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# Optimization of ballistic vest for protective atrocity and stabbing

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## ABSTRACT

In the optimization of the ballistic vest to prevent atrocity and stabbing, two fabrics were utilized: a ballistic plate made of synthetic fiber Endumax® Shield XF 33 and Twaron® SRM 509. Test the thickness and weight of the fabric before being tested for atrocity and stabbing protection. Finally, test the ammunition protection. The results were as follows: (1) The thickness of Twaron® and Endumax® fabrics. The average was 0.44300 and 0.22000 mm., and the standard deviation and variance were low. (2) The weight of Twaron® and Endumax® fabrics. The average was 1.99300 and 1.45100 g., and the standard deviation and variance were low. (3) Protective atrocity P1/B at the L2, E1 level, the average energy is 33.176 joules. The average blade depth is 0 mm., within the specified standard. Protective atrocity P1/B at the L2 and E2 levels has an energy average of 50.52 joules. The average blade depth is 1 mm., which is also within the specified standard criteria. (4) Protective stabbing SP/B at the L2 and E1 levels, the energy average is 33.54 joules. The average blade depth is 0 mm., within the specified standard. Protective stabbing SP/B at the L2 and E2 levels, the average energy is 49.894 joules. The average blade depth is 7.6 mm., which is also within the specified standard criteria. (5) Ballistic vest plate test with 0.44 MAG SJHP ammunition 240 g. The average bullet velocity was 437.78 m/s. The collapse footprint is 19.6 mm., within the specified standard. Tested with 9 mm. FMJ ammunition 124 g. The average bullet velocity was 438.15 m/s. The collapse footprint is 18 mm., which is also within the specified standard criteria. From various test results, it can be concluded that the ballistic vest provides excellent protection according to military standards and is suitable for security officials' work.

*Keywords:* Ballistic vest, Atrocity and stabbing, Ammunition, Blades, Sharp materials

## INTRODUCTION

The situation of violence in Thailand is not only in the southern border provinces alone [1, 2] but also expanding to other provinces, including in the major urban areas of various regions, all of which have more severe problems. Reducing losses in addition to the aforementioned measures for operators to perform the use of special equipment and equipment for the body protection of operators [3] to prevent the danger of gunshots or various types of weapons with bad intentions [4], such as ballistic vests, shields, and personal weapons.

The ballistic vest in use today is primarily used to protect short-barreled handgun shells for soft armor and long-barreled bullets for hard armor [5-7]. Nevertheless, in some cases, ballistic vests are worn by officers in urban or community areas to prevent and suppress riots, rallies, and protests. In order to prevent potential harm and reduce staff losses and injuries from past events, it is the duty of officers to prevent and suppress various incidents. Officers were frequently injured in clashes and the use of weapons by the group.

For the above reasons, the researcher, therefore, has an idea to develop the currently used ballistic vests to be more effective. In addition to protecting against bullets at the desired level. For officers to wear to work in urban areas or communities. In the case of preventing or suppressing non-violent events without using guns. However, other dangerous weapons are used instead, such as pointed weapons or sharp objects. For protection against atrocity and stabbing from sharp objects. By adding another layer of protection against atrocity and sharp objects to the front of the ballistic vest in addition to the general vest. If not in use, this atrocity and stabbing resistant insert can be removed from the ballistic vest.

## MATERIALS AND METHODS

By adopting the fabric that has ballistic properties and the addition of the front armor plate





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that has the ability to protect against sharp and pointed objects. To enhance the effectiveness of the ballistic vest, it should have two types of protection in 1 body [8].

In carrying out this research, we designed experimented with and selected fabrics to determine the patterns by stacking the 2 types of fabrics on top of each other, fabric type 1 was laminated fiber with an average weight of 0.108 grams per square inch. Fabric type 2 was coated woven fabric with an average weight of 0.294 grams per square inch, divided into three patterns. To try the best protection and suitability: (1) Endumax® Shield XF 33 quantity 26 layers + Twaron® SRM 509 quantity 2 layers (2) Endumax® Shield XF 33 quantity 32 layers + Twaron® SRM 509 quantity 3 layers and (3) Endumax® Shield XF 33 quantity 36 floors + Twaron® SRM 509 quantity 3 layers. The number of layers of the three types was determined to determine the best protection and overall weight of the suit to meet military standards.

