

# Study of the Tensile Properties of Materials Destined to Manufacture Protective Clothing for Firemen

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*The work is dedicated to the study of the tensile properties of the seven layers of materials which compose the firemen protective clothing. Protective clothing is used to improve the working place safety, diminishing the action of risk factors, which can be of thermal, chemical, biological, mechanical, physical or electric nature and have direct influence on the life and health of the person who carries out a certain activity. The basic material used in manufacturing these products must possess special characteristics, thus ensuring the accomplishment of certain activities which imply the existence of risk factors. The studied firemen equipment has in its composition NOMEX and KEVLAR technical yarns. The analysis of textile material behaviour in the wearing process shows that these are subject to simple or repeated uniaxial or biaxial tensile stresses. The level of these stresses can be close to breaking strength or it can have small, insignificant values; therefore the designer must anticipate the behaviour to such stresses, and this can be done by determining the indices inferred from the stress - strain diagram.*

*Keywords: protection equipment, stress-strain curve, risk factors, Kevlar, Nomex*

People all around the world depend on the bravery and training of firefighters to offer protection against fires. In turn, firefighters depend on firefighter protective clothing made with DuPont™ Nomex® and Kevlar® fiber to help them meet the demands of a rigorous and challenging job. Together, these innovative fibers help offer fire resistance, strength, durability, and more. Kevlar® is five times stronger than steel on an equal-weight basis, yet fabrics can be lightweight, comfortable, and thermally protective [1-4]. It helps enhance the overall durability and strength of lightweight turnout gear outer-shell-and-thermal-liner systems. Nomex® fiber is also inherently flame resistant, tough and flexible [4-6]. Kevlar is a manmade fibre, is as an organic fibre in aromatic polyamide family. The unique properties and distinct chemical composition of wholly aromatic polyamides (aramids) distinguish them from other man-made fibre [3-7]. Kevlar has a unique combination of high strength, high modulus, toughness and thermal stability. It was developed for demanding industrial and advanced-technology applications. Currently, many types of Kevlar are produced to meet a broad range of end uses [2-10].

The tensile properties of woven fabrics are influenced by the tensile properties of both yarn systems and the woven structural parameters [9-11]. The tensile behaviour of such fabrics can be characterized through a set of indicators calculated from the stress-strain curve, as follows [11-13]:

- *Proportionality (elasticity), yielding and breaking limits;*

- *Work of rupture:*

$$W_L = f_{wL} \cdot P_L \cdot a_L \quad [\text{N.m}] \quad (1)$$

$$W_T = f_{wT} \cdot P_T \cdot a_T \quad [\text{N.m}] \quad (2)$$

where:  $f_L$  and  $f_T$  - the work factor for longitudinal and transversal direction, determined on the stress strain curves;  $P_L$  and  $P_T$  - breaking force for longitudinal and

transversal testing direction;  $a_L$  and  $a_T$  - fabric breaking elongation [mm] for longitudinal and transversal testing direction. The work factor was determined by measuring the stress-strain diagram area by means of the AutoCad program.

The stress-strain diagrams of investigated yarns are used for choosing the level of total deformation so yarns load deformation diagrams can highlight the necessary tension to maintain a fixed deformation [12-16].

The work is dedicated to the study of the tensile properties of the seven layers of materials which compose the firemen protective clothing. The studied firemen equipment has in its composition NOMEX and KEVLAR technical yarns. As the result of the performed study, the centralization was made of the number of functions imposed by the risk factors to which the firemen protective clothing is subject.

## Experimental part

### Materials and methods

The most often met material is Kevlar 49, an aramid with very big crystallinity (aromatic polyamide). The structural unit present in Kevlar 49 includes an amidic group and a benzene nucleus (fig. 1) [15]. The benzene nucleus confers the material toughness, chemical resistance and thermal stability, as compared to aliphatic polyamides. These fibers do not melt; they get carbonized at 800°C, their utilization range being 50 - 160°C. Spinning is carried out from solution, stretching taking place after spinning and conferring an axial arrangement of the material. Very strong hydrogen bonds are created between the chains [15-18].

