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Content

REGULARITIES OF PRODUCING OF NANO-FILLED POLYROPYLENE MICROFIBERS

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Abstract: *The research of the concentration influence of the titanium oxide/silica (TiO_2/SiO_2) combined nanodispersing additive on the rheological properties and the structure-formation processes in a mixture of polypropylene/copolyamide (PP/CPA) has been conducted. Established, that during the flow of melt takes place the allocation of components on phases with the formation of liquid jets (PP microfibers) in the CPA matrix. Changing of content of nano-additive in the mixture melt allows us to control the process of fiber formation in the direction to increasing the fraction of microfibers and reducing their average diameter. The maximum effect of fiber formation improving was achieved at concentration of TiO_2/SiO_2 in a mixture of 1.0 wt%. Nano-filled compositions are characterized by low viscosity, the increased elasticity and spinnability of melt. Complex threads from nano-filled polypropylene microfibers have high hygienic properties thanks to a developed specific surface.*

Key words: *mixture of polymers, nano-additive, fiber formation, microfibers, viscosity*

1 INTRODUCTION

Modifying the properties of synthetic fibers and threads by reducing of the filaments diameter to micro- and nanosize and an introduction to their structure of nano-fillers is a promising trend in technology of chemical fibers. Formation of microfibers by processing of polymer mixture melt is a simple effective method of obtaining filament yarn and staple fibers with diameters from fractions of tenths to a few micrometers. Fiber formation of component of the dispersed phase in the matrix has enough general character and described for many pairs of polymers. However, this phenomenon is most clearly realized subject to the requirements of the components mixtures properties and the conditions of deformation. Thermodynamically incompatible polymers are mixed that in the terms of processing form the polymer dispersion of droplets of one in another. This transition layer has a sufficient extension that ensures the transfer of stress from the matrix to the dispersed phase. One of the traditional methods of influence on the interphase phenomena is addition of a third component – compatibilizator, that promotes interaction between the phases and the formation of a stable fine dispersion and consequently, leads to improved process of fiber formation [1]. In recent years have been shown the compatibilizated action of nano-additives (decrease in surface tension) in molten polymer mixtures. It allows you to manage the processes of structure-formation in the processing of polymeric dispersions and products to provide them with a set of new properties [2-4].

The purpose of the research is: impact of complex nano-additive of titanium oxide/silica on process of polypropylene (PP) fiber formation in copolyamide (CPA) matrix, on the rheological properties of their molten mixtures and on the characteristics of complex threads from PP microfibers.

2 EXPERIMENTAL

2.1 Materials used

For research were used: isotactic polypropylene as fiber forming component, copolyamide – matrix polymer (copolymer of caprolactam and hexamethylene-adipinate in the ratio 50:50) and the mixture PP/CPA of composition 30/70 wt%. Both polymers are industrial polymers, which are produced in large volumes. Characteristics of PP, CPA and mixture PP/CPA are represented in Table 1. Complex substance titanium oxide/silica (TiO_2/SiO_2) was used as nano-additive.

Table 1 Characteristics of initial polymers

Polymer	Melting temperature [°C]	Viscosity [Pa·s] *	Swelling of extrudate (B) *	Maximum degree of stretch (F_{max}) *
PP	169	260	2.0	270
CPA	170	740	1.4	630
PP/CPA	-	170	5.1	102

*at shear stress $5.69 \cdot 10^4$ Pa

Pyrogen silica nanoparticles were covered by nanoparticles of titanium oxide. The nano-additive titanium oxide/silica (TiO_2/SiO_2) has a specific surface area 62 m^2/g and content of TiO_2 7.0 wt%. Mixed oxide was obtained by compatible high-temperature pyrolysis of $SiCl_4$ and $TiCl_4$. The concentration (C) of nano-additive in mixture is of (0.5÷3.0) wt% by weight of polypropylene.

2.2 Methods used

Mixing components were performed on the worm-disc-extruder. In the gap between the movable and immovable discs of it there are intense shear and tensile stress, which contributes to a thin uniform dispersion of dispersed phase component. For maximum concentration of nano-additive in the structure of PP microfibers, it was pre-dispersed in the melt of dispersed phase, and the obtained granules PP/nano-additives were mixed with the matrix polymer (CPA). Rheological properties of melt: viscosity (η) and non-Newton flow index (n) was studied using capillary micro-viscozimeter at a temperature of 190°C in the range of shear stress τ (0.10÷5.69).10^4 Pa. The degree of deviation of flow regime from Newtonian was characterized by the value of «n», which is defined as the the slope of the tangent to the x-axis at a given point of the curve of flow. Melt elasticity was evaluated by largest equilibrium swelling of extrudates "B" as defined by the method [5]. The ability of melts to the longitudinal strain was characterized by a maximum degree of stretch, which was calculated as the ratio of the speed of a jet taking to the linear speed of the melt in the die (F_{max}). Research of remnants of polypropylene after matrix extraction was performed using an optical microscope brands MBI and scanning electron microscope GEOL GSM-35. Quantitative characteristics of the processes of structure-formation in extrudate were evaluated under a microscope by counting the number of all types of polypropylene structures and determining their size in the residue after extraction of matrix polymer. Experimental data were processed by methods of mathematical statistics, resulting in determining the average diameter of the microfibers and particles (d), the variance of their distribution by diameter (σ^2) and a mass fraction of each type of structure. Complex threads of nano-filled PP microfibers were obtained by extraction of matrix polymer by the inert solvent with respect to fiber forming polymer. Composite threads were formed on a laboratory bench with jet stretch 1000% and stretched at 150°C with multiplicity of stretching [6]. The strength at break (P) and breaking elongation (ε) of filament yarn was determined by using tensile testing machines of type KT 7010 AZ. Elastic modulus (E) was calculated by the formula:

$$E = L_0 P_{3\%} /(L_1 - L_0)S \qquad (1)$$

where L_0 – initial length; L_1 – length of thread after elongation of 3%; S – cross-sectional area of thread; $P_{3\%}$ – thread strength at elongation at 3%. The size of the specific surface area (S_{BET}) of polypropylene microfibers was determined by thermogravimetric method by building the sorption-desorption isotherms of moisture relative on humidity of environment, and S_{BET} was calculated by the equation BET [4, 7].

3 RESULTS AND DISCUSSION

The investigation showed that during the flow of melt of initial and nano-filled mixtures there is the effect of phase distribution of components. The polymer of dispersed phase is alloceted in the form of thin streams, which are stretched by the flow of the other polymer (matrix). Thus, the structure of extrudate (monothread) coming out of the die hole is a holistic phase of disperse medium, reinforced with thin streams of dispersed phase, which are remaining as a bundle of PP microfibers after dissolving the matrix polymer (Figrure 1).

Microscopic studies have shown along with the microfibers of continuous lengths, polypropylene forms other types of structures, such as particles, films, short microfibers, fine-fiber outer shell (Table 2).

Addition to melt mixture PP/CPA (0.5÷3.0) wt% of TiO_2/SiO_2 allows you to adjust the extrudate morphology of modified mixture. Data in Table 2 show the compatible effect of nano-additive: increases the uniformity and dispersion degree of component dispersed phase.

Table 2 The characteristics of the microstructure of mixture extrudates PP/CPA/TiO_2/SiO_2*

The content of additive in mixture [wt %]	Continuous fibers			Short fibers		Particles		Films	Shell
	d [µm]	[wt%]	σ^2 [μm^2]	d [µm]	[wt%]	d [µm]	[wt%]	[wt%]	[wt%]
0	4.0	79.5	2.6	3.2	10.8	4.1	2.7	4.1	2.9
0.5	2.7	82.7	1.2	2.4	9.0	2.9	2.6	3.3	2.4
1.0	1.8	94.0	1.2	2.0	1.1	2.4	1.2	1.8	2.0
1.5	2.2	89.9	1.7	2.1	2.3	2.6	3.4	2.5	1.9
3.0	2.5	85.4	1.9	2.3	4.7	3.1	5.8	2.2	1.9

*at $\tau = 5.69 \cdot 10^4$ Pa

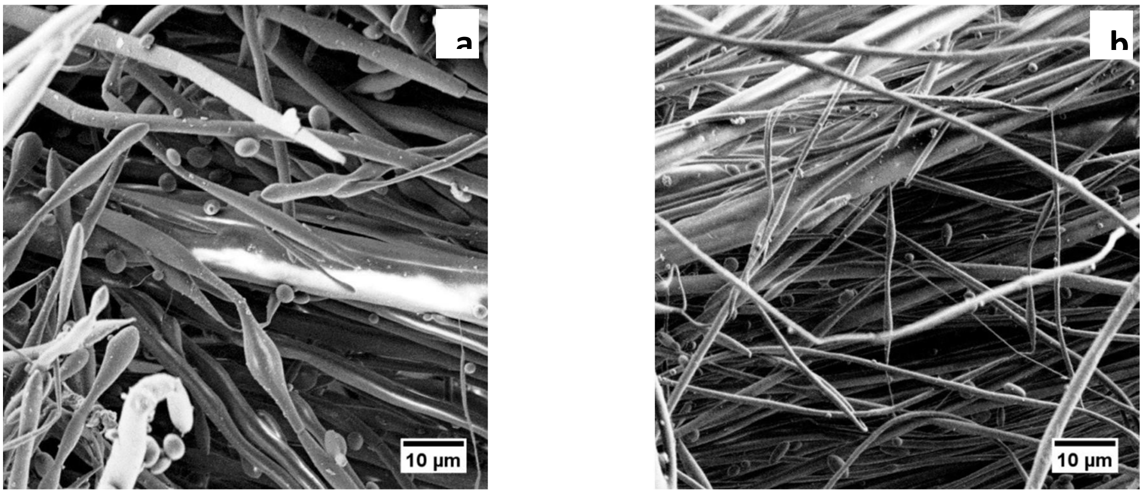

Figure 1 Electron microphotographs of polypropylene microfibers. Content TiO_2/SiO_2: a) 0.0 wt%; b) 1.0 wt%

There is also a fiberization improvement in all investigated range of concentrations of TiO_2/SiO_2: average diameter microfibers continuous length is reduced from 4.0 µm (for the original mixture) to (1.8÷2.7) µm (depending on the concentration of additives), increases the uniformity of distribution by diameter, according to the value of σ^2, increases mass fraction of polypropylene, which forms microfibers. Thus the concentration of nano-filler significantly influences on the size of microfibers and the ratio of types of structures in the extrudate – the diameters of particles and microfibers reach their minimum values and the number of microfibers is the maximum at the content of additive of 1.0 wt%.

Increasing the degree of dispersion of drops of dispersed phase polymer in the presence of 3.0 wt% hydrophilic and hydrophobic silica in the mixtures of polypropylene/polystyrene (PP/PS) and polypropylene/copolymer of ethylene and vinyl acetate (PP/EVAC) was described by Elias [2]. The change of process of structure-formation of the component dispersed phase in the presence of nano-fillers the authors associate with the formation of the advanced transition layer at the interphase area of mixture and with decreasing values of surface tension. The effect is enhanced when nanoparticles are preferentially localized in the interphase area. Thus, it was found that the preliminary introducing silica nanoparticles in PP melt, hydrophilic SiO_2 nanoparticles migrate from the volume of PP to the phase or polystyrene or EVAC, and this determines the decrease of surface tension at the interphase area. Addition of nanoparticles of titanium oxide in a mixture melt of poly(ethylene terephthalate)/PP allows you to adjust the diameter and length of polyester fibrils in a matrix of polypropylene [3]. In the presence of nano-additive the diameter is decreasing and their length is increasing. The authors of [4] has found that additives of pyrogenic silicas exhibit the compatibilization effect on mixture melt polypropylene/copolyamide and decrease the value of interphase tension. This promotes the formation of liquid jets (microfiber) of PP smaller diameters and their stabilization.

Effect of nanoparticles TiO_2/SiO_2, obviously, is also associated with the formation of advanced transition layer at the interphase area of mixture PP/CPA and with a decrease of the value of interphase tension. The significant compatibility effect is achieved thanks to the prevaling localization of nanoparticles TiO_2/SiO_2 in the interphase area. It is known that the nano-fillers are pushed from the melt volume to the interphase area of polymers when they are premixed with a component that has worse polymer affinity to the surface of nanoparticles [2]. Hydrophilic nanoparticles of TiO_2/SiO_2 are poorly wettable by nonpolar polypropylene melt, and they migrate to the interphase area and affect on the properties of the transition layer and the processes of structure-formation.

Formation of fine-fiber outer shell is caused by the fact that during the flow of polypropylene in the nozzle, as liquid with a much lower viscosity, is pushed to the walls and forms a thin boundary layer. The formation of fiber shell of continuous length, filled with microfiber, has practical importance, such as the formation from a mixture of polymers the composite film and getting out of it the filter material after extraction of matrix polymer. Such shell protects the filtration layer from separation of fibers by the filtering liquid and their removal to the filtrate.

The performed investigations showed that addition of nanoparticle TiO_2/SiO_2 affects the rheology of initial polypropylene of melts and also mixture PP/CPA (Figure 2).

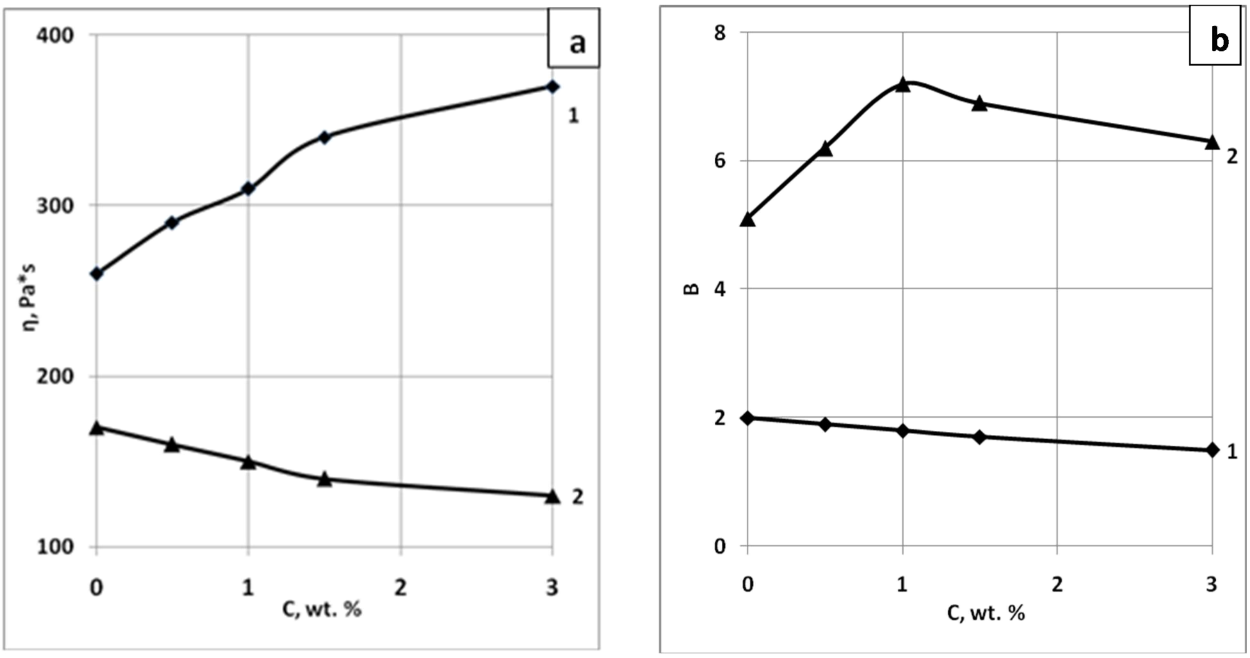

Figure 2 The influence of concentration of nano-additive TiO_2/SiO_2 on viscosity (a): of melts PP (1), the mixture of PP/CPA (2) and extrudate swelling (b): of PP (1) and mixture of PP/CPA (2)

As can be seen from Figure 2a, PP melt viscosity increases in overall range of concentrations of additives, thus appears effect of filling melt with solid substance. Such regularity, as a rule, occurs when filling melts by individual polymers. The melt viscosity of modified mixture decreases by (2.0÷5.7) times compared with *η* of the initial PP and CPA (Table 1, Figure 2a). The sharp drop in viscosity indicates a change in the mechanism of the flow of mixture melt – the transition from segmental movement of polymer macromolecules in the stream to stratified (layered) flow of individual components. Thus the decrease viscosity of melts of researched mixtures can be explained changing their structure. Allocation of PP in a separate phase to form a continuous surface between the components promotes the decrease of the viscosity through sliding of polymer along the surface phase separation. Secondly, for the implementation of flow of the mix with deformed particles is required smaller pressure drop (corresponding lower melt viscosity) than during the flow of individual polymers. Creating the anisotropic structure of component of the dispersed phase and their orientation in the direction of flow also contribute decrease of *η* of mixture melt [6, 7]. Reduced viscosity of melts of nano-filled compositions compared to *η* the initial mixture PP/CPA in the entire range of concentrations of TiO_2/SiO_2 (Figure 2a) is obviously connected with the change in processes of structure-formation of PP in matrix CPA in the presence of nanoparticles of additives. The initial polymers and their mixtures are viscoelastic non-Newtonian fluids. The nature of the modified melt flow of PP and PP/CPA mixture almost not varies depending on the content of nano-filler at all studied concentrations and obeys the Ostwald de Waele correlation (non-Newton flow index (*n*) is in the range of 1.6÷1.8).

An important feature of polymer melts and their mixtures, which can not be explained in terms of classical fluid mechanics, is the extrudate swell (increase in size of the jet) after exiting from the forming hole. While addition of additives TiO_2/SiO_2 in PP melt equilibrium value "B" decreases with increasing of content of nano-additive (Figure 2b), indicating a decrease in the elasticity of the melt by limiting mobility of macromolecules chains. Significant growth of extrudate swelling bi- and three-component mixtures is associated with deformation and orientation in the direction of flow of segments of macromolecules in each phase and also the droplets of dispersed phase themselves. They are the new relaxing elements, typical characteristic only for two-phase systems. The maximum degree of anisotropy is achieved when the dispersed phase forms a liquid jet (microfibers) of continuous length. In a number of studies have been shown that the value of the equilibrium swelling indirectly characterize the process of fiber formation component of the dispersed phase in the matrix. The index "B" is greatest when the microfiber is the only type of structure in the extrudate and their diameters are the smallest [1, 4]. As shown in Figure 2b, the swelling value of ternary compositions in (1.2÷1.4) times higher than for the original mixture.

Dependence "B" = f (the content of TiO_2/SiO_2) is an extreme nature. The maximum is reached in mixture PP/CPA/TiO_2/SiO_2 of content 30/70/1 wt%, whereby fiber formation is implemented in a best way: the average diameter of microfibers is minimum (1.8 μm), and they are the predominant type of structure in extrudate (Table 2). Increasing the fraction of films causes decrease in swelling. Thus formed anisotropic structure (microfibers) are the major contributions to the highly elastic deformation during the flow of polymer dispersions. The total elastic energy, when leaving the capillary, is higher for the composition with the deformable drops, which leads to an increase of swelling in several times in comparison with the "B" of initial polymers.

Forming of fibers can be considered as an process of uniaxial stretching. An important technological feature of melts of polymers and their mixtures which indicates the fiber forming properties, is the value of the maximum degree of stretching F_{max}: the higher its permissible value, the better the ability of the material to recycling or spinnability system. The obtained results indicate that the value of longitudinal strain melt of bi- and three-component mixtures falls sharply compared with F_{max} of the initial components (Table 1, Figure 3).

Minimum spinnability has a melt PP/CPA, due to the incompatibility of polymers and the weak interaction between components in the interphase area. Addition of nano-additive in an amount (0.5÷3.0) wt% is accompanied by an increase of $F_{max.}$ It is related to the increasing of melt viscosity and with improved fiber formation of PP in matrix of CPA. It is known that anisotropic structures increase the ability of melt to longitudinal strain [8]. Simultaneously, there is also significant increase of spinnability of polypropylene melt filled with solid nanoparticles of additive. Revealed regularity can be explained by a change in the processes of crystallization of polypropylene in the presence of nano-additive and forming of more perfect form of supramolecular structures. Results of the complex threads properties study of initial PP microfibers and filled with nanoparticles of TiO_2/SiO_2 are shown in Table 3.

