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

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Abstract

This report presents the results obtained in a study aimed at optimizing the protective properties, in regard to ballistic resistance, of flexible ballistic panels of bulletproof vests with reduced panel weight. Attention is focused on one of the most commonly used bulletproof vests in Bulgaria - those with a level of protection IIIA, according to NIJ (standards of the US National Institute of Justice). The test was conducted in compliance with the conditions and methodology regulated in one of the leading standardization documents in this area - NIJ 0101.04 - Ballistic Resistance of Personal Body Armor. The weapons and their ammunitions used in Bulgaria and the region have been taken into account, as a result of which the samples of flexible ballistic panels of bulletproof vests are additionally tested with two more types of weapons. Analysis and evaluation of the obtained results are presented.

Keywords: *ballistic resistance, bulletproof vests, standardization documents, optimal combinations of materials, flexible ballistic panels, reduced panel weight, weapons and ammunitions*

1. INTRODUCTION

Recently, with the growing terrorist acts, insurgency, riots and disorders on ethnic and religious grounds around the world, the safety of security guard and defense personnel, as well as the critical infrastructure security and protection, have become more and more relevant issue. Important elements in this respect are the means for individual ballistic protection, which significantly contribute to enhancing the safety of officers in the performance of their duties, minimizing the risk to their health and life. One of these means is the modern multi-component armored vest, to which requirements in terms of weight reduction, increased flexibility and comfort of wearing, with improved bullet and fragment resistance, are constantly increasing. An essential role in this regard is played by the materials used in the bulletproof vests production, and in particular those used in the flexible ballistic panel, which is a basic defensive part of the armor. All this necessitates extensive research in this area in order to find optimal combinations of materials for manufacturing flexible ballistic panels of bulletproof vests with reduced panel weight, preserving and even improving their protective properties.

2. MATERIALS AND METHODS

In this report, attention is focused on one of the most widespread bulletproof vests in the country and region - those with a level of protection IIIA, according to the NIJ (standards of the US National Institute of Justice). Depending on their intended use, these bulletproof vests can be used for military, police and civilian needs.

The purpose of the tests is finding optimal combinations of materials used in the flexible ballistic panels with a level of protection IIIA, with the weight of the panel being reduced. Achieving the set goal would bring significant benefits:

- ensuring better physical condition and activity of workers wearing armor-vests throughout the working day or shift;
- possibility of increasing the protective area of the bulletproof vest;

– reducing the likelihood of injuries.

The requirements of the Ministry of Defense of the Republic of Bulgaria and those of the Police of the Republic of Bulgaria, the protective properties and the weight of the bulletproof vests with level of protection IIIA available on the market, as well as the weapons and their ammunition used in Bulgaria and the region, have been taken into consideration during the testing and evaluation of the obtained results.

The protective properties of the finished product are assessed in accordance with the strict requirements set out in the standardization documents which are used internationally.

2.1. Test samples

Twenty six test samples of flexible ballistic panels of a bulletproof vest composed of different combinations of ballistic materials are subjected to testing. This report presents the results of the three of them, showing optimal results with respect to the panel weight and the protective properties required by the NIJ for protection level IIIA.

The different combinations of the test samples are selected on the basis of a detailed and comprehensive study of the materials used in ballistic protection, analysis and evaluation of their physical and mechanical characteristics and taking into account all their advantages and disadvantages.

All test samples are composed of a base and an extra pack that are stationary in a case made of 100% polyester. In the base and the extra pack UHMWPE (high molecular weight polyethylene) and p-aramid fibers, as well as ceramic materials, are used which are more commonly used in the hard ballistic panels and inserts (armored panels). Polyurethane elastic resin is used to bond the two types of materials (textile and sprinkled layer). The ceramic sprinkled layers are applied with the vibro-sieve, then stabilized with a fine layer of lacquer.

Sample 1

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

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

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

The tests are carried out with equipment and apparatuses under the terms and conditions meeting the requirements of NIJ 0101.04.

Environmental conditions of the test field (Figure 1):

- Temperature: 23°C;
- Relative air humidity: 54%;
- No wind and rain.