Nomex® is an inherently flame-resistant, high-temperature resistant meta-aramid fibre that does not melt and drip or support combustion in the air. A key factor in the protection provided by Nomex® is its ability to

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carbonize and thicken when exposed to intense heat. When exposed to extreme heat, Nomex® undergoes a unique reaction, changing its properties to capture more energy in the fabric and give the wearer valuable extra seconds of protection from heat transfer. That is why Nomex® is the world leading fibre for firefighters [15-18]. Nomex and related aramid polymers are related to nylon, but have aromatic backbones, and hence are more rigid and more durable. Nomex is the premier example of a *meta* variant of the aramids (fig. 2), (Kevlar is a *para* aramid) [15-20].

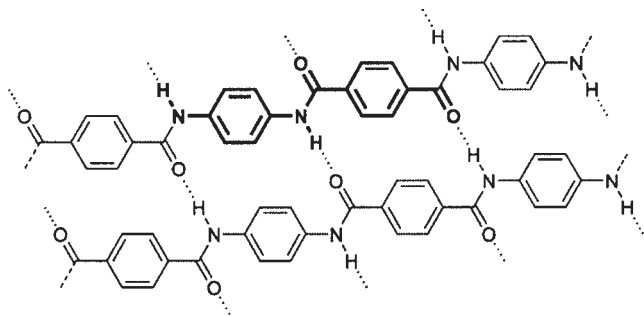


Fig. 1. Kevlar chemical structure

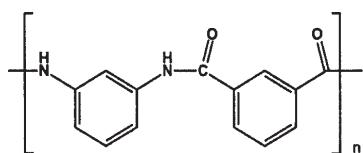


Fig. 2. Nomex formula and structure

The studied firemen protective clothing consists of seven layers, each one with a well-defined role, participating in realization of protection barriers (fig. 3).

Layer 1 is the closest to the human body. It is a lining consisting of Kevlar FR non-woven material quilted with a fireproofed polyester fabric.

Layer 2 is realized by consolidation through Spunlaced procedure with high pressure water jet. It provides the thermal comfort in shoulder and back area.

Layer 3 provides a humidity barrier and is manufactured of Kevlar FR non-woven material which has at the product exterior a Teflon layer. Teflon will provide the protection to consolidation through Spunlace procedure water, having also a positive behaviour in the presence of high temperatures that occur during the user intervention.

Layer 4 is made of KEVLAR, a knitted cloth from weft with lining yarn, which is placed within the product in shoulder area, on sleeves, elbows, knees. It assures a thermal protection for the stressed zones.

Layer 5 is a fabric made of NOMEX yarns (fireproofing, antistatic material) impregnated with fluoro-carbon, waterproofed, which does not soil. It represents the external layer, the one which comes in contact with risk factors from the intervention area.

Layer 6 is a fabric made of NOMEX yarns, fireproofed, which, by means of a strong adhesive makes is one with a plain polyester knitted fabric. The resulted assembly is mounted at the inside of the product, at the lining limits in breast, sleeve and back areas and at trousers frame. Sometimes it can be mounted in the wrist hem, to prevent water and humidity penetration from the exterior.

Layer 7 is a fabric made of NOMEX yarns, stripped, used to make the pockets.

The position of the layers that compose the protective clothing with respect to the user is presented in figure 4.

External layer/flame barrier (a) represents a flame and high temperature resistant barrier; it preserves its thermal

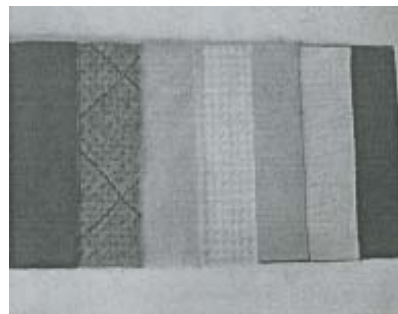


Fig. 3. Layers composing the firemen protective equipment

protection characteristics in time. It is made of a resistant fabric that must confer an efficient thermal protection to fire and high temperatures. It is also called flame barrier, since it has the role not to sustain the burning. For the external layer execution, one uses fabrics of aramidic (meta-aramidic and para-aramidic) thermostable such as NOMEX or KEVLAR, introduced and manufactured by Du Pont Company. The high thermal stability of these materials provides a reduced degradation of the external layer in the case of heat exposure.