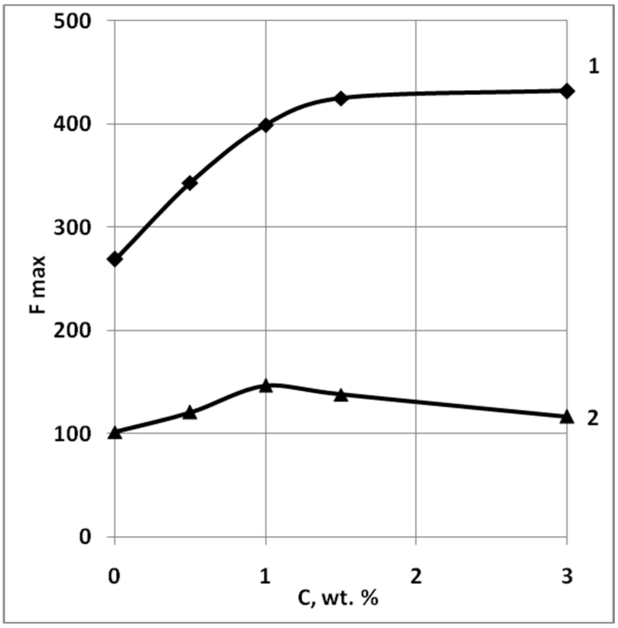

Figure 3 The dependence of the maximum degree of stretching melts PP (1) and mixture PP/CPA (2) on the concentration of nano-additive TiO_2/SiO_2

The obtained data show that the properties of complex threads formed from polymer mixture melts, is largely determined by the type of structures of dispersed phase in the matrix. As expected, addition of nano-additive improves strength and initial elastic modulus of modified threads.

The maximum values of mechanical properties are achieved at additive content 1.0 wt%, when the fiber formation of PP in matrix of CPA is implemented in a best way. It is known that polypropylene is hydrophobic polymer with an equilibrium water absorption of (0.1÷0.2) wt%. For nano-filled PP microfiber hygroscopicity increases approximately 2.5 times in comparison with the original microfibers, and (15÷20) times compared to textile polypropylene threads, obtained by traditional technology. This is due to the increase of specific surface of modified PP microfibers (Table 3).

Table 3 The influence of TiO_2/SiO_2 additives on complex threads properties

Content of TiO_2/SiO_2 [wt%]	Strength [MPa]	Elastic modulus [MPa]	Elongation [%]	Surface area S_{BET} [m^2/g]
0	160	2800	13.3	84
0.5	190	3500	11.8	135
1.0	240	3800	12.6	190
3.0	220	3400	11.7	210

4 CONCLUSIONS

Were investigated physical and chemical regularities of obtaining of polypropylene microfibers filled with complex nano-additive TiO_2/SiO_2, by processing of polypropylene/copolyamide mixture melts. It was established that during flow of melts of initial and nano-filled mixtures there is an effect of phase distribution of components: a polymer of dispersed phase forms a thin jets that remain in the form of microfibers beam after extraction of the matrix polymer from composite monothread. Nanoparticles in quantity (0.5÷3.0) wt% not only does not interfere the implementation of process of fiber formation during flow of melts PP/CPA, but also improve it – the mass fraction of microfibers increases, their diameter and quantity of undesirable structures (films, particles) decreases.

Ability to longitudinal strain of melts of modified compositions in all the studied range of concentrations of additive is lower than in nano-filled polypropylene, but the spinnability of ternary mixtures is sufficient for the formation fibers or films from them.

The obtained complex threads of PP microfibers filled with nano-additive TiO_2/SiO_2 are characterized by high hygienic properties (due to a developed specific surface) and mechanical indexes similar to textile polypropylene threads.

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THE STRUCTURE AND PROPERTIES OF POLYPROPYLENE-HALLOYSITE NANOCLAY FIBRES

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Abstract: *The current Asian dominance in the world production of chemical mainly synthetic fibres results in the necessity to sophisticate European fibre and textile products. The both mass and surface modification of fibres by nanotechnologies is one of the prospective ways how to ensure special mono and multi-functionally modified fibres for clothing and technical textiles. This article presents some results of the study of influence of nanotubes of natural halloysite nanoclay as a potential carrier of chemically and biologically active agents, as well as the effect of uniaxial deformation on the supermolecular structure (orientation, crystallinity and crystallinity index) and basic mechanical properties (fineness, Young´s modulus, tenacity and elongation at break) of undrawn and drawn nanocomposite polypropylene (PP) fibres. The experimental results obtained for nanocomposite fibres are compared with the supermolecular structure and basic mechanical parameters of non-modified PP fibres prepared under same technological conditions.*

Keywords: *halloysite nanoclay, undrawn and drawn PP nanocomposite fibres, structure, mechanical properties.*

1 INTRODUCTION

Asia holds the dominant position in the world production of synthetic fibres. Its share in 2013 was 87% [1, 2]. This implies the necessity of sophistication of European fibre and textile products in today´s highly competitive environment. It particularly concerns the development of modified, mono and multi-functional fibres and textiles necessarily characterized by high functionality, diversification, flexibility and highly effective and environmentally acceptable production [3, 4]. The most perspective way to ensure sophisticated properties of textiles is mass or surface modification by nanotechnologies [3, 4]. The most important nanotechnological procedures in the area of textiles include nano-treatment of their surface and nanoadditive additivation of the fibers mass during their extrusion (nanocomposite fibers). By these procedures, mono or multi-functional properties of textiles even at low concentrations of nanoadditives can be achieved, which is very beneficial from an economic aspect as well. The world nanocomposites market is highly prospective and its volume in 2015 was estimated to have reached 7.3 billion US$ [4, 5].

Nanocomposite systems based on natural layered silicates, particularly montmorillonite and halloysite, belong to the significant studied polymer nanocomposites [6-8]. The advantage of halloysite nanoclay is the shape of the nanotubes with porous inner surface which makes them suitable to be used as the carrier of chemically and biologically active substances for polymer nanocomposite systems [9, 10].

Halloysite ($Al_2Si_2O_5(OH)_4 \bullet 2H_2O$) is a two-layered aluminosilicate, with a predominantly hollow tubular structure in the submicron range and chemically similar to kaolin. The neighboring alumina and silica layers and their waters of hydration curve and form multilayer tubes due to a packing disorder. Halloysite is an economically viable material that can be mined from the corresponding deposit as a raw mineral [11].

In the past decade, halloysite became a focus of many studies and patents, although its nanoscale structure had been identified already since few decades *via* spectroscopic methods. This renewed interest should be ascribed to the rapid developments of nanoscience and nanotechnology in the past two decades, which drive the increasing interest on naturally occurring nanometric structures [12]. In general, halloysite nanotubes vary in length from the submicron scale to several microns, sometimes even > 30 μm [13], in external diameter from approximately 30 to 190 nm, and in internal diameter from approximately 10 to 100 nm [14, 15]. The morphological parameters of halloysite (length, internal/external diameter, ratio, and tube thickness) vary significantly between and even within deposits, and this diversity is due to the formation of halloysite under various crystallization conditions and geological occurrences [13, 14, 16]. Worldwide, large halloysite deposits have been found in

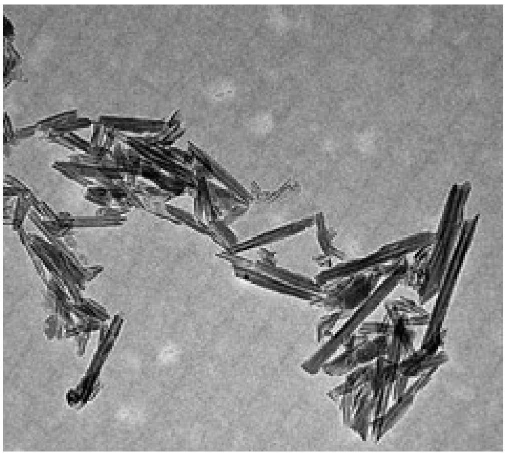
Australia, the United States, China, New Zealand, Mexico, and Brazil [13].

The clay mineral layer has by itself several excellent mechanical properties which is important for its practical applications. As halloysite is used as inorganic filler in clay-polymer nanocomposite, its mechanical properties, combined with other important factors such as loading amount and aspect ratio of the filler, dispersion extent, and compatibility between filler and organic substrate, strongly influences the mechanical properties of the final clay polymer nanocomposite product [17].

2 EXPERIMENTAL AND METHODS

2.1 Materials

Isotactic polypropylene (PP) produced by Slovnaft Company, SK, with MFR=27.6 g/10 min and inorganic nanoadditive of halloysite nanoclay 685445 (Applied Minerals Inc.) PP masterbatch developed by Research Institute for Man-Made Fibres, a.s. Svit (halloisite content 10.0%, MFR=11.0 g/10 min, Filter index = 560 MPa.kg^{-1}) were used during the fibre preparation process.



Picture 1 TEM Image of 50 nm diameter halloysite nanotubules 685445 [11]

2.2 Fibre preparation

The nanocomposite PP fibres were prepared from mechanical mixture of PP granulated polymer and halloysite PP masterbatch using the classical discontinuous process of spinning and drawing. The laboratory POY discontinuous line has an extruder with diameter of D = 32.0 mm, with a discontinuous one-step drawing process. There were used constant processing conditions with the spinning temperature of 220°C, spinning die plate of 2x25 holes with diameter 0.3 mm, final spinning process speed of 1500 m.min^{-1}, the drawing ratio λ = 2.0, the drawing temperature of 132°C and final drawing process speed 100 m.min^{-1}.

2.3 Methods used

<u>*Orientation of fibre (the fibre´s birefringence)*</u>

The orientation of macromolecular chains in fibre expresses the level of anisotropy of oriented polymer system/fibre. The orientation can be evaluated using more methods. One from methods is the measurement of the birefringence. The total orientation of prepared nanocomposite fibres was evaluated using polarization microscope DNP 714BI there were determines the refractive indexes of light in fibre axis as well as in perpendicular direction of fibre. From refractive indexes of light obtained there was calculated the fibre’s birefringence:

$$\Delta n = n_{\parallel} - n_{\perp} \tag{1}$$

<u>*Factor of average orientation of fibers (the sound velocity in fibres)*</u>

Factor of the average orientation (f_α) of fiber is calculated from measuring the speed of sound in oriented fibers, (Eq. 1):

$$f_\alpha = 1 - \frac{c_n^2}{c^2} \tag{2}$$

where: f_α - factor of the average orientation of fiber, c_n - speed of sound in the completely non-oriented fiber [km.s^{-1}] (c_{pp}=1.6 km.s^{-1}), c - speed of sound of fiber [km.s^{-1}].

The speed of sound in PP and modified PP fibers were measured by Dynamic Modulus Tester PPM-SR (USA) and it was used according to standard PND 129-126-06

<u>*Crystallinity index (FT-IR)*</u>

Crystallinity index I_k of PP fibres represents the fraction of the crystalline phase in PP fibres. It is determined as the ratio of integrated absorbance of absorbent band 840 cm^{-1} (A_{i840}) characterizing the regularity of the arrangement of segments of macromolecular chains, and integrated absorbance of absorbent band 2723 cm^{-1} (A_{i2723}) as the internal standard influencing of the degree of crystallinity using equation:

$$I_k = \frac{A_{i840}}{A_{i2723}} \tag{3}$$

Crystallinity index of nanocomposite fibres was evaluated by FT-IR spectrophotometer 8400 Shimadzu.

<u>*Crystallinity of fibres*</u>

DSC 4 apparatus Perkin Elmer was used at the evaluation of thermal properties of non-modified PP and modified PP fibres. There was performed the non-isothermal process of analysis. A sample of original fibre was heated at a rate of 10°C.min^{-1} from 50 to 220°C. All measurements were carried out in nitrogen atmosphere.

From melting endotherm of 1st heating there was determined melting enthalpy (ΔH_m) that was used for the calculation of crystallinity β using the next equation:

$$\beta = \frac{\Delta H_m}{\Delta H_m^0}.100\% \quad (4)$$

where ΔH_m^0 = 198.11 kJ.kg^{-1} is the melting enthalpy of PP with the 100% crystallinity.

Mechanical properties of fibres

Tenacity at break and elongation at break and Young's modulus represent the mechanical properties. The mechanical properties of PP and modified PP fibers were evaluated by the Instron 3343 equipment (USA). Measuring conditions were the length of fiber 125 mm and rate of clamp 500 mm/min. The mechanical characteristics of the PP and modified PP fibers were determined in accordance with standard (Standard ISO 2062:1993) and fineness in accordance with the STN EN ISO 1973.

3 RESULTS AND DISCUSSION

From the carried out experimental spinning and drawing tests it follows that the PP/halloysite nanoclay composite is fibre forming up to 5.0 wt.% of nanofiller in the mass of nanocomposite. The discontinuous spinning and drawing process at drawing ratio λ = 2.0 was stable up to 4.0 wt.% of the solid particles in the fibre. The higher nanoadditive content up to 5.0 wt.% reduces the technological stability of spinning process due to occasional tears of individual fibrils in the spinning zone. The supermolecular structure parameters and basic mechanical properties of pure and nanocomposite PP fibres were evaluated.

The obtained results, in Figures 1 and 2 show the effect of the halloysite nanoclay content on the supermolecular structure parameters of undrawn and drawn nanocomposite PP fibres.

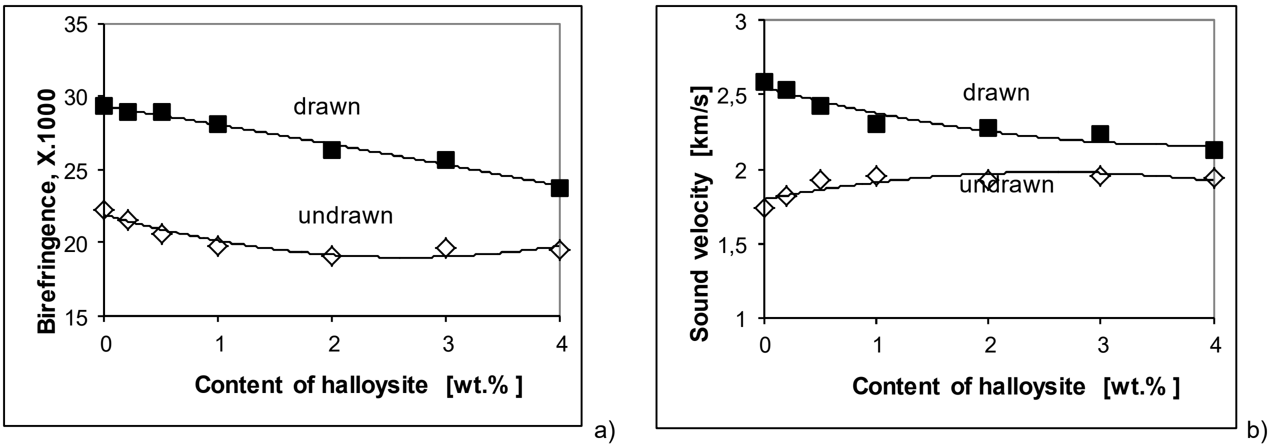


Figure 1 The dependences of birefringence (a) and sound velocity (b) of undrawn and drawn nanocomposite PP fibres on the content of halloysite

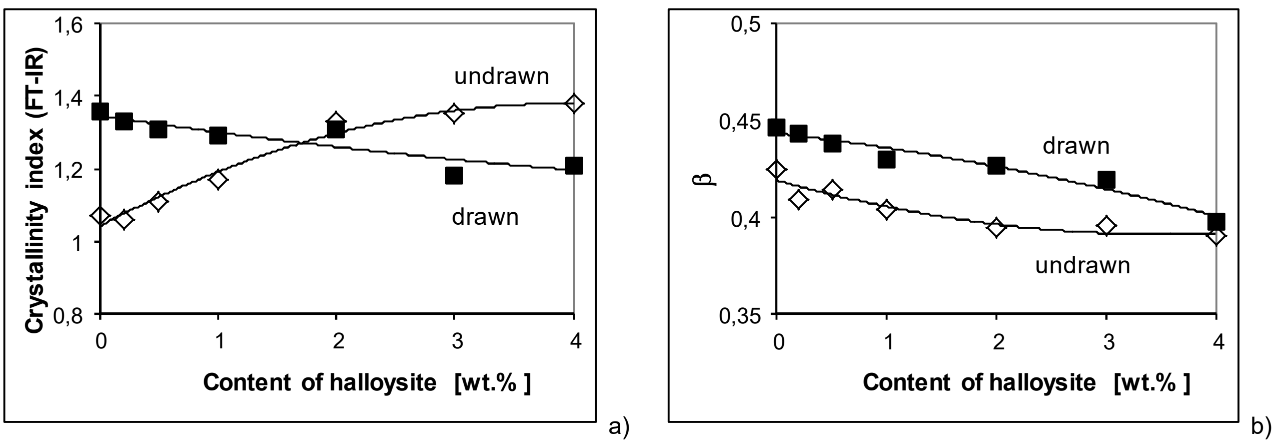


Figure 2 The dependences of crystallinity index (FT-IR) (a) and crystallinity β (b) of undrawn and drawn nanocomposite PP fibres on the content of halloysite

The slight decreasing dependence of birefringence (Figure 1a) and crystalline portion β (Figure 2b) on halloysite content was found. It is the result of a steric braking effect of nanoadditive particles (nanotubes form) on orientation of segments of PP macromolecular chains into the direction of the fibre axis in the spinning zone. This also implies a slight decrease in the crystalline portion β of PP matrix of undrawn nanocomposite fibres with increased content of the nanoadditive in the mass of fibres. At the same time, there is an increase of the sound velocity (orientation - Figure 1b), as well as conformational regularity of their crystalline regions (crystallinity index - Figure 2a). It is probably the result of the nucleating effect of nanofiller particles in the process of formation of undrawn nanocomposite PP fibres in the spinning zone.

The uniaxial deformation of undrawn nanocomposite PP fibres significantly increases total average orientation of macromolecular chains of polymer matrix (birefringence - Figure 1a), orientation of macromolecular chains in surface layers (sound velocity - Figure 1b), as well as crystalline portion β (crystallinity β - Figure 2b) of PP matrix of drawn nanocomposite fibres.

In comparison with drawn nonadditivated standard PP fibre, the increased nanoadditive content in the drawn nanocomposite PP fibres results in the decrease in full average orientation of macromolecular chains (birefringence – Figure 1a), orientation of macromolecular chains in surface layers (sound velocity - Figure 1b), conformational regularity of crystalline regions (crystallinity index - Figure 2a), as well as crystalline portion β (crystallinity β - Figure 2b) of fibres. It is the result of a steric braking effect of nanoadditive particles (nanotubes form) on orientation of segments of PP macromolecular chains in the direction of the fibre axis in the drawing process of nanocomposite fibres.

The results in the Figures 3 and 4 show the effect of the halloysite nanoclay content on the basic mechanical properties of undrawn and drawn nanocomposite PP fibres.

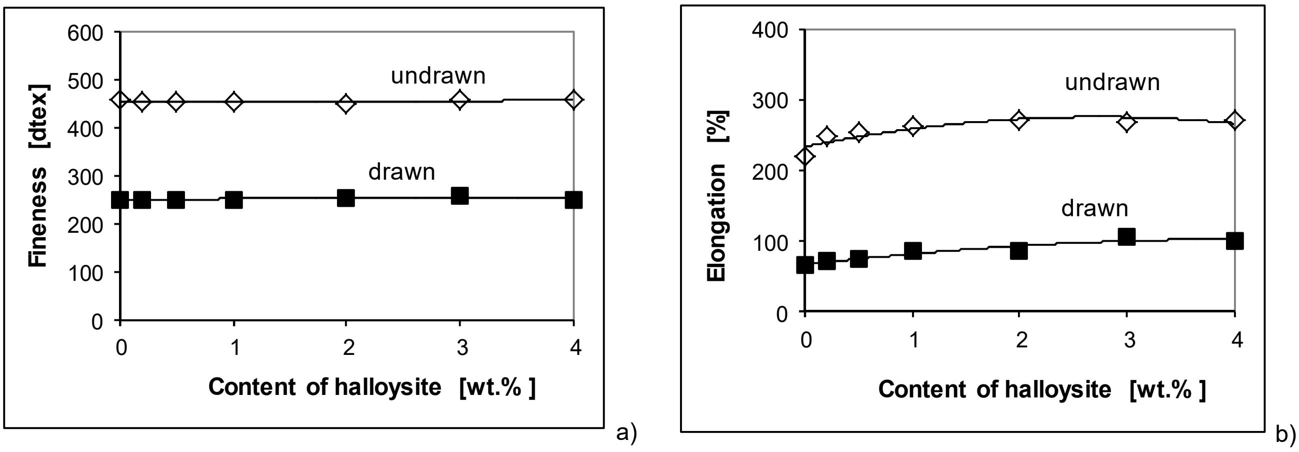


Figure 3 The dependences of fineness (a) and elongation at break (b) of undrawn and drawn nanocomposite PP fibres on the content of nanoadditive

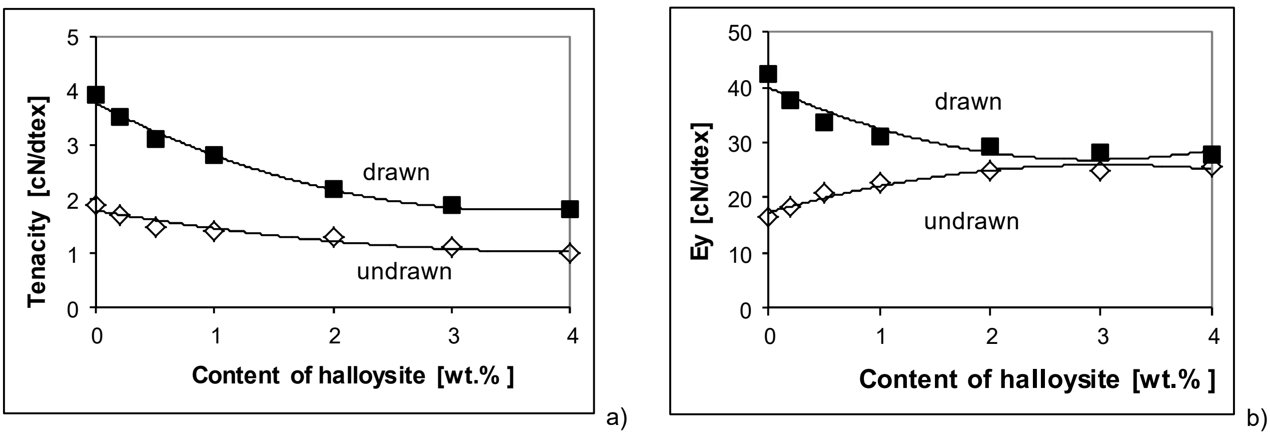


Figure 4 The dependences of tenacity at break (a) and Young´s modulus *Ey* (b) of undrawn and drawn nanocomposite PP fibres on the content of nanoadditive

The fineness of undrawn nanocomposite fibres was found constant in dependence of halloysite content in the fibres (Figure 3a). The slight increase in their elongation (up to cca 50% absolute - Figure 3b) and decrease in their tenacity (up to 45% - Figure 4a) when compared to non additivated standard. This is mainly connected with the decrease in their full average orientation (birefringence - Figure 1a) at increased nanoadditive content in the mass of undrawn nanocomposite fibres.