Ballistic stability tests have been conducted for a level of protection IIIA according to standard NIJ 0101.04. In addition to the test cartridges specified therein, the test samples are also tested with cartridges 357 SIG FMJ FN (used for level of protection IIIA according to NIJ standard 0101.06) and 7.62x25 FMJ RN (GOST P 50744-95). This is done to ensure complex ballistic protection that meets the expected potential threats of the weapons and their ammunition used in Bulgaria and the region. When assessing the protective properties of samples of flexible ballistic panels of the bulletproof vest, the requirements of the Ministry of Defense of the Republic of Bulgaria have also been taken into account in respect of the maximum permissible depth of the indent on the rear face, which should not exceed 30 mm, as well as the vest weight and the minimal required protection area.



Fig. 1. Ballistic resistance test of a flexible ballistic panel of a bulletproof vest under field conditions

The following apparatuses and equipment are used to perform the tests:

- bullet velocity measuring apparatus with precision of ± 0,1 m/s;
- bearing structure for underlying material - a biological tissue simulator;
- biological tissue simulator;

- elastic fastening belts;
- stand for attaching ballistic barrels;
- scales with range up to 10 kg;
- caliper with a range of 0 to 150 mm;
- calibrated roulette with range to 10 m;
- ballistic barrels for cartridges caliber: 9x19mm; .44 Magnum; .357 SIG;
- cartridges: 9-mm FMJ RN; .44 Magnum SJHP; .357 SIG FMJ FN.

The necessary test equipment and apparatuses shall be thoroughly inspected and installed in accordance with the test plan diagram set out in Figure 2. The appliances are calibrated according to the requirements of their manufacturers.

The speedometer is switched on in the standby mode before the measurements are taken.

