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SOME WAYS OF TECHNICAL TEXTILES DEVELOPMENT*

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Introduction. The application of textile fibers and fibrous structures for technical purposes has long tradition. In medieval time were textile based structures used for buildings enforcement as assemblies (nets). One of first protective clothing was silk structures used by Mongolian tribes for protection against enemy's arrows. The ropes were used for transportation and anchoring purposes.

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Technical textiles were used for packing, protection or consolidation. Advent of composites extended application of technical textiles into industrial sphere.

In this time sector of technical textiles is very important for many industrial branches, transport, medicine, agriculture etc. Textile structures are now one of very special light construction materials with some extraordinary properties (as flexibility, shape changeability, viscoelasticity) and simple process ability.

In the first part of this paper the main branches of technical textiles and their development are discussed.

Second part is devoted to the description of National Textile Research Centre II (NTRC) main activities connected partially with technical textiles.

Technical textiles. Majority of textile fibers and fibrous structures can be used without problems for creation of technical textiles. For special applications as barrier textiles it is possible to obtain required effects by finishing techniques as coating, curing, lamination, grafting and top finishing combined with proper construction of fabrics. Especially for achieving of high tenacity and modulus or extra thermal stability the specialty fibers are necessary.

These fibers have majority of required properties (mechanical, thermal, electrical, biological, chemical etc.) as intrinsic. On the other hand there are problems with creation of textile structures (due to brittleness, low deformation to break) and finishing or dyeing. The prices of specialty fibers are generally high as well. More than 90 % of technical textiles are still based on classical fibers.

Technical textiles are classically defined by theirs special properties (electrically conductive, heat resistive, antimicrobial, antistatic, super absorbents etc.). The definition of technical textiles is not simple and therefore the classification based on the main areas of application is widely accepted.

Prevailing technology of technical textiles creation is weaving. Weaved structures are widely applicable in all branches where the relative strength; shape stability and directional orientation are required. Examples are geotextiles, composites and protective clothing. Knitted structures due to their high shape instability are used traditionally in medical sector. Now these materials are used for creation of 3D structures, braiding and special coverings (e.g. car seats). Knitted structures are covering about 3…5% of all technical textiles. In many cases weaved and knitted structure are replaced by nonwovens, especially for products where it is not necessary to have high strength and dimensional stability.

The highest increase of consumption is for nonwovens and composites (5.6% yearly). All kind of technical textiles consumption increase is about 3.7% per year.

Some ways of technical textile development. Development in the technical textiles branch is in close connection with technical level of civilization. Developed countries are not only using advanced technologies but are oriented to protecting human health, increasing quality of life and offering new way of relaxing or leisure activities. New textile structures are reflecting these needs and main innovative activities are focused into these products:

– “Intelligent” body adaptive response apparel textiles having improved comfort controlled by the state of microclimate and wearers needs.

– “Intelligent”-knowledge based technical textiles with specified properties (e.g. locally compressive behaviour) and complex actions (comfort type mattresses for disabled persons, intelligent car seats etc.)

– Hybrid multifunctional textiles for protective clothing combining improved protection (a barrier against the selected types of radiation and particles) with improved comfort.

Especially in the technical textiles branch improvement is influenced by:

– development (computer assisted) of new materials and technological principles

– simulation of the nature (biomimetics)

– non standard combination of fabric creation technologies

– transfer of materials and technologies from another branches

The common doubt is that development is based on the new materials, new patents and new technologies, which is very expensive and time consuming.

It is true that new complex solutions are often results of long term intensive activities of multidisciplinary teams. On the other hand there exist many of surprisingly simple and elegant solution without huge investments.

Very simple is application of new materials appeared already on the market. For example aero gels developed in frame of NASA research can be used for textiles with enhanced temperature insulation. There exist companies in Europe focused to the application of cosmic research results for textile branch. Usually these applications are very simple and straightforward.

Examples of utilization of new materials requiring some research are auxetic textiles, which have negative Poisson ratio. During extension/compression in one direction are these textiles extended/compressed in perpendicular direction as well (Fig. 1).

