TESTING AND EVALUATION OF THE RESISTANCE TO PUNCTURE AND THE PROTECTIVE PROPERTIES OF FLEXIBLE BALLISTIC PANELS OF BULLETPROOF VESTS WITH A LEVEL OF BALLISTIC PROTECTION IIIA, WITH REDUCED WEIGHT OF THE PANEL, AND VARIOUS COMBINATIONS OF THE COMPONENT MATERIALS

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Abstract

This report presents the results obtained in a study aimed at assessing the protective properties and suitability for use of flexible ballistic panels of bulletproof vests with a reduced weight of the panel, in terms of their resistance to puncture. The focus is on some of the most commonly used by the police bulletproof vests - those with a level of ballistic protection IIIA, according to the NIJ (standards of the US National Institute of Justice). The test samples of flexible ballistic panels were previously tested for ballistic resistance and covered Level IIIA requirements of NIJ 0101.04, NIJ 0101.06 (Ballistic Resistance of Personal Body Armor) standards, and with a 7.62x25 FMJ RN cartridge (GOST P 50744-95 - Armor vestment). The test has been specifically designed for a test bench and test methodology that complies with the requirements of two of the leading standardization documents in this area: NIJ 0115.00 - Stab Resistance of Personal Body Armor (standards of the US National Institute of Justice) and HOSDB 2007, Part 3. Knife and Spike Resistance (UK Police Standard). Analysis and evaluation of the obtained results are presented.

Keywords: *resistance to puncture, bulletproof vests, standardization documents, optimal combinations of materials, flexible ballistic panels, reduced panel weight*

1. INTRODUCTION

Against the background of surrounding reality, filled with uncertainty, conflict situations and unrest, the issue of security for police officers and security guards is becoming more and more relevant. Modern multicomponent bulletproof vest is one of the main tools for individual protection of law enforcement personnel. It should provide not only ballistic protection against bullets and fragments, consistent with weapons and ammunition used in the country and region, but also adequate protection against cold weapons piercing. This is due to the fact that much of the injuries to police officers and guards during their duties result from puncture hit by a cool weapon during close contact with the attacker. The striving to create a bulletproof vest with optimal structure in weight and protective properties, by introducing new materials and different combinations of materials in the protective panels production, applying the modular principle, requires extensive research and conducting a number of experiments.

This report represents a continuation of the report “Testing and evaluation of the ballistic resistance of flexible ballistic panels of bulletproof vests with a level of ballistic protection IIIA, with reduced weight of the panel, according to typical weapons and ammunition used in Bulgaria and the region”. Here the results of the additional testing of the test samples to determine their resistance to puncture and the evaluation of their protective qualities for the level of protection IIIA according to the NIJ standards of the National Institute of Justice are presented.

The goal is again to find optimal combinations of materials used to produce flexible ballistic panels of armor vests with reduced panel weights, providing extra protection against cold weapons in close contact with the attacker.

The protective properties of the finished product are assessed in accordance with the strict requirements laid down in the relevant standardization documents.

2. MATERIALS AND METHODS

2.1. Test samples

Testing of 12 test pieces of flexible ballistic panels for armor weights with reduced panel weight is carried out with the aim to determine their resistance to piercing and assess their protective properties.

A pack of 19 sheets of Dyneema® SB51 with a density of 253 g/m^2 is used as a basic pack of each group. Additional packs represent certain combination of materials that is different for each test sample. The main and optional packs are placed in an outer case made of 100% Polyester.

Samples are divided into three groups, depending on the materials used in the extra pack. In the first group the additional pack is made on the basis of UHMWPE materials in combination with ceramics and polyvinyl chloride. In the second group, it is based on p-aramid materials in combination with ceramics and polyvinyl chloride. In the third group, the additive packages are combinations of UHMWPE materials, p-aramid materials, textile materials and ceramics sprinkled layers of SiC, Al_2O_3.

For bonding the UHMWPE, p-aramid and textile materials with ceramic layers, polyurethane elastic resin is used. The ceramic sprinkled layers are applied with the vibro-sieve, then stabilized with a fine layer of lacquer.

For all tested specimens, the face/impact surface is on the side of the optional package.

This report presents the results of the sample from each group that showed the best puncture resistance during the test.

Sample 1 – Sample of the First group

Basic pack: Dyneema SB51 – 19 sheets, weight 4.807 kg/m^2.

Extra pack: Dyneema SB51 with sprinkled layer of green SiC with a grain size 200 μm, connected by polyurethane elastic resin and stabilized with a fine layer of lacquer – 4 sheets with weight 3.197 kg/m^2.

Outer case: 100% Polyester, weight 0.165 kg/m^2.

Total weight of test sample: 8.169 kg/m^2.

Sample 2 – Sample of the Second group

Basic pack: Dyneema SB51 – 19 sheets, weight 4,807 kg/m^2.

Extra pack: Kevlar XP with sprinkled layer of green SiC with a grain size 200 μm, connected by polyurethane elastic resin and stabilized with a fine layer of lacquer – 2 sheets with weight 2.436 kg/m^2.

Outer case: 100% Polyester, weight 0.165 kg/m^2.

Total weight of test sample: 7.408 kg/m^2.

Sample 3 – Sample of the Third group

Basic pack: Dyneema SB51 – 19 sheets, weight 4.807 kg/m^2.

Extra pack: Textile base with sprinkled layer of brown Al_2O_3 with a grain size 600 μm, connected by polyurethane elastic resin and stabilized with a fine layer of lacquer – 4 sheets with weight 1.492 kg/m^2 + Dyneema SB51 with sprinkled layer of SiC with a grain size 200 μm, connected by polyurethane elastic resin and stabilized with a fine layer of lacquer – 1 sheet with weight 0.800 kg/m^2.

