II International scientific conference
„Contemporary trends and innovations in the textile industry"
16-17th May, 2019, Belgrade, Serbia

TEXTILE FIBERS AND MATERIALS FOR DESIGN AND CONSTRUCTION OF CONTEMPORARY MODULAR VEST FOR SPECIAL (MILITARY) PURPOSES

Sanja Risteski, Vineta Srebrenkoska

Faculty of Technology, University „Goce Delcev" Stip, Republic of North Macedonia

ABSTRACT: *Protective vests usually defined as "protective cover clothes "are used to protect the body from physical attacks in dangerous surroundings. In this paper, the selection of fibers and new generation of materials that can be used in design of contemporary modular model of protective vest for the additional level of protection is made. The selected materials are analyzed and their main characteristics are presented. A comparison between materials properties is also shown. The design of the advanced model is also very important, so efforts in the meaning of design and construction have been also made, and new model of protective vest was obtained. The new model is unique, lightweight and meet the requirements for future military purposes.*

Keywords: *design, fibers, fabric, materials.*

TEKSTILNA VLAKNA I MATERIJALI ZA DIZAJN I KONSTRUKCIJU SUVREMENOG MODULARNOG MODELA PRSLUKA ZA SPECIJALNE (VOJNE) SVRHE

APSTRAKT: *Zaštitni prsluci koji se obično definišu kao "zaštitna odeća" služe za zaštitu tela od fizičkog napada u opasnom okruženju. U ovom radu izvršen je izbor vlakana i nove generacije materijala koji se mogu koristiti u dizajniranju savremenog modularnog modela zaštitnog prsluka za dodatni nivo zaštite. Analizirani su odabrani materijali i prikazane su njihove glavne karakteristike. Takođe je prikazano i poređenje između svojstava materijala. Dizajn naprednog modela je takođe veoma važan, tako da su urađeni napori u smislu dizajna i konstrukcije i dobijen novi model savremenog zaštitnog prsluka. Novi model je unikatan, ima malu težinu i ispunjava zahteve za buduće vojne svrhe.*

Ključne reči: *dizajn, vlakna, tkanine, materijali.*

1. INTRODUCTION

Protective clothing has a long history. First forms of protective clothes recorded through centuries were used to protect people from attacks of aggressive animals and from injury in dangerous situations. The very first form of protective clothes were animal skins (leather), but as civilizations became more advanced, people started using metal as more effective material for their personal security. First examples of protective clothes were

found in Europe and East Asia. It is known that the Sumerian people made protective helmets and gowns of metal. About 2000 years B.C., protective clothes were decorated and reinforced with metal scales, and this application continued and lasted through the 18-th century. With the development of metal chains by the Celts in the third century B.C., a facility of soldiers in dangerous situations was significantly, improved. The one of the first evident of soft armor was found in medieval Japan, but the first commercial protective vest was discovered in the late 1800's, and it was made of silk fiber. With technology development and synthetic fibers development in late 1960's, a perfect base for production of protective clothing with a higher and improved level of protection was obtained [1, 2]. When it comes to protective clothing, an assessment of the danger to the wearer should be made, because each type of design is not suitable for any purpose, because a level of protection and the type of danger should be firstly considered. For soldiers, good design means high level of protection and also high comfort that will lead to higher soldier's mobility. But for technologists/engineers, the level of required protection and energy absorption characteristics are more important, because they assure the soldiers life. Designers and engineers should put all these needs in new advanced model of protective clothes, made of new generation of contemporary materials that will assure satisfaction and safety to the soldiers [3-5].