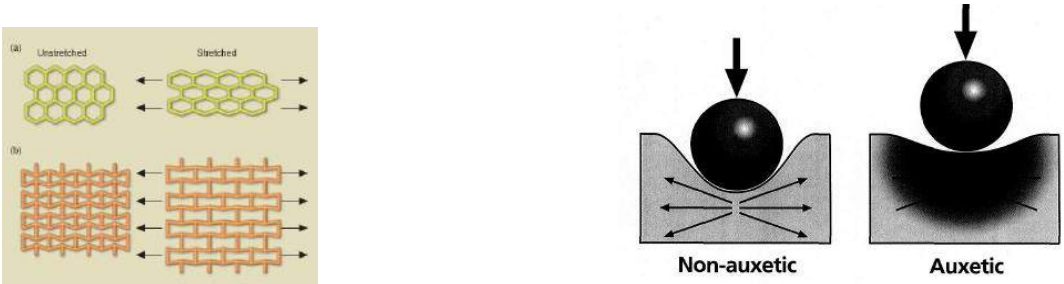


Fig. 1. Non auxetic and auxetic behavior

Poisson ratio of fiber with original cross area S_o and cross section area S changed due to tensile deformation ε is defined as

$$\nu = \frac{\text{lateral deformatin}}{\text{longitudinal extension}} = -\frac{\varepsilon_T}{\varepsilon} \quad \text{where} \quad \varepsilon_T = \frac{S - S_o}{S_o}.$$

Poisson ratio is connected with some mechanical characteristics of solid materials. Initial tensile modulus E for isotropic materials is connected with shear modulus G and volume compression modulus K by these relations:

$$K = \frac{E}{3(1-2\nu)},\; G = \frac{E}{2(1+\nu)},\; \nu = \frac{E}{2G} - 1.$$

Condition G > 0 leads to lower limit of Poisson ratio $\nu > -1$ and condition K > 0 leads to the upper limit of Poisson ratio $\nu <= 1/2$. Most of polymeric fibers obey Poisson ratio in the interval $0.2 \le \nu \le 0.45$. Poisson ratio of auxetic materials is negative, i.e. the shear modulus is high and volume compression modulus is low. Solids with negative Poisson ratio are compressible but resistant to shearing and then tough. Material hardness expressed as indentation resistance H:

$$H \approx \frac{1}{(1-\nu^2)^{2/3}}$$

for auxetic materials is very high as well. The sorting of materials into groups according to relation between shear modulus and volume compression modulus is shown in the Fig. 2. Auxetic materials are in the group of anti rubber (dilatation materials).

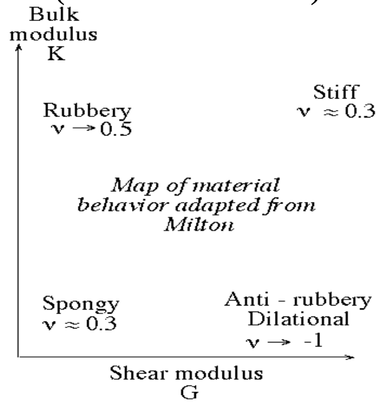


Fig. 2. Sorting of materials according to their behavior

Auxetic behavior can be achieved by special construction of yarns and fabric (Fig. 3).

Fig. 3. Auxetic behavior of cords

Auxetic structures are applicable for composites, textiles with improved cutting resistance, energy absorbers and for controlled dosing of medicals according to the volume changes of healed part of body. Another possibility to improve impact resistance of textiles is to use the special shear thickening fluids (STF) which are able to dramatically increase viscosity during shearing. Simple example of STF is colloid dispersion of silica particles (500 nm) in polyethyleneglycole (molecular weight 200) [7]. Final content of STF on textiles is up to 20%. The improvement of puncture resistance due to STF presence is shown in Fig. 4.

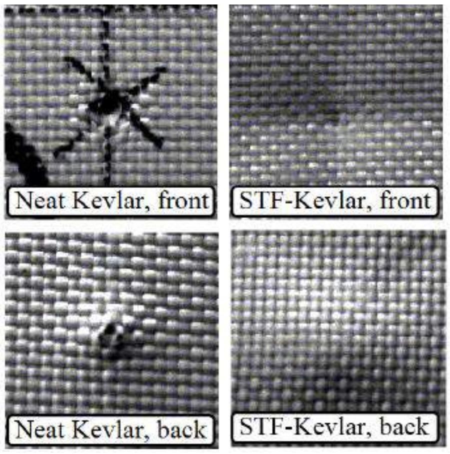


Fig. 4. Influence of STF on puncture resistance [7]

The "active protection" system presented by Dow Chemical company at the last Techtextil exhibition in Frankfurt combines distance fabric with special silicone STF (Fig. 5)

Fig. 5. The "active protection" system of Dow Chemical Co.