**Table 1** Fabric types and layer.

| Fabric | Layer |
|---|---|
| Endumax® + Twaron® | 26 + 2 (28) |
| Endumax® + Twaron® | 32 + 3 (35) |
| Endumax® + Twaron® | 33 + 3 (36) |

*Production process*

Begin by gathering information about the fabric. Manufacturing and testing processes are used in research to optimize ballistic vests for protection against atrocity and stabbing (Figure 1). Then, test the properties of Twaron® SRM 509 and Endumax® Shield XF 33 fabric as follows: the fabric thickness test using the ASTM D 1777-96 standard and the weight of the fabric test using the ASTM D 77-96 standard.

**Figure 1** Fabric for ballistic vest according to the pattern.

Production of ballistic plate with a prototype for protective atrocity and stabbing from Twaron SRM® 509 synthetic fiber and Endumax® Shield XF 33 fabric. According to the details of the pattern of two types of fabric and the size of the ballistic vest specified.

Production of the ballistic vest with a prototype for protective atrocity and stabbing (Figure 2). Sizes can be set as a standard for easy sewing, such as sizes S, M, L and XL or may be customized according to the user's body size. Use of Teijin conex (Xfire) flame retardant fabrics that can prevent fire or splashes. And a ballistic vest is designed to be worn over the inside for the operation of conditions outside of war or general terrorism. Cotton fabric has lightweight properties. Easy to maintain, suitable for the climate in Thailand or Southeast Asia.

**Figure 2** Sewing the body of ballistic vest.

Wear a ballistic plate with a waterproof shielded atrocity and stabbing protection plate inside. Both the front and rear ballistic vests then buttoned the shirt's front (Figure 3).

**Figure 3** Ballistic vest for protective atrocity and stabbing.

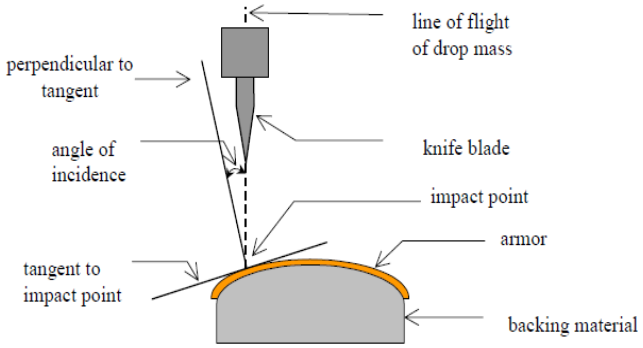


**Figure 4** Atrocity and stabbing test kit.

*Atrocity and stabbing test procedure*

Tested for atrocity and stabbing according to HOSDB Body Armor Standards for UK Police (2007) (Figure 4) at least five times per sample [9, 10]. The test chamber has a temperature of 21 ± 6 °C (70 ± 10 °F) and a relative humidity of 50 ± 20%.



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Prepare a test plate on a support stand and set a distance of 25 ± 2 millimeters from the blade or pointed material. Then, determine the power level used in the test. Which is divided into three levels (Figure 5):

Level 1: The lowest energy value is 24 ± 0.50 joules, and the energy value above level 1 is 36 ± 0.60 joules.

Level 2: The lowest energy value is 33 ± 0.60 joules, and the energy value above level 1 is 55 ± 0.70 joules.

Level 3: The lowest energy value is 43 ± 0.60 joules, and the energy value above level 1 is 65 ± 0.80 joules.

Put four layers of sponge plate on top, the middle layer is 1 layer of foam plate, and the bottom layer is 2 layers of rubber plate. Then, test according to the required standards. The falling speed of the test blade was ± 0.05 m/s. (± 0.16 ft/s).