1.1. Fibers that are mostly used in protective clothes design

Protective clothes are used to preserve the wearer from bullets and others projectiles like shrapnel's metal fragments and flying penetrating objects of various sizes, shapes and velocity. This bullet resistant clothing should stop the bullet from penetration and absorb its kinetic energy, converting it into work of deformation. The performance of protective bulletproof material depends of several primary factors as strength, modulus, elongation at break, deformability of the projectile and the velocity of transverse shock wave in the fiber [6]. Right selection of material or combination of materials is very important, because the selection of materials that will be resistant to impact will assure high level of protection, great comfort and unrestricted movement of the wearer/soldier. Today on the market a new generation of high performance fibers can be found. All these fibers are characterized by high strength and module.
The chemical structure determines the characteristics and performance of each type of fiber. The appearance of synthetic and regenerated fibers and especially high-performance fibers has become so wide that practically for any type of protective clothing could be find adequate fibers [7]. The first synthetic fiber used for protective military clothes design was Nylon (Polyamide) fiber. This fiber compared to the future generation of high-performance fibers had fairly poor ballistic performance, but it was used as a solid base for future continuous improvements of fibers used for this purpose. Currently, on the market, mostly used fibers for protective clothes design are these types of fibers: Polyamide fibers, Aramide fibers such as: Kevlar® (Du Pont) Twaron® (AKZO) Technora® (Teijin), Nomex® and high tenacity polyethylene fibers such as: Dyneema® (DSM) Spectra® (Allied Signal).
The main characteristics of these fibers for which they are used in protective clothes design are shown bellow:

Polyamide (PA) fibers (known as PA 6.6 and PA 6) are mostly used as outer (camouflage) material in the military protective clothes industry because they have the following features and characteristics:

- High crystal morphology.
- Great agility in deformations and excellent elasticity.
- Average conductivity of heat and remain stable at temperatures below 150° C.
- High electrical resistance.
- The melting point for PA 6.6 is 280 °C, and for PA 6 is 215 °C.
- The glassing point for PA 6.6 is 50 °C, and for PA 6 is 40 °C [8].

Aramid fibers are used in industry of protective clothes for the following characteristics:

- High tensile strength, low density and high module.
- High level of energy absorption.
- Have high resistance to impact.
- Good resistance to chemicals, low conductivity and low thermal expansion.

Kevlar® fibers are solid substitute to carbon or fiberglass fibers. Materials (composites) based on this fibers are:

- Resistant to impact.
- Resistant to abrasion.
- Resistant to heat.
- Lightweight, and have high strength.

Twaron® fibers are fibers with a distinctive combination of mechanical properties, resistance to chemicals, thermal stability, excellent durability and easy integrable into production processes.

Technora® fibers are fibers with great performance. They are used in the industry for protective clothes because they are/have:

- Eight times stronger than steel.
- High module.
- Great heat and chemical resistance.
- Exceptional strength and durability.
- Resistant to heat and chemicals, long-term dimensional stability.
- Adjustable to different applications.

Nomex® fibers could be applicative in a lot of applications. They have:

- Good dimension stability.
- Excellent heat resistance.
- Low levels of flammability, are melt resistant at high temperatures and are highly durable in strength compared to carbon fiber.
- High degree of molecular orientation resulting from dense linear molecules as well as from being inclined to form a liquid crystal solution [9-11]. In the table below (Table 1) some types of commercial aramid fibers are presented. From the given fibers Nomex fiber has the greatest elongation to break, the highest strength has Tehnora, and the density of all fibers is approximate. The highest module has Kevlar 29 and Technora. High module also means great rigidity - a feature that is very important for the production of protective clothes for a special purpose.

Table 1: Commercial types of aramid fibers

Trade mark	Company	Density g/cm3	Module GPa	Strength GPa	Elongation at break%
Kelvar 29	DuPont	1.44	72	2.9	3.6
Nomex	DuPont	1.38	11.6	0.59	28.0
Twaron	Teijin Aramid	1.44	70	3.2	3.3
Technora	Teijin Aramid	1.39	73	3.4	4.6

Ultra-high molecular weight polyethylene fibers (UHMWPE) are used in the industry for protective clothes for the characteristics given bellow:

- Have an extremely high specific strength and module.
- Are high chemical resistant and have high abrasion resistance.

Dyneema® is highly resistant to corrosive chemicals except oxidizing acids and has extremely low moisture absorption. The coefficient of friction is very low. This fiber has ability for self-lubricating and also is highly resistant to abrasion.