An increase in Young's modulus with increased halloysite content in the mass of undrawn nanocomposite fibres (up to cca 55% - Figure 4b) is mainly related to the increase in the conformational regularity of their crystalline areas (crystallinity index - Figure 2a).

The process of uniaxial deformation of undrawn POY nanocomposite fibres significantly increases the tenacity and Young´s modulus. In opposite the elongation of fibres decreases in the whole content halloysite up to 4.0 wt.% and up to 2.0% it also increases the Young's modulus of drawn nanocomposite fibres (Figures 3b, 4a, 4b). It is the result of a significant increase in total average orientation of macromolecular chains in polymer matrix (birefringence - Figure 1a), orientation of macromolecular chains in surface layers (sound velocity - Figure 1b), crystalline portion β (crystallinity β - Figure 2b.), and up to 2.0% of nanoadditive content also the crystallinity index of PP matrix of drawn nanocomposite fibres.

The addition of nanoadditive in the nanocomposite PP fibre mass resulted in the decrease in the regularity of arrangement of macromolecular chains in drawn nanocomposite systems. This was reflected in the decrease in tenacity (up to cca 50% - Figure 4a) and Young's modulus (up to cca 35% - Figure 4b), as well as in the slight increase in the elongation (up to cca 35%) of drawn nanocomposite fibres with increased nonadditive content in the fibre mass. It is related to the decrease in total average orientation of macromolecular chains (birefringence - Figure 1a), orientation of macromolecular chains in surface layers (sound velocity - Figure 1b), crystalline portion β (crystallinity β - Figure 2b), as well as the decrease in conformational regularity of crystalline areas (crystallinity index - Figure 2a) with increased nanoadditive content in the mass of drawn nanocomposite fibres.

Obtained values of the basic mechanical properties of nanocomposite PP fibres are in good correlation with determined values of their supermolecular structure parameters.

4 CONCLUSION

The results of the study of the spinning, structure and mechanical properties of nanocomposite fibres presented in this article have showed that the composite PP/halloysite is fibre forming nanocomposite using discontinuous technological process in the range up to 4.0 wt.% of nanoclay nanoparticles. The technological conditions for stable spinning and drawing were found. The basic dependences of the influence of nanoadditive content and uniaxial deformation on the supermolecular structure parameters and basic mechanical properties of undrawn and drawn nanocomposite PP fibres were evaluated. Addition of halloysite into PP fibre prevents to create the regularity and arrangement of supermolecular structure of oriented nanocomposite fibres reduces crystallinity. This led to the decrease in mechanical properties of the tenacity and Young´s modulus of drawn nanocomposite PP fibres.

Based on the obtained results it can be stated that the evaluated nanoadditive halloysite nanoclay proves to be a potential carrier of chemically and biologically active modifying substances for PP nanocomposites, including nanocomposite PP fibres.

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SOMATOMETRY AND COMFORT OF CLOTHING FOR HANDICAPPED PERSONS

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Abstract: *The article analyses the situation of clothing for handicapped persons in wheelchairs. The paper is focused, among others, on the needs of scanning such complicated figure as a human body that is permanently handicapped after birth, as a result of development or during life due to an injury. Scanning and measuring are focused on somatometry of sitting persons in a wheelchair with emphasis on application of the results at made to measure or small series clothing production. Thanks to scanning, which is done by the MaNescan system, measurements of virtual human body, both in sitting or standing positions, can be carried out in MIT_MaNescan 3D software without direct touch and the dimensions that are necessary basis for clothing production can be acquired. The article provides a solution for the question of "the comfort of clothing products for handicapped persons", which is connected with the question of creating a problem solving team and with creating necessary conditions that will ensure realization of clothing suitable for handicapped persons.*

Key words*: Somatometry, MaNescan, MIT_MaNescan, handicapped person in a wheelchair, scanning a sitting person, comfort of clothing, made to measure.*

1 INTRODUCTION

The subject of the research is clothing that is, in fact, a mirror reflecting the whole history of the mankind. All the time it gets other sense and expresses the personality and shows the person's way of living.

An inseparable part of social culture is the culture of clothing, the expression mean of which is clothing that becomes a significant part of lifestyle in the society. Clothing is closely connected with bodily individuality of each person and can also be a clear response about their psyche and social and cultural position within society and also the expression of affiliation to certain social class. Modern times and the corresponding level of culture make new demands on clothing and act as particular form of aesthetic sensitivity of society.

From the moment humans discovered functionality of clothing as protection against adverse effects of climate it did not take long to the moment when humans thought about its styling and aesthetical functions. This implies four basic functions that clothing should meet. They are hygiene, usefulness, trendiness and elegance.

These demands on clothing are made not only by persons with almost perfect figure but also by individuals, who were not gifted with symmetric figure and persons, who are ranked in the group indicated as “handicapped persons”. But also this category of persons has the same rights to life as others and it is certain that these persons, especially young persons, want to be liked.

2 IDENTIFICATION OF HANDICAPPED PERSONS

Besides most healthy people, people with different levels of handicap at the beginning of their lives are born or they are afflicted during their lives, e.g. due to an injury, disease. Physically handicapped persons have always been very noticeable and society's attitude towards them did not use to be positive.

In some ancient slave states, the handicapped persons were eliminated. In the Middle Ages, the handicapped persons were seen more positively. Many of them were provided with food and somewhere, especially at monasteries, certain care. In the 18th century, the beginnings of care for handicapped children can be found; it is, however, care of charitable nature. Full medical, educational and social care is provided to such children as late as at the beginning of the 20th century. Thanks to Rudolf Jedlička, an institute for physically handicapped [1] that has been named after him in various places of our republic was established in Prague in 1913. Rehabilitation care of very good level in that time was implemented there and besides that, educational care, especially preparation of physically handicapped children for various jobs, was provided.

Currently, particularly since 1989, there are many similar institutes and special centres, which publicize and advance the attitudes and interests of handicapped persons, in many places of the Czech Republic. Among these establishments there are: institutions of social care, special pedagogical centres, special kindergartens, special primary schools, secondary schools, vocational schools, special and supporting schools and children's centres and children's homes [1].

In 2007, the Czech Republic registered about 244 896 physically handicapped persons, out of them 42 397 boys and girls aged 0 – 30, which is 17.3% from the total count [2].

A physical handicap is usually caused by nervous system diseases, musculoskeletal system diseases and connective tissue diseases and also by congenital defects and deformations.

3 CLOTHING OF PHYSICALLY HANDICAPPED PERSONS

Based on a research, there are a high percentage of physically handicapped persons. It is a group of inhabitants that are worth noticing not only from medical and pedagogical point of view but also from the clothing point of view. Clothing is something that everyone comes into contact with every day. Getting dressed, getting undressed and wearing clothes can be a considerable problem for handicapped persons, which is connected with selection of the type and size of clothes, the way of putting on and fastening, suitability of materials, etc. Physically handicapped persons often suffer from helplessness and they depend on help of other people. Such dependency on the others could often be solved by suitable clothing.

Where to start and how to proceed when solving the questions connected with clothing for physically handicapped children and youth?

We can assume that the process of solving can be identical to solving clothes for healthy persons. The following question needs to be answered: Shall we produce clothes in individual, i.e. made to measure, or serial production? We can answer only on the basis of a deep research of not only the physical handicap but also somatic characteristics of the persons, among which there are body posture, body shapes and body types, which can be found out only based on somatometry.

Several steps in this area have already been taken at the Technical University in Liberec within solving the diploma and bachelor thesis and within the research at the Clothing Department.

These are the pieces of work dealing with:

- somatometry of physically handicapped children and youth,
- scanning bodily dimensions by contact and contactless methods,
- influence of ergonomics and anthropometry on construction of clothes,
- construction, material a technology solution of clothing for physically handicapped persons.

These works show the way to solution. They always include a certain sample of probands of physically handicapped persons and youth; with them we cannot come to objective conclusions easily. Solution requires more extensive somatometric research, based on which generally applicable conclusions can be reached.

4 SOMATOMETRY OF PHYSICALLY HANDICAPPED PERSONS

Based on experience, we need to assume certain difficulties while performing the measurements, which are related to limited mobility of physically handicapped persons and to necessary consent for measurements of underage probands from their parents.

Solving the question of somatometry requires the list of the names of bodily dimensions of standing and sitting persons, the method of investigation – contact or contactless methods, investigative method, selecting the centres, where measurements will take place, setting the number of probands, time schedule and plan of measurements and, of course, subsequent statistical assessment of the results that will lead to typology and in size range for physically handicapped persons.

Within the article, there is an example of the method of scanning and measuring of the physically handicapped persons bound to wheelchairs using the MaNescan scanning system. The aim is to gain their bodily dimensions more easily for further processing.

4.1 Scanning physically handicapped persons bound to wheelchairs

Contactless scanning of human body using the MaNescan system (Figure 1) was designed and first applied by the author of this article and together with MiT_MaNescan software [3] it was applied at the Technical University in Liberec for measuring healthy persons and subsequently tested also for physically handicapped sitting persons bound to wheelchairs.

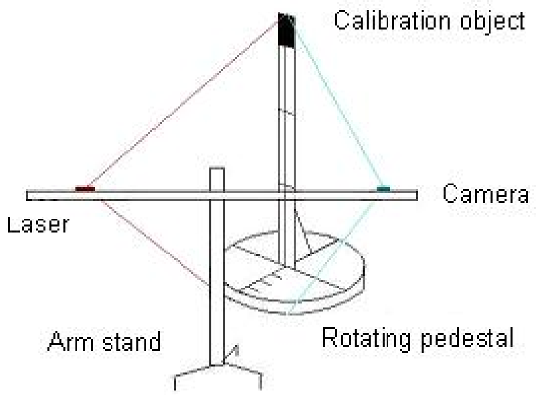

Figure 1 Diagram of the workplace for scanning human body surface

The MaNescan system uses 2D methods of triangulation. The active segment is line laser of class II and picture imager – a camera. Detection or scanning of the human body surface is carried out in the dark. The analysis of the images is a key part of the dissertation thesis – scan images (Figure 2) are transformed into 3D coordinates using the MiT_MaNescan program and subsequently imported to the CATIA 3D CAD system for further applications.

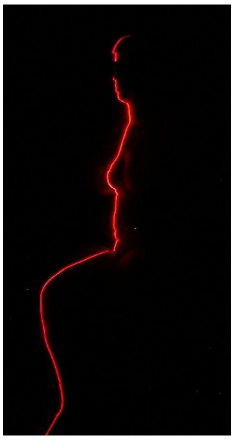

Figure 2 Example of an image of a line scanned on figure

Evaluation of scanned lines can be divided into several steps: processing of calibration pictures, calculation of coordinates *x, y, z* – vectorization, downloading the set of points and display of a “3D digital model” of a human body in the CAD system CATIA (Figure 3) and measuring the human body surface in this program using its tools.

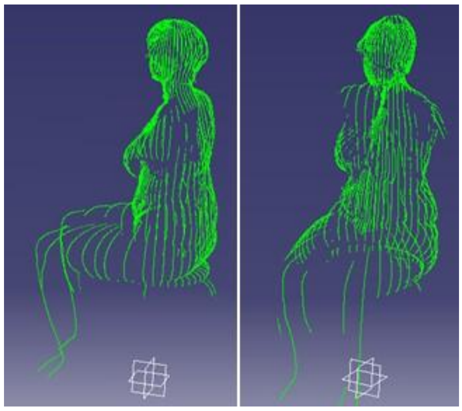

Figure 3 Image of an imported “3D digital model” of a human body into CATIA program

4.2 Determining body dimensions

Height and girth dimensions were measured according to the standard, monitored for girth of chest, waist and sitting point at the levels passing through the respective somatometric points on the body. Contact and contactless investigation was carried out on a set of thirty young women aged 21 to 28 years [4].

3D image analysis of sitting figures is similar to that of standing persons. The analysis is supplemented by other possible measurements of widths, lengths and girths in inclined levels Figures 4 and 5 [5]. The results of measuring body dimensions by a contact and contactless method are displayed in Figure 6.

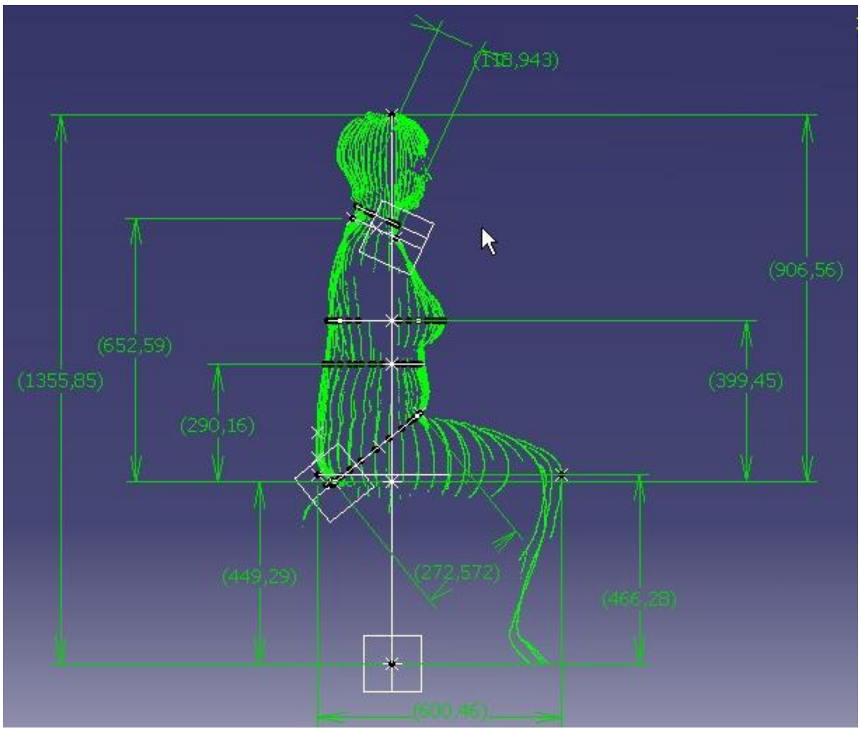

Figure 4 Visualization of imported data in 3D CAD software - measuring height and width with the sitting figure

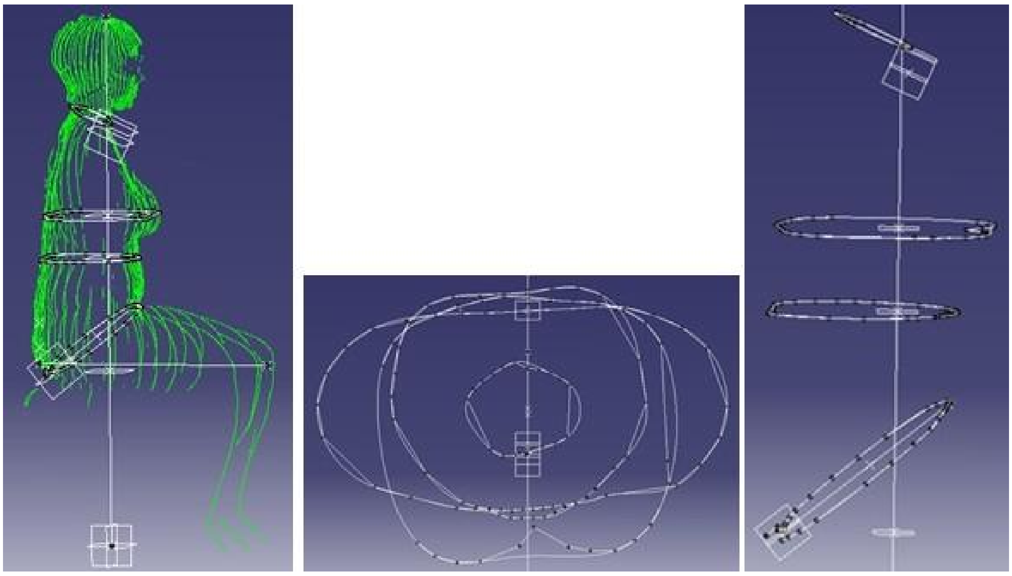

Figure 5 Vizualization of imported data in 3D CAD software – The girth with a sitting figure

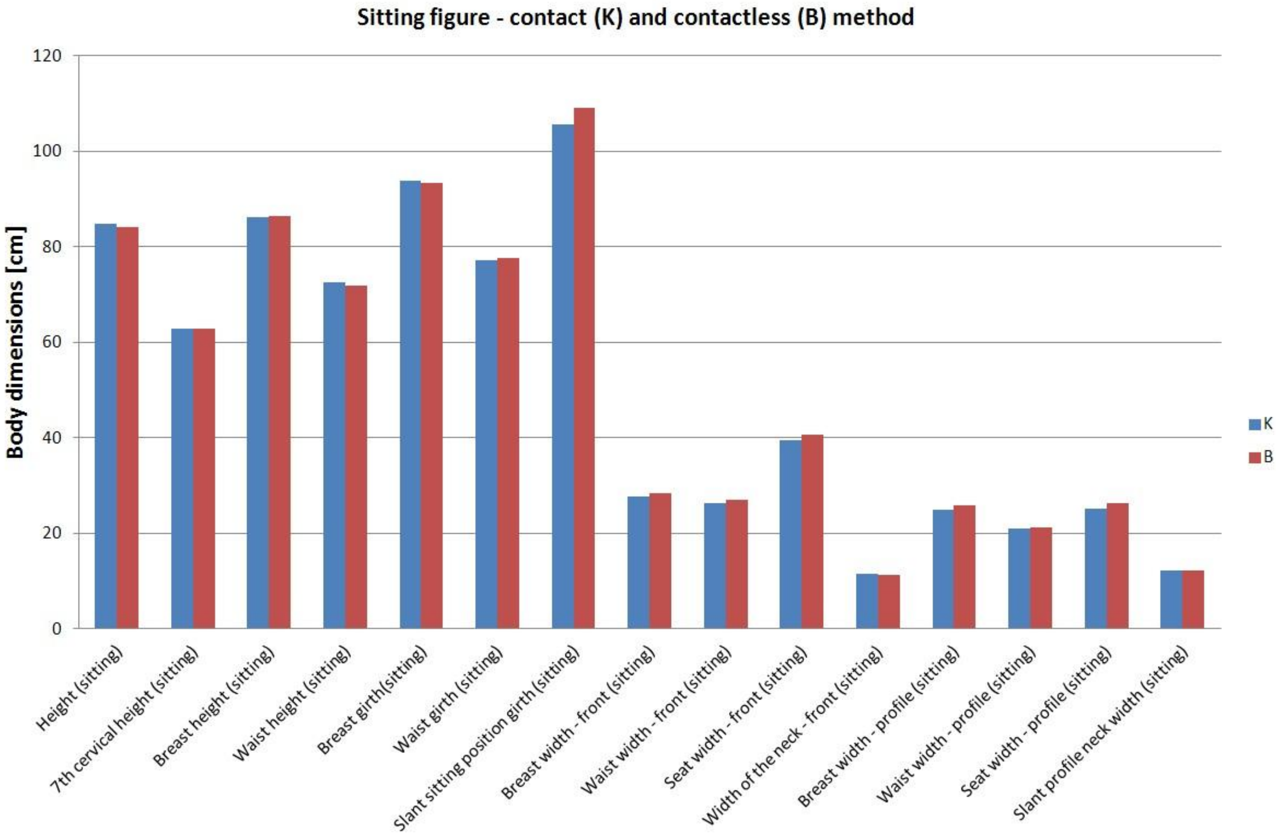

Figure 6 Overview of the measured body dimensions

5 RESULTS AND DISCUSSION

The results in average length, width and girth dimensions are stated in Figure 7 that are required for construction of clothing for sitting persons. The results of the measuring show that the contactless method gives the lower numbers for Height (sitting), Waist height (sitting), Breast girth (sitting) and Slant profile neck width compared to conventional contact method. The difference goes from 0.01 and 0.64 percent.

