INVESTIGATION OF VARIOUS COMBINATIONS OF MATERIALS USED IN ARMORED VESTS FOR KNIFE PENETRATION PROTECTION

Assoc. Prof. Dr. Eng. Nikolova, V. and Prof. Dr. Eng. Petkov, St.
Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamic Centre "Acad. Angel Balevski"
at the Bulgarian Academy of Sciences (IMSETHAC–BAS), Sofia, Bulgaria
E-mail: valya_g@abv.bg; s_petkov63@abv.bg

Abstract: The report presents investigation of the protective characteristics against knife penetration of several combinations of materials used in armored vests. Experimental results for each combination obtained by testing with two types of knives at various energies of impact are analyzed and interpreted.

Key words: *blade, energy, penetration*

INTRODUCTION

The problem of the individual protection is of exceptional relevance in the contemporary complex international and internal situation, related to the occurrence of local conflicts, terrorism, violations of the personality, migration phenomena and others. This necessitates adequate measures of opposition from the security and defense authorities to maintaining the health and safety of soldiers, security personnel, controlling public disorders, police operations, personal protection and critical infrastructure protection.

The use of new materials and their effective combinations is important in this respect, in order to provide resistance to the wide variety of weapons - firearms and cold weapons.

EXPERIMENTAL PART

For the past two to three decades there has been remarkable progress in the experimental and theoretical study of dynamic processes in the penetration of solids bodies in different environments. The accumulated factual experimental material characterizes the physical-mechanical properties of a large number of different types of solid screens for which different model environments have been proposed to describe the movement in a multi-component environment.

Test equipment and procedure

The experimental equipment for conducting tests of the armored vests resistance against stabbing with a knife consists of a specially designed test stand and speed measuring equipment.

The stand is designed to meet the requirements of the two leading standards in the field - NIJ 0115.00 and HOSDB 2007 - Part 3, regulating the test 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 for testing all levels of protection regulated in the aforementioned standardization documents. Coverage of a given level of protection is ensured by performing a number of penetrations with a specified impact energy that must be provided by free fall of the piercing blade from a height calculated for that purpose. The integral testing system is carefully designed to allow the mass to fall under its own weight and to hit the test piece of a bulletproof vest at the specified 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 tests were conducted under the conditions and in the order, described in the methodology developed for this purpose, for the protection levels specified in *Table 1*.

Table 1. Protection levels

Protec-tion 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 provides protection against low energy threats with impact energy ranging from 24 J ± 0.50 J to 36 J ± 0.60 J. The armor must withstand a break with energy of impact of 24 J with the maximum allowable penetration of the blade not greater than 7 mm. After that, a power impact test of 36 J was performed, where the maximum allowable penetration of the blade must not be more than 20 mm.

Level 2 provides protection from medium energy threats with impact energy ranging from 33 J ± 0.60 J to 50 J ± 0.70 J. The armor must withstand puncture impact energy of 33 J with the maximum allowable penetration of the blade not greater than 7 mm. A power impact test 50 J was performed, where the maximum allowable penetration of the blade must not more than 20 mm.

Testing was carried out with engineering knives (high-quality, factory-made knives with cutting edges). Two types of blades were used - type P1 and type S1, which are the two types of sharpened weapons most commonly used in attacks.

Blade type P1 (*Fig.1*) is representative of a simple small knife, it is smaller and thinner and has one sharpened edge, whereas a blade type S1 (*Fig.2*) is representative of a knife used by the commandos, or a large kitchen knife - it is bigger, thicker and has two sharpened edges. Both types of test blades are hardened, with Rockwell hardness, scale C, within the range 50–140 HRC and have a pointed tip and a stable base.

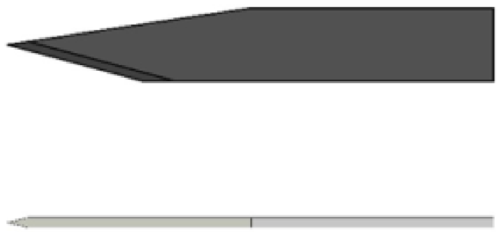

Fig.1. Test blade type P1.

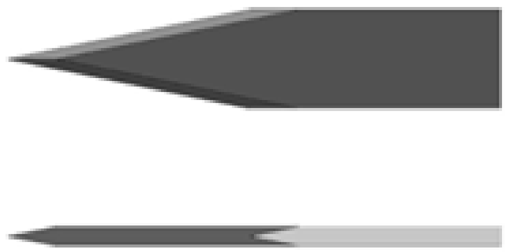

Fig.2. Test blade type S1.

The tests were carried out at a meeting angle of the test blade and the test specimen 0° relative to the normal.

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

The drop height is measured from the tip of the test blade to the surface of the bulletproof test specimen.

$$h = E/mg \qquad (1)$$

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 accuracy of 1 g

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

The places of penetrations were marked on the armor. Then the bolster material, indicator paper and the test sample of a armored vest were placed, ensuring their immobility tightening them to the base of the stand by means of elastic straps of width, fastened with Velcro® strips. After that the test blade was mounted.