Spectra® fibers are known as the strongest and lightest fibers available on the market. Their specific strength that is 40% greater than aramid fiber. Has high tensile strength and low density but, as a negative characteristic, is the strength they give during axial and transverse compression. The coefficient of friction is very low which makes this fiber easy to slick. Comparative characteristics for some polyamide, aramide and polyethylene fibers used for ballistic protection are presented in Table 2. These fibers can provide body armor with exceptionally improved ballistic levels of protection with a remarkably reduced weight - property that is very important for the wearer, because it enhance his mobility and effectiveness [12-14].

Table 2: Mechanical characteristic of some reinforcing fibers that are given above

Type of material	Tensile strength Mpa	Tensile module Gpa	Specific module N/tex	Density g/cm^3
Aramide with low module (LM)	3600	60	40	1,45
Aramide with high module HM	3100	120	80	1,45
Aramide with ultra-high module UHM	3400	180	52	1,47
DyneemaSK60	2700	89	91	0,97
Dyneema SK65	3000	95	97	0,97
Dyneema SK66	3200	99	101	0,97
Polyamide HT	900	6	5	1.14

1.2. Types of materials used for protective clothing and their construction

The classification of textile materials is made according to the orientation of the fibers that are used, or according to the different techniques of construction. According to the orientation of the fibers the four main categories are:

Unidirectional Textile Materials (UD) - where most of the fibers are oriented in only one direction. Generally the primary fibers are oriented at an angle of 0° (longitudinal

direction - warp), but can be oriented at an angle of 90° (transverse direction - weft) Figure 1.

Textile materials at an angle of 0/90° - are used for applications where orientation of the fibers in multiple directions is required. Most of these types of fabrics are obtained by the weaving process.

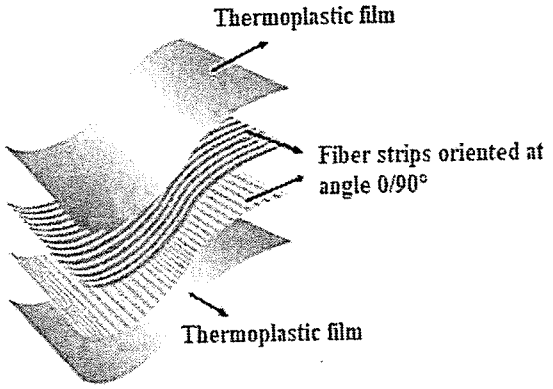

Figure 1: Unidirectional construction

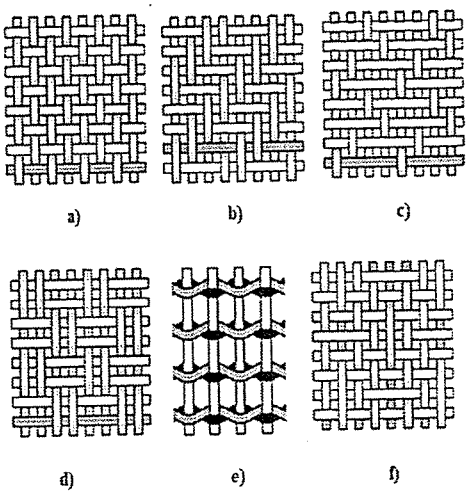

Figure 2: Types of interlace a) plain b) twill c) satin d) basket e) leno f) mock leno [15]

Woven textile materials - obtained by interlacing of two systems of yarns (continuous filaments): warp (0°) and weft (90°) according to the given interlining. The compactness of the fabric depends mainly on the mechanical interlacing of the two yarn systems. The durability, surface appearance and stability of the fabric are controlled primarily by the way of interlacing. The most commonly used types of interlining are given on Figure 2.

Chopped Strand Mat - CSM is a non-woven fabric consisting of randomly oriented chopped fiber bundles which are connected together with a binder [15].

2. EXPERIMENTAL

In the process of designing protective clothes for military purpose there are many factors that should be taken into account. Materials that will be assembled in the model have the main role, but also the design of the model is very important. Used materials should be lightweight and the design should be easy adaptable the wearer's body, with high level of comfort, permeability, maintenance, cost etc. It's very important to note that the design should be contemporary and satisfy the specific needs of the twenty-first-century soldier [14]. The high level of risk to which soldiers are exposed can cause seconds to be crucial to save their lives, especially in situations where the wearer/soldier is injured and his life is in danger.

