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

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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.

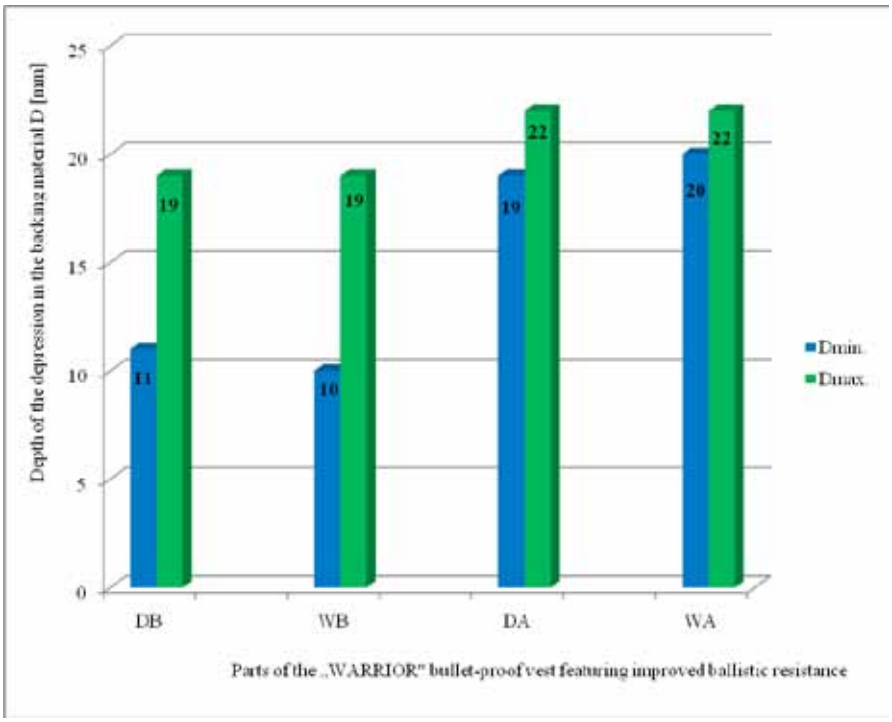
The vests above feature some common properties, namely:

- 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

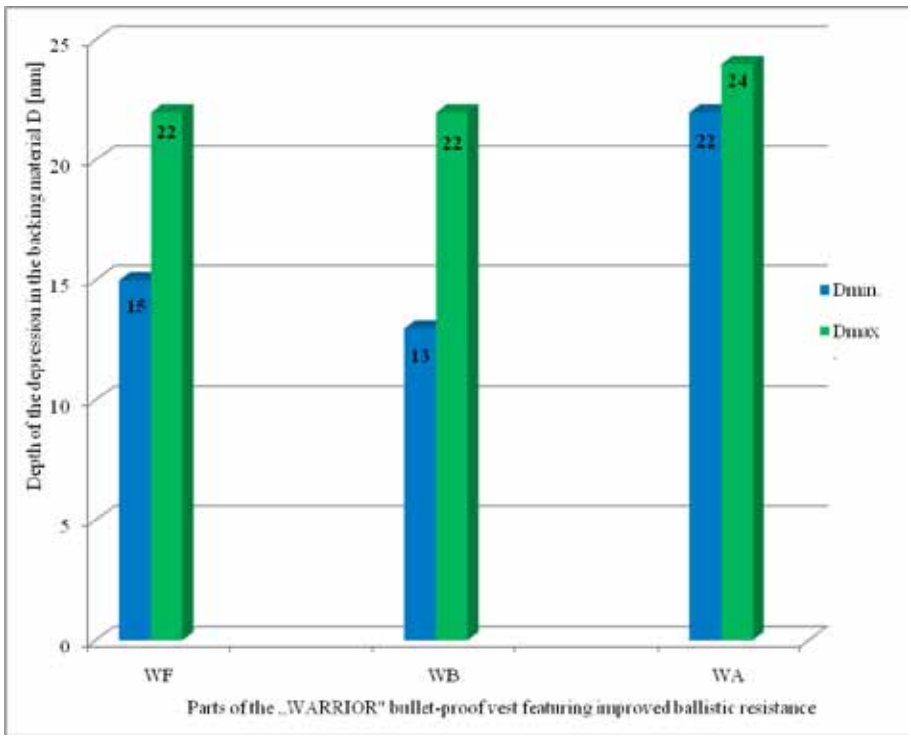
The lab tests of the ballistic resistance of the bullet-proof vests have been completed at the accredited Ballistics Laboratory of the „MORATEX" Institute. The results are presented as charts on the following figures:

- 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.