Outer case: 100% Polyester, weight 0.165 kg/m^2.

Total weight of test sample: 7.264 kg/m^2.

2.2. Test conditions, procedure and equipment

The tests are carried out for levels of protection 1 and 2, according to Table 1, in environmental conditions of test laboratory, as follows:

- Temperature: 22°C;
- Relative air humidity: 56%.

Table 1. Protection levels according to NIJ 0115.00 - Stab Resistance of Personal Body Armor

Protection level	Energy of impact „E1“ ,J	Maximum allowable penetration of the blade, mm	Energy of impact „E2“, J	Maximum allowable penetration of the blade, mm
1	24±0.50	7	36±0.60	20
2	33±0.60	7	50±0.70	20
3	43±0.60	7	65±0.80	20

Level 1 applies to armored vests with low level of protection against piercing, suitable for long wear under clothing. Such a bulletproof vest protects against low energy threats with shock energy 24J. Additionally, it should be tested for impact energy 36J.

Level 2 applies to armored vests with middle level of protection against piercing, suitable for long wear under as well as over clothing. Such a bulletproof vest protects against average high energy threats with shock energy 33J. Additionally, it should be tested for impact energy 50J.

Level 3 applies to armored vests with high level of protection against piercing, suitable for long wear over clothes in extremely dangerous situations with a very high degree of risk. Such a bulletproof vest protects against high energy threats with shock energy 43J. Additionally, it should be tested for impact energy 65J.

The tests are carried out using a prototype of a stand, specially designed for the purposes of the experiments (Figure 1), consisting of a main body and an additional body. The main body is used for testing the resistance to puncture of flexible ballistic panels/armor plates at an angle of impact of 0° for the first and second protection level. When installing an additional body, it is possible to carry out tests for first, second and third level of protection at impact angles of 0°, 15°, 30° and 45°.

In Fig. 1 on the left are shown the main and the additional body and the technology of their connection, and on the right is shown the main body where the tests were carried out.

The stand is designed to meet the requirements of the two leading standards in this area, namely NIJ 0115.00 - Stab Resistance of Personal Body Armor (US National Institute of Justice standards) and HOSDB 2007, Part 3. Knife and Spike Resistance (UK police standard), which regulate the requirements for piercing bulletproof vests and the criteria for determining the respective levels of protection. The construction of the stand is built so that it can be used in testing for all levels of protection regulated in the aforementioned standardization documents. Coverage of a given level of protection is determined by performing certain number of punctures with a specified impact energy provided by free fall of the piercing blade from a calculated height.

The whole system is carefully designed to allow the shuttle carrying the test blade to fall freely under its own weight and to hit the test specimen at a specific point of impact. The guides do not allow rotation of the falling mass around its vertical axis, thus keeping the orientation of the falling body unchanged until the end of the test. The shape of the lower surface of the shuttle is designed to allow for the penetration of the test blade by at least 30 mm at a hit of angle of 45° to the normal.