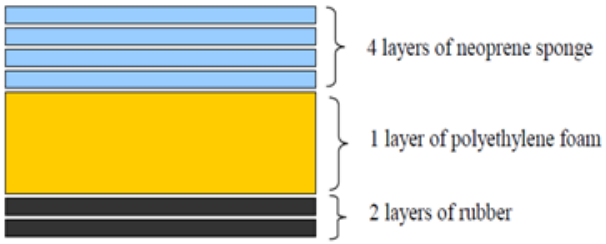


**Figure 5** Test support plate.

*Ballistic vest armor test procedure*

Tested at level IIIA according to NIJ. STANDARD-0101.04 [11]. Utilize two types of ammunition in the test are 9 mm. FMJ, 124 grams. And 0.44 MAG SJHP, 240 grams, shown in table 2. Ensure that the laboratory shall be an enclosed (Figure 6), controlled environment, or protected field. Able to prevent hazards during standardized testing.

**Table 2** Bullet type and speed.

| Bullet | Speed |
|---|---|
| 9 mm. FMJ (124 gr.) | 1430 ± 30 ft/s (436 ± 9.1 m/s) |
| 0.44 MAG SJHP (240 gr.) | 1430 ± 30 ft/s (436 ± 9.1 m/s) |

**Figure 6** Laboratory.

Test processing equipment includes computer-processing bullets, guns, and ammunition velocity measurement devices.

Determine the point of fire on the ballistic vest. There are two types of test point determination, which are 6-point assignment and 12-point assignment, depending on each level of testing according to the NIJ. STANDARD-0101.04 standard (Figure 7) [12].

The test firing points of 6 points are divided into 4 test shots at an angle of 0 degrees, namely positions 1, 2, 3 and 6. In contrast, at an angle of 30 degrees, the number of 2 points is 4 and 5 at least 2 inches apart and at least 3 inches from the edge of the ballistic vest.

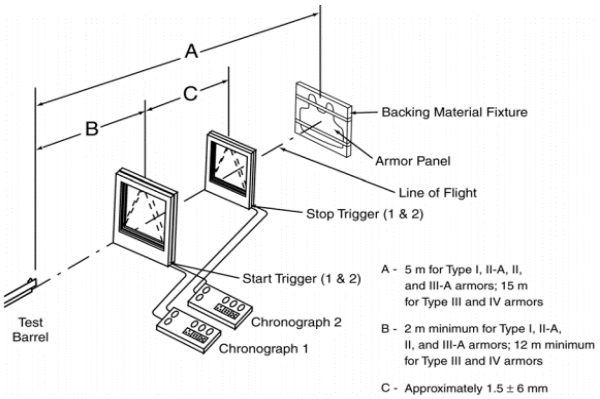


**Figure 7** Placement of tools and testing equipment.

Test to determine the collapse distance of the backing material (Figure 8). Using a spherical steel pendulum released at a height of 2 meters 5 times freely, the values were taken five times to find the mean.

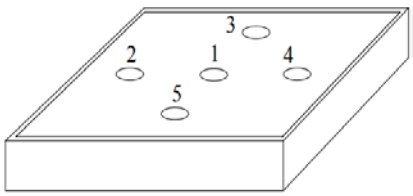


**Figure 8** The position of the test steel pendulum.

Fire a test shot with a shotgun at the specified location. with different caliber projectiles at 0-degree angles and 30-degree angles (Figure 9).

**Figure 9** Test setup.





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Fire a test and check the bullet's penetrating effect. Measure the collapse distance of the backing material (Figure 10).

**Figure 10** Determination of the collapse distance.

## RESULTS AND DISCUSSIONS

According to research studies and tests according to the HOSDB Body Armor Standards for UK Police (2007) [13], the results are as follows:

*Results test fabric properties*

Test results of thickness weight and density of fabric according to table 3.

*Results test atrocity and stabbing armor*

Test results of atrocity and stabbing armor, which are divided into three types above, were tested in this armor plate test, 26 layers of plates with Endumax® Shield XF 33 + 2 layers of Twaron® SRM 509 were tested, and the results are shown in table 4 and table 5.