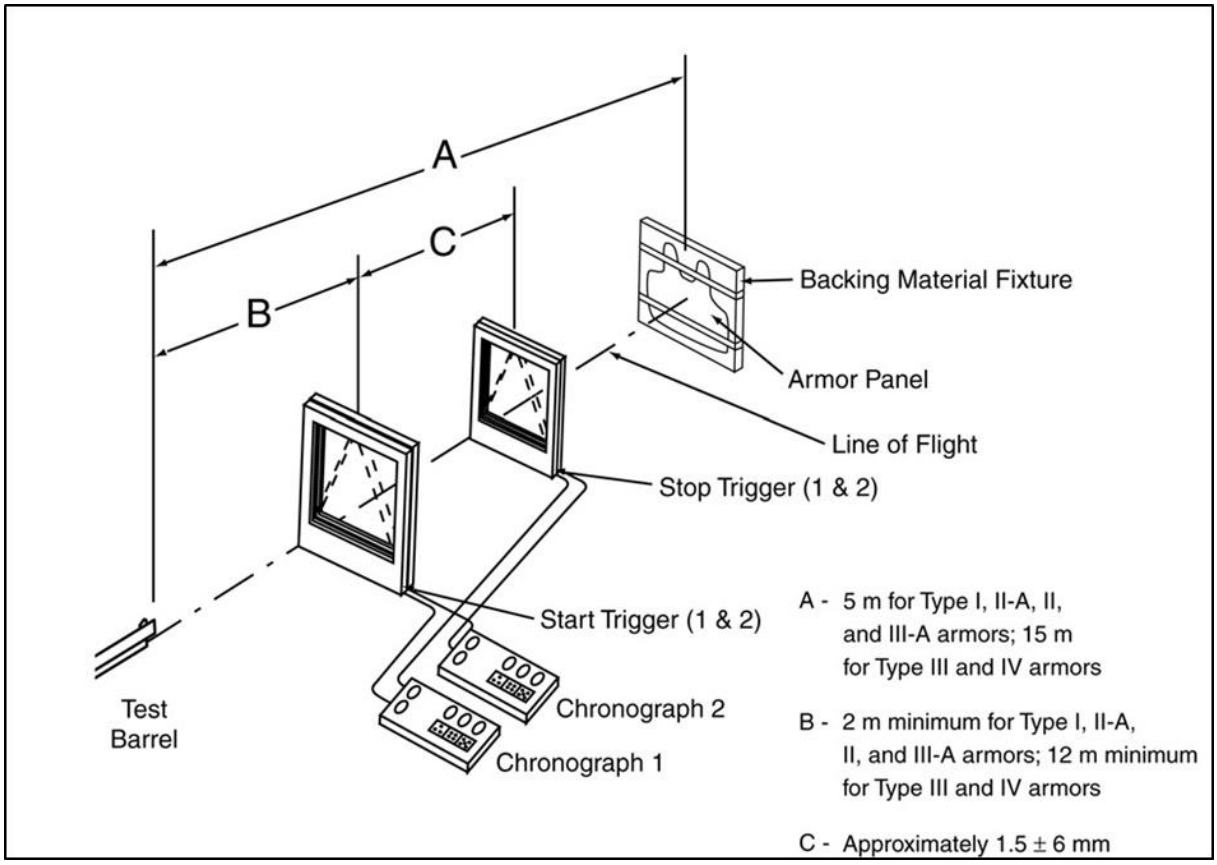


Fig. 2. Schematic of the test field

All test samples of flexible ballistic panels are individually examined for damage, material defects or poor workmanship and have been stored for 12 hours before testing under the relevant polygon conditions.

The locations where the shots will fall are marked on the test sample of a flexible ballistic panel of a bulletproof vest. They must be at least 76 mm from the edge of the test sample and the distance between two separate hits must be at least 51 mm.

The armored vest sample is stationary fixed to the biological tissue simulator vertically, perpendicular to the direction of shooting by means of elastic belts positioned so as not to fall into the marked firing points.

All test specimens are tested for ballistic resistance under the test conditions specified in Table 1, giving the characteristics of the test cartridges used.

Table 1. Test conditions

Test Bullet №	**№ 1**	**№ 2**	**№ 3**	**№ 4**
According to standard	NIJ 0101.04	NIJ 0101.04 NIJ 0101.06	NIJ 0101.06	ГОСТ Р 50744-95
Test Bullet/Cartridge	9-mm FMJ RN	.44 Magnum SJHP	.357 SIG FMJ FN	7,62x25 FMJ RN
Rifle Bullets type	Full Metal Jacket Round Nose 	Semi Jacketed Hollow Point 	Full Metal Jacket Flat Nose 	Full Metal Jacket Round Nose 
Type	pistol	revolver	pistol	pistol
Bullet Weight, g	8	15,6	8,1	5,5
Reference Velocity, m/s	436 ± 9	436 ± 9	448 ± 9	440 ± 9
Ballistic barrels for cartridges	9 x 19mm	.44 Magnum	.357 SIG	7,62 mm

The shooting is carried out with a ballistic barrels from a stand.

After each **hit counted*** (according to NIJ 0101.04), the test sample is carefully removed and thoroughly inspected for the damage caused by the bullet, the depth of the indent in the biological tissue simulator is measured and recorded in the test report, then the surface of the biological tissue simulator is flattened.

***Counted hit:** This is a hit where the bullet falls into the test specimen at an angle of not more than ±5° of the desired firing angle, not closer than 76 mm from the end of the ballistic panel and no closer than 51 mm to the previous hit, at an impact velocity of not less than the required speed for the specified test bullet according to Table 1.

A hit where the bullet has hit at a distance of less than 76 mm from the edge of the test sample or less than 51 mm from a previous hit or at a speed greater than the required speed but has not caused partial penetration or complete drilling of the test sample and has left an indent on the biological tissue simulator with a depth of less than 30 mm, the hit is considered.

Drilling of the test piece of a bulletproof vest shall not be permitted.

No penetration with an indent depth greater than 30 mm is allowed on the biological tissue simulator.

3. RESULTS

The following information shall be recorded for the ballistic stability of the test pieces:

– bullet velocity;

– counted hits;

– impact of the bullet on the test specimen.

For each counted hit, a partial or complete perforation of the bulletproof sample as well as a deformation of the indent depth of more than 30 mm is accepted.

Partial or complete perforation of the bullet proof sample as well as deformation with the indent depth of more than 30 mm at a speed greater than the maximum indicated in Table 1 shall not be considered as a hit and the result shall not be registered in the record.

The absence of partial or complete perforation of the bulletproof sample and the presence of a deflection with an indent depth of less than 30 mm at a speed greater than the maximum indicated in Table 1 shall be considered a hit and the result shall be registered in the record.

The data obtained from the tests for the three samples of flexible ballistic panels showing optimal panel weight and ballistic stability results are presented in tabular form and are illustrated by diagrams, so they can be analyzed and used for assessment of the protective properties of combinations of materials as follows:

– in Table 2 and Figure 3 – for Sample 1;

– in Table 3 and Figure 4 – for Sample 2;

– in Table 4 and Figure 5 – for Sample 3.