Median layer/ humidity barrier (b) has the role to prevent water penetration from the exterior to the human body, yet permitting the water vapors (perspiration) to exit. In this way, the fireman who intervenes under high risk conditions can benefit by protection against water and chemical agents used to extinguish the yarn.

Various lightweight materials are used as humidity barrier, able to increase the comfort in wear and having high water vapor permeability. Usually, this layer is made of FR non-woven materials covered with thermally resistant polyurethane membranes. At European level investigations are performed to obtain a TEFLON-coated material (directly on the external layer) able to provide all the three functions: thermal function, water-proofing and increased comfort in wear.

Internal layer/ thermal barrier (c) is the closest layer to the wearer's skin and it needs, together with the other layers, to satisfy the requirements of the standards in force and, at the same time, to offer an increased comfort at the contact with skin.

The thermal barrier systems are made of several layers, in order to have enough volume and an air layer which is a good heat insulator. In the case that the solution of a quilted lining or voluminous no-woven materials is not adopted, it is recommended to use a material made of the same fibers as the external layer, but lightweight.

A series of orientations with respect to water vapour absorption capacity are directed toward special finishing treatments.

Verification of tensile properties of the textile materials was carried out through dynamometric tests on standard samples, specifying the stress orientation in the direction of a certain yarn system, longitudinal/warp and transversal/weft.

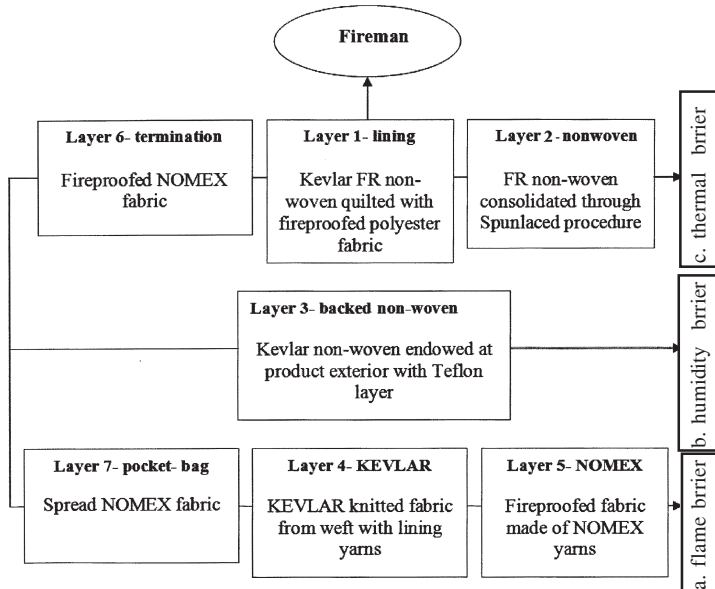


Fig. 4. Component layers of the firemen protective clothing

The mechanical characteristics of the layers (1, 2, 3, 4, 5, 6 and 7) that make together the firemen protective clothing have been determined on the H5K-T Tinius Olsen dynamometer with QMAT TEXTILE specialized calculus software, according to the standard EN ISO 13934-1/1999 [19], on samples with standardized dimensions (300x50mm) stressed along the longitudinal and transversal directions respectively (TEXTILEXPRT Research Laboratory). In order to determine the mechanical characteristics of Layer 4 (Kevlar), we have

used the dynamometer SATRA MATERIAL TESTING CENTRE- STM 466 (Laboratory of fast footwear designing and prototyping), since it has the biggest thickness ( $g = 3.08\text{mm}$ ), a bigger distance between fastening clamps being necessary.