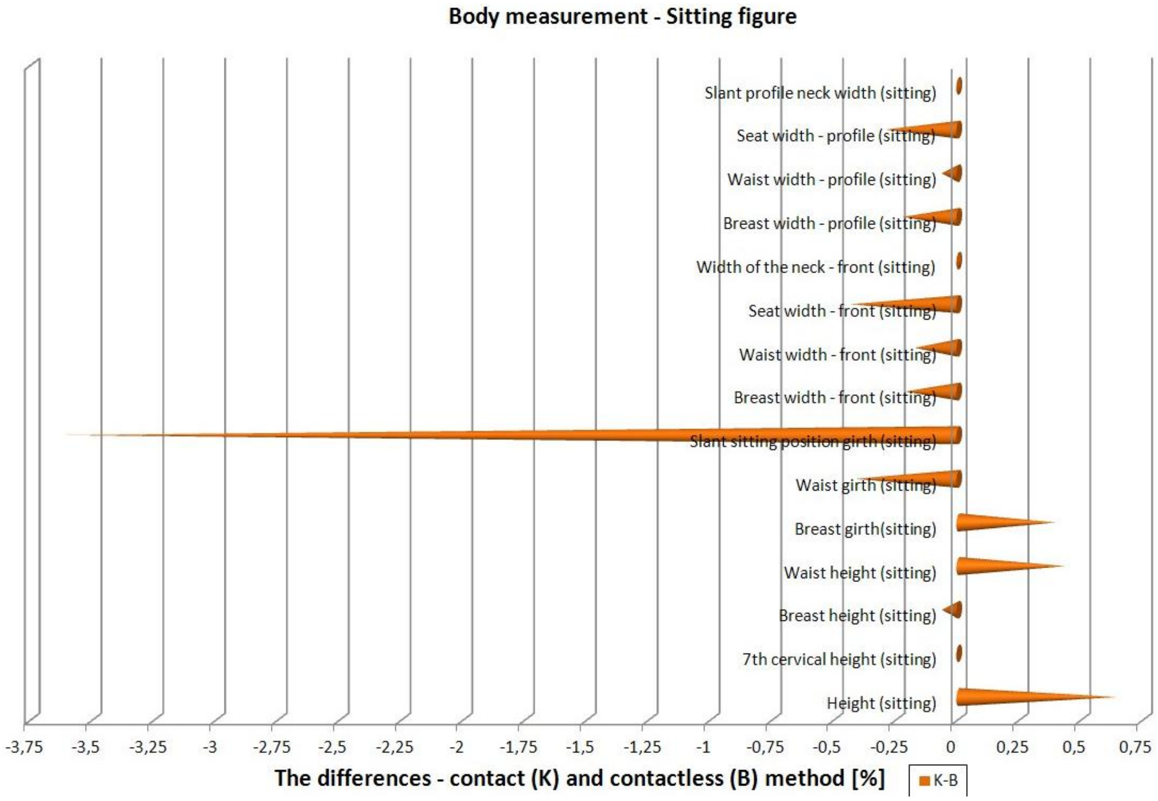

Figure 7 The average value of measurements body size of seated figures – contact (K) and contactless (B) method comparison and the differences in centimetres and percentage

The breast girth (sitting) is 0.39 percent lower, waist girth (sitting) is 0.42 percent height and Slant sitting position girth (sitting) is 3.62 percent height with compared to contact method.

The front and profile width is height with compared to contact method. The difference goes from 0.18 and 0.44 percent.

Of course, the results so far are open to argument. Validity of the method will be verified after somatometric contact and contactless measuring carried out on a larger group of the wheelchair bound people.

Based on previous investigations, we can rather think of made to measure production of clothing but a small series production on customer's individual dimensions is not excluded. This requests perfect mastering of the cut construction for physically handicapped children and youth and adults and related questions of the technology for preparation of the kind of clothing range.

The following question will certainly arise: How and by which form will the orders be done? Who will take charge of such production? Is it realistic? Will this have an impact on the product price?

Yes, higher price of the clothing product must be admitted but it is possible that it is not the price that cannot be solved. If the clothes for physically handicapped children and youth are appropriate, in terms of function and aesthetics, there is no need to be concerned about the parents of handicapped children and youth and the handicapped persons themselves not being interested in such clothes.

Due to the above mentioned information and entire intent of the solving the “comfort of clothing products for handicapped persons”, we must deal with the question of the problem solving team. For this reason, we need to ask what the problem solving team should be like. It should be set of many professions and branches; it means that it should include:

- ministry representatives,
- representatives of the centres for physically handicapped youth,
- representatives of physically handicapped persons,
- representatives of physicians – specialists,
- representatives of textile and clothing professions,
- experienced analysts and programmers,
- and also representatives of production plants for subsequent implementation of the results.

We believe that in the future all difficulties will be overcome and that the idea of solving comfort for physically handicapped children and youth and adults will become a reality and that implementation will not take long.

6 CONCLUSION

So a somatometric research is absolutely necessary. It must be well prepared and more departments should be involved in it, i.e. KOD in Liberec and possibly one of the departments of Pedagogical Faculty at UP in Olomouc dealing with the area of anthropology and anthropometry. TUL students were also engaged in this area and the results of their works refer to certain categorization of physically handicapped persons, i.e. walking, walking on crutches, walking – sitting in a wheelchair, sitting in a wheelchair, lying physically handicapped persons. Such categorisation needs to be verified by greater scope of somatometric investigation.

With respect to such division, we will have to consider, for which category of physically handicapped persons it will be necessary to make clothes in different proportions and sizes and how they will differ from the clothing of healthy children and youth with regard to construction, material and technological processing.

Physically handicapped persons are a part of our society and it is necessary to make their uneasy fate a little easier by something as small, compared to their destiny, as nice and comfortable clothing is.

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THE PROCESS OF DESIGNING THE CHILDREN`S CLOTHES FOR TRAININGS ON ROLLER-SKATES

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Abstract: *The article deals with the ways of improvements in the process of designing the children`s clothes for trainings on roller-skates at the stages of determination the initial data for construction of the base design and development of modified design. It presents the results of anthropometric researches of children at the age of 4 – 5 years. The article describes the method of determination the location and size characteristics of protective elements, which has been proposed by the authors. It is proposed the methodology for development the model designs of multifunctional clothes for children who have trainings on roller-skates.*

Key words: *clothes for rollerbladers, designs-modifications, measures, multifunctional children`s clothes, protective elements.*

1 INTRODUCTION

In the market economy the primary objective of every businessman is the production of competitive products. A demand for children`s clothes is quite high due to a small period of its exploitation because of the rapid changes in anthropometric characteristics of the child`s body. Designing of children`s household garments with additional functions is the up-to-date trend. Such kind of clothing includes children`s clothes for trainings on roller-skates. Researches, which were conducted by the authors [1, 2], showed that parents began to teach their children skating on roller-skates at the age of 4 – 5 years and used for this purpose everyday clothes of sports style, which did not have protective properties against bumps when falling on the parts of the body that were not protected by means of individual protection. In such clothes children felt pain syndrome when falling and it caused a sensation of fear during the further trainings and unwillingness to continue their trainings at all. There are some special protective children`s clothes at the market, but such clothes are not so popular among the consumers because of the high price and narrowly focused purpose. Also its production is inefficient in terms of use of the energy and resources due to the predominance of the product life cycle on the cycle of its usage (the child is growing faster than the cloth of his/her size is wearing out). Therefore, an actual task is to create everyday clothes with enhanced additional functions. The authors consider that one of the main task in designing the children`s clothes for trainings on roller-skates is to create everyday clothes which can be transformed into the clothes with protective elements.

2 PREPARATION OF INITIAL DATA FOR DESIGNING OF MULTIFUNCTIONAL CHILDREN`S CLOTHES FOR TRAININGS ON ROLLER-SKATES

In actual practice the process of designing of the clothes can be divided conventionally into such stages [3]: informational and schematic design; determination of initial data; selection of methods and preliminary estimation of the design; construction of the base design; modeling the base design for obtainment of the draft of the designed model; quality control of the product design.

One of the most important stages in the clothing design process is the construction of a high-quality base design, on the basis of which design engineer through modeling can get the final patterns of the designed product in the future. The quality of the base design as the developed view of the human body depends on the correctness of the initial data (anthropometric characteristics of the human body) as well as on the correctly chosen method of construction and conducted calculations. These two factors affect the quality of the base design independently from the chosen design mode (manual or automated).

Determination of the base design is based on the anthropometric characteristics, which the design engineer determines using the effective normative and technical standards [4-9].

Designing of the children`s clothes is based on the classification of the child population according to the age. As the researches have shown [1, 2], the average age of the children who are starting to have trainings on roller-skates, is 4 – 5 years. This subgroup of consumers is included into the pre-school age group of typical form of children at the age of 3 till 6.5 years. For children from pre-school age group it is recommended to construct the base design of a typical form: height – 110 cm; chest circumference III – 56 cm; waist circumference – 51 cm. The clothes for this group of children for mass production are designed in the diapason of the following measures: height – 98 ÷ 116 cm; chest circumference III – 52 ÷ 60 cm; waist circumference – 48 ÷ 54 cm. Such measure characteristics do not allow determining the basic anthropometric data for 4 – 5 years children. We can assume that dimensional features of this subgroup may be in the middle of diapason of measure characteristics of the whole group; however, we need to conduct the additional anthropometric researches to confirm such assumption.

Also there are researches [10], which show that anthropometric information loses its accuracy in 10 – 15 years due to the process of acceleration. As the abovementioned normative and technical standards were created and put into operation more than 15 years ago, their update for the purpose of designing the multifunctional children`s clothes is quite relevant.

3 RESULTS OF THE EXPERIMENTAL RESEARCHES OF ANTHROPOMETRIC DATA FOR DESIGNING THE CHILDREN`S CLOTHING FOR TRAININGS ON ROLLER-SKATES

The purpose of the experimental researches was to select the limited number of typical forms of the children at the age of 4 – 5 years according to the measures for designing clothes for trainings on roller-skates. This will ensure the high level of satisfaction of consumers demand.

Anthropometric researches were conducted by a contact method, using measuring tape and a set of rulers by the methodology of taking standard measures in accordance with the requirements of normative and technical standards [6, 7]. The children at the age of 4 – 5 years, who live in Kyiv region and attend educational institutions for children of pre-school age, took part in the anthropometric survey.

As the result of such research, it was determined that the abovementioned methodology of taking measures of the human body did not consider the psychological and age characteristics of children from the pre-school age group. So, in this age children show a specific ability for active movable way of communication with the world of adults due to their anatomical and physiological characteristics. Based on the above, it is recommended during the conduction of the anthropometric researches of children of pre-school age group: firstly, to divide all children into small groups of three people; secondly, to use three instruments with the same accuracy class for measures to avoid the accidental errors during the measurement of one value; thirdly, to spend no more than 3 – 5 minutes for taking measures of one child with breaks for taking measures of other members of the group; fourthly, the measures on one value by one measurement instrument should be carried out at least twice; fifthly, before every measurement you should answer all questions, which the child has and allow to hold all instruments which you are planning to use during the measurements if the child wishes so.

The implementation of such recommendations will improve significantly the convenience and accuracy of conduction of the anthropometric researches of children of pre-school age group.

During the process of anthropometric studies 400 children (50% - boys, 50% - girls) were admeasured, the results of such measurements were processed by methods of mathematical statistics. As a result, it was found that 48% of girls at the age of 4 – 5 years have the height of 104 cm; 33% – 100 cm; 50% have chest circumference III 56 cm; 41% – 52 cm; 38% have waist circumference 51 cm; 31% – 48 cm; 44% of boys at the age of 4 – 5 years have the height of 110 cm; 37% – 104 cm; 68% have chest circumference III 56 cm; 24% – 60 cm; 41% have waist circumference 51 cm; 35% – 54 cm.

Those results made it possible to identify the measures of the typical forms, which were the closest to the most frequently encountered measures of children at the age of 4 – 5 years (Tables 1, 2).

Table 1 Fragment of classification of typical forms of girls [4]

Age group (age, years)	**Width group**	**First one**		
	Chest circumference III	52	56	60
	Waist circumference	48	51	54
Pre-school (3.0 – 6.5)	***Height***	98	98	
		104	104	
		110	110	110
			116	116

Table 2 Fragment of classification of typical forms of boys [5]

Age group (age, years)	**Width group**	**First one**		
	Chest circumference III	52	56	60
	Waist circumference	48	51	54
Pre-school (3,0 - 6,5)	***Height***	98	98	
		104	104	104
			110	110
			116	116

Note. The frame encircles the typical forms, on the basis of which the product for mass production is designed. Gray color highlights the typical measures, which are the closest to the measures of children at the age of 4 – 5 years according to the results of the researches

4 CONSTRUCTION OF THE DESIGN OF MULTIFUNCTIONAL CHILDREN`S CLOTHES WITH THE PROTECTIVE ELEMENTS

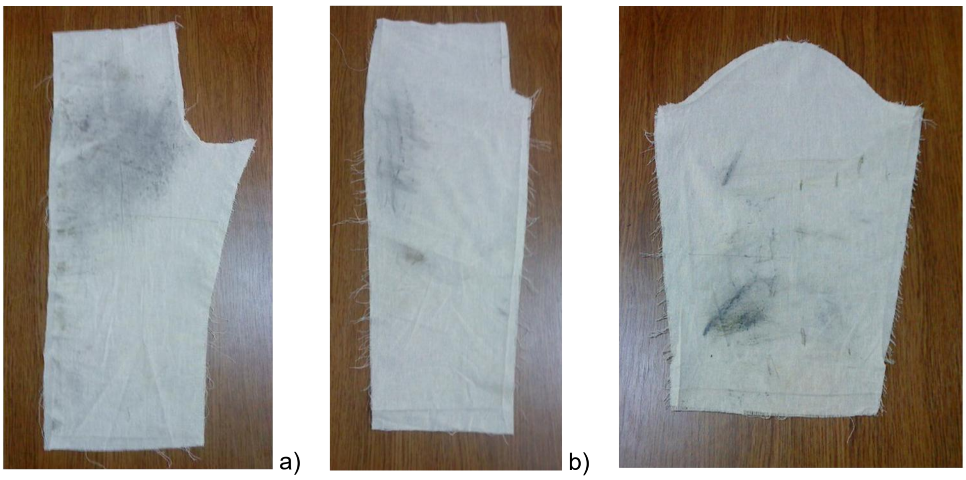
In order to construct the base designs of children`s clothes for trainings on roller-skates, well-known methods of designing, which are offered by many authors, are used. A feature of the construction of the model designs is the necessity to take into consideration not only aesthetic requirements, but also ergonomic ones (for example, place of location of the protective elements for protection of the child`s body when falling, size of details for easy movement, etc.). Therefore, the improvement of the process of designing the model designs of multifunctional children`s clothes with protective functions from the pain at falling for trainings on roller-skates is relevant and in the future will allow to create a competitive children`s garment products of mass production.

To obtain a high-quality design of multifunctional children`s clothes, where all ergonomic requirements are taken into account [2], it is necessary to identify the location of anthropometric points on the child`s body, which take the impact forces at falling, and determine the method of their transferring to the model of the clothes. For this purpose the authors proposed the method of direct contact of production prototypes of the clothes on the child`s body with the surface, which creates the impact forces during the trainings on roller-skates.

A group of children at the amount of 5 persons with the recommended measures (waist circumference – 51 cm, chest circumference III – 56 cm) (see Tables 1, 2) was selected for the experiment. Using the known method, the base design of trousers and outerwear shoulder clothes was constructed for the form: height – 104 cm; chest circumference III – 56 cm with the minimum additions; waist circumference – 51 cm. After that 10 samples of the children`s clothes (trousers and jackets) from prototyping cotton fabric were produced, in which children had trainings on roller-skates on asphalt platform with pre-coated graphite coating (Figure 1).

Figure 1 Photo of the child in prototype sample, after the experiment

After the conducted experiment the details of the prototypes were put on the paper construction and the places of the most intensive contaminations (Figure 2) were transferred on the construction by the method of splitting (Figure 3). The values of the tests of every sample were processed by the methods of mathematical statistics and, as a result, the minimum sizes of the protective elements and their optimal location on the details of design were identified (Figure 3).



a) b) c)

Figure 2 Details of prototypes of the children`s clothes with the graphite contamination in the places where child`s body in the prototyped clothes contacted with the impact surface: a) back half of the trousers; b) front half of the trousers; c) sleeve

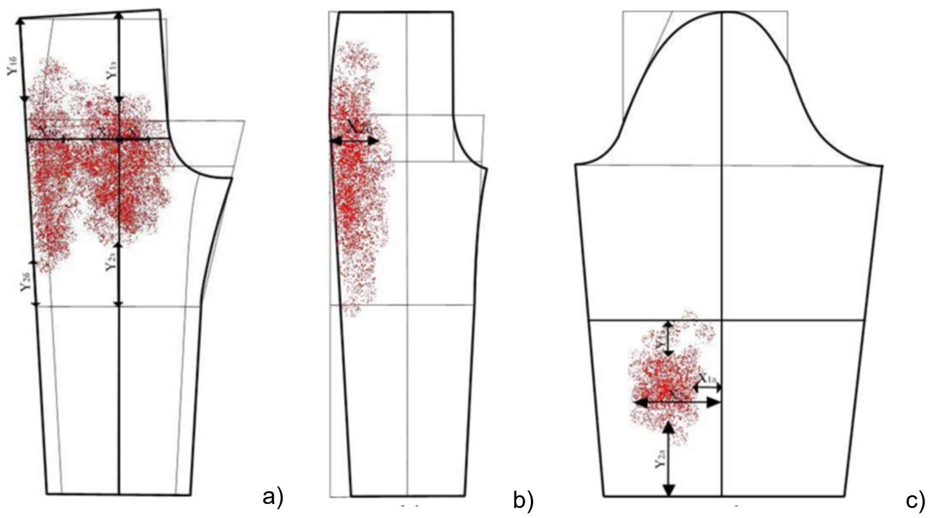


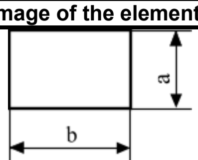
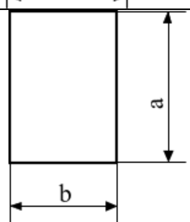
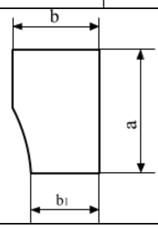
Figure 3 The topography of allocation of areas of contamination at the details of base design of the children`s clothes with obtained segments for its modification: a) back half of the trousers; b) front half of the trousers; c) sleeve

The topography of allocation of areas of contamination at the details of base design of the children`s clothes allowed to get the size characteristics of the protective elements, which are presented in Table 3.

The studies provided the information, which made it possible to develop the sequence of modification of the base construction of the children`s clothes, taking into account ergonomic requirements (place and optimal sizes of the protective elements). The constructed design is presented at Figure 4 by the full line.

Protective elements from the pain at falling, which exist in the clothes nowadays, due to their qualitative and structural characteristics may be divided into three main groups: 1 – multilayered package of traditional materials for clothes; 2 – new composite materials; 3 – cushioning materials for household and industrial purposes. They can be used as removable elements or as structural parts of the clothes.

