International Conference KNOWLEDGE-BASED ORGANIZATION
Vol. XXX No 3 2024

EXPERIMENTAL STUDY OF TWARON T730 FOR TWO THREATS

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Abstract: *This paper presents the result of impact tests with two threats on panels made of Twaron® fabrics T730. Test were done with special equipment, such as firing bench, used for ballistic testing personal protective equipment. There were tested panels with 15 layers against .357 SIG bullets and 9 mm bullets. Working procedure was according with NIJ Standard 0101.06/2008 Ballistic Resistance of Body Armor. Those two panels demonstrated satisfactory ballistic protection capability against the tested projectiles and were able to stop the projectiles before allowing the panel to fully penetrate. These findings highlight the effectiveness of the panels in protecting against ballistic impact and suggest that they may be suitable for various protective applications.*

Keywords: aramid fabric panel, impact, 357 SIG, 9x19 mm

1. Introduction

The personal protection system has been an essential element of soldiers' personal equipment since the early days of organised warfare. Although the development process has been largely empirical, the vast experience accumulated over thousands of years has led to diversity of highly effective protection systems. Modern innovations, such as high-strength synthetics, have evolved from this tradition to create systems that protect against bullets, fragments and similar threats. As a result of these advances, personal protective equipment is now considered an essential element of equipment in both military and police environments [1, 2].

In the face of both bullets and knives, the fundamental need for body armour remains the same; initially, it must absorb the impact and reduce the kinetic energy of the bullet, and then it disperses this energy without compromising the integrity of the armour or the safety of the wearer. Both objectives must be achieved without causing injury or excessive discomfort to the wearer. In addition to these protection requirements, it is obvious that the protection system must be as comfortable and lightweight as possible [3, 4].

Ballistic impact is a highly complex mechanical process, in which a high-velocity, low-mass bullet is launched from a source at a target it hits, with effects concentrated in the impact zone. The absorption of energy before the bullet penetrates the body and the distribution of this energy between ballistic materials are key to understand principles and effects of energy transfer from the bullet. Advances in high-velocity projectiles and explosive materials have reshaped the dynamics of the battlefield, fuelling the continued development of advanced ballistic

DOI: 10.2478/kbo-2024-0093

protection systems. These protection systems are characterised by low cost, damage resistance, flexibility, ease of wear and comfort, together with an efficient energy absorption capability. Around 1970, the DuPont company introduced the new synthetic fibre (commercially named Kevlar), and later, in 1976, the first flexible ballistic armour made entirely of Kevlar was developed. Subsequently, several new fibres were introduced for the development of flexible protection systems, such as DSM's Dyneema, Honeywell's GoldFlex, Spectra and Teijin's Twaron. Despite their higher cost, they have been promoted as being lighter and offering superior ballistic protection [4, 5, 6, 7].

Aramid fibres have experienced a spectacular development in the manufacture of composites because they stand out for their remarkable properties [8]: good specific tensile strength, low density, very low thermal expansion, vibration absorption, thus shock absorbing, excellent shock and fatigue resistance.

The high-performance fibre Twaron is the flagship product of Teijin Aramid BV "It offers a unique combination of mechanical properties, chemical resistance, excellent durability and thermal stability. It is highly valued in a wide range of industrial sectors for the benefits it brings in many high-performance applications" [8].

Twaron fibres offer a unique combination of characteristics that differentiate it from other synthetic fibres [8]: high strength, high modulus of elasticity, high dimensional stability, excellent thermal resistance, no melting point (degradation only starts at 500°C), good resistance against flammability.

2. Materials and Method

The material used in this research paper is supplied by Teijin, the trade name being Twaron® T730 and it is recommended for body armor. Available fabric styles of Twaron fibres are designated by the codes CT (high tenacity) or T (standard tenacity) followed by a 3-digit number. Key attributes of T730 fabric [8] are: plain weave based on standard tenacity (T), designed for economy-based ballistic performance solutions requiring good bullet and fragmentation resistance. Other properties of Twaron T730 are presented in Table 1.

Table 1 Properties of T730 fabric [8]

Property	**Value**
Linear density [dtexnom]	1680 f1000
Twaron Type	1040
Set [per 10 cm]	
Warp and weft	78 x 78
Areal density [g/m^2]	260
Thickness [mm]	0.4
Minimum breaking strength [N/5 cm x 1000]	
Warp	9.4
Weft	10

Individual ballistic panels can also be formed by sewing and pooling a specific number of unidirectional layers together, which is an accepted method of construction, particularly for personal protective systems worn underneath jacket-type clothing [6]. For each application it is necessary to analyse whether the ballistic panels correspond to the type of threat, and if so, to choose the most technically and economically efficient design.