### Results and discussions

In order to respond the demands, any product needs to satisfy a series of functions. As the demands represent "user's voice", in order to determine the product functions, these must be converted in technical terms. Table 1 presents the descriptions (classified list) of the functions

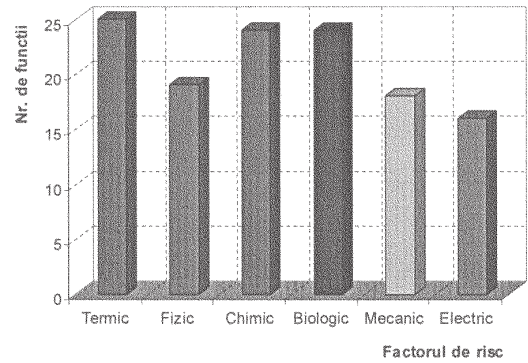


Fig. 5. Functions- risk factor correspondence

Group of functions	Co de	Function name	
		Common functions	Specific extensions of the functions for protective equipment
Safety functions	F1	Products multi-functionality	
	F2	Covering the body	
	F3		Protection against biological factors
	F4	Physico-mechanical protection	
	F5	Chemical protection	
	F6	Protection against open fire and incandescent bodies	
	F7	Impermeability to fluids	Sealing against fluid penetration
	F8		Product visibility
	F9		Auto-immunization
Informational functions	F10	Carrying information	Monitoring
	F11		Communication
	F12	Advertising	
Sano-genetic functions	F13	Thermal protection	
	F14	Humidity absorption	
	F15	Humidity transfer	
	F16	Ventilation capacity	
	F17	Psycho-sensorial comfort	Inoquity
Constructive-ergonomic functions	F18	Dimensional correspondence	
	F19	Easiness to put on/take off	
	F20	Easiness in using the product elements	
	F21	Minimum wear effort	
	F22	Contains objects	Integrate components in product structure
	F23	Fastening on the body	
	F24	Wear resistance	
Reliability and maintainability functions	F25	Stability of shape and dimensions	Matching the shapes and dimensions
	F26	Easy maintenance	Maintenance capacity
	F27	Reconditioning capacity	
	F28		Autonomy of activation source
	F29		Decontamination capacity
Technological-esthetic function	F30	Degree of novelty of the pattern	
	F31	Concordance with life and clothing style	-
	F32	Product aspect and target	
	F33	Esthetics of technological processing	Accuracy of technological processing

