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PANELS MADE OF COMPOSITE COATED ARAMID FABRICS, UNDER SPIKE WEAPON ATTACK

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Abstract: *This paper presents the results of puncture tests on panels made of Twaron® fabrics SRM509. Tests were done with the help of the Instron 9340 drop-test machine for evaluating the influence of the number of layers and the striking energy level on the panel. There were tested panels with 16 layers to 40 layers and the energy levels were 24 J, 33 J and 43 J. The spike has the geometry recommended in NIJ Standard 0115.00 Stab Resistance of Body Armor. The failure mechanisms of the panels are presented at macro to micro levels, with the help of photos and images obtained with a scanning electron microscope.*

Keywords: aramid fabric, spike weapon, puncture, composite coating, energy level

1. Introduction

Body armor is designed to protect against various threats, including edged and spiked weapons [1, 2]. Testing spike weapons on body armor provides a realistic simulation of potential combat situations, allowing researchers to understand how effectively the armor can withstand such attacks [3, 4, 5]. Different types of body armor have varying levels of protection against different threats. Testing spike weapons helps identify weaknesses in the armor design or materials, enabling manufacturers to improve their products to better protect the wearer [7, 8, 9]. Edged and spiked weapons are also prevalent in many combat scenarios, especially in close-quarters combat or in situations where firearms are not available or practical. Testing spike weapons ensures that body armor offers comprehensive protection against a wide range of potential threats. Body armor manufacturers often need to adhere to specific standards and regulations set by governmental agencies or industry organizations [3, 4]. Testing spike weapons on body armor may be a requirement to ensure compliance with these standards. Knowing that body armor has been tested against spike weapons instills confidence in the wearer. Law enforcement officers, military personnel, and civilians who rely on body armor for protection need assurance that their equipment will perform as expected in various combat scenarios. Testing spike weapons on body armor is about meeting current standards and driving innovation and continuous improvement in armor technology.

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2. Materials and Method

The material used in this research paper is supplied by Teijin Limited [6], the trade name being Twaron® SRM and it is recommended for knife and spike threats. It incorporates Twaron® CT microfilament fabric covered with a composite made of polymeric matrix and embedded silicon carbide abrasive particles. Other properties of Twaron SRM509 fabric are: surface density of abrasive particles 127 g/m^2, surface density of coated fabric 426 g/m^2.

There is done a test campaign, using Instron 9340 drop-test machine, well instrumented for measuring force, displacement, velocity and absorbed energy. The panels have the dimensions 130 mm x 130 mm and the thickness depens on the number of layers that are attached by cross sewing in the corners. The panel and the backing materials (Table 1) are pressed by a steel ring with 0.3 MPa. Dimensions of spike weapon are those specified in [4].

Figure 2 presents the stages of puncture process, taking into account the force evolution and description in [10]: I – the spike force on the panel in increasing, almost linearly, till a peak value, during this stage there is no yarn breakage, but the panel and backing material deformation; II – the stage start with a force decrease, meaning the the first layer damaging and then the force increases again till a maximum value and the last stage is characterized by the decrease of the force measured on the spike till zero. The duration of these stages depend on panel thickness and the energy level of the weapon.

a) b)

Figure 1: a) Panel and beaking materials, b) the spike

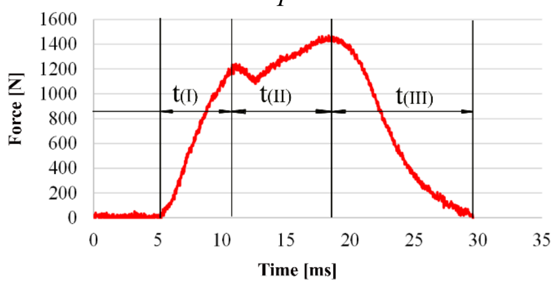


Figure 2: Example of stages on the spike strike, at energy of 24J, on a panel made of 16 layers

The sequence of materials in one test is (taking into account the direction of spike striking): the panel, one polyart paper, three layers of thin sponges of thickness 8 mm, 1 sponge of 30 mm thickness, 2 layers of 2x6 mm rubber at the bottom.

The test with the same parameters was repeated three times and the repeatability was good (Figure 3).

