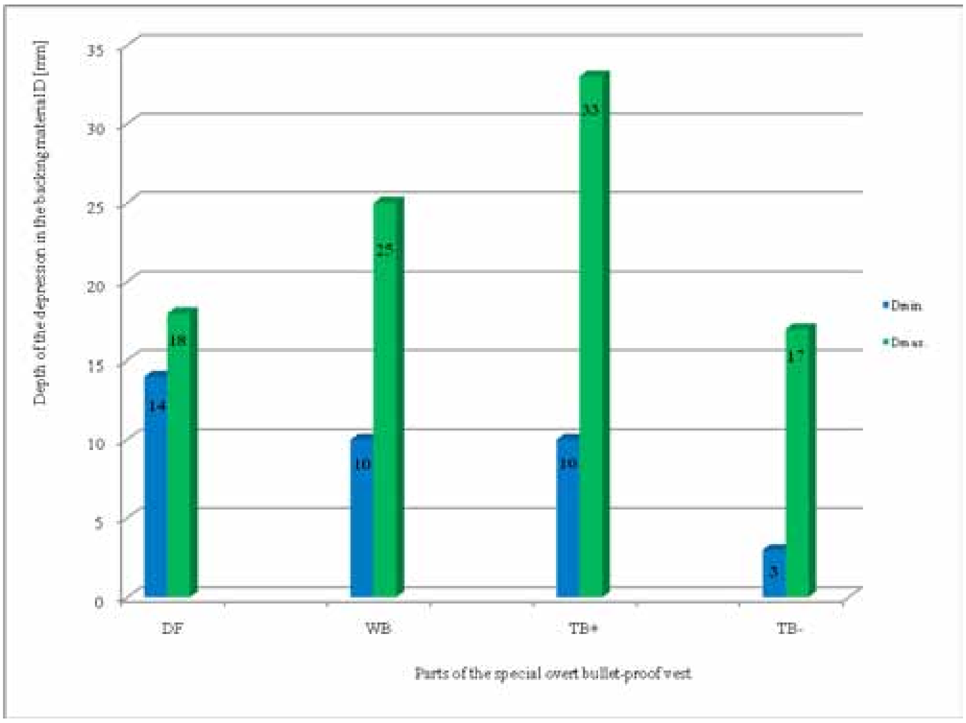
Legend: DF – dry front part, WF – wet conditioned front part, TF+ – front part stabilized thermally at +500C, TF- – front part stabilized thermally at -400C

Fig. 9. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the overt bullet-proof vest for special forces „FIGHTER" – steel core 7.62 mm PS bullets at the hit velocity of 710+20 m/s shot from 7.62 mm AKM rifle – the 4th class of bulletproofness according to PN-V-87000:1999 Standard



Legend: WF – wet conditioned front part, TF- – front part thermally stabilized at -400C, TF+ – front part stabilized thermally at +500C, DB – dry back part, WA – wet conditioned abdomen protector, DA – dry abdomen protector, TA+ – abdomen protector stabilized thermally at +500C, TA- - abdomen protector stabilized thermally at -400C

Fig. 10. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the special overt bullet-proof vest – lead core 7.62 mm bullets at the hit velocity of 420+15 m/s shot from Tokarev pistol 33 TT – the 3rd class of bulletproofness according to PN-V-87000:1999 Standard



Legend: DF - dry front part, WB - wet conditioned back part, TB+ - back part stabilized thermally at +500C, TB- - back part stabilized thermally at 400C

Fig. 11. Depth of the depression in the backing material (minimum and maximum) during tests of bulletproofness of particular parts of the special overt bullet-proof vest – steel core 7.62 mm PS bullets at the hit velocity of 710+20 m/s shot from 7.62 mm AKM rifle – the 4th class of bulletproofness according to PN-V-87000:1999 Standard [10]

1.2.2. Discussion on the results of ballistic resistance tests

The completed tests of the vests' bulletproofness lead to conclusions:

- none of the vests underwent piercing by the bullets for which the ballistic resistance has been assumed;
- for some of the „WARRIOR" bullet-proof vest featuring improved ballistic resistance the following maximum depth of the depression in the backing material have been observed while shooting with certain kinds of bullets (fig. 4 -7):
  - 19 mm (back parts) and 22 mm (abdomen protector) – lead core 7.62 mm bullets at the hit velocity of 420^{+15} m/s shot from Tokarev pistol 33 TT – class 3 of bulletproofness according to PN-V-87000:1999 Standard. The depth of depression of tested parts of vests has been reduced within a range of 45 - 52.5% of acceptable deformation of 40 mm according to the standard;
  - 22 mm (front and back parts) and 24 mm (abdomen protector) - 9 mm FMJ bullets of the level III A of bulletproofness according to the NIJ Standard 0101.04. Method of testing according to PN-V-87000:1999 Standard. The depth of deformation of tested parts of vests has been reduced within a range of 40÷45 % of acceptable deformation of 40 mm according to the PN-V-87000:1999 Standard;
  - 31 mm (front part), 34 mm (back part) and 36 mm (abdomen protector) - 0.44" Magnum bullets of the level III A of bulletproofness according to the NIJ Standard 0101.04. Method of testing according to the PN-V-87000:1999 Standard. The depth of deformation of tested parts of vests has been reduced within a range of 10÷22.5 % of acceptable deformation of 40 mm according to the PN-V-87000:1999 Standard;
  - 6 mm and 7 mm (within the area of bulletproof plates of front parts) – steel core 7.62 mm PS bullets at the hit velocity of 710^{+20} m/s shot from 7.62 mm AKM rifle within the area of extra ballistic inserts – the 4th class of bulletproofness according to the PN-V-87000:1999 Standard. The depth of deformation of tested parts of vests has been reduced within a range of 82.5÷85.0 % of acceptable deformation of 40 mm according to Standard;
- for some of the „FIGHTER" overt bullet-proof vests for special forces, the following maximum depth of depression in test material have been observed while shooting with certain kinds of bullets (fig. 8÷9) [9]:
  - 15 mm, 16 mm, 17 mm (back parts) and 18 mm, 19 mm, 21 mm (abdomen protectors) – lead core 7.62 mm bullets at the hit velocity of 420^{+15} m/s shot from Tokarev gun model 33 TT – the 3rd class of bulletproofness according to PN-V-87000:1999. The depth of deformation of tested parts of vests has been reduced within a range of 47.5÷62.5 % of acceptable deformation of 40 mm according to Standard;
  - 6 mm and 7 mm (within the bullet-proof panels of the front parts) – steel core 7.62 mm PS bullets at the hit velocity of 710^{+20} m/s shot from 7.62 mm AKM rifle within the area of extra ballistic inserts – class 4 of bulletproofness according to the PN-V-87000:1999 Standard. The depth of deformation of tested parts of vests has been reduced within a range of 82.5÷85.0 % of acceptable deformation of 40 mm according to Standard.
- for some of the special overt bullet-proof vests, the following maximum depth of depression in test base have been observed while shooting with certain kinds of bullets (fig. 10÷11) [10]:
  - 14 mm, 13 mm, 10 mm (front and back parts) and 22 mm, 21 mm (abdomen protectors) – lead core 7.62 mm bullets at the hit velocity of 420^{+15} m/s shot from Tokarev pistol model 33 TT – the 3rd class of bulletproofness according to PN-V-87000:1999. The depth of deformation of tested parts of vests has been reduced within a range of 45.0÷70.0 % of acceptable deformation of 40 mm according to Standard;
  - 18 mm, 25 mm, 33 mm and 17 mm (within the bullet-proof panels of the front and back parts) – steel core 7.62 mm PS bullets at the hit velocity of 710^{+20} m/s shot from 7.62 mm AKM rifle, within the area of extra ballistic inserts – the 4th class of bulletproofness according to the PN-V-87000:1999. The depth of deformation of tested parts of vests has been reduced within a range of 17.5÷57.5 % of acceptable deformation of 40 mm according to Standard.