Table 3 Size characteristics of the protective elements of children`s clothes

Name of the elements	Size of the elements	Image of the elements
Protective element of the elbow part of the sleeve	a = 6.0 b = 6.5	
Side protective element of the trousers	a = 14.0 b = 9.0	
Back protective element of the trousers	a = 15.0 b = 8.0 b_1 = 6.0	

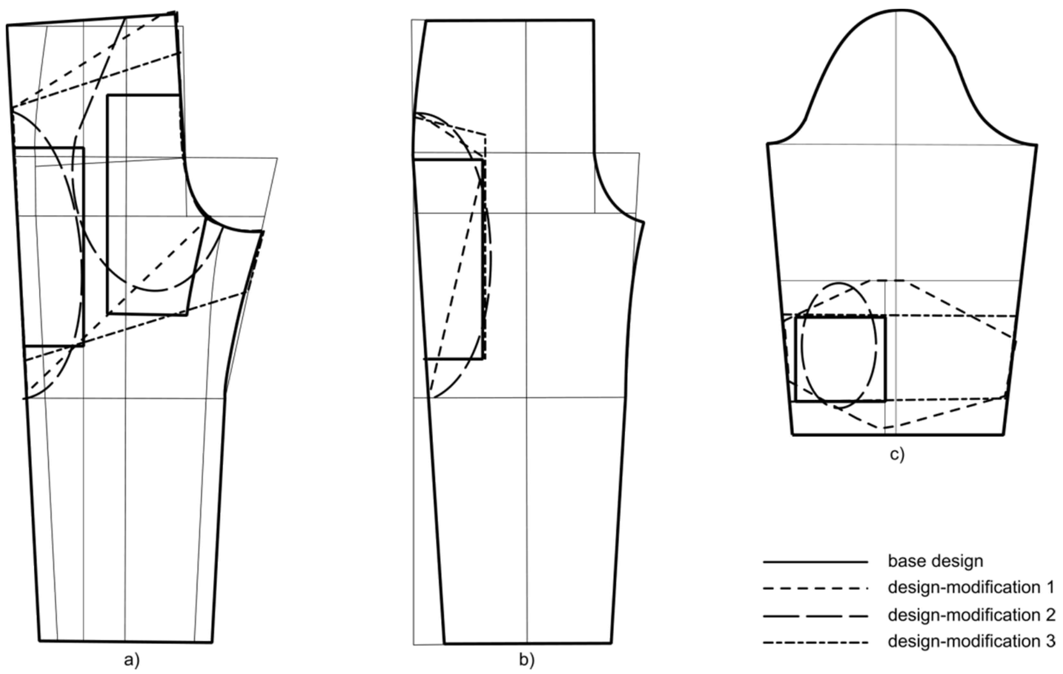


Figure 4 Modified base design of the children`s clothes for trainings on roller-skates with protective elements and modeling of designs-modifications: a) back half of the trousers; b) front half of the trousers; c) sleeve

Using modified design of children`s clothes for trainings on roller-skates, designed by means of constructive modeling (Figure 4), it is possible to get a range of products with a variety of forms and types of protective elements (Figure 5).

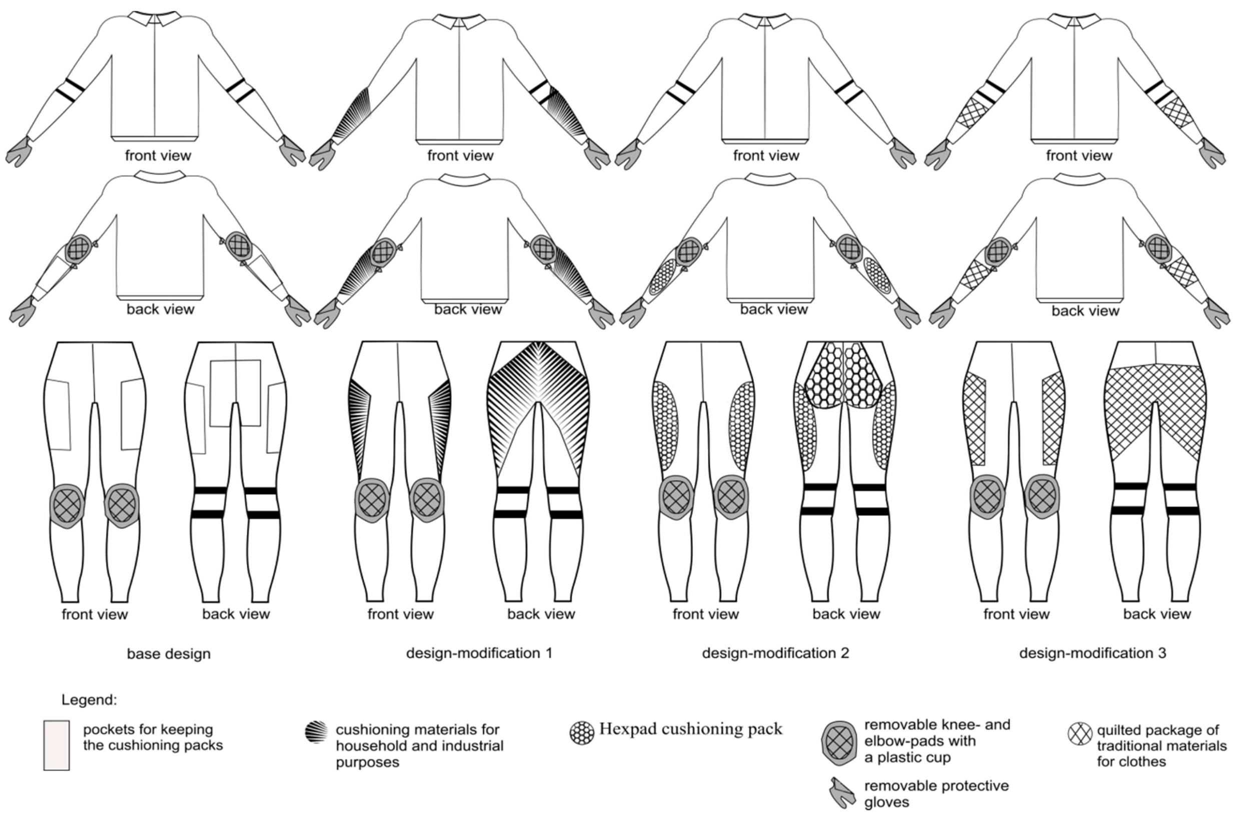


Figure 5 Sketches of the model range of children`s clothes for trainings on roller-skates with different forms and types of protective elements

The package of materials of the base design is the following: top fabric – cotton 95%, elastane 5%, surface density 220 g/m^2; pockets fabric – cotton 100%, surface density 270 g/m^2. The package of materials of the design-modification 1 is the following: top fabric – cotton 100%, surface density 165 g/m^2; protective elements consist of two layers: the protective one – of elastic expanded polyethylene with a uniform closed cell structure, density 25 kg/m^3, thickness – 10 mm, and the coating one – of cotton 30%, PE 70%, surface density 210 g/m^2. The package of materials of the design-modification 2 is the following: top fabric – cotton 100%, surface density 165 g/m^2; protective elements consist of two layers: the protective one – of Hex-Pad material and the coating one – of DuPont Coolmax material. The package of materials of the design-modification 3 is the following: top fabric – cotton 100%, surface density 165 g/m^2; protective elements consist of two layers: the protective multilayer one – of padding polyester (100% PE), surface density 150 g/m^2, and the coating one – of cotton 30%, PE 70%, surface density 210 g/m^2.

5 CONCLUSIONS

Conducted anthropometric studies allowed to identify the most frequently encountered measures of children at the age of 4 – 5 years for designing clothes for trainings on roller-skates. As a result of experimental researches the locations of protective elements on the details of children`s clothing design and its dimensional characteristics were identified. The range of children`s clothes for trainings on roller-skates, considering the received locations of the protective elements, was developed and variants of the materials packages were offered. The proposed methodology of designing the model range of multifunctional children`s clothes for trainings on roller-skates takes into accounting ergonomic requirements and can be implemented into the modern systems of automated designing of the clothes.

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DESIGNING OF RATIONAL STRUCTURE OF RANGE OF INSULATING PROTECTIVE CLOTHING ON THE BASIS OF THE PRINCIPLES OF TRANSFORMATION

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Abstract: *The aim of this work is to develop a range structure of insulating change of clothes with predictable characteristics for the employees of nuclear power plants (NPP). It was applied a systematic approach to solve the assigned tasks, which made it possible to use the principles of transformation through the gradual changes in design and complete of protective clothing. The implementation of the assigned tasks was carried out using the method of structural optimization of construction of insulating protective clothing. The rational structure of range of insulating change of clothes with predictable coefficient of protection, weight and cost was formed on the basis of the principles of transformation by the method of structural optimization. It was obtained the formula for calculation of protection coefficient under constraints on weight, cost, number of material layers (taking into consideration the non-linearity of the objective function), under constraints and discretization of initial information for the packages of protective clothing. Structural and logical matrix for insulating change of protective clothing was formed. There were proposed a structure of insulating change of clothing for NPP employees, structural and technological solutions for the products from the product range. Task-oriented selection of modules and methods of their transformation within the designed object was carried out.*

Key words: *principles of transformation, protection coefficient, insulating protective clothing.*

1 INTRODCUTION

Protective clothes for the employees of nuclear power plants (NPP) belong to the personal protection equipment (PPE) and can be divided into the following groups:

- by the degree of insulation from the aggressive external environment – hermetic, insulating, filtering changes of clothing;
- by the types of hazards – clothing for protection against radioactive contamination, acids, alkalis, moisture, petrochemicals, organic solvents, industrial dust etc.;
- by the duration of use – one-time, with limited term of use, re-usable.

The system of personal protection of NPP employees solves three main tasks: compliance with the requirements to the working conditions, based on the analysis; provision of basic level of protection and reliability indicators; minimization of additional health threats and injury risks for the employees. That is why the selection of species range, completeness and its structure alongside with the materials and methods of details connections in protective clothing as the main component of the change of clothing is determined by the mutual influence of the task which are need to be solved. The effectiveness of the taken decisions depends on the determination of (1) harmful factors and ways of getting them inside the body; (2) characteristics of the materials; (3) topographies of influence of burden factors on the worker; (4) parameters of constructions; (5) manufacturing technology; (6) conditions and modes of use.

Therefore, the aim of designing the rational completeness of the protective clothing and packages of materials in terms of limited material, financial and human resources arises. In such conditions the multivariance of solutions of assigned tasks is quite possible.

A wide range of requirements to the protective clothes, the main function of which is to provide reliable protection against harmful and dangerous factors, is regulated by state standards [1, 2]. Well-known from the various modern sources are the principles of transformation in design of the modern clothes for different purposes, with the help of which you can modify the units of the clothes, details, clothing in general and its completeness to provide it with new functions.

2 EXPERIMENTAL

Nowadays the manufacturers of protective clothing try to combine all stages during the process of creation: from material development, design, manufacturing to the realization stage of protective clothing. Complete implementation of such concept is associated with the need to overcome the methodological issues arising from the direct view of the employee as a consumer of the protective clothing, with the uncertainty of standards and methods of their assessment and also with the imperfections in approaches to the evaluation of changing work conditions and modes of work. Existing approaches in general do not provide the fully integrated solution for designing the reliable change of protective clothing with optimal parameters at the stage of design and mass production [3]. The nature and character of creative concept of work are associated with an individual vision of the authors, with the main trends of development of the project methods and consumers` requirements.

The selection of the optimal solution for the structure of insulating product range is based on the multivariate analysis due to the systemic approach that includes the consideration of the design subject as a system of interrelated material, functional, social and aesthetic elements. Such kind of approach requires the establishment of clear analytic connections in “environment – insulating protective clothing – NPP employee” system. The result of such design approach is the creation of change of protective clothing that meets all requirements. Systematic structural analysis is realized on the basis of principles of transformation, which predict the replacement of (change of) separate modules or their movement within the same form.

The analysis of working conditions at the NPP of Ukraine made it possible to single out the basic requirements to the insulating protective clothing. Complete set of Insulating protective clothing should provide complete protection against α-rays and β-rays of low energy, dust and aerosols with radionuclides, mechanical damages and general pollutions; it should be impervious to oil and water, resistant to alkalis and acids.

2.1 Overview of the modern design approaches

Under the influence of changing requirements to the protective clothing, desire to create products that meet the specific conditions of its use, the further changes in constructive solutions take place. Certain types of protective clothing are replaced by new, more relevant and appropriate in the current conditions. Protective clothing is created from the new polymer materials, which have light weight, increased level of protection against the complex negative impact of chemicals, water solutions, dust and aerosols, ionizing and non-ionizing radiation etc., it is comfortable to wear and could be utilized [4]. The low cost of such materials makes it possible to abandon from re-usable protective clothing that requires constant cleaning and repair. Single use of protective clothing provides an opportunity to reduce the environmental pollution and operating costs [5].

Most of polymeric fibers, suitable for manufacturing of new materials (polyethylene, polyvinylchloride (PVC) and polypropylene), are thermoplastic and provide an opportunity to replace inefficient and time-consuming way to connect clothing details by spinning connection method at more productive – welding method (thermocontact, by high-frequency currents, ultrasonic method). New technologies make it possible to create more advanced forms, systems of general, block and element by element redundancy, improve reliability and protection, taking into accounts the artistic and aesthetic requirements and constraints of additional risks in use.

At all stages of development of theoretical and practical design the following methods are reasonable to use:

- analysis of the problem situation, based on the information about the working conditions of certain categories of the employees;
- determination of concept and methods to solve the problems;
- selection of the material with necessary and sufficient protective characteristics;
- selection of construction methods for the base model;
- use of additional products, design and technological elements of protective clothing to ensure the necessary level of protection.

Insulating re-usable change of protective clothing of the proposed appointment is offered to be made from PVC-plastic, thickness 0.10 – 0.15 mm, surface density 110 - 180 g/m^2, rigidity 2.0 – 2.6 cH. The possibility of using such materials is confirmed by their long period of operation [6].

3 RESULTS AND DISCUSSION

The formation of the range structure of insulating change of protective clothing, which may consist of jacket, pants, semioverall, apron, gloves, armlets, shoe covers and other articles, is realized through the rational choice of assortment, based on the techniques and methods of increasing the protection, reliability and ergonomics indicators. There were proposed the components of insulating change of clothing that provided the optimal combination of protective function and comfort working conditions (Figure 1).

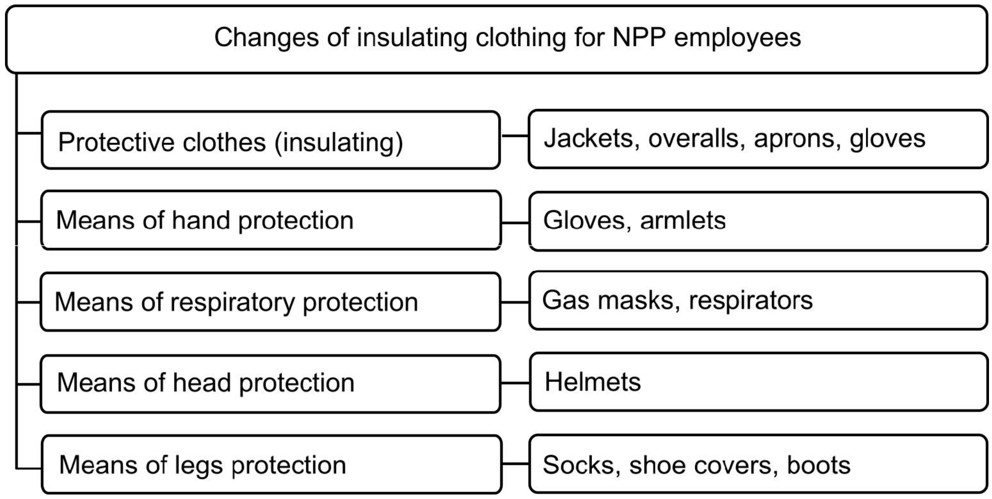

Figure1 Proposed structure of insulating change of clothing for NPP employees

It was found that the typical design feature of the protective clothing is the lack of pockets, clasps, belts, buttons and other protruding details, trims with textile clasps and glue stitches due to the limited possibilities of their deactivation. In addition, when creating the protection clothing, it is necessary to use the material with a smooth surface and construction that helps the liquid radioactive substances to flow down from the surface.

To improve the convenience, increase the speed of dressing and removing the clothes, taking into consideration the specific movements and postures of the employee, a central onboard fastener, stalemates, curtains, shoulder-straps etc. should be provided. In order to prevent from exposure and other professional injuries and diseases, the outer surface should not contact with the skin of the employee, constricted hem of the pants and sleeves with regulating degree of their fit and fastener on the strings will enable it. Deactivation of the protective clothing takes place every time after their use at the temperature of 45-55°C with their further storage in premises with a temperature of 3-15°C.

Structural optimization of PPE change of clothing lays in identifying the opportunity to achieve established parameters of protection, reliability and ergonomics during the process of design and exploitation within the elaborated design. Among the species range of insulating protective clothing, which is planned to be made of PVC-plastic, the preference is given to overalls. The improvement of protection characteristics is achieved by implementation of structural elements, additional layers of materials and reserve products (armlets, knee pads, shoe covers, gloves, etc.), additional structural elements (improved trims, shirrs, flexible inserts and air elements), (Figure 2).

The task of evaluation of the effectiveness of the measures, which are aimed to improve the protection level, can be summarized to the determination of the protection coefficients. Requirements to the insulating protective clothing are often contradictory. The securement of protective properties and increase of reliability and durability leads to the increase of the weight of the item. At the same time during the protective clothing exploitation additional risks for the health and safety of the employees may arise: deterioration of the thermal state due to overheating; increase of static pressure caused by additional weight; complication of working movements that will increase the duration of the work under the influence of external ionizing radiation.

Notwithstanding the meaningful variety of such tasks, all of them from the formal point of view [7] are summarized to one general point: to find the values of changing parameters X_1, X_2,…X_n, which provide the maximum or minimum of a given function $F = f(X_1, X_2 ... X_n, Y_1, Y_2 ... Y_n)$, at presence of limitation

$$F_o = f(X_1, X_2 ... X_n, Y_1, Y_2 ... Y_n) \leq or \geq \Pi_i$$

where $F = f(X, Y)$ – objective function (measure of efficiency, security, reliability or effectiveness of the system); X – vector of the variables of control; Y – vector of the variables of the state (uncontrolled variables); $F_o = f(X, Y)$ – functions of the value limits of i-indicator; Π_i – value of normalized or recommended i-value.

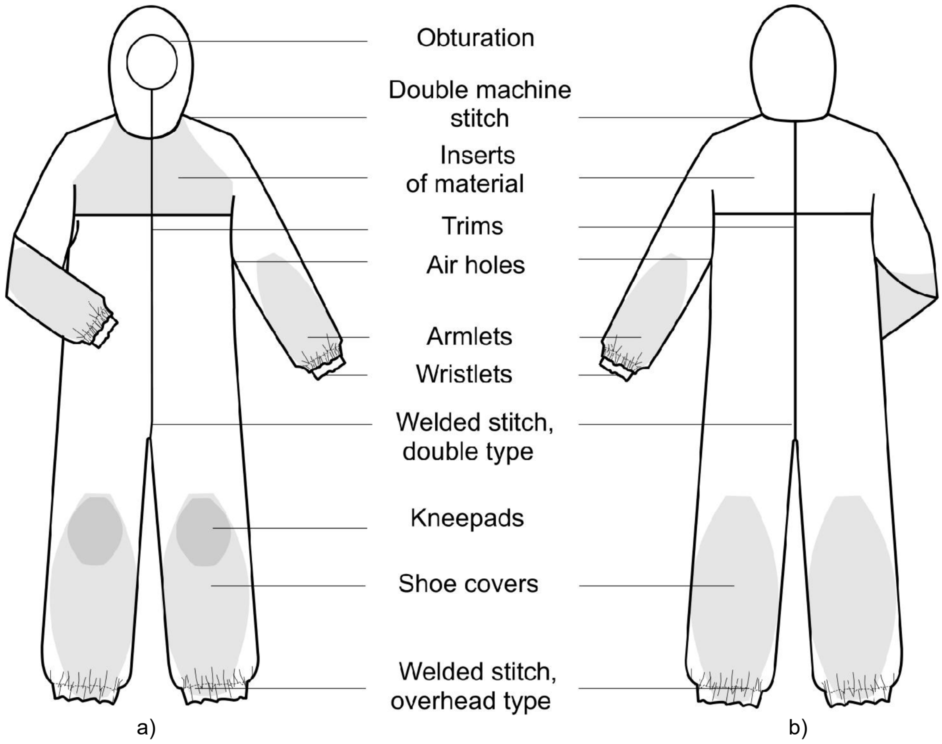

Figure 2 Base model of the product with additional structural elements: a) front view, b) back view

In such circumstances the method of normalized functions was used as a mathematical apparatus for the study of the problem, which belongs to the heuristic methods of optimization and provides an opportunity to get reasonable and univocal decisions in solving a number of problems of different nature [8]. The authors made the modification of computational algorithms of the method of normalized functions (algorithms of minimization and maximization) that made it possible to take into account the design specifics of the insulating clothing structure via:

- the use of area-modular calculation model;
- the compliance with standards of constraints;
- the measurement of uneven distribution of the impact of harmful factors and mechanical stresses as to the zones of the worker`s clothing;

the interconnection between the certain measures and means in design.The initial data is provided via the discrete sequence of standard parameters of protective clothing elements: $X_p, a_p, b_p\ (p = 1, 2 ...)$, where X_p – unknown variables; a_p, b_p – corresponding to *p*-standard parameter technical characteristics, needed for the formation of objective function and limitations. The reasonability of using such discrete sequence is caused by the fact that technical characteristics can't always be approximated accurately using the analytical dependencies from X_p, but in discrete sequence this characteristics can be taken as accurate ones (for example, a lot of elements are determined due to the catalogs, breaking force – according to the results of experimental researches and to the technical conditions).