Table 1 Characteristics of the backing components used in this study

Component	Specifications	Supplier from Romania
Sponge	25 kg/m^3, type HR, pressure resistance 2000 kPa, 8 mm thick	Intex Conect SRL Giurgiu
Soft sponge	35 kg/m^3 density, type HR, pressure resistance 2500 kPa, 30 mm	Intex Conect SRL, Giurgiu
SBR rubber technical plate -	6 mm thick, smooth, black, 1400 mm wide Hardness 65±5°Shore A, 6mm thick	SC Arte Rubber Distribution SRL

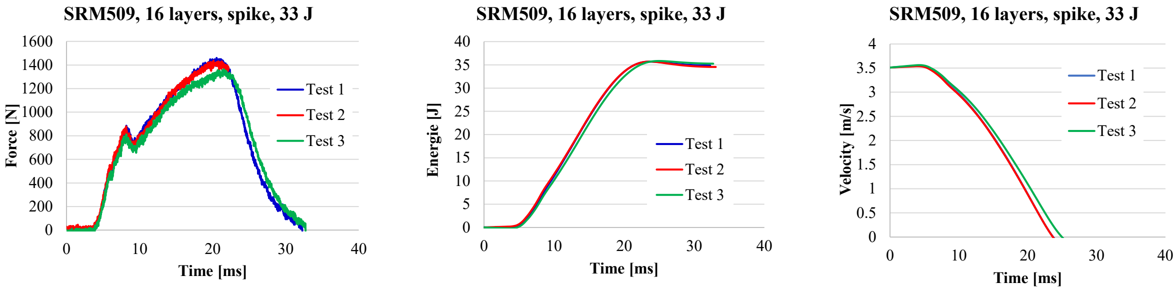


Figure 3: Evolution in time of a) force, b) absorbed energy and c) spike velocity

3. Results

The force increases with the number of layers in the panel, for each striking energy level (Figure 4). Except for panels with 32 layers and 40 layers, the curves have a peak, followed by a low-slope plateau and a decrease of force. The slope of this decrease is greater for thicker panels. For the lower level of energy (24 J), the duration of the puncture process is around 20 ms, longer for thinner panels, but for the following tested energy levels (33 J and 43 J), puncture time decreases with the number of layers (Figure 5). This figure points out the weighting of stages for each test duration (as average values of three tests). Figure 6 presents the average values of maximum force (F_{max}) during penetration.

For each energy level, F_{max} increases with the number of layers, reaching a maximum value of 2400 N for 43 J and 40 layers. These are the only test conditions for which the penetration was partial.