2. Initial and general assumptions for developing Polish designs of inserts based on the fibrous composites.

The lab tests' results shown in section. 1.2.2. of the paper regard three designs of the bullet-proof vests recently developed by „MORATEX" Institute.

They incorporate ballistic inserts based on fibrous composites as the lightweight PE panels, The results are favourable for all presumed kinds of bullets for all particular parts of the vests concerning both lack of piercing and remarkable reduction of base deformation related to their magnitude required by PN-V-87000:1999 Standard. This special kind of inserts, i.e. lightweight and highly-resistant in terms of ballistics shall become a basis for comparative analysis with Polish designs of inserts (panels) dedicated for bullet- and fragment-proof vests under development within the frame of No.POIG.01.03.01-10-005/08 project „Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".

General presumption says, that the inserts for the bullet- and fragment-proof vests are developed as made mainly of the fibrous composites, and in special cases – of the fibrous composites joined with ballistic parts of ceramics The inserts shall be made as several variants of bullet- and fragment-proof panels of initially presumed nominal size of 250 x 300 mm and within their area shall together with or without vests protect upper part of wearer's torso – chest and back against certain kinds of bullets and fragments. The forms of front and back inserts shall be suitably shaped in order to provide usage comfort.

The plan includes providing the ballistic resistance of inserts, i.a. against:

- 7.62 mm 7.9 g lead core PS bullets at the hit velocity of 710^{+20} m/s – the 4th class of bulletproofness according to PN-V-87000:1999,
- 7.62 mm 9.6 g NATO FMJ bullets at the hit velocity of $847^{\pm 9}$ m/s – level III of bulletproofness according to NIJ Standard – 0101.04,
- standard fragments 1.102±0.02 g for V_{50} ballistic protection of:
  - 600 m/s $\leq V_{50} <$ 675 m/s – class 3 of fragmentproofness according to PN-V-87000:1999 Standard,
  - alternatively 675 m/s $\leq V_{50} <$ 750 m/s – the 4th class of fragmentproofness according to PN-V-87000:1999 Standard.

The details of materials, designs and technologies suggested for applying into manufacture of the insert models for bullet- and fragment-proof vests have been included to elaborated „Presumptions concerning materials and design as well as engineering and technology". They currently are the subject of further analysis conformably to the planned schedule of the development project mentioned above.

Within the frame of current project the research will be also carried out on mechanical properties of ballistic composites, including i.e.: tensile and compression strength, resistance to bending, stratification, resilience, etc.

Moreover the ergonomic and psychological assay with individuals or manikins featuring human body functionalities will be made with the recently developed designs of bullet- and fragments-proof vests with the inserts based on textile composites. It will allow for determining the vests comfort usage as well as enrich the knowledge on psychical, physiological, including psychomotor reactions of officers of the services subordinated to the Ministry of Interior and Administration, who use their vests during actions. The above-mentioned research in range of occupational medicine shall contribute to more proper designing the bullet- and fragments-proof vests, which is directly linked with their usability and security. The latter aspect is before all tied with planned ballistic behaviour, which should be invariable within period defined by designer and determined properties of applied materials. Yet the usability includes before all the vest's usage comfort. Admittedly the PN-V-87000:1999 Standard [5] includes the requirements regarding ergonomic properties of the vests, as their functionality of rapid putting on and adjusting to the wearer's body, no obstruction to the wearer's activities anticipated, accessibility and ease of using the pockets and latches designed for carrying and fixing the equipment - dry and within the temperature range from -20^0C up to $+35^0$C. However defines neither testing methods nor any way of assessing the properties. It also assumes no necessity of executing the assessment of the effect of the vest parameters (i.a. design, weight, type of applied materials, etc.) on the usage comfort and psycho -physical abilities of the users.

So, the risk analysis of the potential hazards arising from usage will be important tool for designing of the bullet- and fragments-proof vests. The assessment of psycho-physical abilities including psychomotor ones, of the wearers during long-time usage of mentioned vests will be immensely important, beside the matters related to providing suitable protection effectiveness.

The analysis of potential hazards regarding the comfort of using the bullet- and fragments-proof vests as well as the expected effect resulting from the existence of hazard are presented in the Table 5.

Item no.	Potential hazard regarding usage comfort	Weight of hazard 1 - Minimal risk; 10 – Maximal risk of hazard arising;	Probable result
1.	Weight of product too high	10	a) No possibility of prolonged usage; b) Reduction in the psychomotor efficiency; c) Obstructed concentration; d) Reduced perception; e) Extended time of reaction on the external impulse or external factors; f) Reduced ability to interoperate with a team.
2.	Lack of movement freedom	8	a) Annoyance; b) Extended time of reaction on external impulse or factors; c) Reduction in the psychomotor efficiency; d) Reduction in the operational efficiency; e) Obstructed concentration; f) Armor taken-off often - no ballistic protection.
3.	Feeling of discomfort during normal usage (running, lying, sitting in the car, climbing upstairs and downstairs, crawling, etc.)	5	a) Annoyance; b) Extended time of reaction on impulses or external factors; c) Reduction in the operational efficiency; d) Obstructed concentration.
4.	Un-ergonomic design of additions (pockets, etc.)	5	a) Reduction in the operational efficiency; b) Obstructed concentration; c) No possibility of prolonged usage; d) Reduced ability to interoperate with a team.
5.	Making up of physically irritating materials (i.e. ballistic plates too stiff)	4	a) Reduction in the operational efficiency; b) Obstructed concentration; c) Reduced perception; d) No possibility of prolonged usage; e) Reduced ability in the interoperate with a team f) Temporary lack of ballistic protection.
6.	Applied materials featuring insulation properties	4	a) Annoyance; b) Extended time of reaction on external impulse and factors; c) Reduction in the psychomotor efficiency; d) Reduction in the operational efficiency; e) Obstructed concentration; f) Armour taken-off often - no ballistic protection; g) Excessive sweating during usage under raised temperatures.

7.	Applied materials of variable depending on the temperature and/or humidity	4	a) Annoyance; b) Extended time of reaction to external impulses or factors; c) Reduction of psychomotor efficiency; d) Reduction of operational efficiency; e) Obstructed concentration; f) Lack or deterioration of ballistic protection; g) No possibility of prolonged usage.
8.	Misfit (static/dynamic) to the users silhouette	3	a) No possibility of prolonged usage; b) Reduction of psychomotor efficiency; c) Obstructed concentration; d) Extended time of reaction on the external impulses or factors; e) Reduced ability to interoperate with a team.

Table 5. The analysis of potential hazards regarding the comfort of using the bullet- and fragments-proof vests

Summary

Three recently developed designs for bullet-proof vests from „MORATEX" Institute ie. „WARRIOR" - bullet-proof vest featuring improved ballistic resistance; „FIGHTER" - overt bullet-proof vest for special forces, and special overt bullet-proof vest, which are currently in use among end-users.