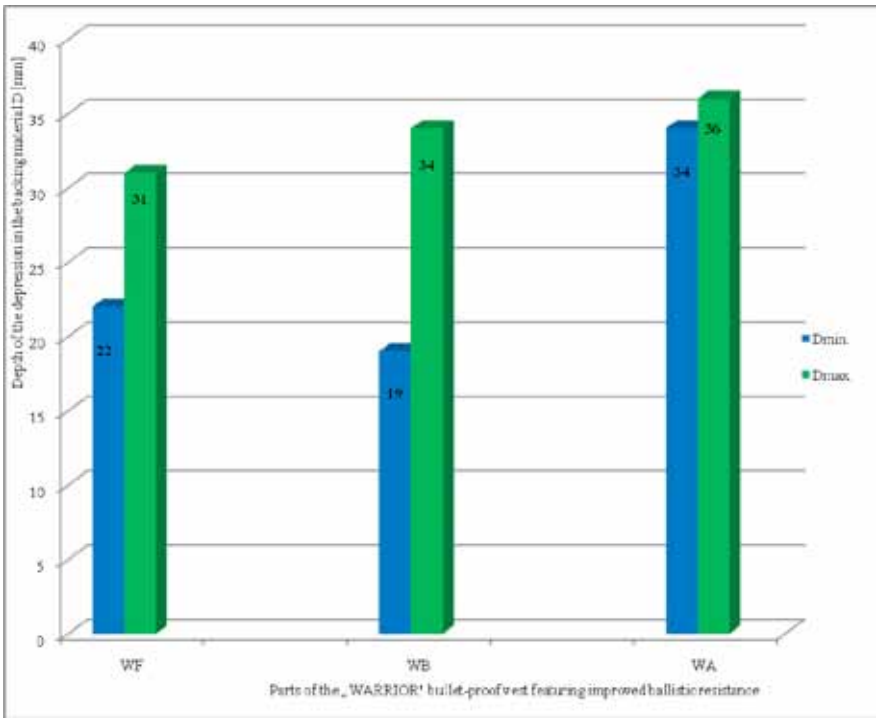
Legend: DB – dry back part, WB – wet conditioned back part, DA – dry abdomen protector, WA – wet conditioned abdomen protector

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



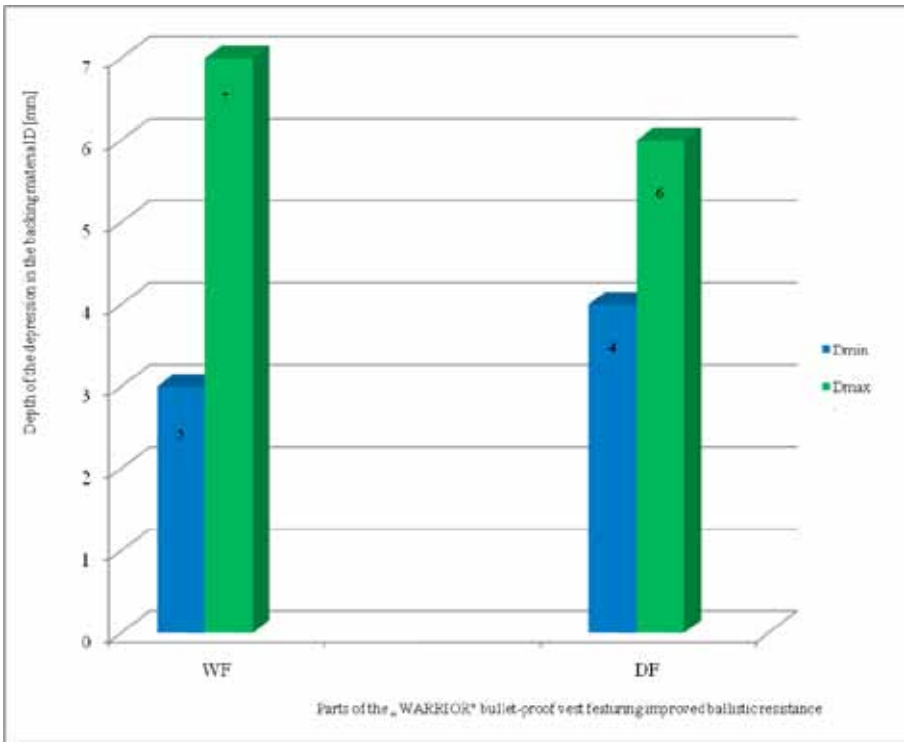
Legend: WF – wet conditioned front part, WB – wet conditioned back part, WA – wet conditioned abdomen protector