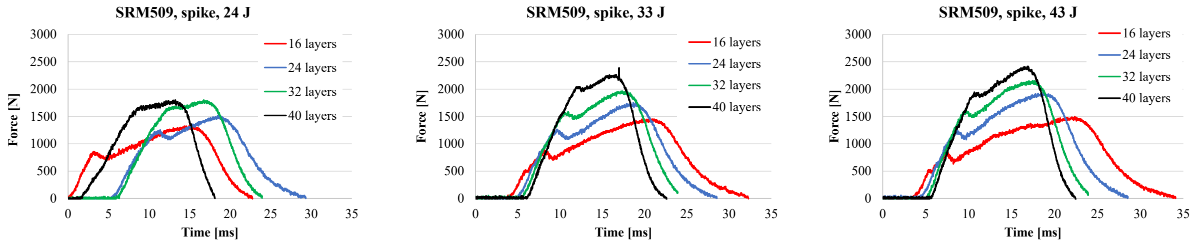


Figure 4: Influence of energy strike and the number of layers

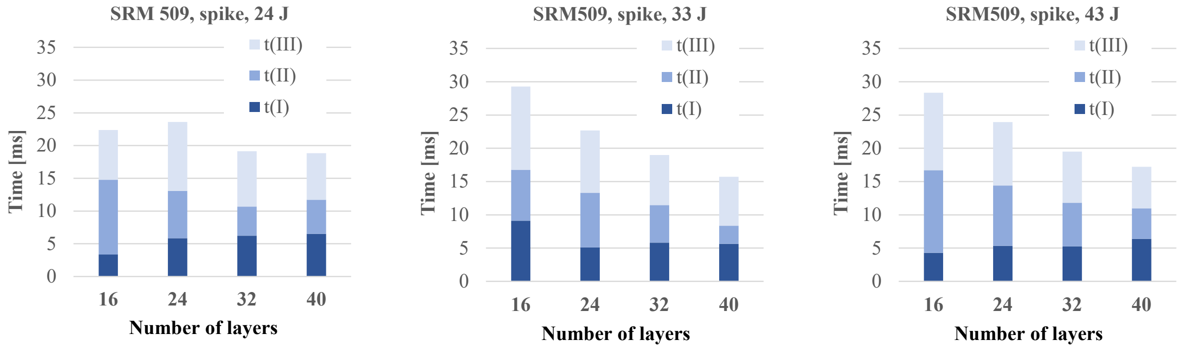


Figure 5: Influence of striking energy and number of layers on the time of puncture process

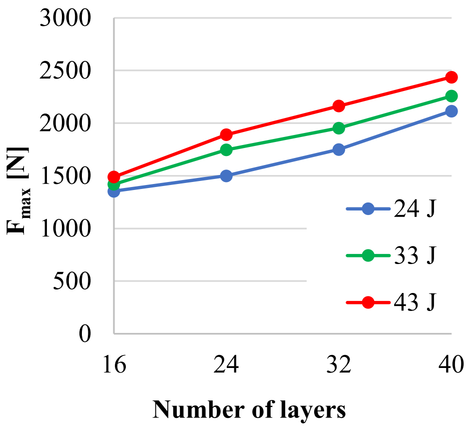


Figure 6: Average values for F_{max}

4. Failure Mechanisms

Figure 7 presents a synthesis of failure mechanisms characterizing spike weapon attack on protective panels made of fabrics. The following photos take into account the scale of failure mechanisms: macro (Figure 8), meso (Figure 9) and micro (Figures 10 and 11). Figure 6 underlines that spike is a particular weapon, designed for puncturing and penetrating. The orifices on the panel face are very similar, even if the striking energy is different. Unlike a knife, which has a blade with various edges, a spike has a single pointed end. It could be more efficient at piercing through materials, including flesh and bone, causing severe damage with less effort. While a knife can cause serious injury through slashing or stabbing motions, a spike is primarily focused on penetration. This means that a spike can potentially reach deeper into the body, hitting vital organs or major blood vessels more easily. The depth of penetration can lead to more severe injuries and increase the likelihood of fatal wounds. A spike lacks defensive capabilities. Its singular focus on penetration means that it is primarily suited for offensive actions. When compared to a knife [11], a spike presents a smaller target for defence. Its pointed end can be harder to see and predict, especially in low-light or chaotic situations. This makes it more challenging for a potential victim to defend against or avoid an attack using a spike, increasing its effectiveness as a weapon.