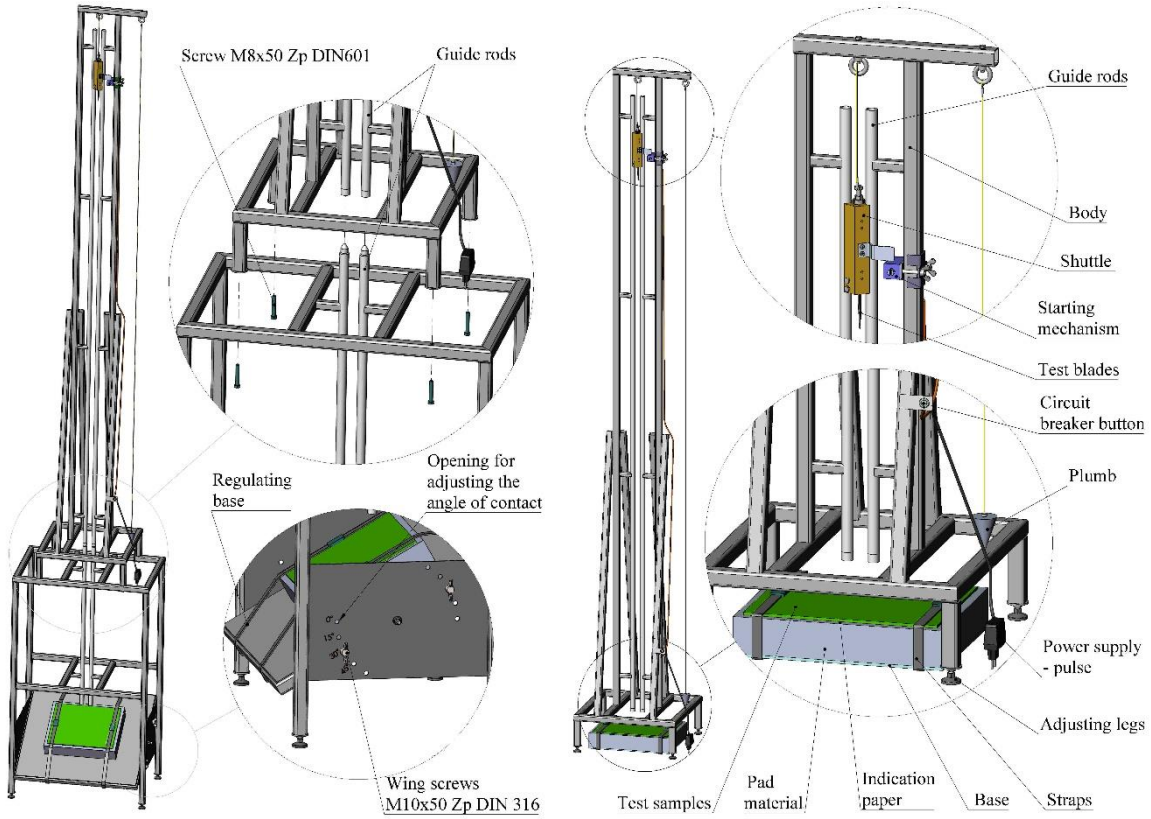

Fig. 1. Design of the stand for testing the piercing resistance of bulletproof vests – 3D model

The tests are carried out with engineering knives (high quality, factory-made cutting edge knives) using two types of blade blades - type P1 and type S1. They are the two types of sharpened weapons most commonly used in attack.

Blade type P1 (Figure 2 - to the left) is a representative of small knives, it is small and thin and has a sharpened edge, whereas blade S1 (Figure 2 - to the right) is representative of knives used by the commandos, or a large kitchen knife, it is larger and thicker than P1 and has two sharpened edges.

Both types of test blades are hardened, Rockwell hardness, scale C within the range 50HRC - 140HRC and have a pointed tip and a stable base.

The tests are carried out at contact angle of the test blade with the test sample 0° to the normal.

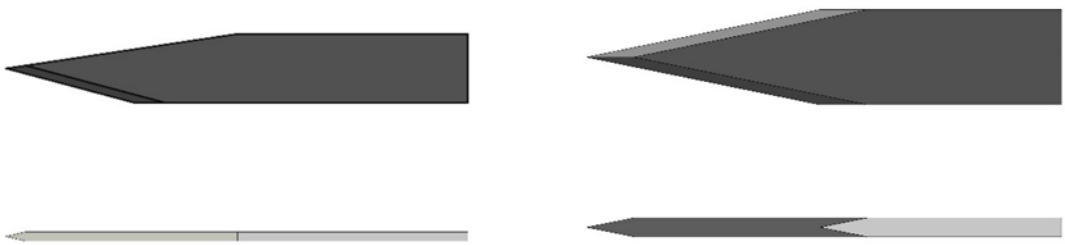

Fig. 2. Test blade type P1 (left), type S1 (right)

Before the tests, the impact energy is calibrated by calculating the fall height required for achieving the desired speeds corresponding to the respective impact energy, for each impact energy and for each type of test blade using formula (1).

The fall height is measured from the tip of the test blade to the surface of the bulletproof test sample.

$$h = \frac{E}{mg} \quad (1)$$

where:

h is the height of the fall, m;

E is the kinetic energy of impact, J;

m is the mass of the falling shuttle with the test blade with an accuracy to 1 g;

g is the gravitational acceleration, m/s^2.

The locations where the punches will be made are marked on the armor vest according to the requirements of NIJ 0115.00.

The pad material, the indicator paper and the test sample of a bulletproof vest are placed and their immobility is secured by clamping to the base of the stand using 50 mm elastic belts fastened with Velcro® strips.

The test blade is mounted.

The exact impact velocity measurement is provided by a pair of photoelectric light screens mounted at a distance of 25 mm ± 2 mm from the point of impact on the test specimen. They provide measurement with an accuracy of ± 0.2 m / s.

In conducting the puncture resistance tests, to meet the requirements at a given level, for each combination of materials composing the flexible ballistic panel of a bulletproof vest, a series of tests according to Table 2 are made.

Table 2. Test conditions

Number of stab hits	Contact angle	Test blade type	Energy level
6	0°	P1	E1
6	0°	P1	E2
6	0°	S1	E1
6	0°	S1	E2

The validity of the hit is determined.*

***** A hit is counted in which the impact energy meets the material requirements. The length of the notch obtained in the indicator paper is measured.

The measured data are converted to penetration depth according to the penetration depth tables given in standard NIJ 0115.00.

A perforation of the bulletproof sample with penetration of the test blade at depths greater than 7 mm at impact energy E1 is considered negative score.

A perforation of the bulletproof sample with penetration of the test blade greater than 20 mm is considered negative score for each counted hit at impact energy E2.

The data are recorded in the test report.

3. RESULTS

The data obtained from the tests of the flexible ballistic panel sample of the given group showing optimum results in terms of panel weight and puncture resistance are presented in tabular form and are illustrated by diagrams so they can be analyzed and used to assess the protective properties of combinations of materials.

Sample 1 - best sample from Group One

The results obtained from the tests for protection level 1 are presented in the table 3 and Fig. 3, for level 2 - in tab. 4 and Fig. 4.