The sample making process consisted of measuring and marking the material samples (Figure 1), cutting the material

using a cutting machine, forming ballistic panels by sewing together layers of 300 mm x 300 mm, with an area of 0.09 m^2, which places the panels made for this study as the NIJ-C-1 template type (0.09 m^2) for small areas according to NIJ 0101.06/2008 [9].
The panels were sewn together on all four edges to maintain the integrity and order of the layers.


Figure 1: Cutting sheets of fabrics

After the cutting process was performed, they were arranged in 2 panels of 15 layers each for testing with two calibers, .357 SIG and 9x19 mm Luger. The test with the same parameters was repeated three times and the repeatability was good (Figure 3).
The experimental test programme aimed to evaluate the behaviour of the ballistic protection panels made, to the action of 9 mm FMJ and .357 SIG FMJ bullets, through firing and partial verification of compliance with NIJ Standard-0101.06/2008. Partial compliance comes from the fact that in order to obtain a level of protection, testing with two calibers specific to the levels of protection is required. In the case of NIJ 0101.06, the ammunition used corresponds to protection level II (9 mm FMJ ammunition) and protection level IIIA (.357 SIG FMJ ammunition). Three rounds were fired for each test [9].
A range of basic equipment was used to conduct ballistic testing activities:

- the firing bench, the ballistic barrel of the required calibre and the laser sighting system (Figure 2a);
- the velocity measurement system (Figure 2b);
- the sample mounting stand, consisting of a crate filled with ballistic clay, mounting straps, remote-controlled table allowing up-down, left-right movement and angle adjustment system (Figure 2c);
- Photron Fastcam SAZ high-speed camera; the following camera settings were used: frame rates: 20,000 fps, shutter speed: 1/48, resolution: 1024×1024 pixels.

The test conditions that have been followed for testing the ballistic panels are those given in NIJ 0101.06.

3. Results

The first test was to determine the impact resistance of 9 mm bullets for a 15-layer Twaron T730 ballistic panel.
To determine whether the personal protective equipment will provide sufficient protection, the depth of the indentation measured on the rear face of the personal protective equipment must be examined.
According to NIJ 0101.06/2008, all measured backface signature (BFS) depths must be 44 mm or less [9].

a) b) c)

Figure 2: Equipment used in ballistic testing; a) firing bench, b) ballistic chronograph, c) sample mounting stand [10, 11, 12, 13].

Table 2 Experimental results for the panel made of 15 layers of T730, hit by 9 mm FMJ

Hit	Velocity [m/s]	Penetration	Backface signature (BFS) [mm]
1	370	PP*	36
2	376	PP	35
3	372	PP	36

**PP- partial penetration*

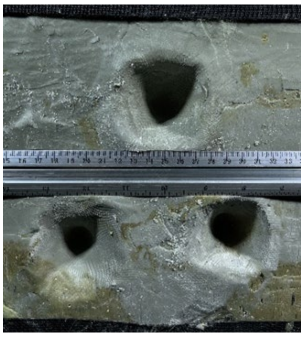

Figure 3: Front view of the backing material after impaction of the sample with 9 mm bullet

Figure 3 shows the BFS on the backing material, indicating that there was no complete penetration of the sample. Figure 4 presents the back of the sample and the marks left by the bullet impact in the material. Deformation and stretching of the material can also be seen.

Figure 5 shows the bullet entry hole on the first layer of the structure, showing how the wires break and the dent left by the bullet.

Three key stages can be seen in Figure 6. Stage I is dominated by deformation and energy dissipation mechanisms; momentum transfer between projectile and fabric leads to an increase in the kinetic energy of the fabric, which initially leads to pyramidal deformation. Stage II is dominated by the friction produced when the yarn is pulled; one or more yarns may be pulled from the fabric and a large amount of energy is dissipated by this sliding friction. Stage III corresponds to the post-impact region, for non-penetrating impact, the projectile may be retained in the fabric, with a rebound.

Figure 4. Back side view of the 15-layer protection system after hit by 9 mm bullet

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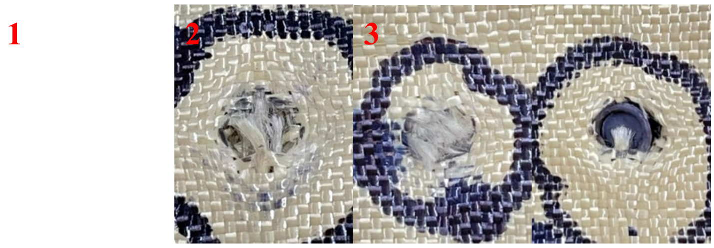

Figure 5. Details of panel front for the impacted zones.