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



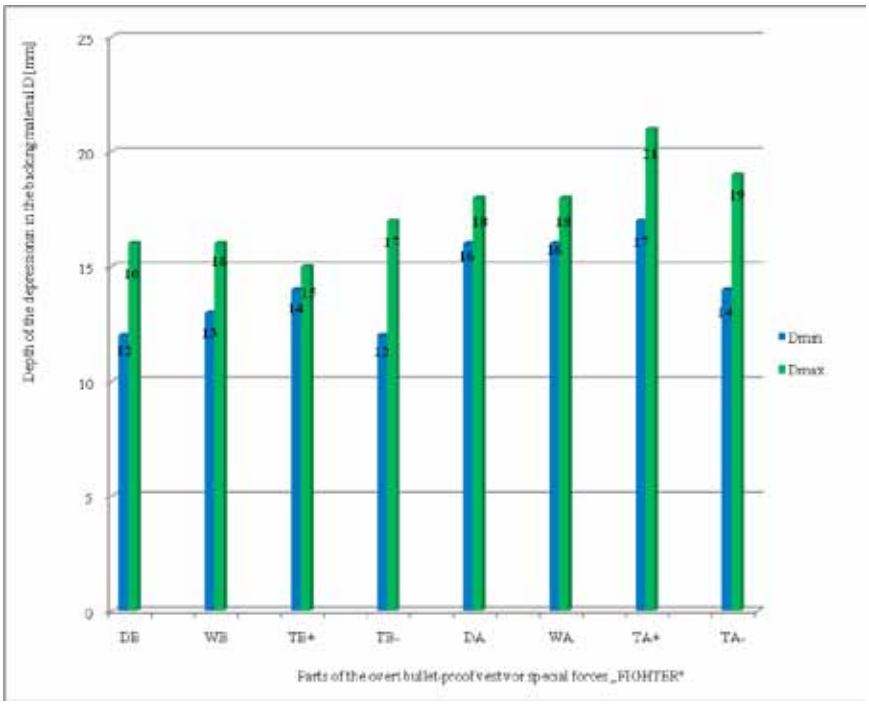
Legend: WF – wet conditioned front part, WB – wet conditioned back part,
WA – wet conditioned abdomen protector sprinkled

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



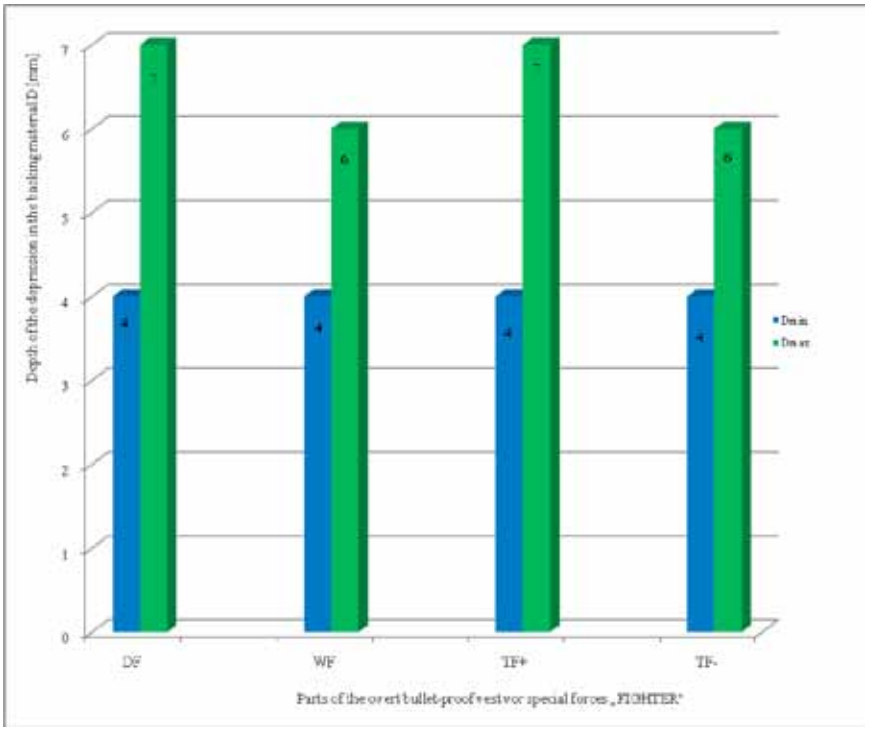
Legend: WF – wet conditioned front part , DF – dry front part