Table 3. Sample 1 – results for level 1

Experiment №	Protection level 1						
	Sample 1			Knife type P1	Knife type S1	Knife type P1	Knife type S1
	One sheet weight kg/m^2	Number of sheets	Panel weight kg/m^2	E1=24J±0,50J ≤ 7mm	E1=24J±0,50J ≤ 7mm	E2=36J±0,60J ≤ 20mm	E2=36J±0,60J ≤ 20mm
	0,253	19	4,807	Cut length, mm	Cut length, mm	Cut length, mm	Cut length, mm
	0,799	4	3,197				
			0,165				
	Total		8,169				
1				2,600	0,810	8,110	1,220
2				2,690	0,820	8,090	1,180
3				2,710	0,830	8,120	1,240
4				2,800	0,790	8,080	1,179
5				2,790	0,800	8,080	1,230
6				2,810	0,810	8,100	1,190
Average cut length, mm				**2,733**	**0,810**	**8,097**	**1,207**
Average depth of penetration, mm				**6,5**	**2,0**	**19,0**	**2,7**
Standard requirements				**7,0**	**7,0**	**20,0**	**20,0**
Covers a standard				**yes**	**yes**	**yes**	**yes**

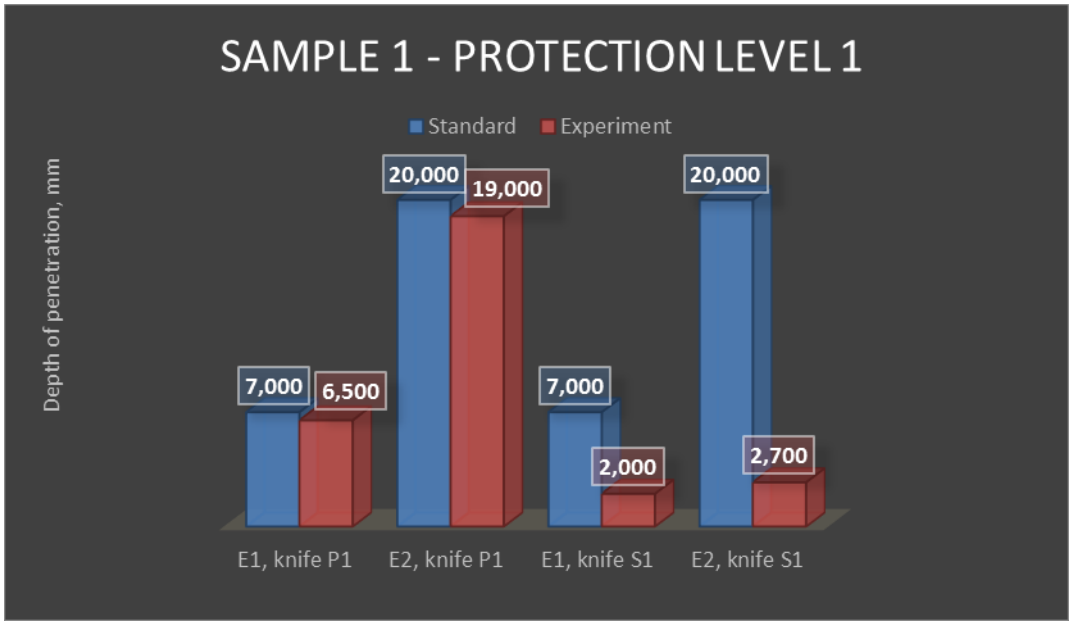

Fig. 3. Sample 1 – results for level 1

Table 4. Sample 1 – results for level 2

Experiment №	Protection level 2						
	Sample 1			Knife type P1	Knife type S1	Knife type P1	Knife type S1
	One sheet weight kg/m^2	Number of sheets	Panel weight kg/m^2	E1=33J±0,60J, ≤ 7mm	E1=33J±0,60J, ≤ 7mm	E2=50J±0,70J ≤ 20mm	E2=50J±0,70J ≤ 20mm
	0,253	19	4,807	Cut length, mm	Cut length, mm	Cut length, mm	Cut length, mm
	0,799	4	3,197				
			0,165				
	Total		8,169				
1				7,690	0,554	12,100	3,660
2				7,780	0,563	12,200	3,460
3				7,670	0,499	12,150	3,560
4				7,820	0,578	12,250	3,760
5				7,720	0,572	12,180	3,690
6				7,670	0,550	12,280	3,630
Average cut length, mm				**7,725**	**0,553**	**12,193**	**3,627**
Average depth of penetration, mm				**16,9**	**1,4**	**30,5**	**9,0**
Standard requirements				**7,0**	**7,0**	**20,0**	**20,0**
Covers a standard				**no**	**yes**	**no**	**yes**