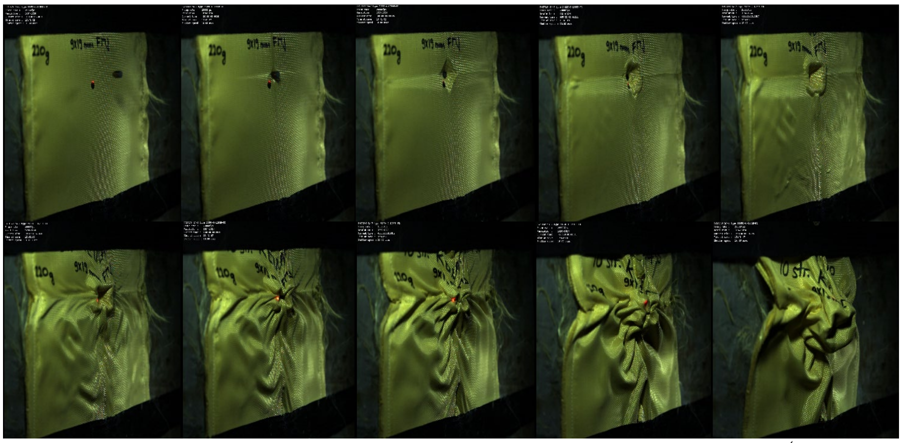

Figure 6. Successive moment of impact of the 9 mm bullet, 1st hit

The second test was to determine the impact resistance for .357 SIG bullets on a 15-layer Twaron T730 ballistic panel. Results are presented in Table 3.

Table 3 Experimental results for the panel made of 15 layers of T730, hit by .357 SIG

Hit	Velocity [m/s]	Penetration	Backface signature (BFS) [mm]
1	445	PP	40
2	447	PP	44
3	447	CP*	-

**CP- complete penetration*

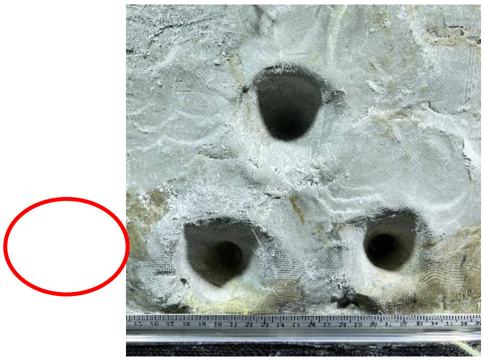

Figure 7: Front view of the backing material after hits with .357 SIG bullet

Figure 7 shows the imprints (characterized by their BFSs) left in the backing material and the impact that penetrated the sample completely (red circle).

Figure 8 shows the back of the sample and the marks left by the bullet impact in the material. The total penetration of the panel can be seen in the red circle.

From Table 4, one may notice that, taking into account average values, projectile .357 SIG is characterized by an impact velocity V_0 with 19.76% higher than that of projectile 9x19 mm, but its kinetic energy is with 44.15% higher as referred to the energy of 9x19 mm bullet.

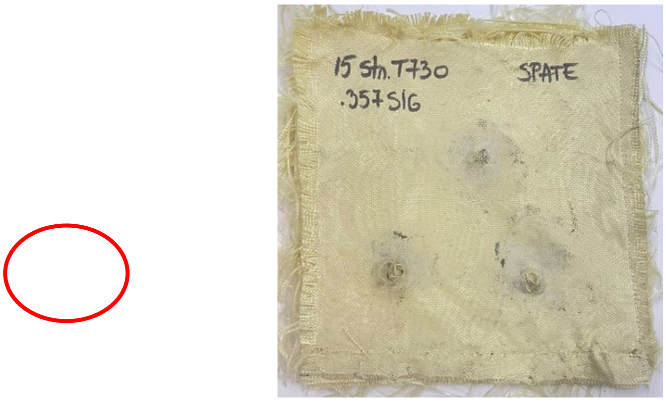

Figure 8: Back side view of the 15-layer panel after testing with .357 SIG bullet

Table 4 Kinetic energy of each projectile

Projectile 9x19 mm			
Hit number	m (kg)	v_0 (m/s)	E (J)
1	0.008	370	548
2	0.008	376	566
3	0.008	372	554
Average	0.008	372.66	555.54
SD		2.49	7.44
Projectile .357 SIG			
Hit number	m (kg)	v_0 (m/s)	E (J)
1	0.00804	445	796
2	0.00804	447	803
3	0.00804	447	803
Average		446.33	800.84
SD		1.15	4.14

*SD – standard deviation

The same stages as in Figure 6 are pointed out in Figure 9, in the frames captured with the impact of the .357 SIG bullet.