In order to enhance their usability advantages, including comfort and ergonomics and to provide maximum available security, the modern materials are applied into the bulletproof vests, including: covering, anti-deflection and distance as well as lightweight fibrous composite bullet-proof panels (instead of steel ones).

The verification results of metrological tests prove their physical and mechanical properties, including especially draw strength and tear strength of materials applied into making-up the vests.

All the „MORATEX" Instiute's recently-developed bullet-proof vests with ballistic inserts based on fibrous composites, where lightweight PE panels are applied, the favourable results of ballistic resistance have been gained regarding both lack of piercing and remarkable reduction of depth of depression of backing material in relation to the magnitude required by the PN-V-87000:1999 Standard.

The lightweight inserts applied to the vests, that feature high ballistic resistance themselves, shall be the basis for comparative analysis with Polish designs of inserts (panels) dedicated for bullet- and fragment-proof vests under development within the frame of POIG project No.01.03.01-10-005/08 „Modern ballistic body armours and covers for transportation means as well as for buildings made on a basis of textile composites".

The modern designs of composite ballistic inserts developed during presented project will be subject with the recently-developed vests to multi-directional tests, including ballistic behaviour and usage comfort. This shall allow for assessment of not only protection efficiency, but also the ergonomics together with estimation of psycho-physical and psychomotor abilities of the wearers during long-time using of such a product.

Bibliography

1. *Research project No. 0T 00A 013 12 „Research on developing the composite armours". ITWW „MORATEX", Lodz 2000.*
2. *Research project No. 3 T09B 132 10 „Polymers and metal composites designed for individual ballistic armour", ITWW „MORATEX", Lodz 1998.*
3. *Report of executing the research No. 08.023.02.00.90. Developing new solutions of design, material and technology for new products of special purpose. ITB „MORATEX" , Lodz, 2008.*
4. *Grabowska G., Polak J., Błaszczyk J.: „Proposals of modernisation of bullet-proof vests currently in use". TWW, Lodz, 2008, nr 3-4.*
5. *PN-V-87000:1999 Standard Light ballistic armours – Ballistic protection vests – General requirements and tests.*

Modeling of the Shock Wave Impact on the Flexible Shell

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Introduction

The underwater explosion and its effects on the floating structure represent a matter of considerable interest for researchers. The sequence of events associated to an underwater explosion of a typical military explosive in their order of occurrence can be summarized as [1]:

- detonation,
- shock wave propagation,
- motion of the gas bubble.

Chemical reaction of the mass occurring during the explosion results in a perturbation of the surrounding water (shock wave) and the creation of a gas bubble. Designers should realistically estimate the possible damage condition to effectively design a floating structure resistant to any various underwater weapons.

The main aim of the performed work was to simulate the behavior of flexible shell under wave impact. The non-linear simulation was also performed for the example structure affected by the underwater explosion. The results were compared with behavior of floating shell in ordinary exploitation.

The numerical part of current work was based on non-linear, explicit, dynamic, finite element analysis (FEA) using the LS-DYNA computer code. This so-called hydrocode is used for the purpose of a wide variety of analyses, including airbag and water dynamics or to estimate exploitation loading.

The preliminary analysis of a new ballistic protection system is demonstrated in the paper,.

Problem statement

A new structure of a floating bridge was developed. The floating bridges consist of a continuous metal roadway leaned on the floats or pontoons. Pneumatic floats are airtight compartments made of a rubberized fabric inflated with the air.

The FE model of the floating bridge (see Figure 1) used for the preliminary analysis included a frame/cassette in which the folded, empty flexible composite shell was mounted. Pair of doors was attached to the frame with revolute joints. These elements reflected hinges placed in the actual object. The shell included three different components – upper and lower envelopes as well as additional webs located inside the shell. They reinforced the structure of the fully opened shell and made its shape more compact. The selected configurations during filling the floating bridge are presented in Figure 2.

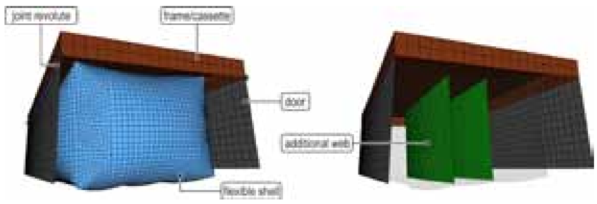

Figure 1. The single segment of the floating bridge – the flexible shell filled with air

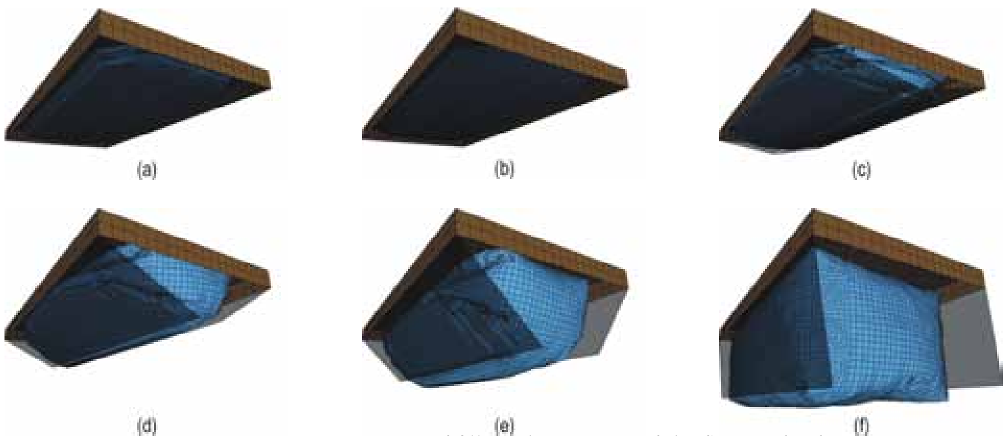

Figure 2. Successive stages of filling the pontoon of the floating bridge

FE modeling and analysis

The FE models of the float bridge were developed base on Altair HyperMesh software, whereas the LS -Prepost program was a preprocessor for defining all necessary parameters such as boundary conditions, element properties, material properties, solution type, and many others. Complete FE models were exported as a key files with the LS-DYNA preferences. In order to prescribe behavior of the selected materials (e.g. water, HE charge) as well as the complete structures (e.g. airbags) equations of state were used. Each equation defines the state by different variables. The coefficient for each equation come from data-fitting, phenomenological descriptions, or derivations based on classical thermodynamics [3, 4].

Presented FE model consist of about 12,000 shell elements used for the frame/cassette, door and the float modeling. About 180,000 solid elements were applied for the water FE model. The float shell was modeled with use of the Belytschko-Tsay membrane element with 2 integration points through the element thickness. These elements are based on a combined co-rotational and velocity-strain formulation. The fabric elastic - perfectly plastic material model was applied for the purpose of shell modeling. Properties of the fiber are presented in Table 1. Since, the reference configuration of the flexible shell is taken as the folded configuration the geometrical accuracy of the deployed shell will be affected by both the stretching and the compression of elements during the folding process. The elastic float was attached to the rigid frame with an extra nodes set. Nodes for the surface type of contact was applied to describe an interaction between the flexible shell and other components of the floating bridge and the water as well.

Two different types of airbag model were selected depending on the considered case. The airbag models allow to describe the behavior of the gas flow into the volume as well as the closed volume already inflated with gas [3, 4].

Simple airbag model was used in analysis of the inflating shell. In this case a curve describing the input mass flow rate had to be determined and declared in the model. Proposed curve is depicted in Figure 3.