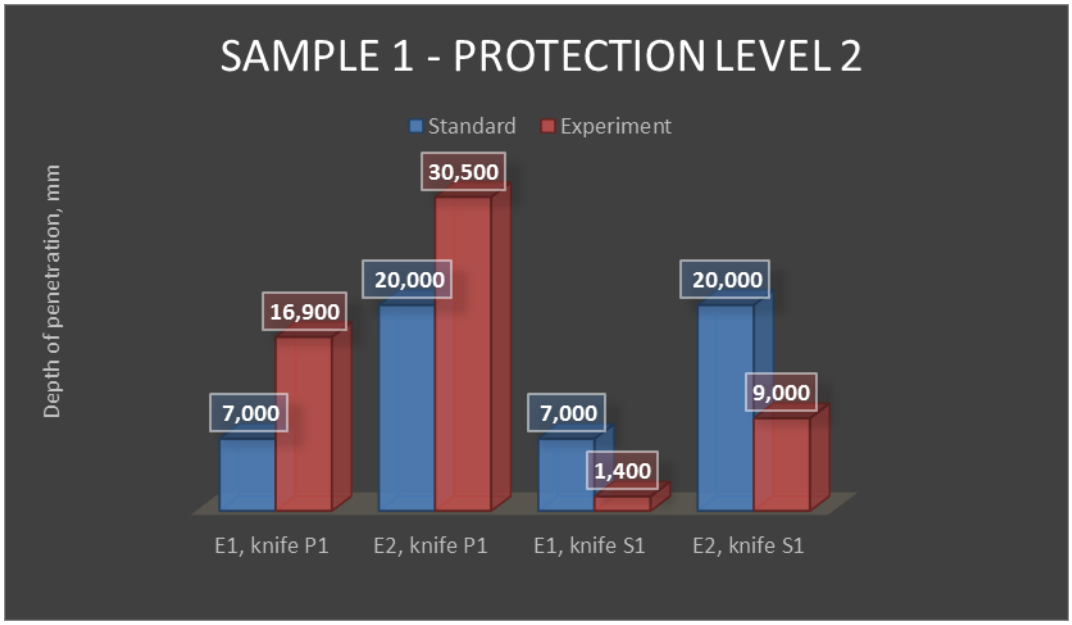

Fig. 4. Sample 1 – results for level 2

Sample 2 - best sample from Group Two

The data obtained from the tests for protection level 1 are presented in the table 5 and Fig. 5, for level 2 - in tab. 6 and Fig. 6.

Table 5. Sample 2 – results for level 1

Experiment №	**Protection level 1**						
	Sample 2			Knife type P1	Knife type S1	Knife type P1	Knife type S1
	One sheet weight kg/m^2	Number of sheets	Panel weight kg/m^2	E1=24J±0,50J ≤ 7mm	E1=24J±0,50J ≤ 7mm	E2=36J±0,60J ≤ 20mm	E2=36J±0,60J ≤ 20mm
	0,253	19	4,807	Cut length, mm	Cut length, mm	Cut length, mm	Cut length, mm
	1,218	2	2,436				
			0,165				
	Total		7,408				
1				5,630	0,650	9,450	1,220
2				5,550	0,550	9,550	1,200
3				5,750	0,680	9,490	1,180
4				5,690	0,730	9,650	1,160
5				5,730	0,740	9,350	1,190
6				5,640	0,600	9,400	1,210
Average cut length, mm				**5,665**	**0,658**	**9,482**	**1,19**
Average depth of penetration, mm				**13,0**	**1,5**	**22,5**	**2,7**
Standard requirements				**7,0**	**7,0**	**20,0**	**20,0**
Covers a standard				**no**	**yes**	**no**	**yes**

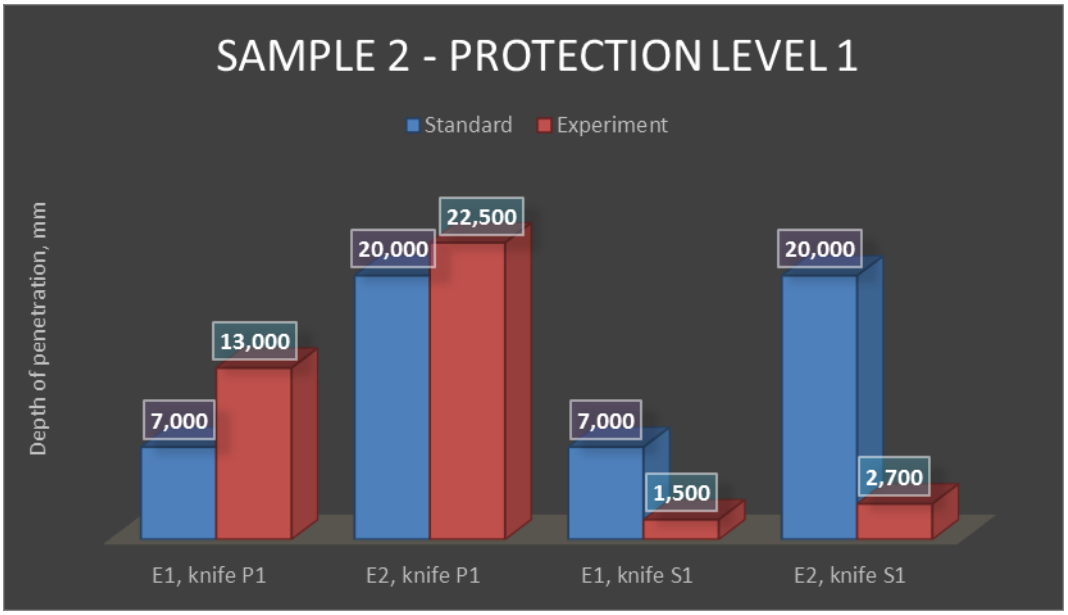

Fig. 5. Sample 2 – results for level 1

Table 6. Sample 2 – results for level 2

Experiment №	Protection level 2						
	Sample 2			Knife type P1	Knife type S1	Knife type P1	Knife type S1
	One sheet weight kg/m^2	Number of sheets	Panel weight kg/m^2	E1=33J±0,60J, ≤ 7mm	E1=33J±0,60J, ≤ 7mm	E2=50J±0,70J ≤ 20mm	E2=50J±0,70J ≤ 20mm
	0,253	19	4,807	Cut length, mm	Cut length, mm	Cut length, mm	Cut length, mm
	1,218	2	2,436				
			0,165				
	Total		7,408				
1				8,520	0,810	10,510	1,220
2				8,110	0,790	10,590	1,230
3				8,340	0,830	10,610	1,250
4				8,450	0,780	10,570	1,320
5				8,390	0,810	10,530	1,340
6				8,490	0,830	10,580	1,380
Average cut length, mm				**8,383**	**0,808**	**10,565**	**1,290**
Average depth of penetration, mm				**19,5**	**2,0**	**25,0**	**3,5**
Standard requirements				**7,0**	**7,0**	**20,0**	**20,0**
Covers a standard				**no**	**yes**	**no**	**yes**