*Results ballistic vest armor*

The results of testing the properties of the fabric for ballistic vest protection were a atrocity and stabbing resistant armor plate containing 32 layers of Endumax® Shield XF 33 + 3 layers of Twaron® SRM 509, fire tested with 0.44 MAG SJHP, 240 grams ammunition, and an atrocity and stabbing resistant armor plate with 36 layers of Endumax® Shield XF 33 + 3 layers of Twaron® SRM 509. Fire tested with 9 mm. FMJ, 124 grams. ammunition. Test results are shown in table 5 and table 6.

**Table 3** Test result of thickness weight and density fabric.

| **Fabric** | **Twaron® SRM 509** | | | **Endumax® Shield XF 33** | | |
|---|---|---|---|---|---|---|
| Item | Thickness (mm.) | Weight (g.) | Density (g.m$^2$) | Thickness (mm.) | Weight (g.) | Density (g.m$^2$) |
| 1 | 0.44 | 1.98 | 198 | 0.22 | 1.46 | 146 |
| 2 | 0.45 | 2.00 | 200 | 0.23 | 1.45 | 145 |
| 3 | 0.44 | 1.99 | 199 | 0.22 | 1.45 | 145 |
| 4 | 0.44 | 2.00 | 200 | 0.21 | 1.45 | 145 |
| 5 | 0.45 | 1.99 | 199 | 0.22 | 1.44 | 144 |
| 6 | 0.44 | 2.00 | 200 | 0.22 | 1.45 | 145 |
| 7 | 0.45 | 1.99 | 199 | 0.22 | 1.46 | 146 |
| 8 | 0.44 | 1.99 | 199 | 0.23 | 1.44 | 144 |
| 9 | 0.44 | 2.01 | 201 | 0.22 | 1.45 | 145 |
| 10 | 0.44 | 1.98 | 198 | 0.21 | 1.46 | 146 |
| Average | 0.443 | 1.984 | 199.3 | 0.22 | 1.451 | 145.1 |
| SD. | 0.00483 | 0.03098 | 0.94868 | 0.00667 | 0.00738 | 0.73786 |
| variance | 0.00002 | 0.000098 | 0.90000 | 0.00004 | 0.00005 | 0.54444 |

**Table 4** Test result of P1/B test at levels L2, E1 and L2, E2 with SP/B at levels L2, E1

| **NO.** | **Sample Description** | **Blade (P1, S1, Spike)** | **Angle (deg.)** | **Desired Energy** | **Drop Height** | | | **Blade Mass (g)** | **HRC** | **Time (ms)** | **Velocity 1 (m/s)** | **Impact Energy (J)** | **Penet. (mm)** | **Footnotes** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Level** | **J** | **(ft.)** | **(in.)** | | | | | | | |
| 1 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E1 | 33 | 5 | 10 | 19.04 | - 104 | 5.1463 | 6 | 33.11 | 0 | |
| 2 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E1 | 33 | 5 | 10 | 18.92 | - 125 | 5.1229 | 6 | 33.42 | 0 | |
| 3 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E1 | 33 | 5 | 10 | 19.09 | - 148 | 5.1415 | 6 | 33.18 | 0 | |
| 4 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E1 | 33 | 5 | 10 | 19.06 | - 145 | 5.1515 | 6 | 33.05 | 0 | |
| 5 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E1 | 33 | 5 | 10 | 19.03 | - 146 | 5.1458 | 6 | 33.12 | 0 | |
| 6 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E2 | 50 | 8 | 11.5 | 19.08 | - 136 | 4.1536 | 7 | 50.44 | 1 | |
| 7 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E2 | 50 | 8 | 11.5 | 18.99 | - 141 | 4.1448 | 7 | 50.65 | 1 | |
| 8 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E2 | 50 | 8 | 11.5 | 18.95 | - 104 | 4.1477 | 7 | 50.58 | 1 | |
| 9 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E2 | 50 | 8 | 11.5 | 19.06 | - 109 | 4.1524 | 7 | 50.47 | 0 | |
| 10 | GF-BV-RT-A220-01 | P1/B | 0 | L2, E2 | 50 | 8 | 11.5 | 19.08 | - 117 | 4.1527 | 7 | 50.46 | 1 | |
| 11 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E1 | 33 | 5 | 10 | 7.83 | - 112 | 5.1495 | 6 | 33.04 | 0 | |