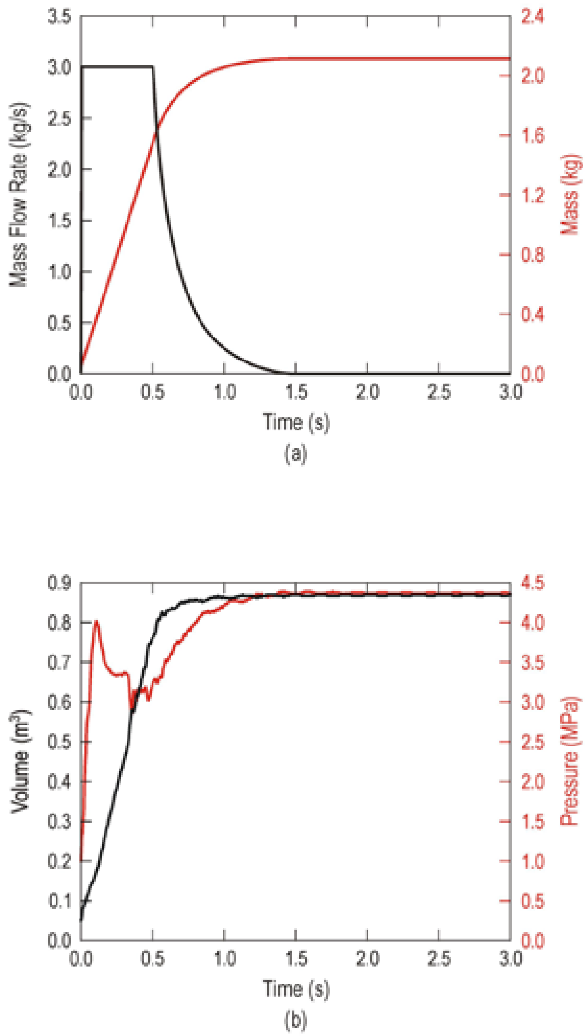

Figure 3. The input mass flow rate curve for the simple airbag model (a) and selected results (b)

Table 1. Properties of the fiber applied in the LS-Dyna fabric material model [5]

Young's moduluses (GPa)			Poisson's ratios			Shear moduluses (GPa)		
E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	v_{12} (–)	v_{23} (–)	v_{13} (–)	G_{12} (GPa)	G_{23} (GPa)	G_{31} (GPa)
24.1	24.1	10.4	0.12	0.12	0.12	5.9	5.9	5.9

For the second case—a fully inflated float—simple pressure volume airbag model was applied. A constant value of the pressure inside the float was declared on the basis of the final results taken from the first case.

All water was simulated by the solid element with one point integration. The Gruneisen equation of state with cubic shock velocity vs. particle velocity relation was used to describe the internal characteristic of water. This below equation defines pressure for compressed materials [3]

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu+1} - S_3 \frac{\mu^3}{(\mu+1)^2}\right]^2} + (\gamma_0 + a\mu)E \qquad (1)$$

and for expanded materials

$$p = \rho_0 C^2 \mu + (\gamma_0 + a\mu)E \qquad (2)$$

where C is the intercept of the u_s–u_p curve; S_1, S_2, S_3 are the coefficients of the slope of the u_s–u_p curve; γ_0 is the Gruneisen gamma; α in the first order volume correction to γ_0; and $\mu = (\rho / \rho_0) - 1$.

Necessary parameters declared in the Gruneisen equation of state are provided in Table 2.

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} \qquad (3)$$

The detonation of the high explosive under water was modeled. The Jones Wilkins Lee equation of state is defined as an exponential function form given by:

where V is the initial relative volume; E is the internal energy per unit volume; A, B, $R1$, $R2$, and ω are material constants obtained from the experiments.

Material constants in the JWL equation for the TNT (Trinitrotoluene) applied in current model are provided in Table 3.

The variation of pressure for the blast wave propagating in the water FE model are presented in Figure 4. The graphs based on values of the pressure in selected elements along the vertical line initiated in the center of the HE charge, are depicted in Figure 5. The outline of the contours presented in the figure is not exactly circular due to FE water model mesh shape. However, obtained results are thoroughly satisfying.

Table 2. Parameters applied in the Gruneisen equation of state for the water FE model [2]

Mass density	Intercept of the u_s–u_p curve	Gruneisen coefficients			Gruneisen gamma
ρ (kg/mm³)	C (mm/ms)	S_1 (–)	S_2 (–)	S_3 (–)	γ_0 (–)
	2417	1.41	—	—	1

Table 3. Material properties of the TNT used for the HE material model [2]

Mass density	Detonation velocity	Chapman-Jouget pressure	Internal energy per unit volume	Initial relative volume
ρ (kg/mm³)	D (mm/ms)	p_{CJ} (GPa)	E (J/mm³)	V
$1.63 \cdot 10^{-6}$	7840	26	4.3	1
		Constants		
A (GPa)	B (GPa)	R_1 (–)	R_2 (–)	ω (–)
371	3.73	4.15	0.95	0.3

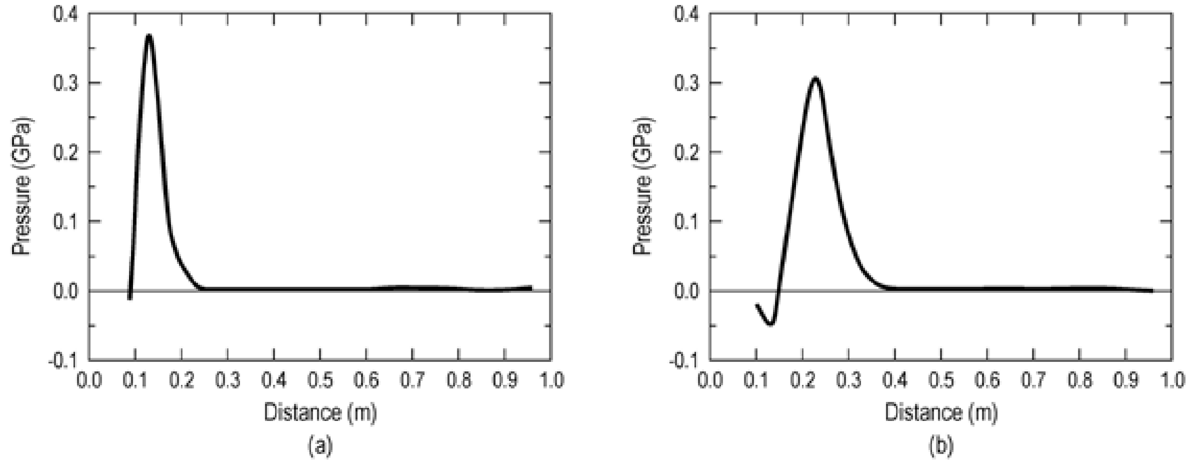

Figure 4. Variation of the pressure of the blast wave front in the water FE model: time = 0.05 ms (a), and time = 0.10 ms