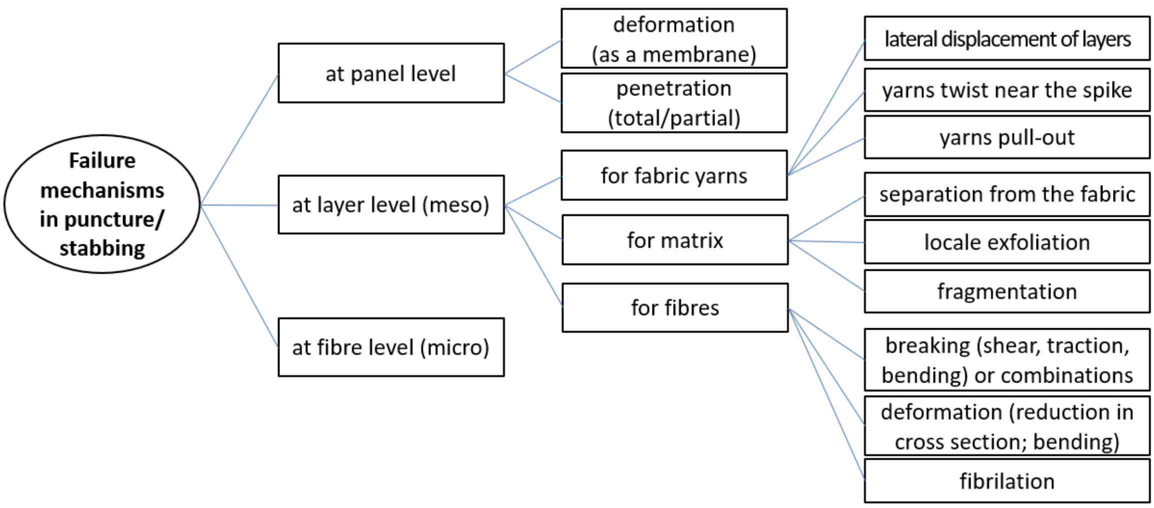
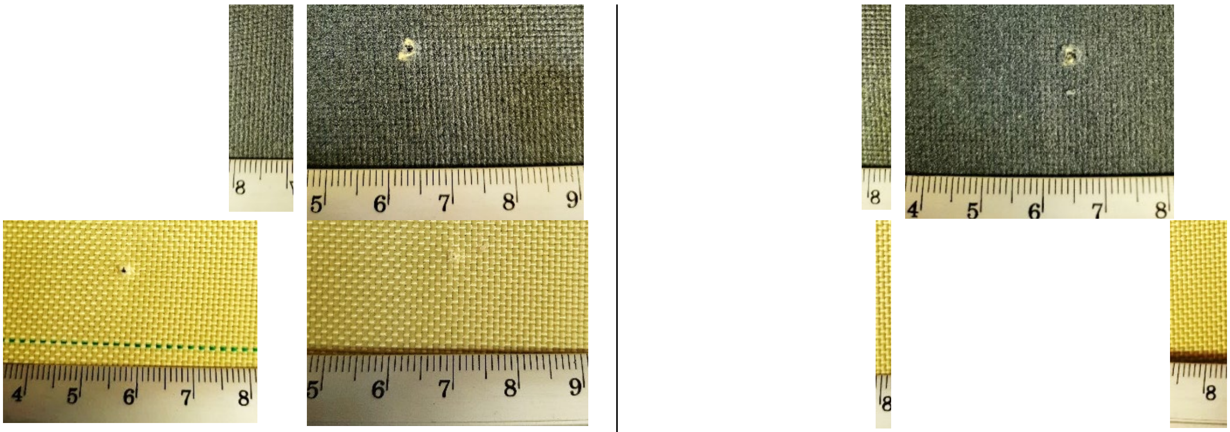


Figure 7: Failure mechanisms characterizing the puncture or stabbing process

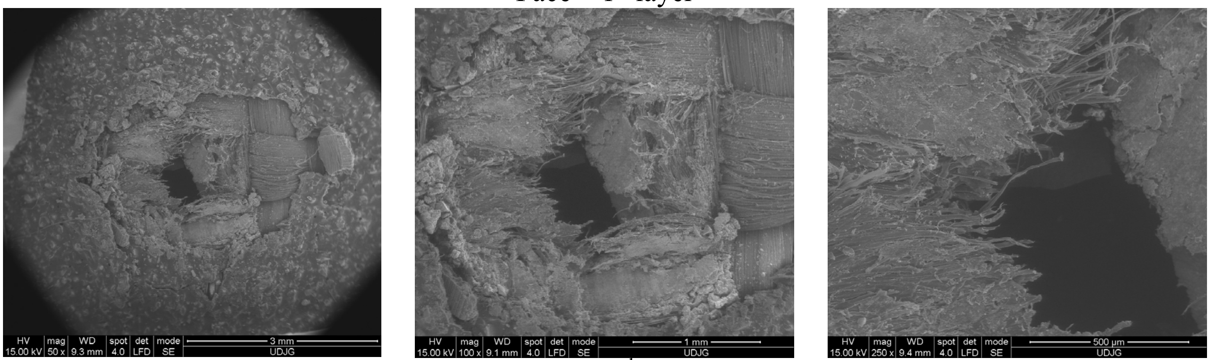


32 layers **40 layers** **32 layers** **40 layers**

24 J **43 J**

Figure 8: Panels penetrated with the spike, at different energies (up – 1st layer face, down – last layer back)