The silicone composition consists of polymers which show transient bonding to a cross-linking component. Under normal conditions, the polymers are bonded to the cross-linker in such a way that the bonds become open when subjected to a long period deformation force, which allows the material to flow. When this force is removed, the bonds easily reform again, returning the silicone to its original lightly cross-linked soft solid state. If the silicone is subjected to a sudden deformation force, the cross-linking bonds do not have time to open; the material resists the deformation force, and appears as a solid. This dilatant nature of the silicone means that when it is being impacted it instantly transforms from a soft flexible material to a rigid solid, but only for the duration of the impacting force. After the force has been dissipated through the dilatant/fabric construction, the silicone is again soft and flexible.

Choice of fabric used as the carrier plays an important role in performance. The typical carrier has a diamond surface configuration made from multifilament polyester yarns, with the spacer yarns formed from monofilament polyester to create the three dimensional structure, that is just 4.5mm thick. When this fabric is impregnated with the silicone, it is particularly important to present the silicone in such a way that it can readily absorb the impacting force through the spacer yarns in the direction of the force. By careful design of the dimensions of the spacer textile, this orientation is assured; allowing the silicone to absorb maximum force, yet leaving the fabric completely breathable (Fig. 6).

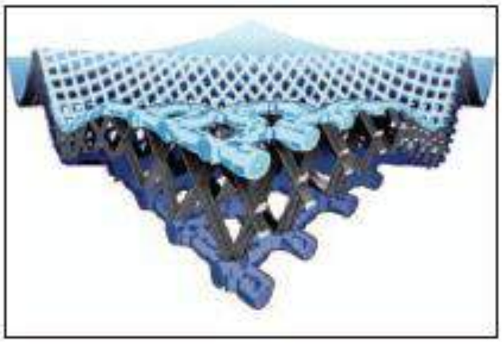


Fig. 6. The three dimensional spacer textile support of Dow Chemical Co

Relatively new example of biomimetic solution are shape memory membranes. For temperatures below activation point the structure of membranes is in glassy state, molecular structure is rigid, permeability is low and body heat is retained. For temperature above activation point structure is in the rubbery state. Micro-Brownian movement creates gaps between molecules, permeability is increasing and moisture or body heat can escape.

Very popular tools for innovations of higher order are nano technologies and nano materials. Materials are usually defined as materials having one dimension fewer than 100…500 nm. There are three possibilities of nano materials preparation:

– Top down approach (from bigger to smaller objects – Freymam "There is a plenty of room at the bottom"). Etching by laser, electron or ion beam.

– Bottom up approach (molecular machines – molecular biology and molecular chemistry). Self organization – the spontaneous transition from chaos to order.

– Molecular manufacturing (scanning probe microscopes).Carving out nano parts from appropriate surfaces.

Nano particles (less 100 nm) contain 1 million atoms or less (1 nm radius has approx. 25 atoms) and majority of atoms are on the surface. It is well known that many properties of matter depend on the size range. In nano scale there are in some cases extra effects not following the bulk materials because the particle/wave nature of matter appears (quantum effects, tunneling, self-assembling). Selected properties of nano materials are:

– Extreme specific surface area

– Similarity of dimensions with UV and visible rays. Color and scattering depends on nano particle size.

– Critical length (mean free path, scattering length) of materials properties (conductivity, diffusion) is comparable or higher than mano particles dimension.

– Toxicity of particles increases with decreasing particles size.

Very common mistake is assumption that nano particles have better mechanical properties in comparison with more voluminous particles. In facts cohesion energy per atom (diameter d) is dependent on the diameter of particles (D) by relation

$$E = E_b\left(1-\frac{d}{D}\right) = E_b\left(1-\frac{1}{L}\right),$$

where E_b is cohesive energy for bulk material. For nano particles ratio d/D is 0.1…0.01 and cohesive energy is increasing with particle diameter. It is interesting that starting from diameter of nano particles around 100 nm E is practically constant. This is one natural definition of nano range. Typical length ratio L = D/d can be simply used for computation of:

- Number of atoms in particle $n = L^3$
- Particle mass $M_c = M_h L^3/6.022\cdot10^{23}$,

M_h is molecular mass of material.