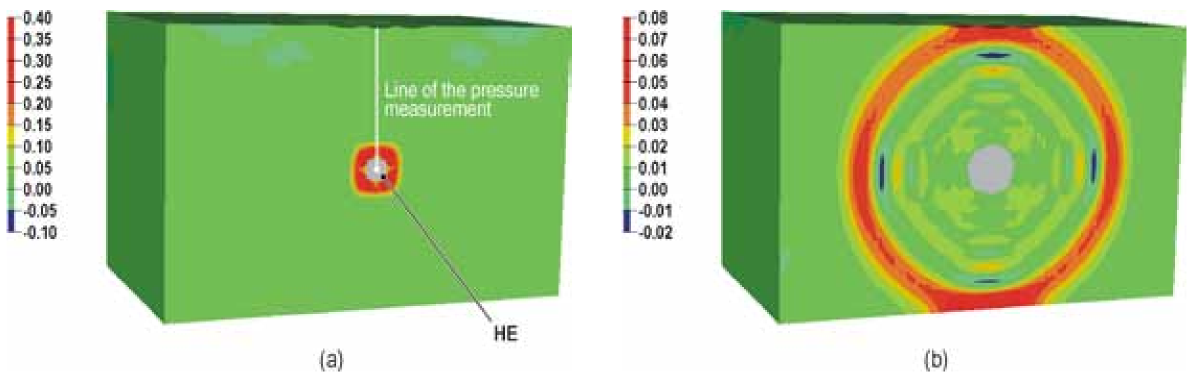

Figure 5. Contours of the pressure (GPa) for the cross-section of the water FE model: time = 0.05 ms (a), time = 0.40 ms (b)

Results and Conclusions

The purpose of this paper was to present the single segment of the floating bridge supported on the flexible shell preliminary analysis. Description of interacting flexible shell, rigid bodies and water is a complex problem which also desires the consideration of the contact problem.

During the explosion a blast wave influenced on the flexible shell. Values of the strains for selected elements of the flexible shell FE model (Figure 6) located above the HE charge were registered and compared with values obtained for the model without explosion. Four elements were selected as representatives for the analysis, and the average value of strains were taken into consideration. The HE charge was located in a different distance from the flexible shell - between 0.1 m through 1.0 m. Changes in values of the strains for selected distances are depicted in Figure 7a. About 40% increase was observed for the HE charge located in distance of 0.1 meter from the float surface. Explosion does not affect the pressure inside the float to a high degree (Figure 7b). The changes do not exceed 0.5%.

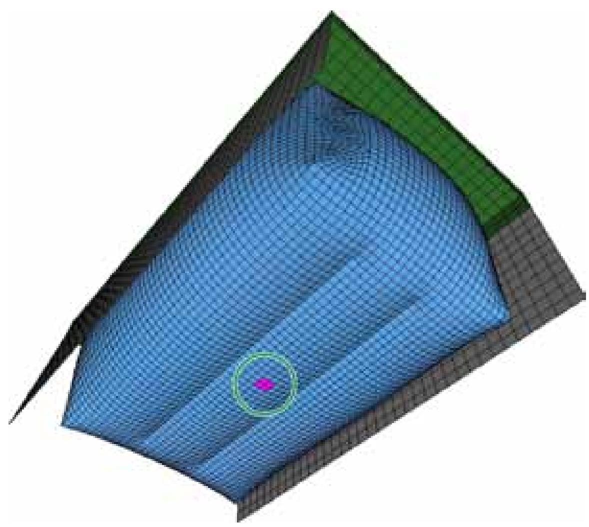

Figure 6. Location of the elements taken into consideration in the strain analysis state for the water FE model [2]

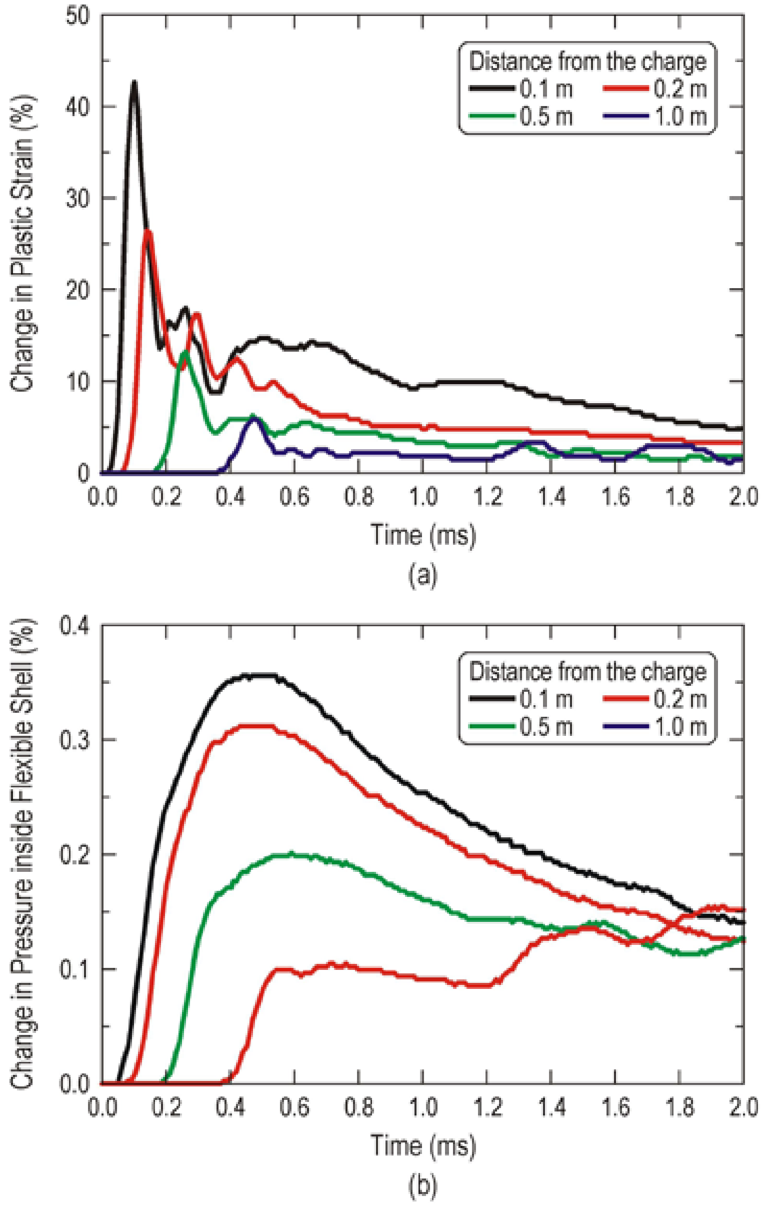

Figure 7. Change in values of the plastic strain (a) and the pressure inside the float (b) subjected to the blast wave

The global model is utilized to obtain displacement/stress/strain to be applied to the local model of flexible structure. Further development of the presented analysis is being carried out to determine the optimal structure.

Literature

1. *Cole R. H.: Underwater Explosions, Princeton University Press, Princeton 1948.*
2. *Kim J.-H., Shin H.-C.: Application of the ALE technique for underwater explosion analysis of a submarine liquefied oxygen tank, Ocean Engineering, Vol. 35, No. 8–9, 2008, pp. 812–822.*
3. *LS-Dyna Theory Manual, Livermore Software Technology Corporation, Livermore 2007.*
4. *LS-Dyna Keyword User's Manual, Vol. I, Livermore Software Technology Corporation, Livermore 2007.*
5. *Ma Z.-D., Wang H., Cui Y., Rose D., Socks A., Ostberg D.: Designing an Innovate Composite Armor System for Affordable Ballistic Protection, Proceedings of the 25th Army Science Conference, Orlando, Florida, United States 2006.*

Numerical Analysis of the Composite-Foam Panels Applied to Protect Pipelines Against the Blast Wave

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Introduction

The tremendous progress of the computational techniques allows to study of more and more various physical phenomena as detonation and blast wave interaction with different structures. A concern for passive protection of the structures [1, 2] causes necessity of searching the completely new solutions in the form of additional protective layers. Additionally mathematical description of the detonation process and the blast wave propagation is very difficult, hence many scientific publications on this phenomena can be found [3, 4, 5].