Considering that the developer of the insulating change of clothing is tasked to achieve the protection coefficient at the level not less than defined, the formulation of the problem involves maximization of the objective function as a protection factors K_p:

$$F(X) = K_p \rightarrow max \quad (1)$$

Figure 2 shows the possible places for introduction of additional measures and their coded identification. The magnitudes of the basic parameters changes, which include material consumption, weight and cost of the product, as well as estimated parameters that vary during the optimization process (coefficient of protection, reliability, breathability, etc.), depend on the technological design, which in turn depends on the implementation of one or another measure. The list of measures considered with the relevant parameters of replaced items, listed in the Table 1.

Table 1 The list of the measures to optimize the insulating protective clothing

The name of variable elements, products	Coded identification	Indices of the elements	
		Additional cost ΔC [%]	Weight m [g]
Structural elements			
n-layer insertions of material	I_n $(n = 1, 2, 3)$	30.0	380-550
trims	*T*	5.0	100
obturation of pants	*O1*	3.0	50
obturation of sleeves	*O2*	2.5	50
air hole	*AH*	15.0	10
Additional items			
armlets	*A1*	7.50	1200
knee pads	*P*	8.50	350
wristlets	*W*	2.0	250
shoe covers	*SC*	12.0	1500
gloves	*G*	11.0	120
apron	*A2*	25.0	1700
Technological elements			
double machine stitch	*S1*	15.0	
welded stitch, overhead type	*S2*	10.0	
welded stitch, double type	*S3*	10.0	

So, we have a discrete sequence of individual technical means and technical measures, which help to improve the protection factor that increases the cost ΔC_i and weight Δm of the product.

To formalize the procedure of calculation schemes preparation, the notation for variables of control X_i was introduced, the main characteristics of which were given in Table 1. Variables of control were presented as logical functions: notations « $\wedge, \vee$ » correspond to the signs of logic operations accordingly «AND» or «OR».

$$
\begin{gathered}
X1 := S1 \vee S2 \vee S3\ ;\ X2 := I1 \vee I2 \vee I3 \\
X3 := AH \wedge (I_n \vee A2)\ ;\ X4 := A1 \vee G \\
X5 := P \vee SC\ ;\ X6 := O1 \wedge SC \\
X7 := A1 \wedge (W \vee O2) \wedge G\ ;\ X8 := T
\end{gathered}
\tag{2}
$$

The process of optimization is carried out through the selection of volumes and priority of replacement of structural and additional elements, which allow the producers to improve the product. Area-modular scheme was used as the scheme for calculations that provides the division of clothing model at nine zones, which have different requirements [9]. The selection of the numbers and areas is connected with the topographic areas of the clothes and with the protection level of parts / areas of the body and internal organs. Module is source element that can be repeated and inserted into the clothing without changing its integral form. Products (for example, armlets), as well as their components (the layer of material), which can also have different functional purpose (trims), were used as a separate module. Every module of the product in the relevant area or areas has a specific purpose according to its protective functions and is characterized by certain technical and cost parameters (Figure 3).

The head (brain, breathing and vision organs) is singled into the first zone with coded symbol Z1 because its protection can be provided by means of head protection, means of face, eyes and breathing organs protection. The second zone includes neck with such a vital organ as thyroid gland. The front part of the human`s body is divided into two areas: chest, top of the abdomen (shoulder joint, esophagus, stomach, liver, lungs) (coded zone symbol Z3) and lower part of the abdomen (reproductive organs, urinary bladder, large intestine) (zone with coded symbol Z4). The back side of the human`s body, especially shoulder girdle, back, buttocks (lungs, red bone marrow) is the area with coded symbol Z5. The arms are divided into two zones (with coded symbols Z6 and Z7): the elbows and shoulders belong to zone Z6, the forearms belong to zone Z7. Two areas with coded symbols Z8 and Z9 include the lower extremities. Thus, upper legs and knees are included into zone Z8, lower legs and foots – into zone Z9.

Structuring of the measures with the use of logic functions enabled to form a matrix in which the possible measures are indicated in a row, the zones areas with confidence interval – in the columns (Table 2).

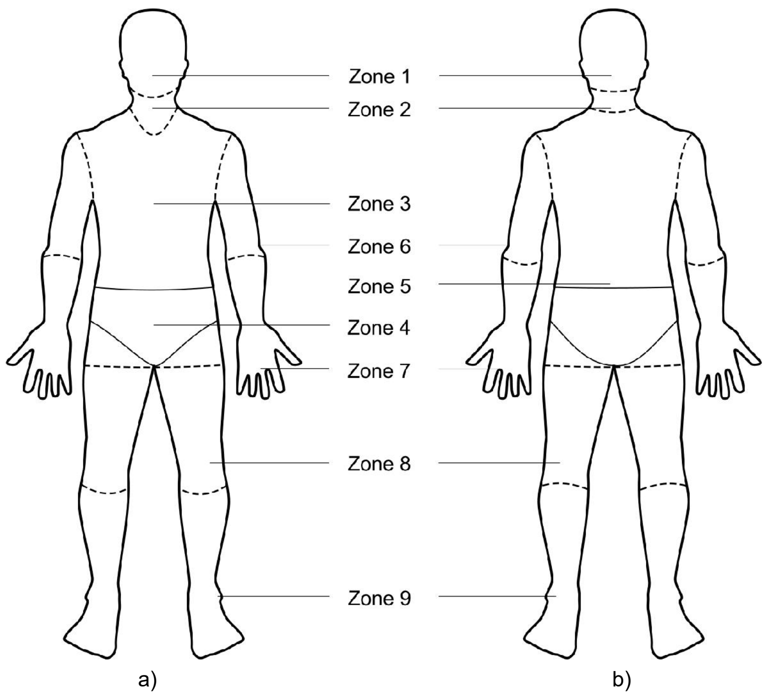

Figure 3 The appearance of the human body with zones notations: a) front view, b) back view

Table 2 Structural and logical matrix for the insulating change of protective clothing

List of measures	**Name of zone (its area), $S_i \cdot 10^{-2}$ [m^2]**								
	Zone 1 (10.5±0.4)	Zone 2 (0.26±0.01)	Zone 3 (2.4±0.09)	Zone 4 (1.45±0.06)	Zone 5 (4.2±0.16)	Zone 6 (2.3±0.16)	Zone 7 (1.74±0.1)	Zone 8 (3.6±0.25)	Zone 9 (4.0±0.23)
Additional layers of material	X2	X2	X3	X2	X3	X3	X2	X3	X2
Trims		X2vX8	X3vX8	X8					
Obturation	X8						X4vX7	X5	X6
Types of stitches	X1	X1	X1	X1	X1	X1	X1	X1	X1

The first column contains the list of possible measures in order to increase the protective properties, namely:

- addition of an extra layer of PVC-plastic in the head and neck areas, front part of the body, in the lower abdomen and inguinal fold areas;
- strengthening of the trims by replacing the open clasp on the buttons to clasp-zippers or replacing the clasp-zippers on model with improved physical and mechanical properties or on additional surface layer of the material along the length of the clasp;
- implementation of the obturation with a rubber elastic tape on the hood, on the sleeves and on the lower part of the pants or simultaneous use of the insulating protective clothing and shoe covers;
- usage of additional items: armlets, knee pads, shoe covers, gloves and wristbands;
- selection of the types of stitches when connecting the individual modules of the product.

The optimization task is formulated as follows: to maximize the objective function for the coefficient of protection against product β-radiation at presence of limitations on the quantity of additional layers of material in the module, on the total weight and value of the products.

The study of the protective properties of PVC [10] provides the possibility to determine the analytical dependence of the protective coefficient against the β-radiation in the following form:

$$K_{p\beta} = 0{,}153 \frac{\sum_{i=1}^{9} n_i \cdot w_i \cdot S_{Mi}}{S_a} + 0{,}451 \rightarrow max \qquad (3)$$

where S_{ii} - the area of the module of i-zone, cm^2; n_i, - the number of layers in the module; w_i - weight coefficient; i - the number of zones, i = 1,2…9; S_a - the total area of the product.

The increase of the protection coefficient can be achieved by changing every multiplier in the formula. The area and number of layers in separate modules belong to the structural measures. The weight ratio takes into account the unbalanced loads and irregular impact of the ionizing radiation on the separate zones and should be adjusted during the optimization calculation at the presence of such limitations:

- by weight:

$$F(m) : m \in \left[\sum_{i=1}^{9} m_i \le m_{per} \right] \quad (4)$$

where m_i - the weight of the separate module in i-zone, g; m_{per} - permissible weight of the change of clothes, which is 3 kg;

- by the number of the layers of material in separate modules:

$$F(n) : n \in [n \le 2...k] \quad (5)$$

where n - the number of the layers of material in the separate module, which in some modules may not exceed three layers due to technological conditions;

- by the cost:

$$F(C) : C \in \left[(\sum_{i=1}^{9} C_{Mi} + C_j) \le C_{per} \right] \quad (6)$$

where C_{Mi} - cost of *i*-module; C_j - cost of the additional elements; C_{per} - acceptable cost of the clothing, which is determined by market conditions.

The criterion for optimal variant of structural and technological solution of the product is to ensure the necessary level of protection at the presence of limitation on the total weight of the clothing. As optimization criterion *KR* the next correlation is selected:

$$KR = min\left\{ \left(\frac{m_{j+1} - m_j}{K_{po} - K_{pj}} \right) \right\} = \left\{ \frac{\Delta m_j}{\Delta K_{pj}} \right\} \quad (7)$$

where K_{po} - protection coefficient that needs to be achieved according to the technological task for development; K_{pj} - protection coefficient for the *j*-step of optimization; ΔK_p - augmentation of protection coefficient; m_j - the weight of the clothing during the *j*-step of optimization; Δm - augmentation of the weight.

Integrated criterion of optimization varies depending on the level of protection and increase in weight in case of addition of extra layers of protective material or use of additional products.

Basic construction (Figure 2) has a certain protection coefficient, weight and cost. Such data was used as the initial information during the optimization calculation (zero step). Variables of control are set as a structural and logical matrix (Table 2). During the next steps of optimization using the criterion (7) the most effective measure is defined, which is fixed after reviewing of all possible modules for its installation. Then calculate the appropriate growth of the protection coefficient ΔK_p and growth of the weight Δm. The process continues until all means will be considered from the original sequence and achieved the desired protection coefficient. Development of protective clothing design is based on the specification, where the customer specifies the main requirements to the product, namely the desired protection coefficient, weight and cost. Limitations on total weight and cost of the product may cause a premature end of calculations when the limit values achieved. As a result of the optimization calculation we get an ordered set of measures to improve the protection coefficient on every step of weight and cost increment.

The considered algorithm is implemented as a computer program and, as a result of optimization calculation, for selected model the following results were introduced; to produce the insulation PC the technology of welding by currents of high frequency using double stitches was selected; strengthened obturation in zones Z5, Z6 and Z8 was introduced; double clasp and strengthened trims were set in Z3; one additional layer of protective material was added in Z1, Z2 and Z3; armlets, shoe covers and apron were used; air hole is provided in Z6. The sequence of implementation of the measures according to their effectiveness is presented at Figure 4.

The implementation of such consistent modules into the design and technological development of change of the insulating protective clothing provides the following results: the protection coefficient against β-radiation increased and was not less than 0,95; protection coefficient against α-radiation was 1; the increase of such protection coefficients led to the growth of the weight of the clothing on 56% in comparison with the original weight (less than 1800 g); the cost of the clothing increased on 80%.

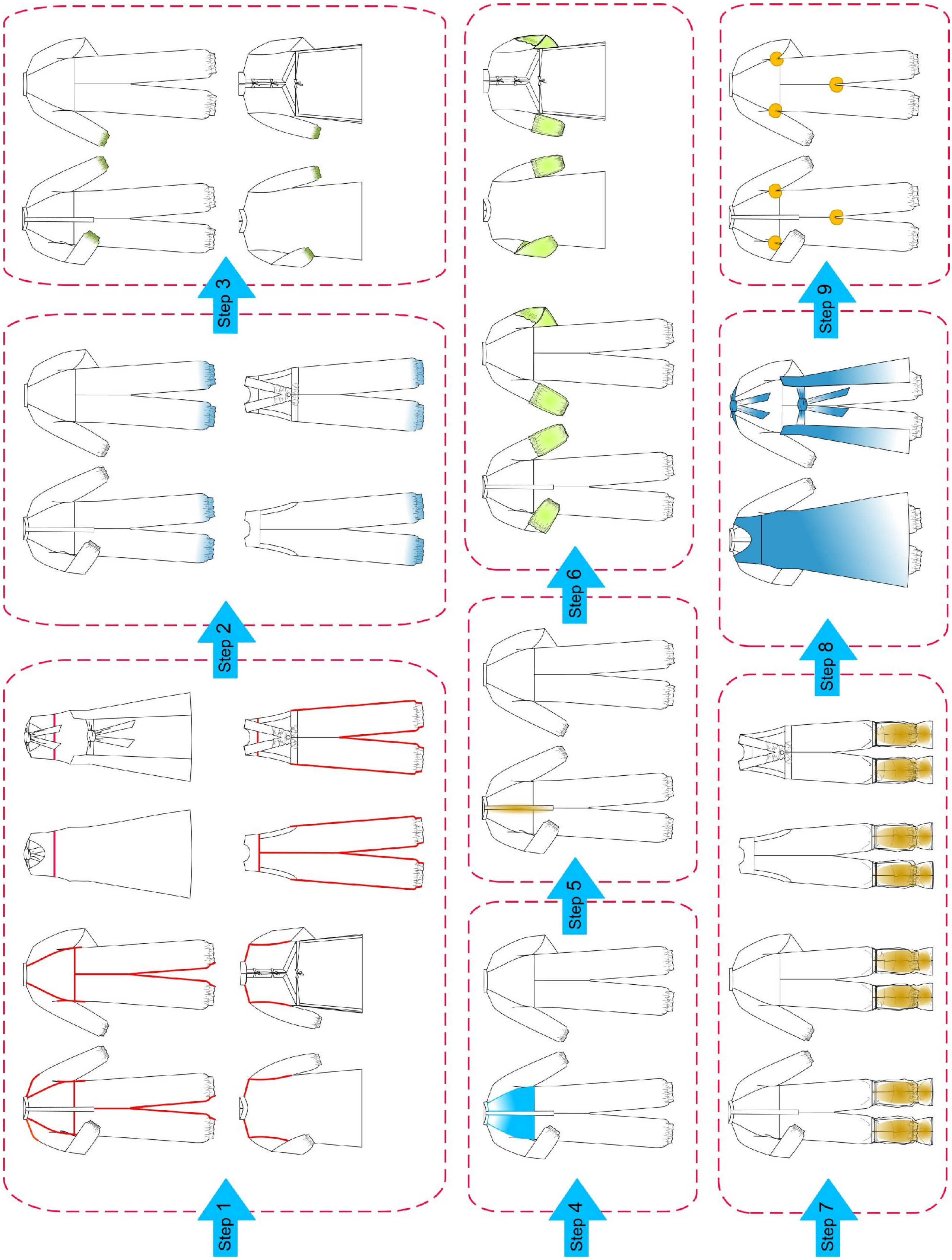

Figure 4 Example of the product range of insulating change of clothing with step by step realization of optimization calculation

4 CONCLUSIONS

It was proposed a new conception of the project design of protective clothing with specific functionality, based on the systemic approach which envisages the design of the product portfolio as a system of interrelated material, functional, social and aesthetic elements. Such systemic approach provides the establishment of clear analytic connections between the environment, separate parts of protective clothing and the processes, which take place with the participation of the workers and aimed at improving the protective effectiveness, reliability and efficiency of the personal protection system.

The research presents the new methodological basis for the process of design and technological development using the method of transformation. The method of transformation enables to develop the changes of protection clothes for specific operating conditions, taking into account the customer requirements on restriction of the impact of the harmful production factors, ergonomic characteristics and economic indicators. It was formed the range structure of the insulating change of clothes by developing the constructive and technological solutions for the components of the products for the employees of nuclear power plants on the basis of transformation principles by the method of structural step by step optimization, which allowed to make a targeted selection of modules and methods of their transformation within the projected object. The method aims to meet the challenges of maximizing the protection coefficient at the presence of limitations on weight and cost, taking into consideration the non-linearity of the objective function, limitations and discrete of the initial information for the packages of the protective clothing.

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YARN CROSS-SECTIONAL DEFORMATION IN WOVEN FABRIC

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Abstract: *This experimental work investigates the geometry of yarn cross-section before and after weaving. To analyze the effect of pick density and yarn type on yarn deformation in woven fabric, two different types of fabric set have been prepared by using airjet and rotor yarns in weft while keeping the same warp yarn. For each fabric, pick density has been changed gradually. Cross-sectional diameter of yarn and its packing density has been analyzed to find out the differences between both yarns. Cross-section of yarn in fabric has also been analyzed to examine the deformation in yarn. The effective yarn diameter and packing density have been found to be almost same for both yarns. Whereas the airjet yarn has more deformation in fabric than rotor yarn and flatness is more obvious at higher pick density in both yarns.*

Key words: *Woven fabric, Yarn deformation, Airjet yarn, Rotor yarn, Pick density*

1 INTRODUCTION

It is well known that fabric geometry is very complex structural parameter and it is affected by component materials, manufacturing process and the cross-sectional geometry of its constituent yarns [1, 2]. Cross-sectional deformation in yarn is affected by yarn and fabric parameters such as fibre type, yarn twist factor, yarn linear density, cover factors of warp and weft, type of weave, woven technology and shrinkage in fabric and this eventually affects the performance properties of the fabric [3]. Yarn geometry in the fabric demands extensive attention as it significantly affects fabric thickness, comfort, thermal, and draping properties of final cloth [2].

Warp and weft yarns, depending upon their properties press each other at the crossing points in a woven fabric. At the intersections the cross-sectional deformation is dependent upon the tension difference between warp and weft yarn, the flexibility, the surface configuration of the yarns and the conditions of the adjacent unit cells [4].

The geometry of yarn cross-section of plain weave cotton fabric at weaving process and in relaxed stage was studied by Alamdar-Yazdi and Heppler. They found that the fabrics with the highest density and the highest twisted yarns had a circular cross-sectional shape, whereas the fabrics with the lowest fabric density and the lowest twisted yarns had the most flattened yarn cross-sections [4]. The size variation and cross-section shape of yarn in fabric, made by different weave types and at different pick densities have been examined by Raziye and Ayse. They concluded that both of these structural properties formed yarn's path and cross-sectional shape [5]. While Siavash and Ali studied the effect of yarn twist on its geometrical parameters in plain woven fabric and analysed that the major diameter of the elliptical shape of the yarn cross-section decreases as the yarn twist increases while the minor diameter of the elliptical shape of yarn cross-section increases as the yarn twist increases [6].

Different spinning systems available are producing yarns with different structural characteristics. In rotor spun yarns, wrapper fiber are irregularly wrapped around the core fibers with varying angles and core fibers are twisted as well [7, 8]. While in airjet spun yarns, wrapper fibers are encircling the core fibers and unlike rotor spun yarns, the core fibers are arranged parallel to the yarn axis without twisting [8].

The previous studies explain the work on yarn cross-section at loom and after loom stage, with different weave types, varying twist level and pick densities. In this research work the effect of different spinning techniques on yarn structure in satin weave has been analyzed. For this purpose airjet and rotor yarns have been used as weft to produce woven fabric with different pick densities and the effect in cross-sectional geometry of yarn in the woven fabric at intersecting region has been studied.

2 MATERIALS AND METHOD

2.1 Yarn and fabric production

16 tex yarns were produced by Rieter airjet and rotor spinning units using 100% viscose fibers at optimal conditions which produces stable yarn. Satin fabric was made by using these spun yarns in weft. Satin weave was selected because of its ease to make samples with high weft setting and cover factor. Rapier loom with eight frames and weft insertion speed of 330 picks/min was used to weave two sets of fabrics with different pick densities. The warp tension was kept the same for all fabric samples.

6x2 tex twisted compact cotton ring spun yarn was used as warp and its density (setting) was kept the same for both set of fabrics, i.e. 58 ends/cm. Ten different samples were made, five with airjet weft and five with rotor weft. To study the geometry of the yarn cross-section in fabric and its variation affected by the density, the pick densities for both sets were kept 10, 20, 30, 40 and 50 picks/cm. Yarns were kept in the conditioning room for 24 hours at standard temperature (20 ± 2°C.) and relative humidity (65%) before yarn testing and fabric production.