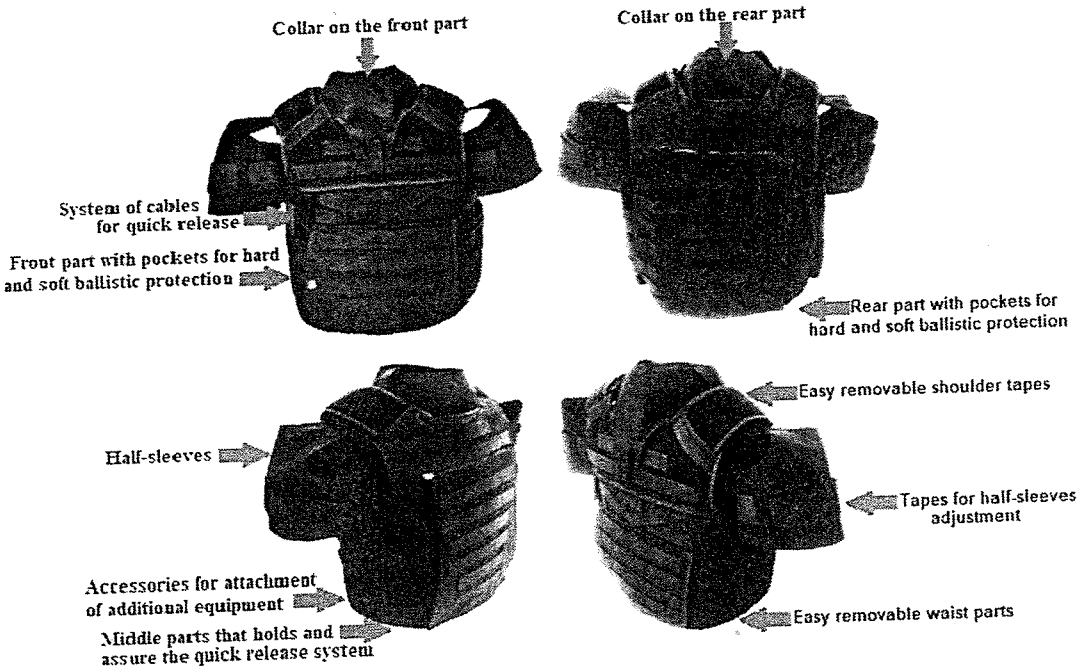

Figure 3: Appearance of model of contemporary vest for military purpose

With modular and easy removable protective clothes the soldier could be easily evacuated from the danger, so he can quickly save his life and life's of other wounded soldiers.
For this purpose a new design of vest for special purposes was made (in the size L/Large).

The vest is modular and easy removable from the wearer's body. The main construction parts in the new model are: The front and rear parts, inner and external parts, collar, half-sleeves, easy removable parts and cables for quick release system. As can be seen, the model has layers of soft protective material and special designed pockets for soft and hard ballistic protection, pockets that holds and assure the quick release system, as well as accessories for attachment of additional necessary equipment.

3. RESULT AND DISCUSSION

The presented model of protective vest is water resistant, with carefully selected materials that provide a low weight of the vest with a high level of protection. The model is made of few layers of material (which is necessary for quick release system to function), but they do not affect negatively on the freedom and unrestricted movement of the wearer. The following materials were incorporated into the new model:

- **For external (coating and layers material)** - Polyamide 6.6 HT of DuPont-Invista.

- **For soft Balistic protection** - Aramide fabric T717, or optionally can be used HPPE UD tapes SB 51. Both materials satisfy the requirements for the level of protection III-A according to the standard NIJ 0101.06. The difference is only in the weight of the soft protective part. Therefore, the unidirectional tapes find greater application and are superior to the woven textile materials. But in applications where price is a priority, bi-directional composites are mostly used.

