EVALUATION OF BALLISTIC SUITABILITY OF TEXTILES POSSIBILITY OF MEASUREMENTS AND EVALUATION OF BALLISTIC SUITABILITY OF TEXTILES

Radim DEJL[1], Jan GRÉGR[1], Miroslava MARŠÁLKOVÁ[2], Gabriela KRUPINCOVÁ[3]

[1] *Technical University of Liberec, Faculty of Science, Humanities and Education, Department of Chemistry, Liberec, Czech Republic*

[2] *Technical University of Liberec, Faculty of Textile Engineering, Department of Textile Materials, Liberec, Czech Republic*

[3] *Technical University of Liberec, Faculty of Textile Engineering, Department of Textile Technologies, Liberec, Czech Republic*

radim.dejl@tul.cz, jan.gregr@tul.cz, miroslava.marsalkova@tul.cz, gabriela.krupincova@tul.cz

Abstract

The article refers about two types of ballistic vests used for the same purpose – to protect soldier in a battlefield against flying fragments. However, these types of vest differ from inside material, war era and country of origin, they can both protect a man in the same way, even the new one is made from much modern, high-modulus fiber – aramid fiber. Today, Kevlar is traditional material for ballistic purpose. This article offers a description of used materials and possibility of measurements and evaluation of ballistic suitability of textiles. This evaluation is related to the acoustic velocity in fiber which could be use for the estimation V50. V50 denotes the velocity at which 50 % of the bullets penetrate.

Key words: ballistic vests, special fibers, aramid, velocity, penetration

1. Introduction

We analyzed three types of ballistic soft armors. Two of them are not bulletproof but they give enough fragments protection (grenade and bomb fragments). The first one was American nylon vest and its construction comes from Vietnam War era (years 1965-1972). The inlay was made from reinforced ballistic nylon. The second vest was German Kevlar vest and its construction comes from 1995. The inlay was made from probably Kevlar 129 according to our results. The third type of vest, we analyzed, was a typical modern tactical bulletproof vests of Special Air Service (SAS, British Army), but its inlay was so sewn trough that was impossible to make a sample for testing. Tow and fabric were too damaged by our ripping.

Fig 1. US Nylon vest

Fig 2. BW German Kevlar vest

Fig 3. SAS British Kevlar vest

The American protective vest is made of 12 layers in front and 12 layers in back of ballistic nylon fabric. The inlay is reinforced between ninth and tenth layer by plastic 0,2 mm thick cross shape lamella in the front and in the back. The whole inlay (front and back part) is sewn together and put in a PVC water-protective bag. Finally it is put in a camouflaged green nylon cover.

Fig 5. Inlay layers

Fig 4. Nylon front inlay

The German protective vest is made of 13 layers in front and 14 layers in back of Kevlar fabric. It is not reinforced by any type of hard panel or lamella. The front part and back part is not sewn up. The collar is also filled by 13 layers of Kevlar fabric. The ballistic soft panels are attached to the camouflaged cover by Velcro panels and hidden in big inner pockets.

Fig 7. Inlay layers

Fig 6. Kevlar back inlay

The British tactical bulletproof vest is made of 26 layers of Kevlar fabric, 3 layers of Kevlar knitting with steel wire (knife and arrow protection) and 1 anti-shock 0,4 mm thick composite. All parts are hidden in front and back big inner pockets. These 3 main parts are not sewn and are not attached to the camouflaged cover.

Fig 7. 26 Kevlar layers sewn together

Fig 8. Knife and arrow protection

Fig 9. Anti-shock composite layer

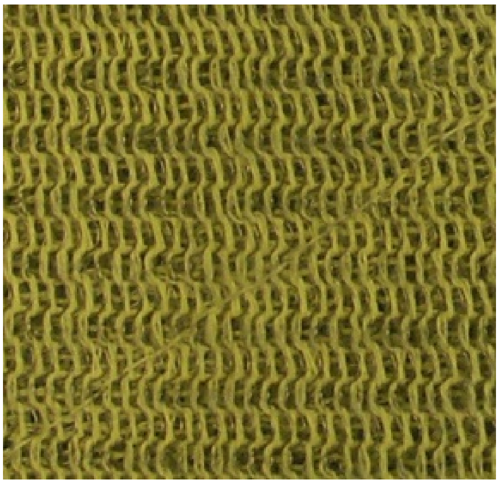

Fig 10. Detail of Kevlar-steel wire knitting

2. Material characteristics

We made several samples for testing prepared from each ballistic inlay. They were tested for its tensile strength, tensile modulus, elongation and data important for material density calculation. It was impossible to make a same sample of fabric or yarn from British vest because of high damage level during preparation samples. We also tested a tow of each layer of ballistic inlay for its acoustic velocity.

Layers are numbered as follows: the closer to the body, the lower number.