Table 2. Results for Sample 1

Shots №	Sample 1 - Test Bullet								Angle of Incidence, °
	9-mm FMJ		.44 Magnum SJHP		.357 SIG FMJ FN		7,62x25 FMJ RN		
	Velocity, m/s	BFS, mm	Velocity, m/s	BFS, mm	Velocity, m/s	BFS, mm	Velocity, m/s	BFS, mm	
1.	429	16	442	30	447	25	446	20	0°
2.	433	17	436	29	447	26	449	21	0°
3.	428	15	443	30	450	28	446	20	0°
4.	437	18	443	30	439	20	448	20	0°
5.	428	15	441	29	444	24	438	18	30°
6.	430	15	440	28	445	24	440	19	30°
Bullets passed, count	0	0	0	0	0	0	0	0	-
Bullets held, count	6	6	6	6	6	6	6	6	-

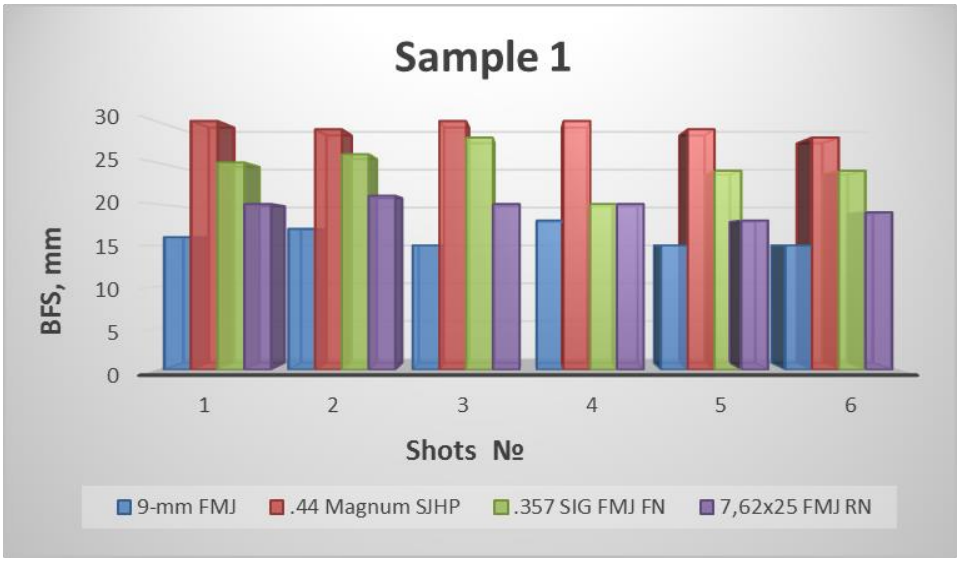


Fig. 3. Results for Sample 1

Table 3. Results for Sample 2

Shots №	Sample 2 - Test Bullet								Angle of Incidence, °
	9-mm FMJ		.44 Magnum SJHP		.357 SIG FMJ FN		7,62x25 FMJ RN		
	Velocity , m/s	BFS, mm	Velocity , m/s	BFS, mm	Velocity , m/s	BFS, mm	Velocity , m/s	BFS, mm	
1.	435	19	444	30	449	27	447	23	0°
2.	436	20	442	30	450	28	451	24	0°
3.	433	18	443	30	451	29	446	23	0°
4.	435	19	442	29	451	28	449	24	0°
5.	433	17	444	30	449	26	448	22	30°
6.	430	16	443	29	447	26	446	23	30°
Bullets passed, count	0	0	0	0	0	0	0	0	-
Bullets held, count	6	6	6	6	6	6	6	6	-