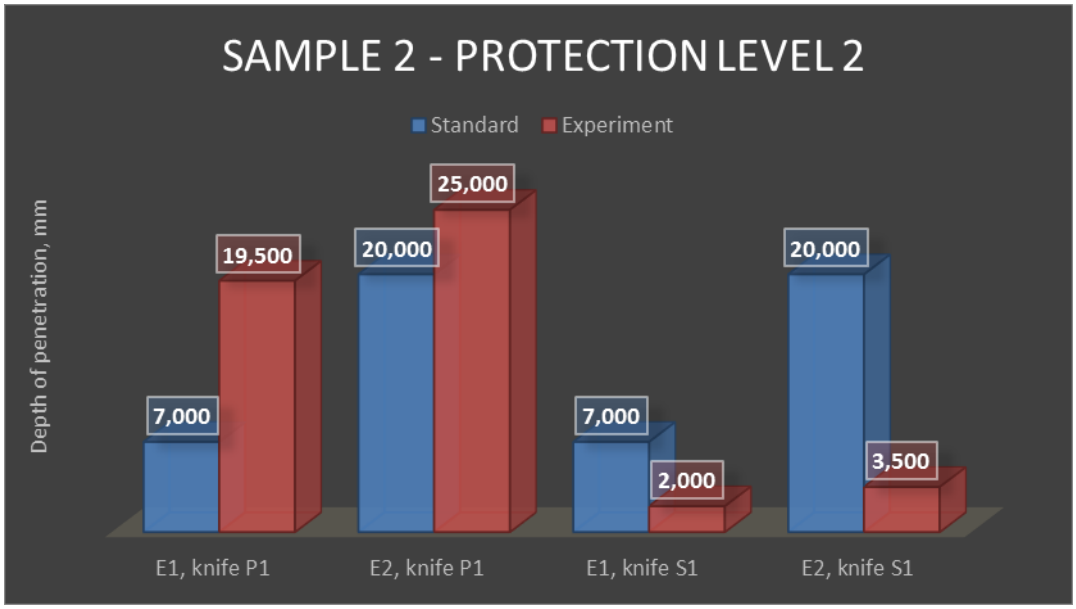

Fig. 6. Sample 2 – results for level 2

Sample 3 - best sample from Group Three

The data obtained from the tests for protection level 1 are presented in the table 7 and Fig. 7, for level 2 - in tab. 8 and Fig. 8.

Table 7. Sample 3 – results for level 1

Experiment №	Protection level 1						
	Sample 3			Knife type P1	Knife type S1	Knife type P1	Knife type S1
	One sheet weight kg/m^2	Number of sheets	Panel weight kg/m^2	E1=24J±0,50J ≤ 7mm	E1=24J±0,50J ≤ 7mm	E2=36J±0,60J ≤ 20mm	E2=36J±0,60J ≤ 20mm
	0,253	19	4,807	Cut length, mm	Cut length, mm	Cut length, mm	Cut length, mm
	0,373	4	1,492				
	0,800	1	0,800				
			0,165				
	Total		7,264				
1				2,690	0,410	3,900	0,810
2				2,760	0,420	3,790	0,830
3				2,810	0,490	3,890	0,790
4				2,880	0,400	4,020	0,800
5				2,690	0,410	4,080	0,840
6				3,020	0,400	3,820	0,830
Average cut length, mm				**2,808**	**0,422**	**3,917**	**0,817**
Average depth of penetration, mm				**6,5**	**1,0**	**9,0**	**2,0**
Standard requirements				**7,0**	**7,0**	**20,0**	**20,0**
Covers a standard				**yes**	**yes**	**yes**	**yes**