In current work, an attempt was made to simulate interaction of the blast wave with structures using a method that couples these elements. The Arbitrary Lagrangian Eulerian (ALE) method was used to couple an effect of the fluid on the structure. The fluid is described in Euler formulation, whereas the structures – in Lagrange one. Such method is applied in the standard implementation of the MSC. Dytran software [6]. An explicit scheme was selected to integrate the equation of motion in performed analysis.

General description of finite element models

Numerical analysis was carried out for two pipeline finite element (FE) models – with and without a protective panel. The pipeline—the main object of conducted research—was made of the L415MB steel. Its material properties based on the strength test [7] are provided in Table 1. One meter long fragment of the pipeline with inside diameter of 400 mm and the wall thickness of 7 mm was taken into consideration. Deformation effects of the protective panel and composite outer plate were also taken into account during the simulation.

The fluid domain has a cylindrical shape. It was simulated in the Eulerian domain using Hex 8 elements with the properties of the ideal gas – mass density of 1.2829 kg/m^3 and g = 1.4. A free flow of fluid through the boundary faces of the elements was assumed as initial condition. The Eulerian domain was limited by two planes of symmetry to reduce the CPU time.

The pipe and the protective panel, which is made from composite and aluminum foam, were modeled in the Lagrangian domain formulation. The Quad 4 shell elements were used for the pipe FE model, whereas the Hex 8 solid ones – for the panel. The two different the FE models (Figure 1 and 2) were used in analysis:

- Model 1 without the protective panel (in Lagrange domain is only pipeline),
- Model 2 with the 60 mm thick composite-foam protective panel (50 mm foamed aluminum and 10 mm reinforced polymer composite).

For both models, high explosive HE was located 100 mm from the pipe surface. Detonation of HE was modeled by defining appropriate initial conditions for selected elements in the Eulerian domain. Material properties of these elements based on the typical parameters of explosive materials and they are provided in Table 2. The initial values correspond with 100g of TNT. The Initial constraints were not declared in Lagrangian domain Therefore, velocities and displacements at the beginning (t = 0) were zero.

Table 1. Material properties of the L415MB steel [7]

Young's modulus	Poisson's ratio	Ultimate strength	Yield strength
E (MPa)	ν (–)	R_m (MPa)	$R_{0.2}$ (MPa)
195300	0.285	476	387

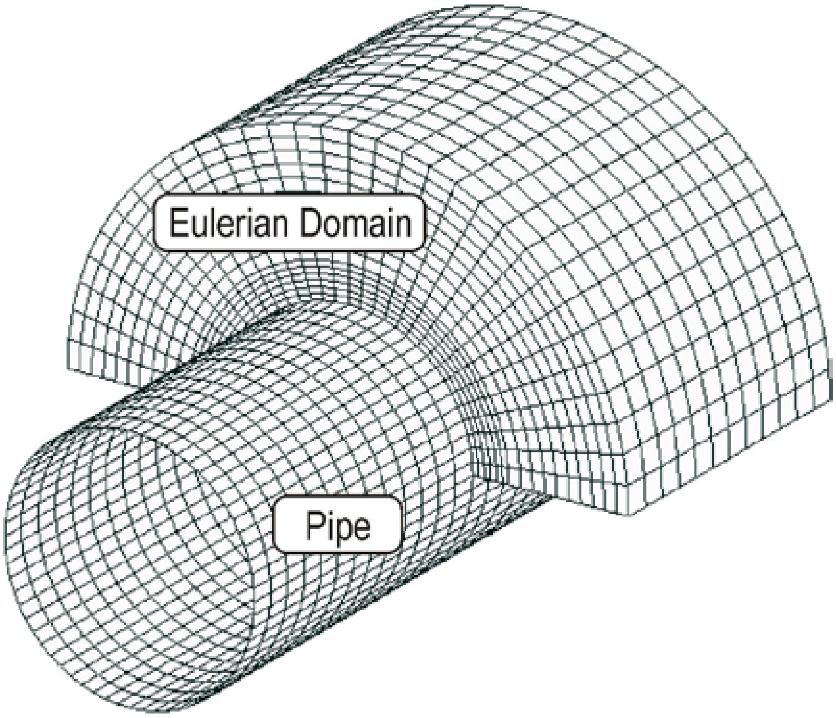

Figure 1. FE model of the pipe (Lagrange domain) and fluid – air (Euler domain)

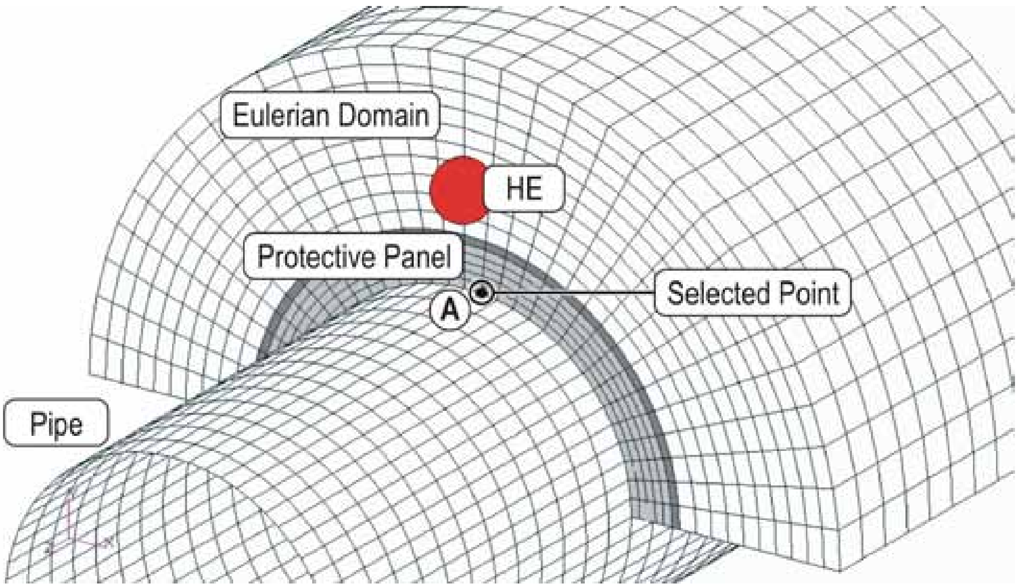

Figure 2. FE model of the pipe with the protective panel and fluid. Location of the HE and the selected point A is presented

Table 2. Material properties of the HE material

Mass density	Internal energy density
ρ (kg/m^3)	E (MJ/kg)
1600	4.2

Appropriate constrains were applied in the pipe FE model on the bottom edge.

The phenomenon of a detonation process was not simulated itself. However, there are some publications on modeling such phenomenon. The results presented in available publications reveal that taking above-mentioned phenomena into consideration has slight influence on the quality of obtained results.

The simple analytical model of the point charge detonation was made use of describing blast wave propagation. It be described by Taylor's so-called "similarity solution", which after transformation can be given as

$$p(r) = 0.155 E_0 \, r^{-3} \qquad (1)$$

where E_0 is the initial internal energy; r is the current radius of the blast wave.