- **For hard Balistic protection plates**- Dyneema HB 2 or optionally can be used Dyneema HB 210. Both analyzed materials meet the protection level III criteria according to NIJ 0101.06 standard. The difference between unidirectional Dyneema HB 2 and Dyneema HB 210 is due primarily to the different type of thermoplastic matrix used in these materials and the different ratio of constituents. Namely, Dyneema HB 2 contains 78-84% of fibers while Dyneema HB 210 contains 79-83% fibers.

The new model of protective has the following advantages:

- The system for quick release - solves one of the biggest problem related to the time that is need for evacuation of the injured soldiers form the place of danger, without the possibility of additional injuries (which may occur) through efforts to remove the vest from the body as soon as possible. The system safety is assured with specially designed hidden pocket.
- The new model of a protective vest has a contemporary design that meets the requirements of the market for dedicated clothing and together with the all assembling parts for soft and hard protection reaches a weight not exceeding 4000 grams (for a model of size L).
- The vest is comfortable, lightweight and it can be removed from the wearers only in a few seconds.
- The vest is constructed of modular parts that can be easily attached or removed from the wearer's body with velcro tape, according to the danger and risk assessment.
- The number of pockets for adding additional equipment or accessories is increased.
- The model is made of advanced materials and has futuristic look which corresponds with functionality and high level of protection and quality.

4. CONCLUSION

In this paper is presented a new design of protective clothes in accordance with the current requirements of soldiers and their specific needs. By analyzing the materials that are mostly used in design of the protective clothes, a selection of suitable materials was made. The chosen materials that were incorporated in the new design completely satisfy the function of this specific type of clothes. The new model of protective military clothes has contemporary design and the design is in correlation with all of the mobile constructive parts without any chance to reduce or distort their function and comfort. The new design of this protective vest with the system for quick-release is a step ahead in modernizing protective clothing, and satisfy the needs of the soldiers in 21-st century.

REFERENCES

[1] Abott TA. (1982). *Protective clothing.* Publisher: Shirley Publications Manchester, UK, 41.
[2] Łotysz, Sławomir. (2014). Tailored to the Times: *The Story of Casimir Zeglen's Silk Bullet-Proof Vest Arms & Armour*, pp. 164–186.
[3] Maj. James C. Beyer, MC, William F. Enos, M.D. Col. Robert H. & Holmes, MC. (2009). *Personnel Protective Armor*, Office of medical history.
[4] Bajaj, P. & Sriram. (1997). Ballistic protective clothing. *Indian Journal of fibre & Textile Research*, Vol. 22, pp. 274-291.
[5] Beyer, J., Enos, W. F. & Holmes, R. H. (2009). *Personnel Protective Armor*, Vol. 11, pp. 642-687.
[6] Roerdink, E. & Van Dingenen, J. (2002). Past and Future of High Performance Fibers. *Polymer Fibers Symposium, Heerlen*, pp. 235-245.
[7] Scott, R. A. (2005). *Textiles for Protection.* The Textile Institute, Woodhead Publishing Limited, England, pp. 15-17.
[8] Kuklane, K & Holmer, I. (2000). *Ergonomics of protective clothing*, 8, pp. 124-130.
[9] Hongu, T. & Phillips, G. O. (1997). *New Fibers.* (2nd ed.). Woodhead Publishing Ltd.
[10] Hearle, J. (2001). *High-Performance Fibers.* England: Woodhead Publishing Ltd.
[11] Horrocks, R., & Subhash, A. (2000). *Handbook of technical textiles.* Cambridge: Woodhead limited.
[12] I. Karacan. (2005). Structure-Property Relationship In High Strength High Modulus Polyethylene Fibers, *Fibres And Textiles*, 13, pp. 15-21
[13] Kirchbaum, R. (1986). High strength/high modulus polyethylene fibers. *25 Internationale Chemifasertagung, Dornbirn (Austria)*, pp. 229-235.
[14] Kumar, S. (1991). Advances in high performance fibers. *Indian Journal of Fibre & Textile research,* Vol.16, pp. 52-64.
[15] Sp systems guide to composites. http://www.composites.ugent.be/home_made_composites/documentation/SP_Composites_Guide.pdf.