- Particle volume $V_c = \pi d^2 L^3 / 4$.

In the textile branch the following nano materials are used: nano fibers (electrospinning), nano particles (powders), nano porous materials, nano composites, quantum dots and carbon nanotubes.

All these examples illustrate the huge varieties of innovation possibilities in technical textiles sector.

Activities of Czech National Textile Research Centre. The National Textile Research Centre II (NTRC) is five-year project administrated by Czech ministry as a continuation of the project of the TEXTIL Centre solved in 2000…2004. The Technical University of Liberec and Research Institute of Textile Machines, Plc Liberec are the founders. The researchers from cooperating research institutions, namely INOTEX Ltd. Dvůr Králové, Resesach Institute of Cotton Ústí n. Orlicí and SPOLSIN Česká Třebová are integrated into the particular groups according to their specialization.

Long-term research program of NTRC II is oriented above all to conceptual and application research in areas of design and optimization of textile structures, designs of textile machines including use of mechatronics and related technologies, product innovations of higher order for special protective fabrics and use of new materials for design of special sensors and sensors on clothing. The following projects connected with technical textiles or textile technologies are solved:

Extension of system of the fabric projection. Aim of project is completion of complex system of fabric design starting from system of creation – structure – and properties of separate textile fibrous formations (result of preceding Centrum TEXTIL) by following parts.

1. Prediction of the fiber properties from their chemical composition and basic structural parameters. The basic fiber forming polymers polyethylene, polypropylene, polyehtylenterephtalate, polyamide 6, Kevlar (Fig. 7) and polyacrylonitrile were investigated. The tables containing molecular descriptors, properties and models were created.

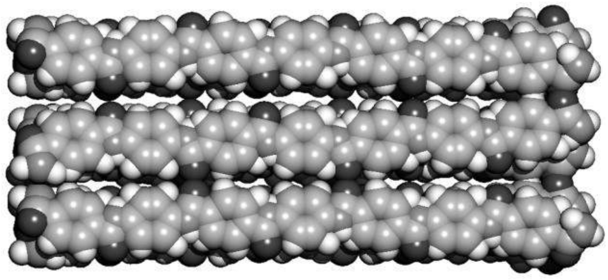


Fig. 7. Molecular model image of Kevlar (3x3 chains, optimizing with Chem3D – Cambridge Soft software) [12]

2. New types of yarns. The complex quality QI of typical cotton fibers varieties was used for prediction of rotor yarn strength YS (Fig. 8). The image analysis was used for description of structural parameters of compact, Sirospun and Vortex yarns. The structure and properties of yarns from blends of cotton and polypropylene were investigated.

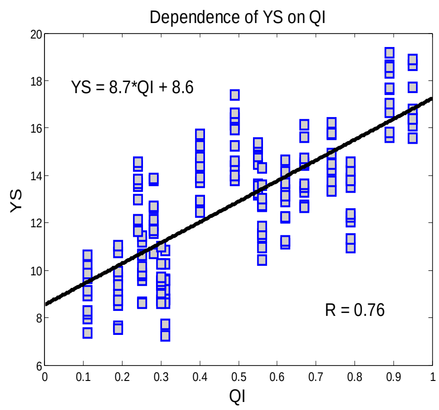


Fig. 8. Regression line for dependence of *YS* on *QI*

3. Prediction of selected organoleptic properties. The contactless method for evaluation of surface roughness was created. The roughness was separated into micro and macro roughness (Fig. 9). The evaluation of bed linen fabric hand was standardized.