The initial propagation of the blast wave is spherical. Values from the presented analysis correspond to those calculated analytically. The phenomena of the blast wave propagation in the FE model is shown in Figure 3.

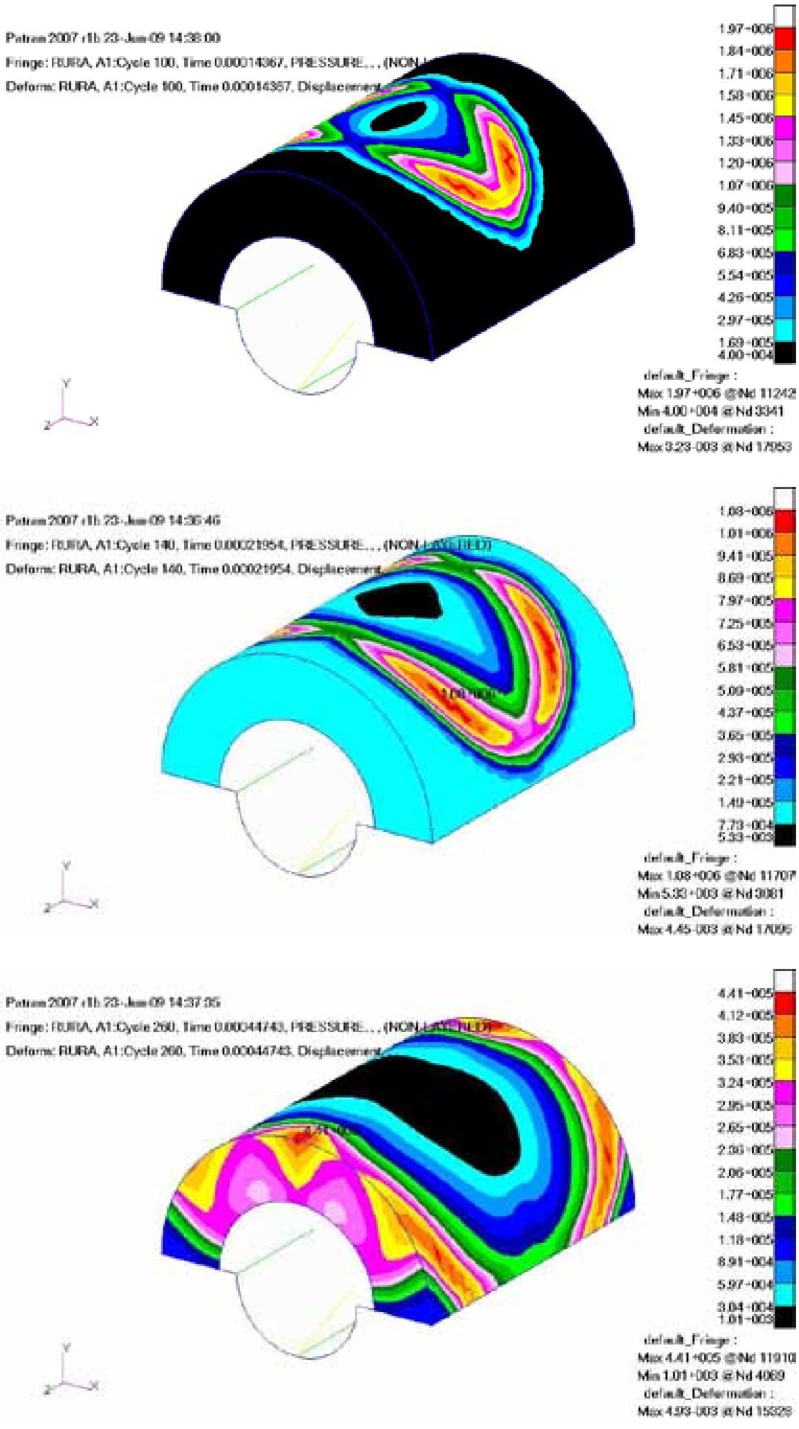

Figure 3. Distribution of the pressure inside the Eulerian domain for different time instants

FE Analysis and Results

Node A in the pipe FE model (see Figure 2) located on its top surface was selected for describing the results. Numerical analysis was performed for the time of 0.07 s. This time provided sufficient the blast wave interaction with considered structure to obtain an visible effect and decay of the pressure in the Eulerian domain, simultaneously.

The goal of conducted analysis was to assess the level of energy absorbed by each component of the tested structure. The graph of the deformation energy vs. time is presented in Figure 4. The maximum deformation energy of the pipe without the protective panel is equals to about 1750 J.

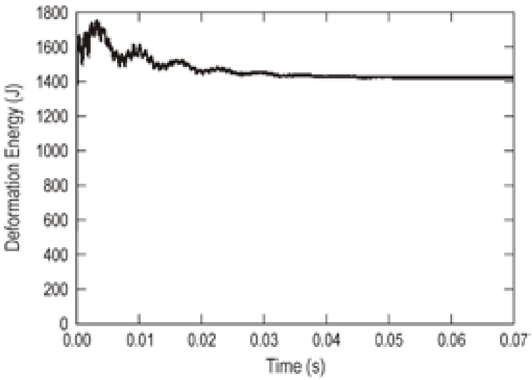

Figure 4. Variation of deformation energy for the pipe FE model subjected to blast wave

Displacements of selected node A from the pipe FE model is compared to those obtained for the model including the protective panel (Model 2), as presented in Figure 5. The maximum deflection for the Model 1 without the panel is 12 mm. The final form of deformation of the FE model with the contour of the deformation energy is shown in Figure 6. The contour of model deformation in the final stage is presented in Figure 7.

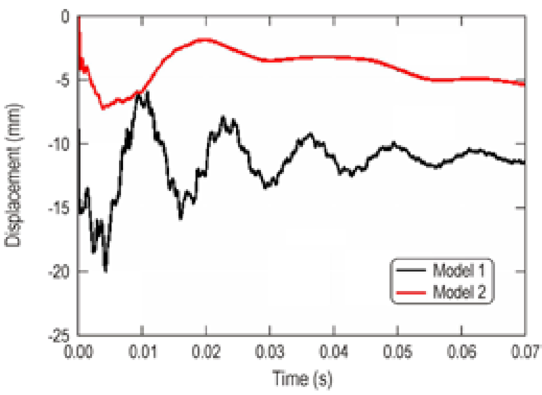

Figure 5. Displacements of the selected node A for the both FE models

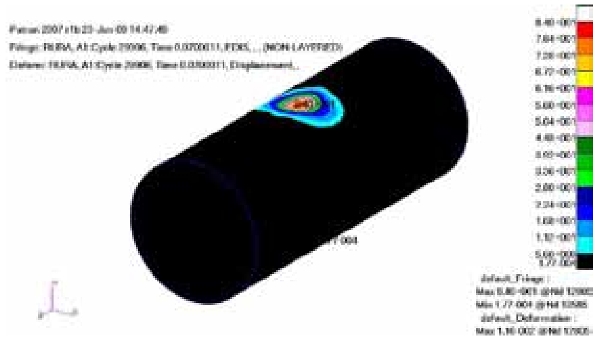

Figure 6. The final deformation energy (gradient) for the Model 1

Figure 7. The final deformation of the Model 1 – contour of the displacements (mm)

In the second model, with the protective panel, the energy of the blast wave was absorbed by each component – the composite plate, aluminum foam, and by the pipe. The energies absorbed by each component are compared in Figure 8. Maximum deformation energy—around 2,700 J—is absorbed by the foam layer. The pipe in Model 2 subjected to blast wave absorbs only 150 kJ of the energy—about ten times less than the pipe in Model 1 (without protective panel). The composite plate absorbs merely about 50 J. Contours of the deformation energy and displacement in the final stage are presented in Figure 9 and 10, respectively.