2.2 Yarn cross-sectional diameter and packing density

Cross-sectional diameter of yarn is usually considered as the diameter of the cylinder, where most of the fibers are concentrated, while the packing density (μ) is the ratio between fiber volume and the total volume of fibrous assembly, where μ = <0;1>. Packing density can also be calculated by the ratio between the area of fibers in a yarn cross-section and the total cross-sectional area of yarn [9].

The cross-section of yarn is a section perpendicular to the direction of the output material. Image analysis method was used to measure the cross-sectional diameter of airjet and rotor yarn. Ten yarn samples were selected randomly from airjet and rotor yarn cones with cutting dimension of 15 cm. Afterwards, these were completely impregnated in a mixture of dispersion glue (Gama Fix Henkel) and a powerful soaking agent (Spolion 8) in 1:1 ratio under a relax condition. Then these samples were kept for first drying for 24 hours. The second impregnation was prepared from dispersion glue only, and then again drying at standard atmosphere for 24 hours. These samples were fixed with gluing tape into tinny tubs having notch of 1 mm width. After that warm mixture of bee's wax and paraffin (ratio 2:3) was poured into these tubs. Upon cooling of wax in the tubs, the samples were placed in freezer for hardening under the temperature of 18°C for 24 hours [10].

Afterward hardened blocks were removed from the tubs one by one and clamped to the microtome to make slices with the cutter. The thickness of section (slice) was then set to 15 µm. The individual section was removed from the top of the cutter with the help of a needle and placed on an underlying glass immersed with a few drops of distillated water and then dried at a temperature of about 20°C. In this way the samples were prepared. In the next operation, a drop of Xylen was put on the slices, as it is well known that Xylen dissolves wax. Then the sections were examined using projection microscope (×20 magnifications) equipped with a digital camera, which was later processed by LUCIA and Prize software to calculate the effective diameter and effective packing density of yarn. One section was obtained from each block [10].

2.3 Yarn cross-sectional shape in fabric

In order to measure the geometry of the yarn cross-section in fabric, 10 fabric samples were selected randomly from each fabric sample with cutting dimension of 10x10 cm. After that, the same procedure of impregnation and drying used for yarn was followed. The prepared hard bodies were then cut into pieces of 3 mm thickness in a manner that the cutter was perpendicular to the fabric surface and one group of either warp or weft ends to cut them vertically. This time samples were fixed into tinny tubs having notch of 4 mm and warm mixture of bee's wax and paraffin (ratio 2:3) was poured into the tubs. After cooling of wax in the tubs, the samples were placed in freezer for hardening. Later, the same procedure of slicing and imaging used for yarns was followed except for the slice thickness, which was 35 µm and microscope zoom was x2 magnification [10].

2.4 Shape

Shape (roundness) is a factor which can influence the appearance of the end product of the yarn. Spinning methods have an immediate effect on the shape and density of yarns [11]. It is the ratio of short to long axis of ellipse (circular = 1).

To calculate the shape factor of the yarn cross-section, the major diameter (*a*) of yarn in the plane approximately parallel to the fabric surface and minor diameter (*b*) of yarn in the plane approximately perpendicular to the fabric surface of the elliptical yarn, were measured in each image as shown in Figure 1.

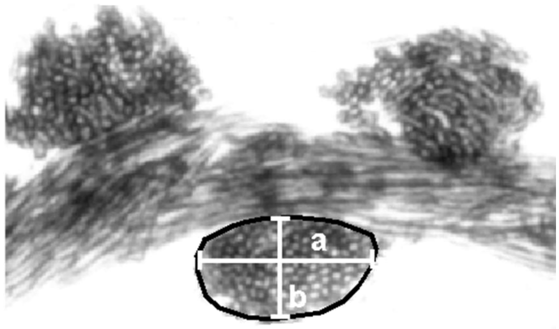

Figure 1 Measuring method of yarn cross section

2.5 Yarn Testing

Uster 4 was used in order to measure yarn irregularity, imperfections, hairiness and shape factor. For each yarn sample ten readings were recorded and the testing speed was kept 200 m/min for one minute.

2.6 Analysis of variance

To check the significance of yarn type and pick densities on characteristics of yarn in fabric, analysis of variance (anova) was carried out using sas proc glm (alpha level of 0.05).

Table 1 Airjet and rotor yarn properties

Sample	Count [Tex]	CV_m [%]	Thin [-50%/km]	Thick [+50%/km]	Neps [+140%/km]	IPI /km	Hairiness [H]	Shape
Airjet	16	14.12	35.6	29.2	166	230.8	3.96	0.80
Rotor	16	14.72	18.4	29.6	792.4	840.4	3.54	0.82

3 RESULTS AND DISCUSSION

3.1 Realization of single yarn

Test results of Uster for both yarns are shown in Table 1. It can be seen that irregularity of rotor yarn is slightly higher than airjet yarn due to presence of irregular wrappings. Differences in thin and thick places are insignificant for both yarns, while neps in rotor yarns are found very high. Similarly the shape factor of rotor yarn is also slightly higher than its corresponding airjet yarn. The reason for this is the difference in structure as airjet yarn has more parallel fibers in core and continuous wrapping, while in rotor yarn the fibers are not parallel in core and sheath, causing the more irregular shape. Twist liveliness of both yarns was also same.

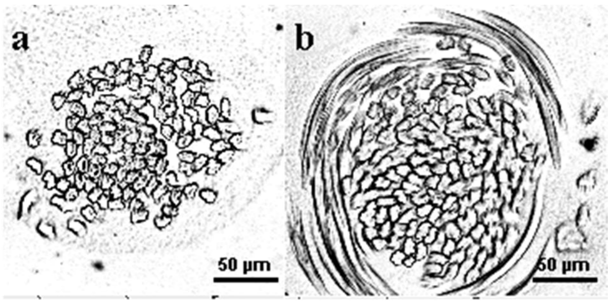

Figure 2 Cross-sectional view of yarn (a) airjet (b) rotor

Figure 2 shows the cross-sectional images of airjet and rotor yarn. It can be observed that in rotor yarns, wrapper fiber are irregularly wrapped around the core fibers with varying angles and some of them can be seen forming an angle of 90° taking the belt shape. While in airjet yarns, wrappping effect is much regular and wrapper fibers are identifiable forming a cap-like shape as shown in longitudinal view in Figure 3.

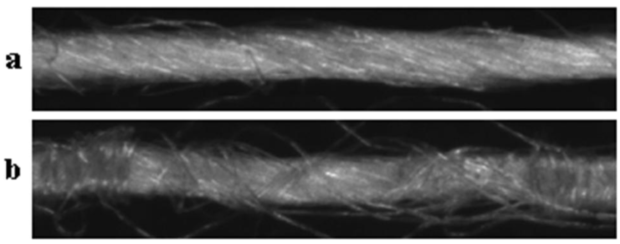

Figure 3 Longitudinal view of yarn (a) airjet (b) rotor

The average values of yarn cross-sectional results for both airjet and rotor yarns are shown in Table 2. Diameter of airjet and rotor yarn is the same and the difference in packing density of both yarn systems is insignificant. So it can be said that the fiber and yarn parameters are almost the same for both systems.

Table 2 Cross-sectional results of yarn

System	Airjet	Rotor
Fiber fineness [tex]	0.13	0.13
Yarn fineness [tex]	16	16
No. of fibers in cross section [-]	118	127
Effective diameter [mm]	0.15	0.15
Effective packing density [-]	0.64	0.63

3.2 Realization of yarn in fabric

Figure 4 shows the cross-sectional images of airjet and rotor samples with different pick densities. It can be seen that with the increase in pick density, free spaces in weft reduces and forces on weft yarn in intersecting region increases, which causes its deformation (flatness) in fabric. Two kinds of forces are acting at the contact point of yarn here, one is vertical and second is lateral force. The vertical force causes the ellipticity in yarn, while lateral force causes it to remain circular. The net effect of these forces allows the yarn to deform in new shape. Vertical force increases with the increase in pick densities and lateral forces are more prominent when there is less or no free space between yarns i.e., high pick densities. So it can be said that both forces increases with increase in pick density of woven fabric.

To study the effect of pick densities and yarn type, the major and minor diameter of the elliptical shape of each yarn cross-section was measured and the results are shown in Figures 5 and 6.

Figure 5 depicts the behavior of major diameter of yarn in which upon increase in weft density in fabric the major diameter (flatness) decreases, at 40 picks/cm it increases and then a small decrease can be seen at highest pick density of 50 picks/cm. This can be explained as when the weft density in fabric is low, the free spaces between the adjacent weft yarns are more so they find more opportunity to flatten and it is shown from 10 to 30 picks/cm.

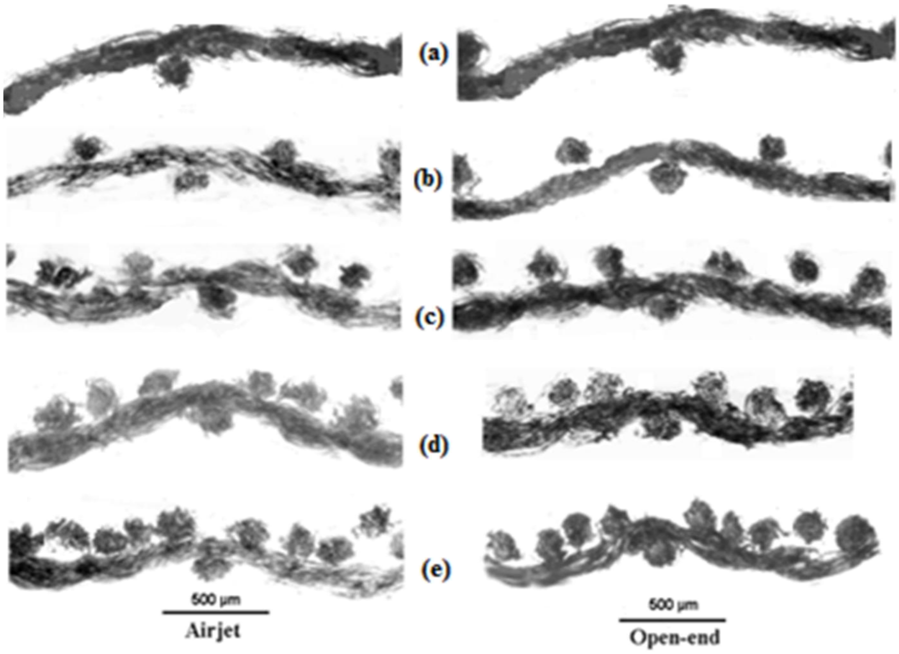

Figure 4 Cross sectional images of airjet and rotor fabrics with different pick densities (a) 10, (b) 20, (c) 30, (d) 40, (e) 50

The deformation (flatness) is more phenomenal at higher settings (40 and 50 picks/cm), causing by the vertical forces, which are more prominent at higher pick densities.Whereas in rotor yarn flatness first reduces from 10 to 20 picks per centimeter, then it increases continuously up to 50 picks per centimeter (vertical forces prominent at higher densities). The variation in this trend between both yarns could be attributed to the variation of fabric relaxation after taking off the loom; there is a tendency to non-uniform bulkiness. This tendency causes non-uniform changes in the yarn cross-sectional shape. The yarn bulkiness causes an increase in the cross-sectional area, but does so in a non-uniform way [4], so it may affect flatness in some cases. Also the more IPI of rotor yarn can affect the deformation at the binding point which can be minimized by taking more and more readings for a specific pick density.Moreover, it can be scrutinized from Figure 5 that the flatness (major diameter) of airjet yarn is more than that of rotor yarn in fabric, which is also statistically significant as shown in Table 3 and this is because unlike rotor spun, the core fibers in airjet are arranged parallel to the yarn axis without twisting and are enclosed periodically by the wrapper fibers as described earlier. So upon same warp tension (force) airjet yarn have a tendency to deform more than rotor spun yarn.

In Figure 6, the changes in minor diameter for both airjet and rotor yarn in fabric can be observed. These changes are in accordance with the major diameter (Figure 5) in a sense when the major diameter increases the corresponding minor diameter decrease and vice versa. In overall minor diameter of airjet yarns is less than rotor yarns at different pick densities because the flatness (major diameter) in airjet yarns is more than rotor yarns as described earlier in Figure 5.

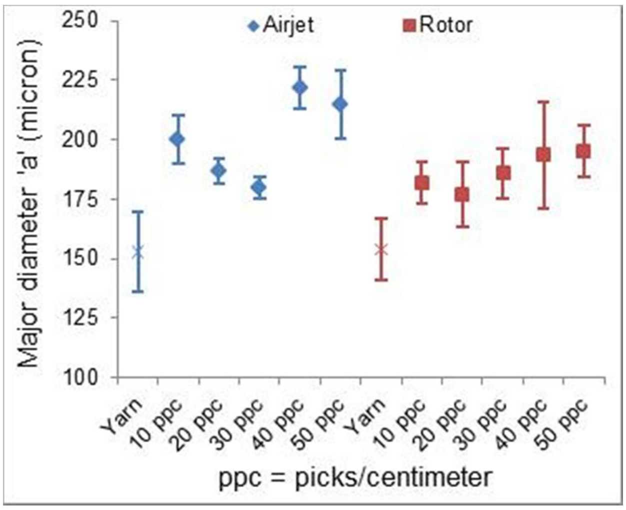

Figure 5 Effect of pick density on major diameter of airjet and rotor yarn in fabric

The cross-sectional diameter of major and minor axis of airjet and rotor yarn before weaving can also be observed in Figures 5 and 6. It is clear that a very slight difference in major and minor diameters exists for both yarns while these diameters have changed in the fabric because of the acting forces on it, which results in the deformation of yarn in the fabric.

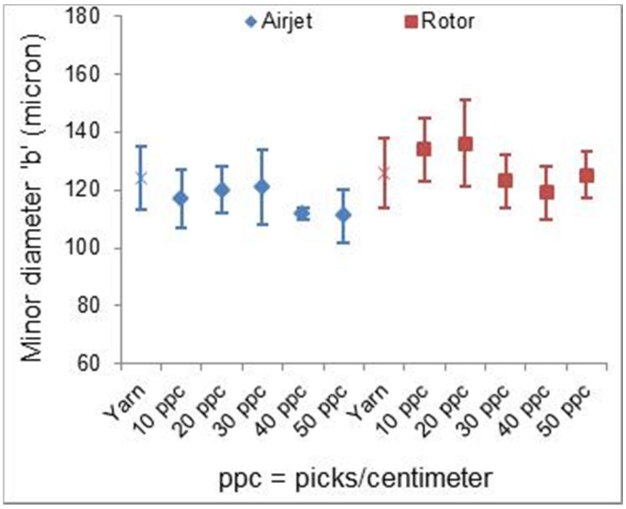

Figure 6 Effect of pick density on minor diameter of airjet and rotor yarn in fabric

The ratio of minor diameter *b* to major diameter *a* (which is referred to as ellipticity ratio or shape) of weft cross-sections is calculated in order to consider the effect of pick densities on the cross-sectional geometry of yarns in the fabric. The ellipticity ratio changes between 0 and 1. The bigger the ellipticity ratio, the closer is the circular like cross-section. Figure 7 shows the ellipticity (*b/a* ratio) of weft cross-sections for single yarns and yarns inside the satin fabric. Ellipticity of single yarn is more than that of yarn inside the fabrics. It decreases at high pick densities in both airjet and rotor yarns; effect of vertical forces is more prominent than the lateral forces. Here it can also be observed that the ellipticity of rotor yarns in fabric is more than that of airjet yarns in fabrics which is also statistically significant. So the rotor yarns tend to deform less in fabrics.

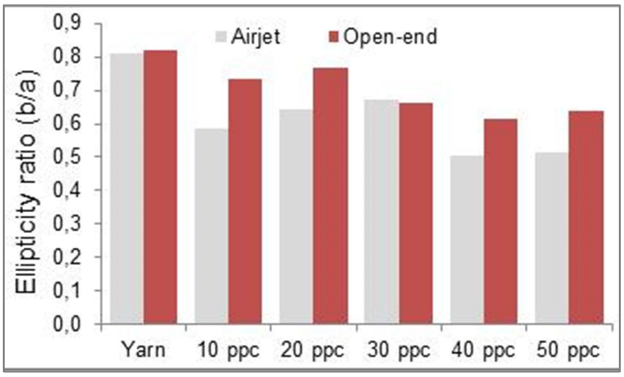

Figure 7 Ellipticity ratio of airjet and rotor

In Table 3, the results of analysis of variance are shown which depict that yarn type and pick density affect the major diameter, minor diameter and ellipticity significantly at confidence interval of 95%.

Table 3 Anova results for yarn in fabric

Dependent variables	Yarn type	Pick density	Interaction effect (yarn type*pick densities)
Major diameter	s	s	s
Minor diameter	s	s	ns
Ellipticity	s	s	s

ns = not significant, s = significant

4 CONCLUSION

The results presented here indicate that though the airjet and rotor yarns have two different structures, but their effective diameter and packing density is almost the same for same count of yarn. While using them in weft and upon increase in pick densities the flatness (major diameter) increases in both airjet and rotor yarns, while increase in flatness in rotor yarn is comparatively less than airjet yarn. This is because the core of airjet yarn has a parallel position of fibres and chaotic position of fibres is present on the surface only. While rotor yarn has chaotic fibre positions in all structure of yarn. So upon same tension and forces inside woven fabric; airjet yarns can get bigger deformation. On the other hand change in minor diameter is in accordance with the major diameter in a sense when the major diameter increases the corresponding minor diameter decreases and vice versa, while the minor diameter of rotor yarns is more than airjet yarns.

The value of major diameter of single yarn is less than its corresponding value in the fabric; this confirms the deformation of the yarn into fabric. Moreover the flatness of airjet yarn is more than that of rotor yarn in fabric. The ellipticity ratio is higher in rotor yarn fabrics as compared to airjet yarn fabrics and it decreases with the increase in pick densities. Effect of yarn type and pick density are found to be significant for yarns in fabric.

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POSSIBILITIES OF TESTING AND EVALUATION OF FUNCIONAL MEMBRANE TEXTILES

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Abstract: *The presented contribution deals with the possibilities of objective evaluation of functional utility properties of membranes made by reputable producers. There are many international norms and standards for evaluation of functional textiles and membranes. The article describes the most fundamental principles of objective testing of functional membrane textiles under accurately defined conditions in compliance with the international ISO standards and it deals with the requirements for their basic evaluation. In the theoretical part, the principles of functioning of individual types of membranes are described. For mutual comparison, the individual types of membranes are depicted using SEM (Scanning Electron Microscope) technology. The most significant evaluation criterion in functional membranes is evaluation of water vapour permeability but only in common evaluation and comparison with another important membrane functional property – water column. Based on the results of the experimental part, it is evident that only by comparing these two fundamental properties, designed membrane textile can be evaluated partially and recommended for its utilization in tough conditions, under which the user expects maximum comfort of the clothing.*

Key words: *functional membrane; functional apparel; objective evaluation; clothing comfort.*

1 INTRODUCTION

Clothing production increasingly focuses on modern functional clothing - professional, sports and leisure time. As a standard, such clothes consist of three layers. The first layer touches the wearer's skin and particularly, it has to transport moisture while maintaining very good sensory properties. The second layer is thermal insulation, which is needed during winter season. The third layer is protective and it must protect the wearer against rain and wind [1]. All these layers must provide water vapour permeability and, eventually, air permeability [2]. Semipermeable membranes are successfully used as the third layers. The membranes themselves would, however, have a very little mechanical resistance and that is why they are usually connected by lamination with classic textiles that particularly provide strengthening and increase mechanical resistance. Application of semipermeable membranes is important for the third clothing layer such as jackets, coats, working vests but also gloves, shoes and other clothing accessories.

The presented contribution deals with the possibilities of objective evaluation of these membranes and comparison of reputable brands and principles of the membrane types based on objective measurements in compliance with ISO 11092 standards for evaluating water vapour permeability and comparing with water column, another important property, in compliance with EN 20811 [3-4]. By merely comparing the two basic properties, designed membrane can be partially evaluated. Selecting only one of the properties is only of informative and marketing character ant it does not prove producer's reliable approach towards users.

Transport of liquid moisture and transmission of moisture through functional textile has a crucial role in the physiological comfort of functional clothing as described in several studies [5-7]. From the view of the overall assessment of garments, we must also consider other aspects such as the shape of clothing construction, pattern construction of a textile etc., which have an impact on required good fitting of a clothing layer on human body surface [8-9]. Provision of optimal comfort of clothing by application of sophisticated functional membranes is important not only for sports activities but also for persons with reduced mobility, for whom it can mean improvement of the quality of their lives [10].