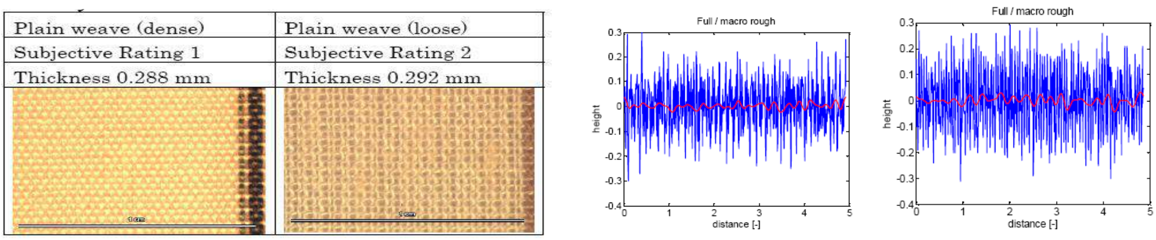


Fig. 9. Full and macro roughness for two plain weaves

4. Specification of models of the twisted yarns and fabrics. The unevenness and hairiness of yarns was described by using stochastic models (see Fig. 10). The program HYARN in MATLAB for complex analysis of mass and geometric unevenness of linear structures was created. The models for prediction of mechanical properties of woven structures were modified. The anisotropy of mechanical properties of woven structures was investigated.

5. The blending optimization. The prediction of blended yarns from cotton and polypropylene is investigated.

6. Influence of type finishing technologies on change of properties. The basic properties of finished cotton type fabrics were evaluated by using laboratory simulation. The operation of cotton pretreatment, hydrophobic finishing and pigment printing were described.

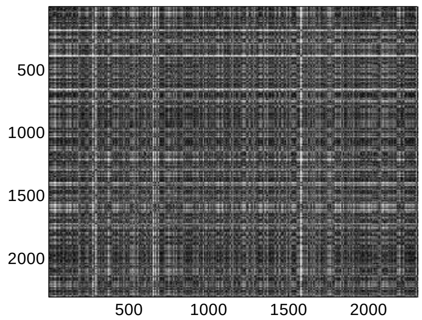


Fig. 10. Real yarn recurrence plot for D=2

Optimum designs of textile products. In frame of this project the following tasks are performed.

1. Modeling the special properties of textiles, transport behavior and interactions with gases or liquids. Fabrics thermal conductivity was predicted. The best model is based on the parallel arrangements of fiber mass and air (Fig. 11).

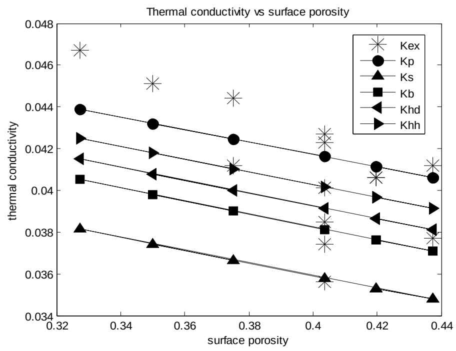


Fig. 11. Prediction of cotton fabrics thermal conductivity (optimal is $K_P = P_O K_y + (1 - P_O) K_a$)

2. Databases of type products and their properties. The database of type products was updated and extended.

3. Creating stochastic models on the basis of neuron nets and non-linear methods for dimensional reduction. The selected techniques of dimension reduction were compared. The Matlab programs for multivariate data treatment were created (Fig. 12).

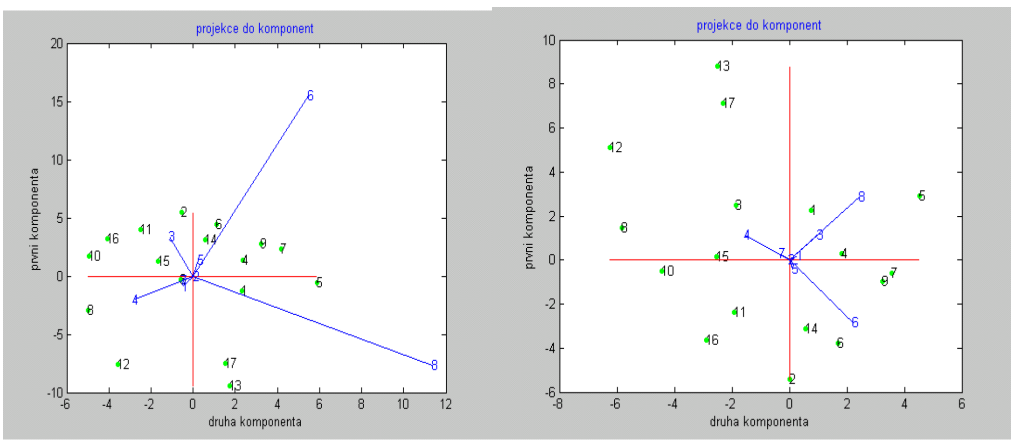
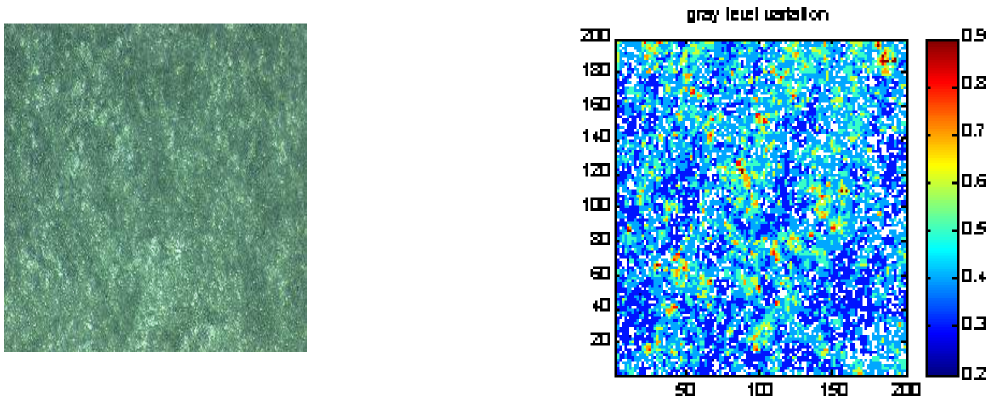