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| NO. | Sample Description | Blade (P1, S1, Spike) | Angle (deg.) | Desired Energy | Drop Height | | | Blade Mass (g) | HRC | Time (ms) | Velocity 1 (m/s) | Impact Energy (J) | Penet. (mm) | Footnotes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Level | J | (ft.) | (in.) | | | | | | | |
| 12 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E1 | 33 | 5 | 10 | 7.92 | - 103 | 5.1444 | 6 | 33.10 | 0 | |
| 13 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E1 | 33 | 5 | 10 | 7.81 | - 110 | 5.1618 | 6 | 32.88 | 0 | |
| 14 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E1 | 33 | 5 | 10 | 7.85 | - 124 | 5.1577 | 6 | 32.93 | 0 | |
| 15 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E1 | 33 | 5 | 10 | 7.92 | - 145 | 5.13 | 6 | 33.32 | 0 | |

Remarks:
1. Sabot Mass includes the average weight of dampers
2. Holder Mass includes the average weight of blades/spikes
3. Height is for reference only and may vary to meet energy requirements
4. D Time Base is the distance between velocity sensors
5. Standoff Distance is measured from blade tip to armor surface when drop mass is at 0 position (just breaking bottom velocity sensor beam)
6. Impact energy is estimated based on calculated energy and efficiency
7. For energy level E1, a max penetration of 7mm is allowed
8. For energy level E2, a max penetration of 20mm is allowed

Footnotes :
a = Excessive energy (above tol)
b = insufficient energy (below tol)
c = Too close (< 2 in) to armor edge
d = Too close (< 2 in) to backing matl edge
e = Too close (< 2 in) to prior impact
f = Reliable measurement not possible
g = impact on seam
h = Threat instrument bent
i = Threat instrument broke
j = Unfair double strike (bounce)
k = Other (See remarks)

**Table 5** Test result of SP/B at level L2, E2

| NO. | Sample Description | Blade (P1, S1, Spike) | Angle (deg.) | Desired Energy | Drop Height | | | Blade Mass (g) | HRC | Time (ms) | Velocity 1 (m/s) | Impact Energy (J) | Penet. (mm) | Footnotes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Level | J | (ft.) | (in.) | | | | | | | |
| 1 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E2 | 50 | 8 | 11.5 | 7.95 | - 108 | 4.1807 | 7 | 49.73 | 3 | |
| 2 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E2 | 50 | 8 | 11.5 | 7.83 | - 114 | 4.1812 | 7 | 49.72 | 6 | |
| 3 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E2 | 50 | 8 | 11.5 | 7.83 | - 134 | 4.1752 | 7 | 49.86 | 8 | |
| 4 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E2 | 50 | 8 | 11.5 | 7.89 | - 148 | 4.1658 | 7 | 50.09 | 17 | |
| 5 | GF-BV-RT-A220-01 | SP/B | 0 | L2, E2 | 50 | 8 | 11.5 | 7.84 | - 126 | 4.1666 | 7 | 50.07 | 4 | |

Remarks:
1. Sabot Mass includes the average weight of dampers
2. Holder Mass includes the average weight of blades/spikes
3. Height is for reference only and may vary to meet energy requirements
4. D Time Base is the distance between velocity sensors
5. Standoff Distance is measured from blade tip to armor surface when drop mass is at 0 position (just breaking bottom velocity sensor beam)
6. Impact energy is estimated based on calculated energy and efficiency
7. For energy level E1, a max penetration of 7mm is allowed
8. For energy level E2, a max penetration of 20mm is allowed