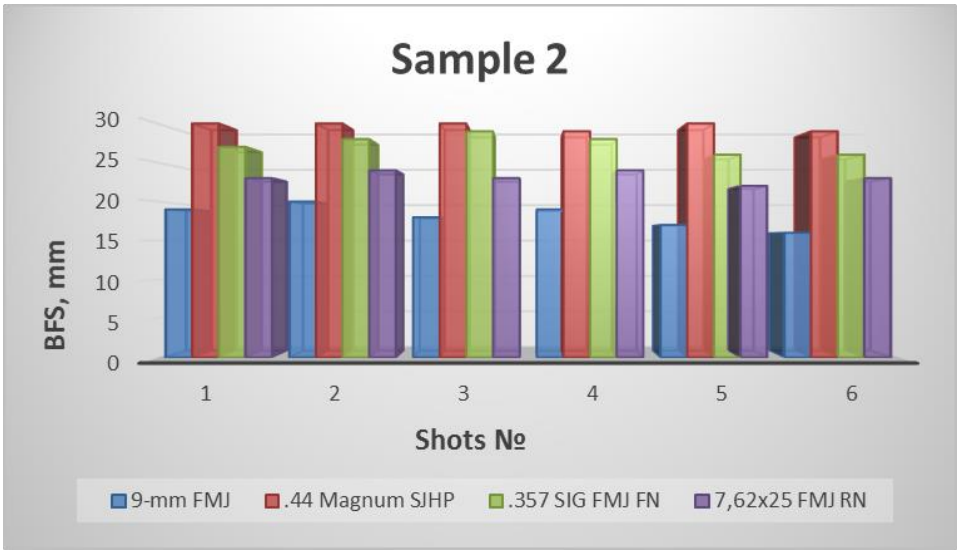


Fig. 4. Results for Sample 2

Table 4. Results for Sample 3

Shots №	Sample 3 - Test Bullet								Angle of Incidence, °
	9-mm FMJ		.44 Magnum SJHP		.357 SIG FMJ FN		7,62x25 FMJ RN		
	Velocity , m/s	BFS, mm	Velocity , m/s	BFS, mm	Velocity , m/s	BFS, mm	Velocity , m/s	BFS, mm	
1.	437	18	443	30	450	28	447	22	0°
2.	432	16	445	30	452	29	446	22	0°
3.	437	18	444	30	449	28	450	23	0°
4.	436	18	441	29	449	28	447	22	0°
5.	432	16	437	29	448	24	446	21	30°
6.	436	17	446	30	449	26	443	20	30°
Bullets passed, count	0	0	0	0	0	0	0	0	-
Bullets held, count	6	6	6	6	6	6	6	6	-

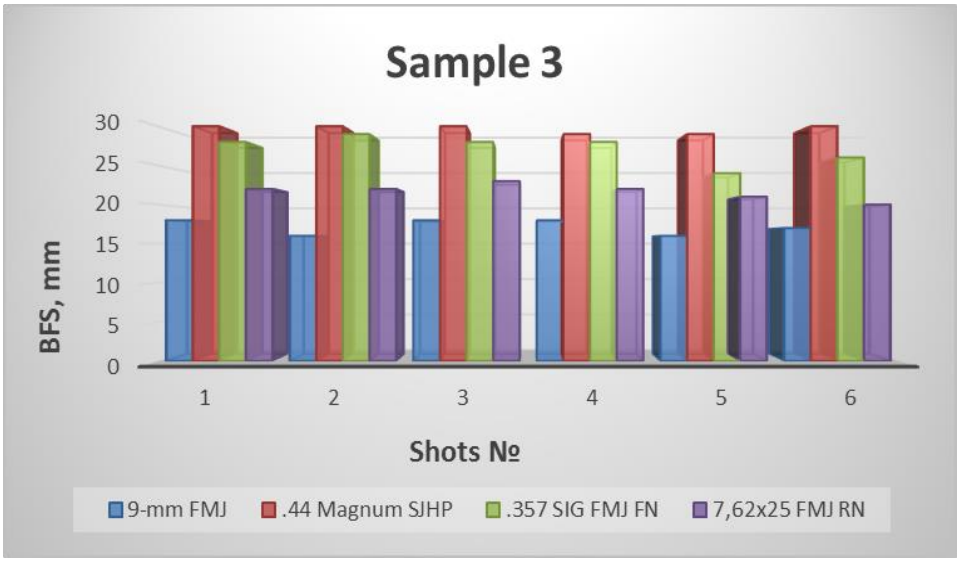


Fig. 5. Results for Sample 3

After processing and analysis of the ballistic stability, the test results for the tested combinations are summarized and shown in Table 5 and Figure 6.