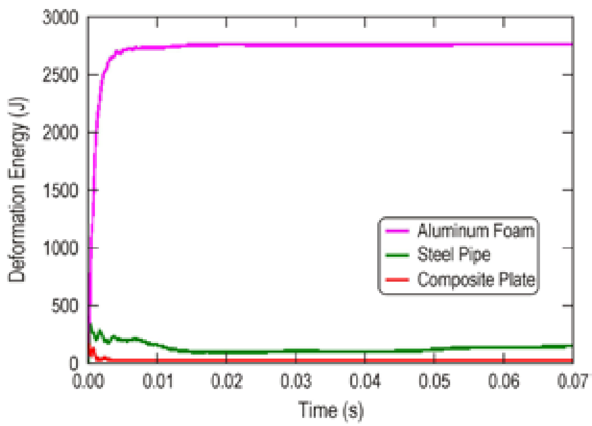

Figure 8. Comparison of the deformation energy for each component of the structure including the protective panel

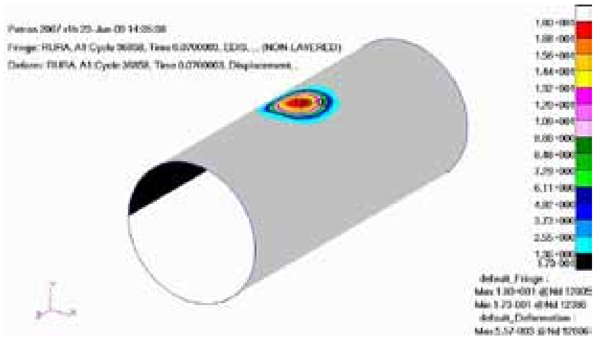

Figure 9. The final deformation energy (gradient) for the Model 2

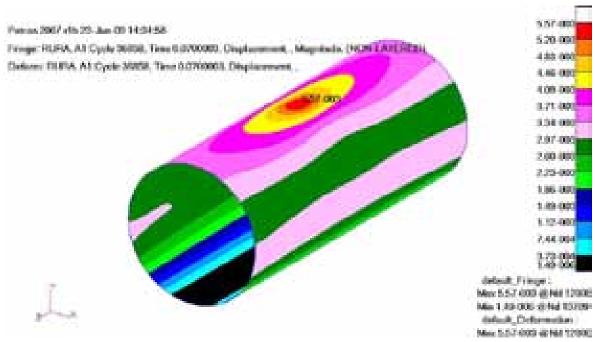

Figure 10. The final deformation of the Model 2 – contour of the displacements (mm)

The deformation energies for both models - with and without the protective panel - are compared in Figure 11. Performed analysis shows that the significant amount of the deformation energy is lost in the foam layer. Such disproportion of the energy absorbed by each component is caused by using the stiff composite plate and its surface-effect influenced on aluminum foam and the pipe.

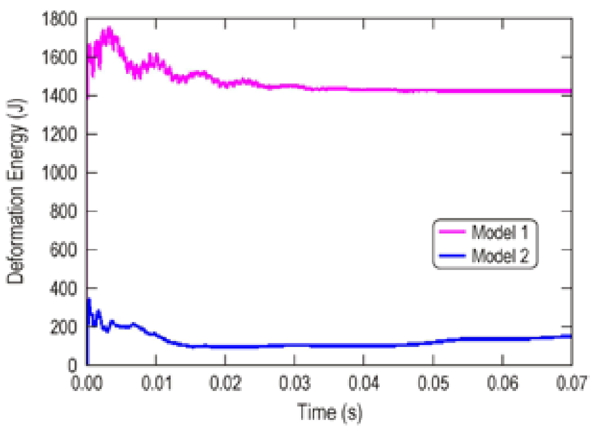

Figure 11. Comparison of the deformation energies for the pipe FE models subjected to blast wave

The blast wave causes an local effect on the pipe wall if the protective panel was not applied. It may caused large displacement of nodes, and a damage of pipe, consequently. The protective panel allows to reduce the displacement of the node A to 5 mm. Deformation energy for the Model 2 is about ten times lower in comparison with the Model 1, and its contour is different. In the Model 2 displacements of nodes are smooth and quite uniform due to surface-distribution of the blast wave on the pipe.

Conclusions

The results of preliminary analysis of the composite-foam protective panels are presented in the paper. Modeling of the dynamic loads generated by the explosives using the fluid–structure interaction - coupled Arbitrary Lagrangian Eulerian method applied in MSC.Dytran is much easier than the traditional approach. There is no need to generate the loads in external software and transfer them to the structural analysis software afterwards. Proposed approach is characterized by quite good conformity with the theoretical solutions. Applying the ALE methods allows to avoid transferring the loads onto modified mesh of the structural model. Deformations of the structure are taken into consideration automatically in the part of calculation regarding the fluid mechanics. In the traditional approach, considering of the influence of the shape changeability for the fluid channel is very time consuming and difficult to carry out.

Further work should be focused on a selection of properties of the foam and composite applied in the protective panels. Selection should be oriented on determining the optimal quantity of such panels. Furthermore, it is necessary to change the mass density of the used material to reduce the weight of the protection panel. Performed analysis allowed to determine the fundamental assumption to conduct the experimental test in order to verification and validation of developed FE models.

Literature

1. *Barnat W.: Transporter Opancerzony Adi Bushmaster, Myśl Wojskowa 5/2005, (in polish).*
2. *Nurick G. N., Shave G. C.: The Deformation and Tearing of Thin Sqare Plates Subjected to Impulsive Loads: An Experimental Study, International Journal of Impact Engineering, Vol. 18, No. 1, 1996, pp. 99–116.*

3. *Włodarczyk E.: Wstęp do mechaniki wybuchu, Wydawnictwo Naukowe PWN, Warszawa 1994, (in polish).*
4. *Zukas J. A., Nicholas T., Swift H. F., Greszczuk L. B., Curran D. R.: Impact Dynamics, John Wiley & Sons, New York 1982.*
5. *Krzewiński R., Rekucki R.: Roboty budowlane przy użyciu materiałów wybuchowych, Wydawnictwo Polcen, Warszawa 2005, (in polish).*
6. *Krzewiński R.: Dynamika Wybuchu. Część I: Metody określania obciążeń, Wydawnictwo WAT, Warszawa 1982, (in polish).*
7. *Ochelski S., Kiczko A.: Metody badania deformacji i wytrzymałości rur zginanych, XXI Sympozjum Mechaniki Eksperymentalnej Ciała Stałego, Jachranka, 2004, str. 255–260, (in polish).*
8. *Trzciński W. Trębiński R. Cudziło S.: Investigation of the Behaviour of Steel and Laminated Fabric Plates under Blast Wave Load. Part I: Experimental Approach, Proceedings of the V International Armament Conference, Waplewo 2005.*
9. *MSC.Dytran Example Problem Manual, Version 3.0, MSC 1996.*
10. *Jones N.: Structures under Impact, VIII Edition, Witt Press, Boston 2004.*
11. *Dobrociński S.: Stabilność rozwiązań zagadnień odporności udarowej konstrukcji, Wydawnictwo Akademii Marynarki Wojennej, Gdynia 2000, (in polish).*

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