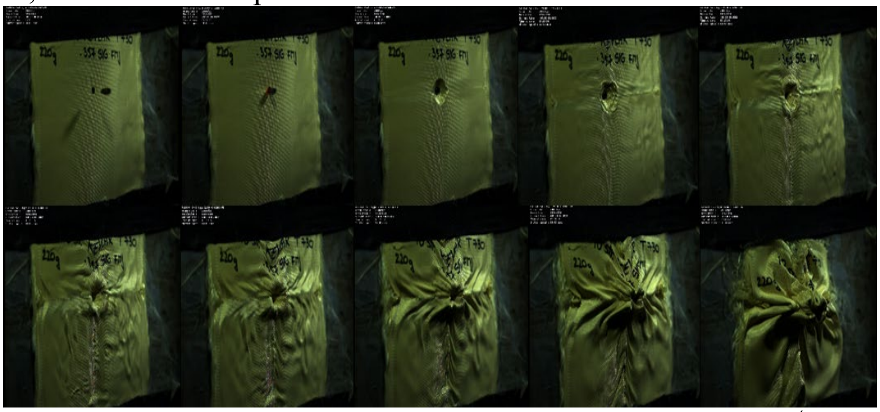

Figure 9: Successive moment of impact of the .357 SIG bullet, 1st hit

Comparing the highest values of BFS, this parameter for .357 SIG is with 22% greater than that obtained for 9x19 mm. These tests have to be continued for in order to fulfil the statistics given in [9], meaning 24 hits for new panels with 15 layers only for the projectile 9x19 mm. For the projectile .357 SIG, panels should be thicker (or with more than 15 layers) in order not to produce complete penetration and BFS lower than the permissive one.

4. Conclusions

Testing with two types of ammunition increased the probability that the protective structure was of high quality, demonstrating a tendency to resist a wider range of potential threats. For the projectile 9x19 mm the panel made of 15 layers of Twaron T730 has acceptable BFS, but for .357 SIG the panel has to be thicker as these preliminary test does not prove compliance with standard requirements.

Acknowledgements

The authors would like to thank colleagues at the Research and Innovation Center for CBRN Defense and Ecology, as they provided effective recommendations for the conduct of this study and also supported the conduct of these tests.

References List

[1] Sparks E., (2012). *Advances in military textiles and personal equipment*, Woodhead Publishing Series in Textiles, 122.

[2] Messiry M El, El-Tarfawy S. (2015). Performance of weave structure multi-layer bulletproof flexible armor. In: *The 3rd conference of the national campaign for textile industries, NRC, "Recent Manufacturing Technologies and Human and Administrative Development"*, 218-225, Cairo.

[3] Chen X., Yang D. (2010). Use of 3D angle-interlock woven fabric for seamless female body Armour: Part I: Ballistic evaluation. *Sage Journals*, Volume 80, Issue 15, https://doi.org/10.1177/0040517510363187

[4] Sun D, Chen X, Wells G. (2013). *Engineering and analysis of gripping fabrics for improved ballistic performance.* J Compos Mater.

[5] Abtew M.A., Boussu F., Bruniaux P. (2021). Dynamic impact protective body armour: A comprehensive appraisal on panel engineering design and its prospective materials. *Defense Technology* 17 2027-2049.

[6] Pîrvu C., (2015). *Contributions to Experimental and Numerical Study of Ballistic Protection Packages with Aramid Fibres*, PhD thesis, "Dunarea de Jos" University, Galati, Romania.
[7] Børvik T., Hanssen A.G., Dey S. (2008). Langberg H., Langseth M., On the Ballistic and Blast Load Response of a 20 ft ISO Container protected with aluminium panels filled with a local mass. Phase I. Design of protective system, *Engineering Structures*, vol. 30, Issue 6, pp. 1605–1620, https://doi.org/10.1016/j.engstruct.2007.10.010.
[8] Teijin – Ballistic materials handbook. Aramids by Teijin.
[9] NIJ Standard 0101.06/2008 - Ballistic Resistance of Body Armor
[10] B472 Precision Light Screen, accessed 10.04.2024, https://www.hpi-gmbh.com/index.php/standard-ballistic/product/view/2/12
[11] B803 Remote Controlled Sample Carrier, accessed 10.04.2024, https://www.hpi-gmbh.com/index.php/protection-material/product/view/3/11
[12] B299 Machine Rest, accessed 10.04.2024, https://www.hpi-gmbh.com/index.php/standard-ballistic/product/view/2/15
[13] B292UR EPVAT Receiver Unit, accessed 10.04.2024, https://www.hpi-gmbh.com/index.php/standard-ballistic/product/view/2/9