Table 1. Thread Count of Ballistic Fabric (plain weave)

	American (Nylon)	German (Kevlar)	British (Kevlar)
Weft/Warp [cm^{-1}]	45/50	50/45	45/45 and 35/35
Layers (front/back)	all 12/all 12	all 13/all 14	1-4, 26 and 5-25

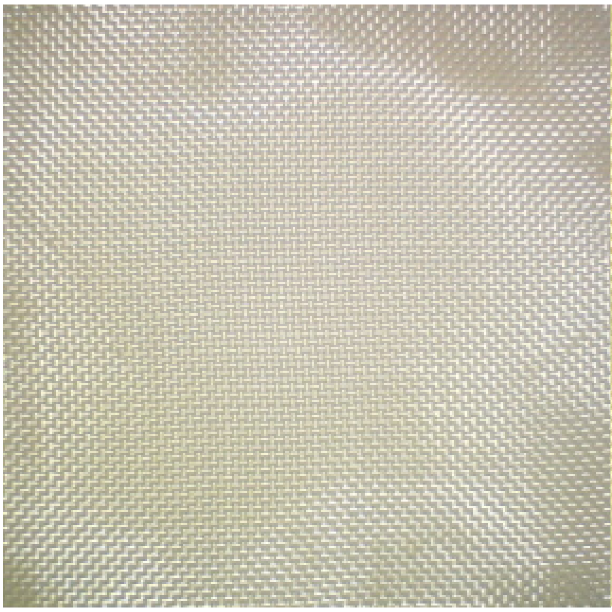

Fig 11. Detail of ballistic nylon fabric

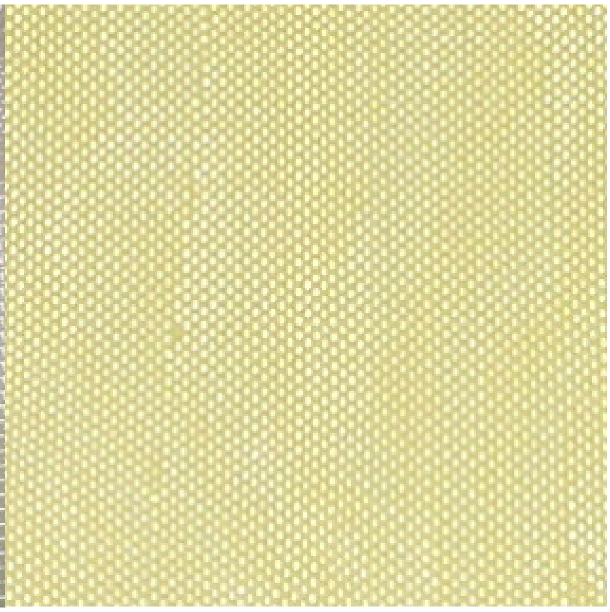

Fig 12. Detail of Kevlar fabric

Material density is one of the important keys to estimate a minimal velocity to shoot through the vest.

Table 2. Main Fabric Properties

		Nylon	Kevlar
Areal Density	$kg.m^{-2}$	0,49	0,19
Volume Density	$kg.m^{-3}$	664,93	696,02
Thickness	mm	0,75	0,28
Fiber Fineness	dtex	7,06	1,67
Fiber Diameter	μm	28,59	12,19
Density	$kg.m^{-3}$	1099	1430
Porosity	%	39,50	51,33

We also need to know the tensile strength and tensile modulus to calculate the velocity $U^{*1/3}$, which is the key factor to evaluate, if the textile is suitable for ballistic application or not before testing with real firearms or simulating machines e.g. light gas cannon.

Table 3. Mechanical Properties (American and German vests)

	Tensile Strength		Tensile Modulus		Elongation	Density
	$cN.tex^{-1}$	MPa	$cN.tex^{-1}$	GPa	%	$kg.m^{-3}$
Nylon	0,7	81	30	3,3	36	1099
Weft				3,0	34	
Warp				3,6	38	
Kevlar	23,8	3432	131,6	18,9	3,3	1430
Weft				18,4	3,1	
Warp				19,4	3,4	

3. Velocity comparison

From our results there is certain possibility to estimate a minimal penetrating velocity which we can shoot through the vest – V_E. The estimated minimal penetrating velocity corresponds to a half quantum of velocity $U^{*1/3}$.

$U^{*1/3}$ is product of fiber specific toughness and strain wave velocity. This is a basic value that allows characterizing and determining if the material is suitable for the ballistic application [1]. V_{50} denotes the velocity at which 50 % of the bullets penetrate [2]. Although we tested mainly fragmentation protective suits, according our results, we should say that German Kevlar vest should stop a 9 mm bullet, so it could conform to American NIJ standards Type II (National Institute of Justice ballistic standard) [3] [4].

Table 4. Velocity Comparison

	Specific Toughness m^2/s^2	Sound Velocity m/s	$U^{*1/3}$ m/s	V_{50} m/s	V_E m/s
Nylon	25357	1615	345	175	173
Kevlar	78554	8150	858	434	429

3.1 Velocity $U^{*1/3}$

To calculate the velocity we use equation (1),

$$U^{*1/3} = \frac{\sigma E}{2\rho}\sqrt{\frac{E}{\rho}} \qquad (1)$$

where σ is Tensile Strength, ρ is density and E is Tensile Modulus. Specific Toughness is represented by the first fraction and Sound Velocity by the second.

To calculate V_{50} without real shooting is practically impossible, but it seems that it corresponds to the half quantum of velocity $U^{*1/3}$. We marked it as V_E – velocity estimated, which is lower only by 2 % than real V_{50} . 50 % of all projectiles shot against the vest faster than V_E will penetrate the vest. All data are compared to the caliber 9 mm Luger.

4. Conclusion

Besides the measurements of mechanical properties, we also tried to measure acoustic velocity in tows of Kevlar and ballistic nylon, but we have not found any relations to V_{50} yet. We use the Dynamic Modulus Tester DMT PPM-5R. We need to make more measurements for more types of ballistic soft materials to be able to compare their properties.

Contemporary world military trend in ballistic protection is using light tactical vests with front and back composite panels such as Strike Face. Composites have higher degree of areal density which can stop wider range of bullets and fragments trying to penetrate the armor.

5. References

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