Table 1  
PRODUCT LIST OF THE FUNCTIONS OF CLOTHING PRODUCTS

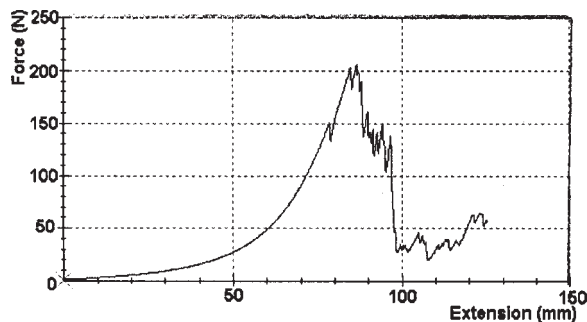


Fig. 6. Stress-strain diagram for Layer 4 stressed in longitudinal direction

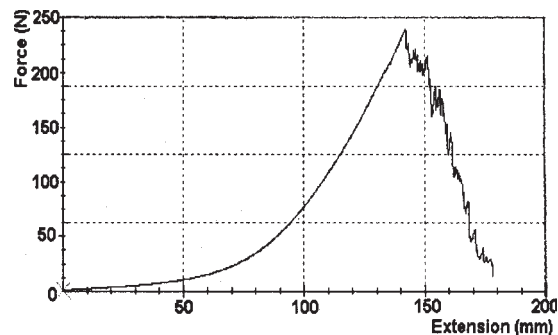


Fig. 7. Stress-strain diagram for Layer 4 stressed in transversal direction

Code Art.	P (N)		$\varepsilon$ (%)		a (mm)		$f_w$		W (N.m)	
	L	T	L	T	L	T	L	T	L	T
Layer 1	892.8	695.4	39.74	41.33	95.90	179.6	0.58	0.34	49.57	45.16
Layer 2	45.88	24.21	61.88	54.7	125.8	115.0	0.52	0.41	2.537	1.296
Layer 3	262.8	226.7	54.24	85.08	112.2	173.4	0.68	0.56	15.20	19.08
Layer 4	410.7	233.0	94	49.34	188.0	98.68	0.71	0.55	38.65	11.36
Layer 5	648.2	556.9	17.72	12.25	42.60	45.22	0.64	0.44	12.85	11.52
Layer 6	530.4	301.6	17.54	20.6	63.12	41.2	0.62	0.46	16.2	34.27
Layer 7	355.6	239.7	14.66	21.63	33.61	56.18	0.65	0.52	5.982	5.130

L - longitudinal; T - transversal

Table 2  
MEAN VALUES OF TENSILE  
PROPERTIES ASSESSMENT

of clothing products, which includes for the 33 common functions also the specific extensions for protective equipment [20]. As the result of the performed study, the centralization was made of the number of functions imposed by the risk factors to which the firemen protective clothing is subject (fig.1).

From figure 5, one can notice that the thermal risk factor is on the first place, accumulating the highest number of functions (25), followed by the chemical and biological risk factors with the same score (24 functions), while the physical risk factor implies 19 functions, the mechanical risk implies 18 functions, and the electric risk factor implies 16 functions.

The stress-strain diagrams are relevant for the global aspects of the deformation process. For example, the stress-strain diagram for Layer 6, stressed in longitudinal direction is given in figure 6, and in transversal direction in figure 7.

The variation limits of the indicators of tensile properties assessment (mean values) are presented in table 2. The analysis of the values and of the graphical representations leads to the following conclusions:

- maximum mean value of the breaking force, as well as of the breaking;

- deformation energy of the textile materials stressed both in longitudinal and transversal direction was obtained for the Layer 1:  $P_L = 892.8$  N,  $P_T = 695.4$  N,  $W_L = 49.57$  N.m,  $W_T = 45.16$  N.m. This is justified by the fact that it consists of a fabric and a quilted non-woven material joined together by means of seams.

- minimum mean value of the breaking force, as well as the breaking deformation energy of the textile materials stressed both in longitudinal and transversal direction was obtained for the Layer 2,  $P_L = 45.88$  N,  $P_T = 24.21$  N,  $W_L = 2.537$  N.m,  $W_T = 1.296$  N.m, because it consists of a non-woven material consolidated through Spunlace technology with high pressure water jet, on whose surface a seam was applied;

- maximum mean value of the absolute elongation of textile materials stressed in the longitudinal direction was obtained at the Layer 4,  $a_L = 188$  mm, and in the transversal direction was obtained at the Layer 1,  $a_T = 179.62$  mm;

- minimum mean value of the absolute elongation of textile materials stressed in longitudinal direction was

obtained at the Layer 7,  $a_T = 33.6161$  mm, and in the transversal direction was obtained for the Layer 6,  $a_T = 41.2$  mm;

- depending on shape of the stress-strain curve, the mechanical work factor can have one from the following values:  $f_w = 0.5$  - ideal case;  $f_w < 0.5$  case in which both yarn systems manifest a reduced deformation strength;  $f_w > 0.5$  case in which both yarn systems manifest an increased deformation strength. From the experimental data results that the mechanical work factor has values over 0.5 for the seven layers, larger on longitudinal direction.

## Conclusions

From the analysis of the tensile properties of the seven material layers studied by investigating the stress-strain diagrams, the following general observations result:

- the factors of influence on the tensile strength are: metric count, technological warp and weft yarn set, and the weave type;

- values of assessment indicators of the tensile properties are higher on longitudinal direction than on transversal direction.

In practice, the woven material must exhibit an optimum behaviour to repeated strains, flexions and abrasions during wearing process.

The nature of risk factors is influenced by the working place conditions (thermal, chemical, biologic, electric, mechanic) or the working means specific to the professional categories (physical, chemical, biological, special environment).

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