Table 5. Summarized results for Samples 1, 2 and 3

Name	9-mm FMJ	.44 Magnum SJHP	.357 SIG FMJ FN	7,62x25 FMJ RN
	Average value of BFS, mm			
Sample 1	16,000	29,333	24,500	19,667
Sample 2	18,167	29,667	27,333	23,167
Sample 3	17,167	29,667	27,167	21,667

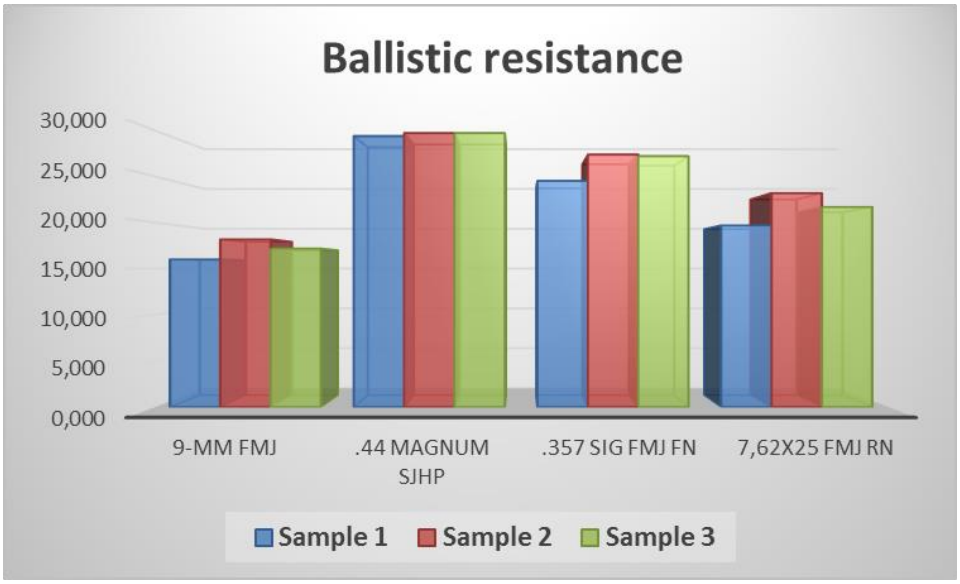


Fig. 6. Summarized results for Samples 1, 2 and 3

4. DISCUSSION AND CONCLUSIONS

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 weapon 9x19 Para FMJ and .44 Magnum SJHP, and through the additional inserts to provide enhanced protection of vital torso areas against armor-piercing bullets for long-barrel firearms up to 7.62 mm. The maximum depth of deformation on the back should not exceed 30 mm.

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.

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 armor 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.

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.

The area weights of the three tested samples showing the best results in ballistic resistance and panel weight, as well as those required by the Ministry of Defense (MoD) and the Ministry of Interior (MI) of the Republic of Bulgaria, are given in Table 6.

Table 6. A comparison of the achieved results with the requirements

	Protective area, m^2	**Weight, kg**	**Area weight, kg/m^2**
MoD requirement	0,49	4,6	9,388
MI requirement	0,435	4,2	9,655
Sample 1	0,49 0,435	4,01 3,55	8,169
Sample 2	0,49 0,435	3,63 3,22	7,408
Sample 3	0,49 0,435	3,56 3,16	7,264

The processing and analysis of the data obtained from ballistic resistance tests carried out on the above-described test samples of flexible ballistic panels or armored vests give the following conclusions:

The three test samples meet the ballistic resistance sequirements for protection level IIIA according to NIJ 0101.04 and NIJ 0101.06, and further resist to 7.62x25 FMJ RN cartridge. In this way the requirements of the Ministry of Defense of the Republic of Bulgaria and those of the Police of the Republic of Bulgaria are also covered.

A correlation is observed between the size of the indent and the test cartridge used, which is the same for all three test samples, namely: Magnum SJHP cartridge bullets give the greatest depth of indent. Depth decreases little when shot with a 357 SIG FMJ FN cartridge, and more when shooting with a 7.62x25 FMJ RN cartridge. The smallest indent comes from the 9 mm FMJ RN cartridge bullet.

It was found that from all tested samples the best protective properties in terms of ballistic resistance are shown in Sample 3 which has the lowest area mass.

A bulletproof vest manufactured with the combination of materials used in Test sample 3 will not only meet the ballistic resistance requirements of the Ministry of Defense and the Police of the Republic of Bulgaria with regard to the minimum protection area and the maximum mass but will allow the production of a bulletproof vest with a reduced weight and/or an increased protection area to be competitive on both the domestic and the international market.

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