Fig. 12. PCA BiPlot for raw and standardized data

5. Unevenness prediction in the surface. The 2D spectral analysis, autocorrelation function and variogram were used for planar unevenness characterization. The planar unevenness of nonwovens was characterized by using spatial statistical tools (Fig. 13).



a) b)

Fig. 13. Raw image (a) and mean grey levels in squares (b)

The project is focused on the testing of special sensors (temperature, humidity and chemicals) considering their installation and functioning in textile structures. The application possibilities of special dyestuffs for UV radiation dosimeter or detection of bacteria and toxic substances are investigated. In frame of this project the following tasks are performed:

1. Studying the properties of sensors and their selectivity or humidity.

2. The ways of installation of sensors into textile structures.

3. Testing the usability of sensors considering the wear and maintenance of textiles.

4. Selection, verification and testing of chosen dyestuffs and filters for the design of textile UV radiation dosimeters.

5. Selection, verifying and testing of chosen dyestuffs or means for indication of chosen bacteria and toxic substances.

The Sensirion SHT15/75 relative humidity and temperature sensors were embedded into various places in ski suits. One extra sensor measures ambient condition on a surface of measuring unit box which is further equipped with 2-axis digital acceleration and inclination sensor. The testing stand for hard sensors and sensor of temperature was developed (Fig. 14).

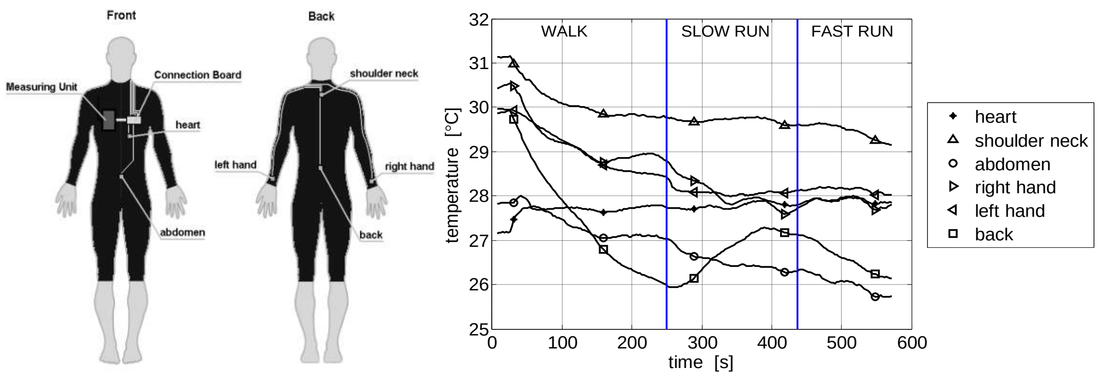


Fig. 14. Temperature during motion [13]

Principles of stabilizing active substances on textile substrates. In frame of this project the following tasks are performed:

1. New procedures. The in situ creation of silver nano particles on the surface of cotton fibers by two phase method was investigated (Fig. 15).