Face – 1st layer



Back – 16th layer

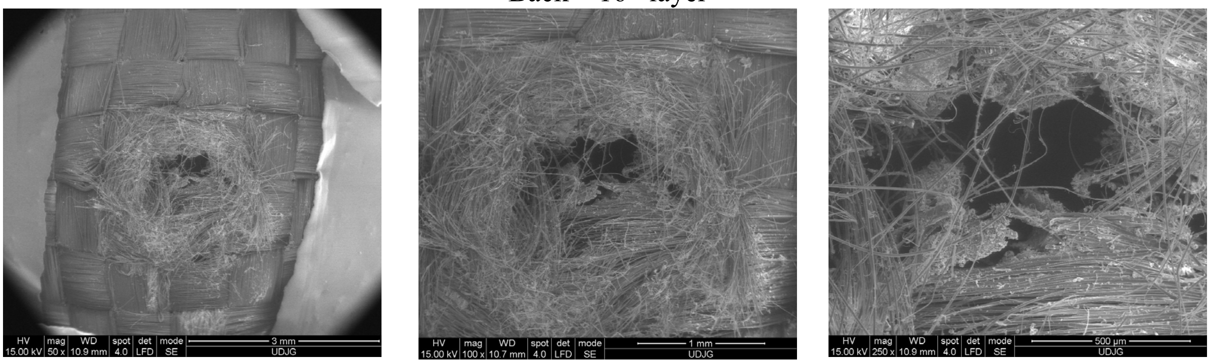
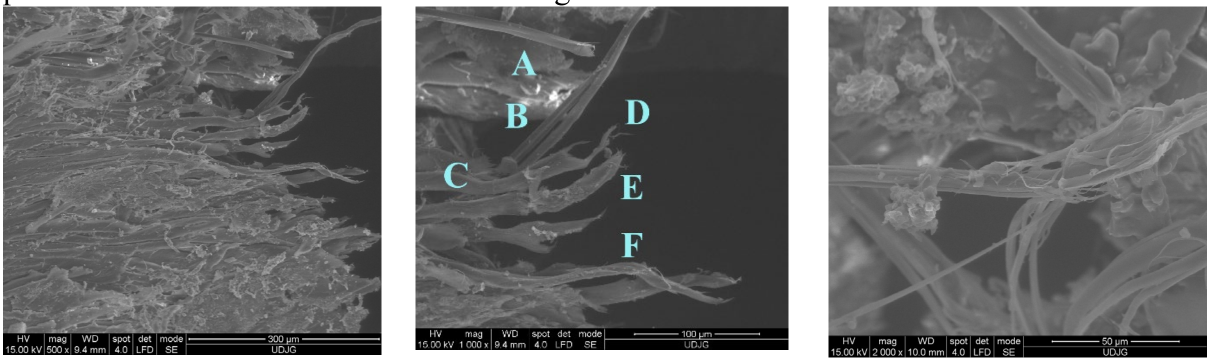


Figure 9: Penetration orifice on the panel made of 16 layers of fabric Twaron SRM 509

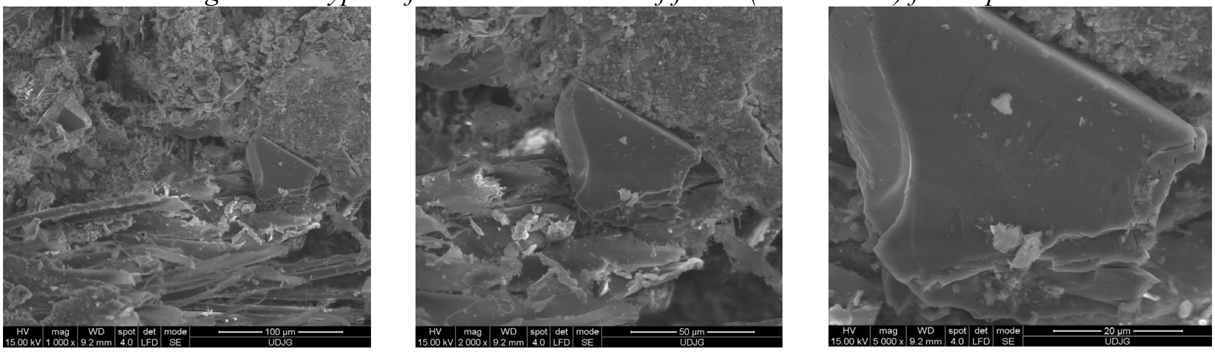
At meso scale (magnifications x50, x100, Figure 9, first two columns), one may notice the orifice produced by the spike and the dislocation of composite coating. The third column, at magnification x250, start a micro scale evaluation, the yarn breakage being very different as comparing the yarn on the first layer to that on the last layer (the 16th one).