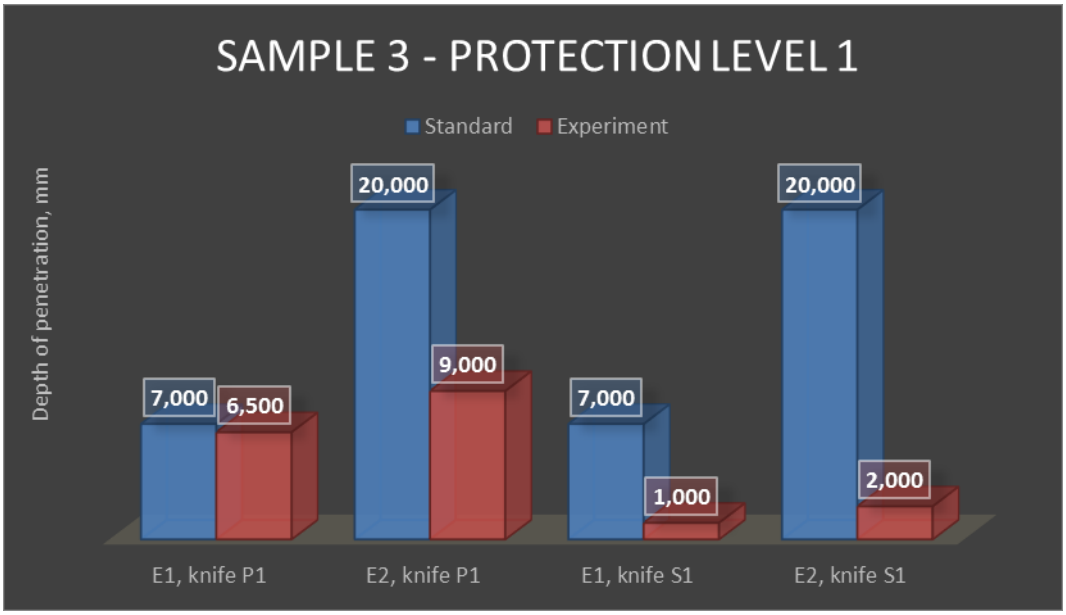

Fig. 7. Sample 3 – results for level 1

Table 8. Sample 3 – results for level 2

Experiment №	Protection level 2						
	Sample 3			Knife type P1	Knife type S1	Knife type P1	Knife type S1
	One sheet weight kg/m^2	Number of sheets	Panel weight kg/m^2	E1=33J±0,60J, ≤ 7mm	E1=33J±0,60J, ≤ 7mm	E2=50J±0,70J ≤ 20mm	E2=50J±0,70J ≤ 20mm
	0,253	19	4,807	Cut length, mm	Cut length, mm	Cut length, mm	Cut length, mm
	0,373	4	1,492				
	0,800	1	0,800				
			0,165				
	Total		7,264				
1				3,130	0,650	7,690	3,660
2				3,080	0,720	7,340	3,680
3				2,900	0,710	7,720	3,460
4				2,960	0,690	7,540	3,950
5				2,990	0,740	7,620	3,860
6				3,120	0,730	7,780	3,760
Average cut length, mm				**3,030**	**0,707**	**7,615**	**3,728**
Average depth of penetration, mm				**7,0**	**1,8**	**18,0**	**9,4**
Standard requirements				**7,0**	**7,0**	**20,0**	**20,0**
Covers a standard				**yes**	**yes**	**yes**	**yes**

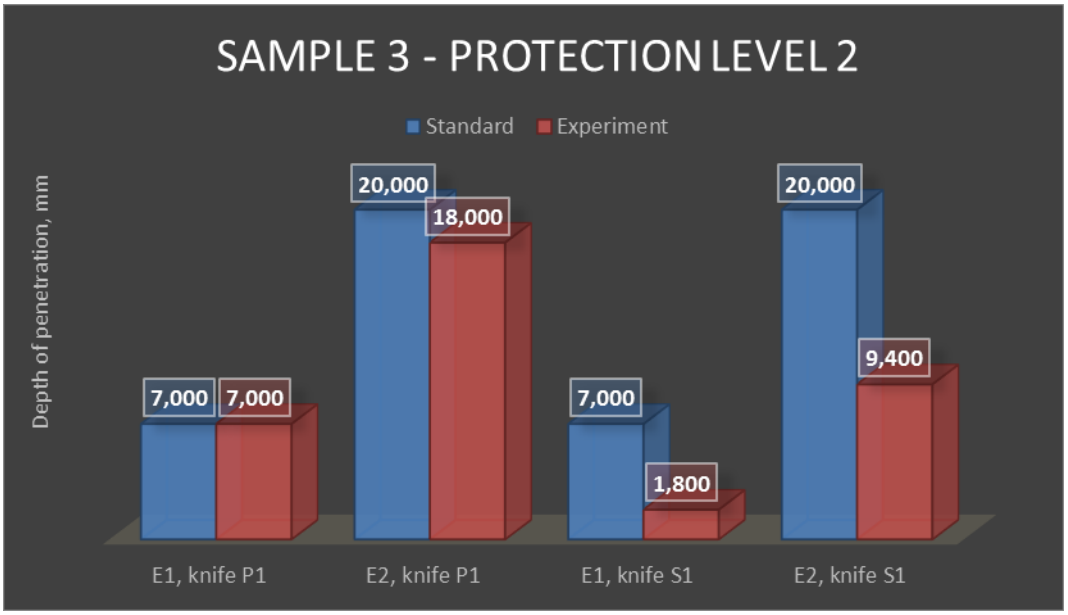

Fig. 8. Sample 3 – results for level 2

4. DISCUSSION AND CONCLUSIONS

Requirements of the Ministry of Defense and the Police of the Republic of Bulgaria

According to the requirements of the Ministry of Defense of the Republic of Bulgaria, the bulletproof vest shall provide ballistic protection of the torso, groin and neck against the most common rounds of short-barrel weapons (9x19 Para FMJ and .44 Magnum SJHP) and long-barrel firearms caliber 7.62 mm at maximum acceptable depth of deformation on the back 30 mm. In addition to ballistic protection, the bulletproof vest should also protect against cool weapons. The protection against cold weapons must meet the requirements for level 2, according to NIJ standard 0115.00.

The protective area of a vest size L (52-54) should be as follows:

– major part - not less than 0.4 m^2;
– collar - not less than 0.03 m^2;
– groin protector - not less than 0.06 m^2;
– additional inserts - not less than 0.073 m^2 each;
– total 0.490 m^2 (without additional inserts).

The mass of a bulletproof vest size L (52-54) without additional inserts (armored panels) shall not exceed 4.6 kg and with additional inserts not to exceed 11 kg.

Penetration by engineering knife PSDB / P1 and PSDB / S1 is not acceptable:

– more than 7 mm, at impact energy El =33 J ±0,60J;
– more than 20 mm, at impact energy E2=50 J ±0,70J.

According to the "Public procurement documentation for the conclusion of a framework agreement with the subject: Supply of funds for individual ballistic protection" for the police of the Republic of Bulgaria on, the bulletproof vest must provide reliable protection against bullets of pistols and revolver cartridges, as well as against cold weapons.

In terms of ballistic protection, the armored vest should provide a level of protection IIIA + 7.62x25mm TT according to NIJ 0101.04 (protection from: 9x19 Para FMJ with V=436±9 m/s; 44

Magnum SJHP with V=436±9 m/s and 7.62x25mm TT with V=440±9 m/s) along its entire protective area. The maximum depth of deformation at the rear side should not exceed 44 mm.