Footnotes :
a = Excessive energy (above tol)
b = insufficient energy (below tol)
c = Too close (< 2 in) to armor edge
d = Too close (< 2 in) to backing matl edge
e = Too close (< 2 in) to prior impact
f = Reliable measurement not possible
g = impact on seam
h = Threat instrument bent
i = Threat instrument broke
j = Unfair double strike (bounce)
k = Other (See remarks)

**Table 6** Test result of firing with 0.44 MAG SJHP ammunition, 240 gr.

| Shot No. | Ammo. | Time 1 (usec) | Velocity 1 (m/s) | Time 2 (usec) | Velocity 2 (m/s) | Avg.Vel. (m/s) | Penetration | Footnotes |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 3472 | 438.9 | 3467 | 439.6 | 439.3 | None | DEF. 10mm |
| 2 | 1 | 3485 | 437.3 | 3480 | 437.9 | 437.6 | None | |
| 3 | 1 | 3476 | 438.4 | 3485 | 437.3 | 437.9 | None | DEF. 13mm |
| 4 | 1 | 3489 | 436.8 | 3512 | 433.9 | 435.4 | None | (a) |
| 5 | 1 | 3478 | 438.2 | 3487 | 437.1 | 437.6 | None | (a) |
| 6 | 1 | 3487 | 437.1 | 3498 | 435.8 | 436.4 | None | |

REMARKS :
REQUIRED BLP: 436 m/s.

FOOTNOTES :
(a) SHOT IMPACTED AT A 30° ANGLE.





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**Table 7** Test result of firing with 9 mm. FMJ, 124 gr.

| Shot No. | Ammo. | Time 1 (usec) | Velocity 1 (m/s) | Time 2 (usec) | Velocity 2 (m/s) | Avg.Vel. (m/s) | Penetration | Footnotes |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 3525 | 432.3 | 3534 | 431.2 | 431.8 | None | DEF. 1mm |
| 2 | 1 | 3553 | 428.9 | 3563 | 427.7 | 428.3 | None | |
| 3 | 1 | 3449 | 441.9 | 3459 | 440.6 | 441.2 | None | DEF. 4mm |
| 4 | 1 | 3451 | 441.6 | 3461 | 440.3 | 441.0 | None | (a) |
| 5 | 1 | 3422 | 445.4 | 3432 | 444.1 | 444.7 | None | (a) |
| 6 | 1 | 3473 | 438.8 | 3483 | 437.6 | 438.2 | None | |

REMARKS :
REQUIRED BLP: 436 m/s.

FOOTNOTES :
(a) SHOT IMPACTED AT A 30° ANGLE.

## CONCLUSION

From the research results, the results can be summarized as follows:

The results of the 10-time Twaron® SRM 509 fabric thickness and weight tests. It can be concluded that both types of fabrics have good uniform weight and thickness for the production of cut and stab- resistant armor plates, including ammunition protection.

The result of the test result of the atrocity P1/B at L2, E1 5 times and at L2, E2 5 times, which is within the specified standard, is the blade depth of not more than 25 mm. This means that the fabric has the same standard to prevent cuts from weapons being sharp at a good level.

The results of the test of stabbing armor plate SP/B at level L2, E1 5 times and at level L2, E2 5 times are within the specified standard, i.e., the depth of the blade passing through the armor plate does not exceed 25 mm and that the fabric qualified for stabilization of pointed weapons at a reasonable level in both benchmarks.

The results of the atrocity and stabbing armor plates were tested with 0.44 MAG SJHP, 240 grams, and 9 mm. FMJ, 124 grams ammunition. It showed that the atrocity and stabbing armor plates tested with both types of ammunition showed good protection as standard.

In summary, the results of the research were the results of the fabric test in terms of thickness, weight, atrocity protection, stabbing protection, ammunition protection, power and capability of preventing atrocity and stabbing, and ammunition according to the objectives and assumptions set by the standards. The HOSDB Body Armor Standards for UK Police (2007) and the NIJ. STANDARD-0101.04 atrocity and stabbing protection tests are tested. By H.P. WHITE LABORATORY, INC., USA.

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