Figure 10 presents a) broken fibers at the edge of the penetration orifice, b) a detail that reveals the failure mechanisms for these fibres: A – broken fibre by shear, B – fibre broken by tearing/ traction in a zone when, very probably, there was a fibre defect, C – locally strained fibre by traction/crushing and D – broken end by shear, with several fibrils excessively elongated, E – traction breakage, F – fibre's local deformation by twisting and narrowing and breakage by stretching and c) different aspect of the broken fibres on the face of 16th layer (many fibres with fibrillation, stretching zones near the penetration orifice. The fibre stretching allow for their lateral displacement and the easier spike weapon penetration.



a) b) [11] c)

Figure 10: Typical failure mechanisms of fibres (micro scale) for a spike



a) b) c)

Figure 11: A hard particle after being hit by the spike: a) x1000, b) x2000, c) x5000

Figure 11 presents, at different magnifications, a hard particle at the edge of the penetration orifice: a) near the particle, there are broken fibres and fractured coating, b) the particle is partially dislocated from its matrix and c) the right side of the particle is fractured by the spikes, meaning this is a supplementary process of energy dissipation.

5. Conclusions

Instrumented tests on panels at spike penetration underlines the force increasing with energy level and number of layers in a panel. Photos and images obtained with the help of scanning electron microscope (SEM) revealed failure mechanisms of the composite coating and aramid fibres.

References List

[1] Abtew M.A., Boussu F., Bruniaux P. (2021). Dynamic impact protective body armour: A comprehensive appraisal on panel engineering design and its prospective materials. *Advanced Engineering Materials*, 14(4), 185-194.

[2] El Messiry M. (2013). Study of puncture cut resistance in protective fabrics. *ICCE-21*, Tenerife.

[3] Croft J., Longhurst D. (2007), *HOSDB Body Armour Standards for UK Police*. Part 3: Knife and Spike Resistance – 39/07/C, Home Office, London.

[4] NIJ Standard 0115.00 (2000), *Stab Resistance of Body Armor, National Institute of Justice*, Washington, DC.

[5] Nayak R., Crouch I., Kanesalingam S., Wang L., Ding J., Tan P., Lee B., Miao M., Ganga D., Padhye R. (2018). Body armor for stab and spike protection, Part 2: a review of test methods. 89(16).
[6] Catalog Teijin Ballistics Material Handbook, Twaron®. *The power of aramid*, 38-14-05/2012, https://pdf.directindustry.com/pdf/teijin-aramid/ballistics-material-handbook1/18087-309131.html
[7] Hasanzadeh M., Mottaghitalab V., Sharma P., (2017). Puncture Resistance Enhancement of Woven Fabrics Using Concentrated Nanosilica Suspension, *Procedia Engineering* 173, 1494-1498
[8] Xu J., Zhang Y., Wang Y., Song J., Zhao Y., Zhang L. (2021). Quasi-static puncture resistance behaviors of architectural coated fabric. *Composite Structures* 273, 114307.
[9] Luo C., Sun Y., Wakatsuki K., Morikawa H., Bao L., (2022). Consideration of Yarn Anisotropy in the Investigation of the Puncture Resistance of Fibrous Materials, Polymers, 14, 883
[10] Termonia Y. (2006). Puncture resistance of fibrous structures. *International Journal of Impact Engineering.* 32(9), 1512-1520
[11] Totolici Rusu V. (2023) *An Experimental and Theoretical Study on Stabbing and Puncture Resistance of Stratified Panels*, PhD thesis, "Dunarea de Jos" University, Galati, Romania