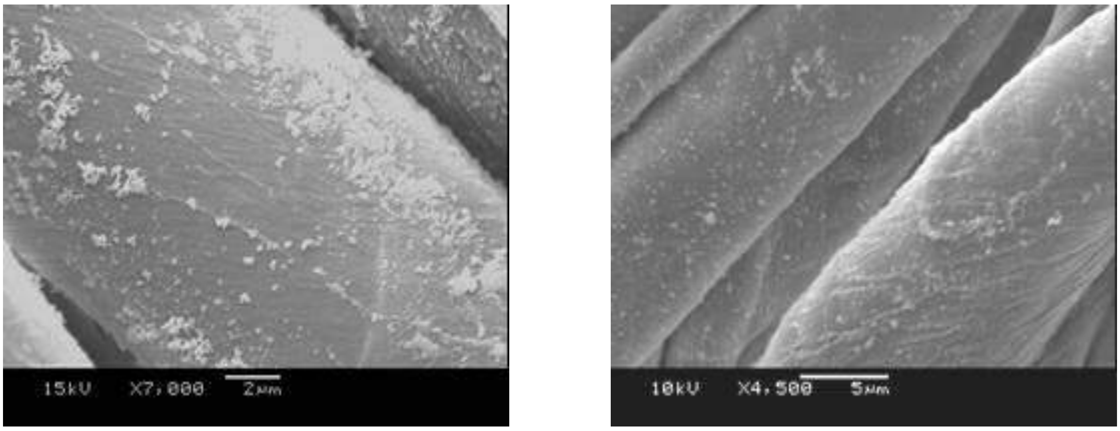


Fig. 15. Cotton fibres with silver nanoparticles [14]

2. New energetic resources. The application of atmospheric plasma for surface modification of selected materials (cotton, wool, Kevlar) and for realization of surface finishing was described. Utilization of the atmospheric plasma pretreatment and enzyme surface degradation (by esterase) was used for hydrophilization of polyester fabric. The microwave radiation was used for drying special textile structures. Research of the use of IR laser was used for surface ablation and local dyestuff removal.

Textiles for special applications. The project is focused on product-oriented research and development of textile structures for designs of special types of nonwovens and cryogenic drying as part of waste textiles treatment. Very effective ways for consolidation of fibrous assemblies or joining of nonwoven structures are so called quasi yarns created by simultaneous rotating and moving of cylindrical or conical - shaped body on the nonwovens surface. By suitable adjustment of the rotating body and the textile fabric surface it is possible to bond textile fabrics together by "surface-broad" lamination.

Czech patent CZ 192693 (European patent 0 648 877 A1) was used for quasi-yarn creation. A scheme of line enabling the production of 3D nonwovens textiles is shown on Fig. 16.

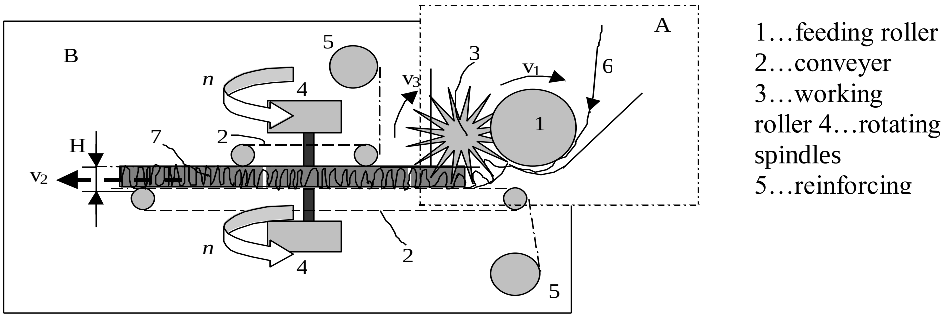


Fig. 16. System for 3D nonwovens processing fixed by quasi-yarns and by two reinforcing nets [16]

CONCLUSION

The innovations in the technical textiles branch are dependent on the many factors and in some cases the interdisciplinary cooperation is necessary. Some solutions are simple and depend on the skills and knowledge. The National Textile Research Center II is oriented to the long term research in the major fields influencing of textile technology and production of new fabrics. In all projects, complex research and development from the selection of fibers via yarn constructions up to final and special treatments is used.

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