An correct measurement of the impact velocity was provided by a pair of photoelectric light screens mounted at a distance of 25 mm ± 2 mm from the point of impact of the test sample of the armored vest, providing measurement with an accuracy up to ± 0.2 m/s.

When conducting the puncture resistance tests to meet the requirements at a given level, a series of tests according to *Table 2* were performed for each combination of materials composing a flexible ballistic panel of a armored vest.

Table 2. Test conditions

Number of punches	Angle of meeting	Test blade type	Energy level
6	0°	P1	E1
6	0°	P1	E2
6	0°	S1	E1
6	0°	S1	E2

The measured results were converted to the depth of penetration according to the penetration depth conversion tables. The results were recorded in a test report.

The average arithmetic values of the measured penetration depths were determined using the equation (2).

$$d\text{cp} = \frac{1}{n}\sum_{i=1}^{n} di \qquad (2)$$

where:

d is the depth of penetration, mm

n is the number of experiments conducted

i is a sequential experiment number.

Test samples

Tests have been carried out to determine the protective properties of flexible ballistic flasks of armored vests in terms of their resistance to penetration, made up of different combinations of materials.

The tested samples of flexible ballistic panels were divided into three groups, depending on the materials used and their combinations.

A packet of Dyneema® SB51 sheet with a density of 253 g/m^2 was used for the core packet of each group. The base packet weight was 4.807 kg/m^2.

The additional packages represent a certain combination of materials and are different for each specimen.

The main and additional packs were placed in an outer 100% Polyester pouch weighing 0.165 kg/m^2.

For all specimens, the face (impact) surface was on the side of the additional package.

First group of samples

To the base package is added an additional package made up of a different combination of Dyneema® SB51 based materials on which SiC, Al_2O_3 and polyvinyl chloride were strewd. For bonding between the two materials resin is used.

Second group of samples

To the base package is added an additional package made up of a different combination of Kevlar® XP based materials on which SiC, Al_2O_3 and polyvinyl chloride were strewd. For bonding between the two materials resin is used.

Third group of samples

An additional package is added to the basic package, made up of a different combination of textile-based materials on which Al_2O_3 and SiC were strewd. For bonding between the two materials resin is used. To some combinations Kevlar® XP or Dyneema® SB51 were added.

EXPERIMENTAL RESULTS ANALYSIS

As a result of the analysis, evaluation and comparison of the results from the conducted tests for penetration resistance of the samples, it was obtained, as follows:

- For the First group of samples:

Sample 1.1 covers the penetration requirements for level 1 and for level 2 only with a test tip S1. Using a P1 test blade, the protection levels are not covered.

Sample 1.2 covers level 1 for both types of test blades (P1 and S1). Level 2 is only covered with a test blade type S1. This is the lowest weight sample of the group, which shows the best puncture resistance. The sample has been subjected to a ballistic resistance test for the protection level IIIA tested.

Sample 1.3 covers level 1 with both types of test blades (P1 and S1). Level 2 is only covered with a test blade type S1.

Sample 1.4 covers the penetration requirements for protection levels 1 and 2 only with a S1 test blade. Using a P1 test blade, the protection levels are not covered.

- For the Second group of samples:

All samples in this group (Sample 2.1, Sample 2.2, Sample 2.3 and Sample 2.4) meet the penetration requirements for Level 1 and Level 2 with a type S1 test blade only. Using the P1 type test blade, the protection levels are not covered.

Sample 2.2 has the lowest weight of this group. It also exhibits the best puncture resistance. This sample has been subjected to a ballistic resistance test for the protection level IIIA tested.

- For the Third group of samples:

Sample 3.1 and Sample 3.4 meet the penetration requirements for protection levels 1 and 2, both with the type S1 test blade and the type P1 test blade.

Sample 3.2 and Sample 3.3 meet the penetration requirements for level 1 with both types of blades (P1 and S1). Level 2 is only covered with a test blade type S1.

Sample 3.4 has the lowest weight of this group. It also exhibits the best puncture resistance. The sample has been subjected to a ballistic resistance test for the protection level IIIA tested.

CONCLUSIONS

1. It was found that from all tested samples the best protective properties with respect to puncture resistance and ballistic resistance are shown by Sample 3.4, which has the lowest overall weight of the panel.

2. In the process of improving the resistance of bulletproof vests various materials can be used such as Dyneema SB51, Al_2O_3, SiC, which, in the tested combination (Sample 3.4), show optimum results in weight of the panel and the protective properties against piercing.

3. The specimens additionally tested for ballistic resistance cover the requirements for level of protection IIIA, according to NIJ 0101.04 and NIJ 0101.06, further supporting a 7.62x25 FMJ RN cartridge.

4. An armored vest by materials of the combination used in Sample 3.4 is manufactured, which will meet the requirements of the Ministry of Defense of the Republic of Bulgaria and those of the Police of the Republic of Bulgaria in terms of weight and protective properties and will be competitive on both the national and the international market.

LITERATURE

[1] NIJ 0101.04
[2] NIJ 0101.06
[3] NIJ 0115.00
[4] HOSDB 2007