In terms of protection against cold weapons the armored vest should provide a level of protection 2 according to NIJ standard 0115.00.

The protective area of a vest size L (52-54) should be as follows:

– major part - not less than 0.385 m^2;

– panel for protection of groins - not less than 0.05 m^2;

– total 0.435 m^2.

The mass of size L (52-54) bulletproof vest without additional inserts should not exceed 4.2 kg and that of the armor plate should not exceed 1.7 kg.

Contemporary state of the bulletproof vests with level of ballistic protection IIIA + 7.62x25 mm made in Bulgaria and the region is studied. On this basis, a comparison of several of them in terms of their weight and their protection area with the results of the three models described in the report and with the requirements of the Ministry of Defense and the Police of the Republic of Bulgaria is presented in Table 9.

Table 9. A comparison of the results achieved with national requirements and the commercially available bulletproof vests

Requirements for Level IIIA + 7.62x25mm (sizes 52-54, base and groins panel)	**Protective area, m^2**	**Mass, kg**	**Ballistic protection**	**Piercing protection**
DoD of R. of Bulgaria	up to 0.490	up to 4.6	indent up to 30 mm	Level 2 - NIJ 0115.00
Police of R. of Bulgaria	up to 0.390	up to 4.2	indent up to 44 mm	Level 2 - NIJ 0115.00
Tested samples	**Results achieved**			
Sample 1	0.490	4.01	IIIA+ 7.62x25mm with indent less than 30 mm	Level 1 - NIJ 0115.00
	0.435	3.55		
Sample 2	0.490	3.63	IIIA+ 7.62x25mm with indent less than 30 mm	without NIJ 0115.00
	0.435	3.22		
Sample 3	0.490	3.56	IIIA+ 7.62x25mm with indent less than 30 mm	Level 2 - NIJ 0115.00
	0.435	3.16		
Bulletproof on the market	**Characteristics**			
Bulgaria Mars Armor® Police tactical	0.40	4.38	IIIA+ 7.62x25mm NIJ 0101.04	without NIJ 0115.00
	0.40	4.40	IIIA+ 7.62x25mm NIJ 0101.04	Level 1 - NIJ 0115.00
	0.40	4.80	IIIA+ 7.62x25mm NIJ 0101.04	Level 2 - NIJ 0115.00
Bulgaria Mars Armor®	0.55	4.29	IIIA+ 7.62x25mm NIJ 0101.04	without NIJ 0115.00

Military tactical	0.55	5.59	IIIA+ 7.62x25mm NIJ 0101.04	Level 1 - NIJ 0115.00
	0.55	6.10	IIIA+ 7.62x25mm NIJ 0101.04	Level 2 - NIJ 0115.00
Serbia Mile Dragic Production M-MD vest	0.44	-	IIIA+ 7.62x25mm NIJ 0101.04	Level 2 - NIJ 0115.00
Serbia Mile Dragic Production Tactical vest	0.482	-	IIIA+ 7.62x25mm NIJ 0101.04	Level 2 - NIJ 0115.00
Serbia Mile Dragic Production Sentry vest	0.408	-	IIIA+ 7.62x25mm NIJ 0101.04	Level 2 - NIJ 0115.00
Turkey Garanti Police tactical vest	0.609	3.610	IIIA NIJ 0101.06	without NIJ 0115.00
Turkey Garanti Special forces tactical vest	0.603	3.020	IIIA NIJ 0101.06	without NIJ 0115.00
Ukraine TEMP 3000 Model Corsair M3m	0.680	3.0 4.2 4.8 5.1 5.0 6.0	IIIA NIJ 0101.04	without NIJ 0115.00
Russia OOO „TECHEXPORT“ Model “Shipka-Y”	0.430	3.9	IIIA+ 7.62x25mm NIJ 0101.04	Level 2 - NIJ 0115.00

As a result of the analysis, evaluation and comparison of results of the conducted test it can be concluded that:

Sample 1 covers protection level 1 for both types of test blades - P1 and S1. Level 2 is only covered with a test tip type S1.

Sample 2 meets the penetration requirements for protection levels 1 and 2 only with a test tip S1. Using P1 test blade, the protection levels are not covered.

Sample 3 covers the penetration requirements for level 1 and 2, both with a Type S1 test blade and a P1 test blade.

Sample 3 has the lowest panel weight per unit area of the three test specimens discussed herein and also shows the best puncture resistance. It meets the requirements for protection against piercing with the so-called engineering knives for level of protection 2 according to NIJ 0115.00 and for level of protection KR2 according to HOSDB2007 Part 3. “Knife and Spike Resistance”.

All test samples have previously been tested for ballistic resistance and meet the requirements for level IIIA according to NIJ 0101.04 and NIJ 0101.06, further resisting to 7.62x25 FMJ RN cartridge.

In the process of improving the structure of the bulletproof vests in terms of puncture resistance, reducing weight and increasing their protective area, it is advisable to use combinations of different

protective materials in manufacturing flexible protective panels providing maximum synergy protection. The materials used in Sample 3 are exactly the same, therefore it showed the best protective properties.

The results of the studies can be used and implemented in practice. A bulletproof vest with flexible ballistic panels manufactured from the combination of materials used in Test Sample 3 will meet the requirements for ballistic resistance of the Ministry of Defense and the Police of the Republic of Bulgaria and will allow for producing bulletproof vest with reduced weight and/or increased protection area which will be competitive both at the national and the international market.

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