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



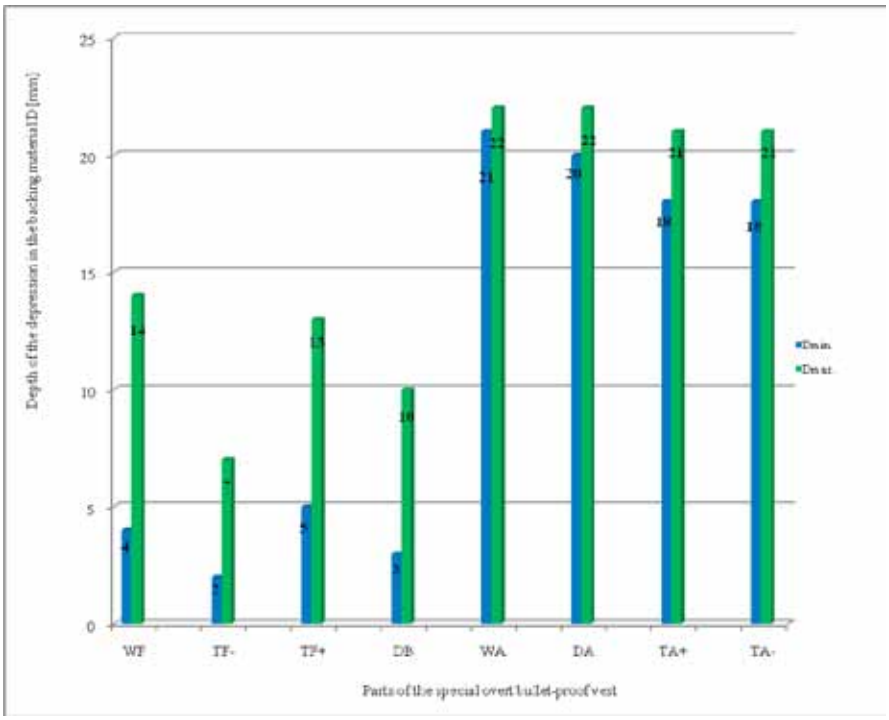
Legend: DB – dry back part, WB – wet conditioned back part, TB+ - back part stabilized thermally at +500C, TB- - back part stabilized thermally at -400C, DA – dry abdomen protector, WA – wet conditioned abdomen protector, TA+ - abdomen protector stabilized thermally at +500C, TA- abdomen protector stabilized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



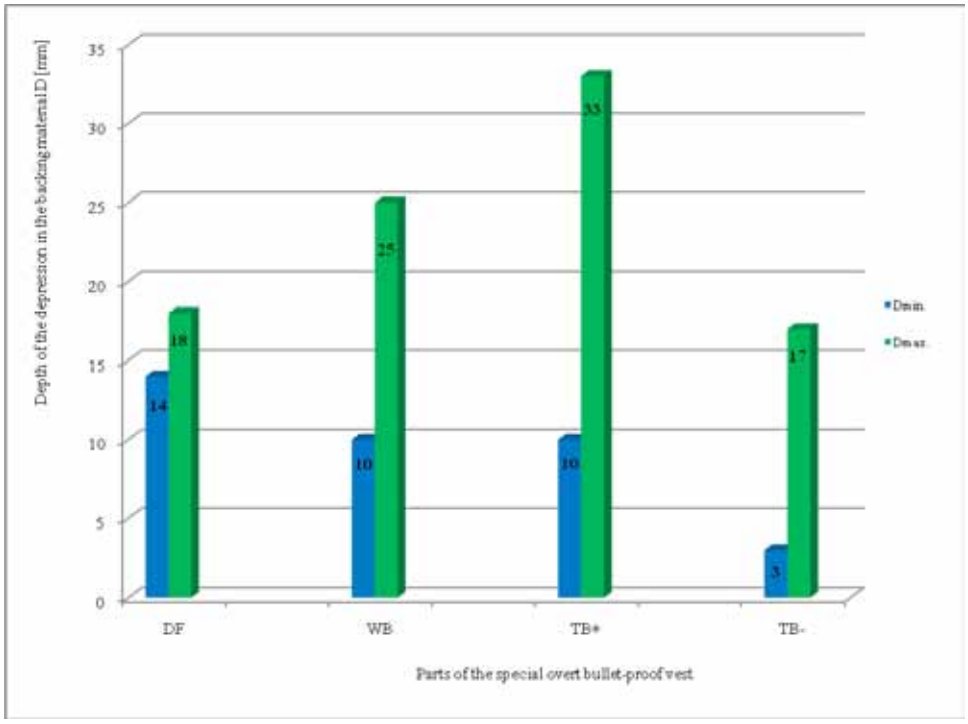
Legend: DF – dry front part, WF – wet conditioned front part, TF+ – front part stabilized thermally at +500C, TF- – front part stabilized thermally at -400C

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 ≤ V_{50} < 675 m/s – class 3 of fragment-proofness according to PN-V-87000:1999 Standard,
  - alternatively 675 m/s ≤ 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.

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