2 TYPES OF MEMBRANES AND EVALUATION OF SELECTED PROPERTIES

Membranes do not let liquid water through but they let through under the condition of a difference of partial pressures of water vapour molecule on a simple principle, which, in porous membranes, lies in large quantities of small pores with their diameter of c. 1-2 μm, in the number of (1.4 mil. pores/cm^2 = data for Goretex). Pores are much smaller that the smallest drop of water, thus excellent water-repellent property is ensured. The second principle applied to membranes is hydrophilic membranes that can uniformly transport molecules of water in the form of water vapour; naturally, they do not let liquid water through. Both principles of semipermeable membranes have permanently been improving with the aim of ensuring the best utility properties possible. Semipermeable membranes are used for many outdoor sports such as e.g. cycling, running, sailing, mountaineering but also for professional protective clothing, military and police uniforms, etc., where protection against adverse weather conditions is required. Due to high market potential, such textiles are nowadays very common and very successful, as for marketing.

Barrier textiles can be divided into two main groups:

- Laminated: ready membrane is bonded to the textile bearer (porous membranes and non-porous hydrophilic membranes)
- Coated: polymer is melted and applied directly onto textile bearer.

Coated textiles are water vapour permeable due to micro-pores (diameter 1-2 μm) and they work on the above mentioned principle, which is shown in Figure 1, where micro-pores in the membrane are smaller than the smallest water drops (diameter min 100 μm) that cannot get through the membrane.

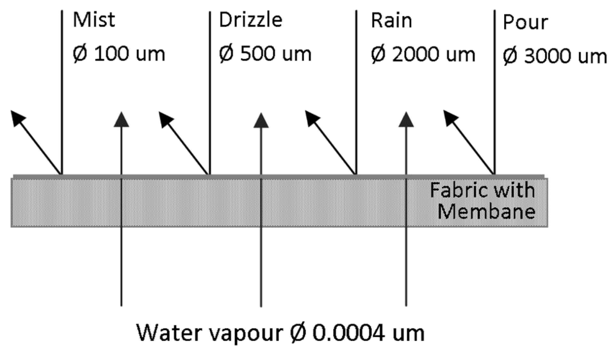

Figure 1 Principal depiction of water vapour transfer and barrier function through membrane textile

Among porous membranes, there are also membranes made of nanofibers layered into fleece. Alternative principle of a membrane or coating is called hydrophilic. Hydrophilic macromolecules are applied in these membranes. Membrane is fully closed and water-resistant but water vapour molecules can be transported from one functional end group to another and move to the outside. An example is the type of Sympatex membrane. Both principles – microporous and hydrophilic – can be combined.

Laminated textiles can be divided into various groups:

- Two-layer laminates consist of a textile bearer and membrane. If the membrane is bounded to the outer layer, such two-layer laminate is usually applied in combination with a free inner insert that mechanically protects the membrane.
- Membrane can also be connected to the inner insert. The 'insert' is in combination with outer or upper material.
- Three-layer laminates consist of an upper textile, membrane and insert that are fixed together.

All layered or barrier constructions are confronted by a principal dilemma: membrane cannot differentiate between rain that has to be blocked and liquid sweat that has to be transported. This is the reason why in situations with high production of sweat (increased to extreme sweating) that are typical for sports, water-resistant construction usually offers only limited or poor transport of vapour and in the inner side, sweat can precipitate due to reaching the dew point temperature [11]. That is why hydrophilic inner inserts have been successfully tested and applied instead of commonly used hydrophobic inserts. Sweat drop is (in the inner side of the 3rd layer of clothing) absorbed by the insert/lining and distributed to larger surface because membrane does not allow transporting sweat as a liquid. However, this significantly enlarges the area allowing vaporization of sweat through the membrane. Then the problem of moisture condensation in the inner layer needs to be solved by sophisticated construction of clothing.

3 THE CHARACTERISTICS OF THE SELECTED TYPES OF MEMBRANES

The following samples of membranes from leading producers were selected for testing. The basic material characteristics and view of their internal structure is shown in the following Figures 2-9 and Table 1.

Table 1 Indication, type and basic material parameters of tested and functional membranes

Sample	Membrane type	Thermal conductivity λ [$W.m^{-1}.K^{-1}$]	Weight [g/m^2]
No.1	Nano-membrane	0.0672	122
No.2	Hydrophilic non-porous	0.0688	168
No.3	Hydrophilic non-porous	0.0814	115
No.4	Nano-membrane	0.0572	150

The experimental part focuses on measurements of selected properties of functional membranes that directly influence utility properties and overall comfort of the clothes perceived by the user while wearing the clothes.

Sample No. 1 – Nano-membrane

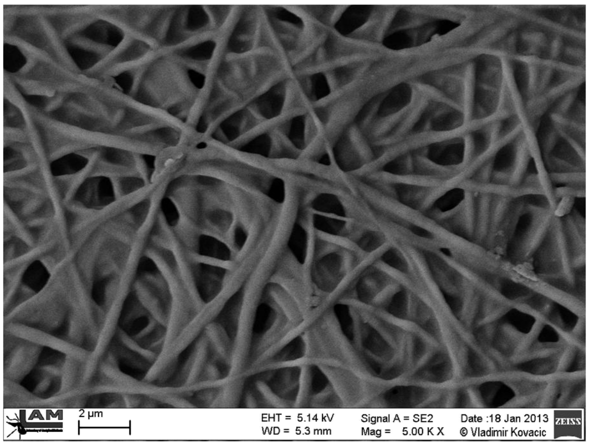

Figure 2 View of the obverse side of sample No. 1 depicted using SEM

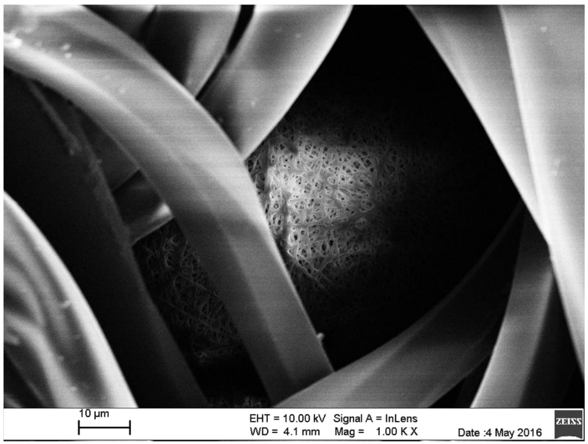

Figure 3 View of the reverse side of sample No. 1 depicted using SEM

Sample No. 2 – Hydrophilic non-porous membrane

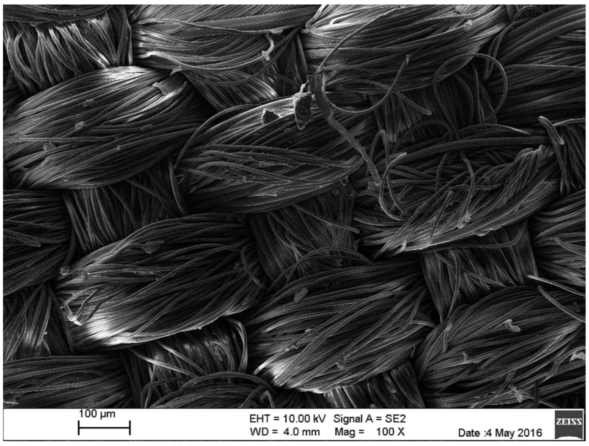

Figure 4 View of the obverse side of sample No.2 depicted using SEM

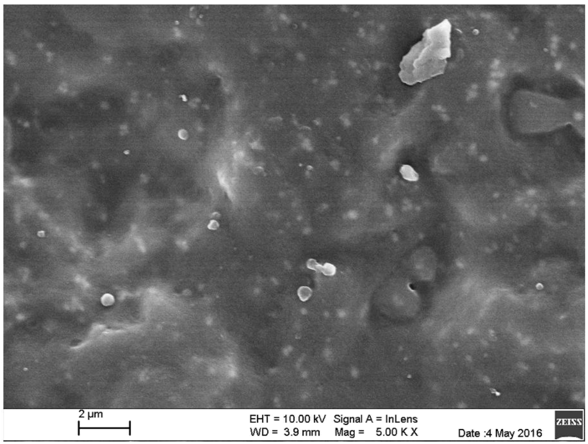

Figure 5 View of the reverse side of sample No.2 depicted using SEM

Sample No. 3 – Hydrophilic non-porous membrane

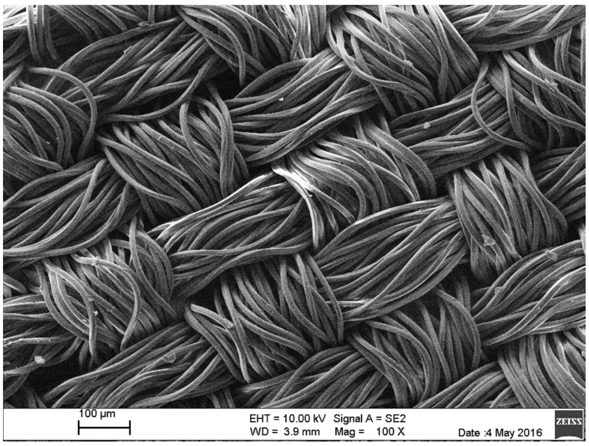

Figure 6 View of the obverse side of sample No. 3 depicted using SEM

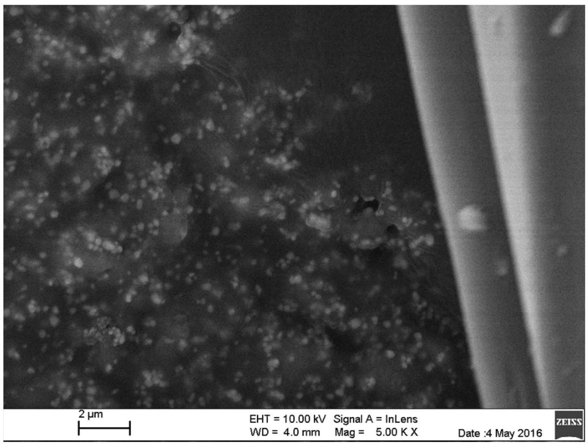

Figure 7 View of the reverse side of sample No.3 depicted using SEM

Sample No. 4 – Nano-membrane

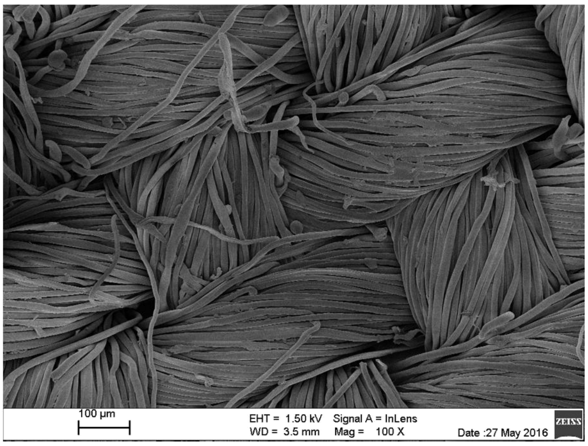

Figure 8 View of the obverse side of sample No.4 depicted using SEM

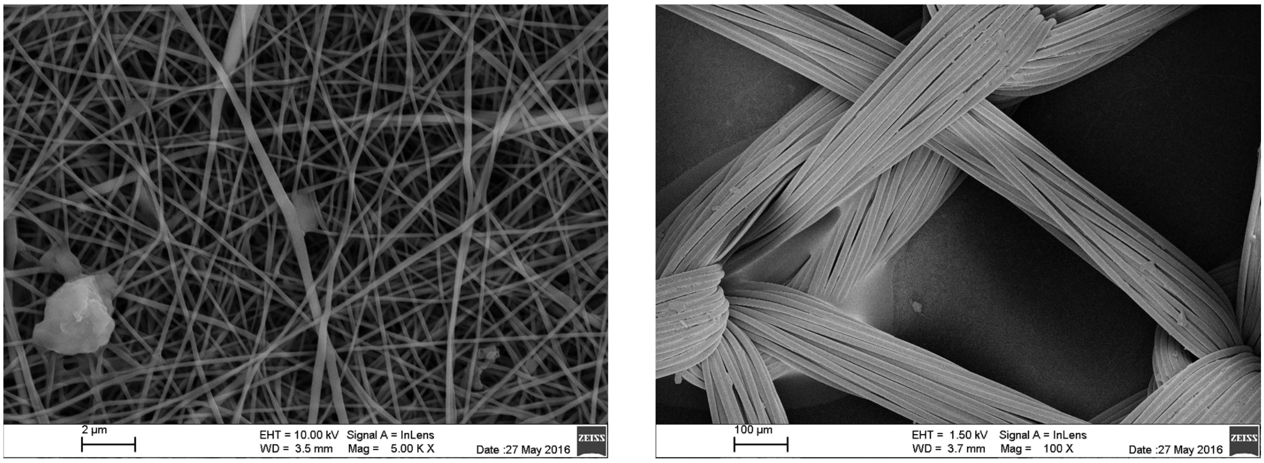

Figure 9 View of the reverse side of sample No.4 depicted using SEM. The figure above shows detail view of nano-layer

4 EVALUATION OF THE FUNCTIONAL MEMBRANE AND EXPERIMENT

The following evaluation methods have been selected for evaluation of functional membranes in terms of utility properties:

4.1 SGHP - (Sweating Guarded Hot Plate)

Model of sweating hot skin was developed for measurement of thermal temperature resistance (R_{ct}) and resistance to water vapour (R_{et}) in textile materials. Testing is carried out in compliance with ISO 11092 and ASTM F1868 [3, 12]. During R_{et} test, distilled water is supplied into the equipment; water is warmed under the testing surface and it permeates, in the form of water vapour, through cellophane membrane and to the tested sample. To achieve stable standardized conditions, SGHP is located in a climatic chamber with high accuracy of temperature and humidity.

4.2 Determining resistance to permeation of water – water pressure test

The SDL M018 device is used for determination of resistance to permeation of water. Fastened textile is stressed by pressure using compressed air and distilled water. The water column height, in which water permeates into the sample in three places, is recorded. The speed of increasing the pressure is set at 60 $cm.min^{-1}$ and the test is carried out in compliance with ČSN EN 20811 (80 0818) [4]. Material that endures at least 1500 mm of water column can be considered waterproof. Higher values of the water column are requested in heavier-duty products.

4.3 Determination of resistance of textiles to surface wetting (spray test)

The test is carried out in compliance with EN ISO 4920:2012 using the SDL M 232 device. A sample fastened with its obverse side up is sprayed under the angle of 45° with 250 ml of distilled water. When spraying is finished, the sample is flipped off and evaluated in accordance with the comparative scale with degree 1 (wetting of the entire surface) to degree 5 (no wetting). Photographic ISO scale [13] can also be used for evaluation.

Individual types of functional membranes were tested every time on 5 samples and the results of individual I.-III. testing phases are stated in Table 2.

Table 1 Results of the experimental part

Sample	R_{et} [Pa.m^2.W^{-1}]	Pressure water [m]	Spray test [-]
No.1	3.8899	10	ISO 4-5
No.2	6.4211	>20	ISO 5
No.3	4.3810	11	ISO 5
No.4	3.2966	0	ISO 0

5 CONCLUSION

Semipermeable membranes are integral parts of modern functional clothing, especially of the third layers of clothing. These materials can protect the person wearing the clothes against rain and water in liquid form and, vice versa, they can permeate water vapour in limited extent. These utility properties can be evaluated accurately in accordance with various methods and devices, e.g. hot skin model, water column (ISO 11092, EN 20811). It is absolutely fundamental and necessary to evaluate these properties in accordance with defined methodologies and standards under exactly defined temperature and humidity because a change of ambient conditions significantly influences the measured values. The essential condition for partial evaluation of functional membranes is, at least, evaluation of water vapour permeability and water column because a highly vapour permeable membrane that is highly air-permeable but without sufficient waterproofness can be created. Since even highly vapour-permeable materials are not applicable to functional clothing of the 3rd layer in case of small resistance to water permeation from 8-10 m of water column. Other important properties of functional clothing/membranes are mechanical resistances, e.g. abrasion, wear.

By the above stated reasons we consider evaluation of barrier textiles, and especially vapour permeable membranes only in terms of vapour permeability absolutely nonsensical (improper) because we can find the whole range of textiles that will be vapour permeable and will permeate liquid water too, thus they will not have any barrier function. Usually also so called waterproof effect is evaluated; it is impermeability for liquid water (not only water-repellence is concerned). Generally it is required to evaluate the whole set of determining utility properties of clothing in accordance with assumed purpose of its application.

Standard membranes of renowned brands that show approximately equal functional properties are evaluated in the presented contribution. As a matter of interest, a barrier textile with a nanofiber layer with high vapour permeability but with little waterproofness – thus practically inapplicable to clothing intended for extreme conditions – is mentioned too.

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SOURCES OF RECEIVING INFORMATION OF MODERN TENDENCIES IN FASHION INDUSTRY

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Abstract. *The sources of information affecting the formation and expansion of modern tendencies in consuming world are considered in the article. Literal survey of various ways of getting information of modern tendencies in the fashion is analysed. The predictable methods of fashionable clothes in the market are described. An extent of influence of certain fashionable tendencies' sources on particular consuming audience is defined. The ways of getting information of modern tendencies in the fashion world (PR-System) are described. The participant's patterns of fashion process are concerned. The criterions of consuming attitude to fashion standards and fashion goods to be substantiated in sociological and marketing researches are defined.*

Keywords: *fashion industry, fashion trend information, trend-book, subjects of design, prognosis analysis.*

1 INTRODUCTION

Modern fashion market presented with various trends covers all stratums of the consumers. Designing of clothes as fashion product is turning into the global economic tool dealing with the consuming motives.

Fashion industry conduction as complicated multilateral phenomenon having aim to distribute fashion standards among the all stratum of the consumers (the strategy of fashion industry conduction), production, expansion and fashion good's consuming (the functioning tactics) is worth to be considered as very important factor of fashion's expansion in the modern world. It's out of question that norms and tendencies of fashion development are mostly dependent on consuming supply and demand to be effected with. That's why the studying and applying of theoretical conceptions of functioning and fashion development and fashion behaviour in society is very important for the planning production and fashion clothes designing. To satisfy customers' demands on one or another fashion goods in context of modern tendencies and innovations to be very popular now are correspond to the development of this branch of economy too.

On the other hand, the activity of fashion industry, especially in mass-market segment, as the main sphere of consuming demands is aimed at to be mentioned too.

As we know, the prognosis of modern tendencies, based on the development of fashion clothes selection, is considered to be an integral part of the activity of fashion's participants, which deal with the development of fashionable product. To resume, it can be said that observing the development of modern clothes selection and on its basis one can mention, that the work of designer starts with the defining of that fashion product which can attract the customer to their trade mark long before the new season's fashions.

The allocation of fashionable clothes can be considered as certain conduction and production of types of clothes as well as the segmentation of modern clothes for the masses. According to the classification all selection of fashionable clothes can be divided into such classes as:

- haute couture
- pret-a-porter (pret-a-porter de lux, and, actually, pret-a-porter)
- bridge (low-bridge, middle-bridge, high-bridge)
- moderate (mass clothes)
- mass-market (retail, budget, non-brand) is clothes of economy-class.

The designer's role in producing of clothes for the masses in fashion industry when modern tendencies' predicting differs but, of course, it has an effect upon the selection of fashionable product, which is aimed to meet their customers' demands.

2 ANALYSIS OF PREVIOUS RESEARCHES AND PUBLICATIONS

The criterions of modern sketches' costume development of the 20 century especially in the context of social and economic development of society are analysed in the works of E. Kosareva, M. Romanovskaya, F. Bodo, etc. The questions of social and historical development of fashionable clothes are stressed on in the M. Romanovskaya's work. According to this work women can have more functions and can play their own roles in society [1].

In the same time, E. Kosareva analyses the perfect project in each historical period of the development of fashion industry considering the dynamic model of clothes' formulation as the product of fashion, in the context of sociological and psychological consumption [2].

Furthermore, the problem of inside contradictions and tendencies of modern standards' development and forming of criterions prognosticated is analysed in the works of A. Lynch and M.D. Strauss. They studied the functioning aspects of fashion industry to create the applied prognosis of evolution of these standards [3]. The results of all participants of this investigation (designers, journalists, advertising, retailers, etc.) which make its contribution to the forming of perfect fashion ideal in the formation of fashionable standards of modern consuming society are presented in the Y. Karamura's work [4].

So, there are many official sources of information of fashionable tendencies that many designer companies and trade-marks can use them in their activities. Moreover, the informal observing of what is worn, what is interested in, what is potential customers speaking about is considered to be invaluable way of getting information. The compilation of information about modern tendencies of clients' preferences, the combination of minds and opinions in professional surveys are available for designers and can be dependent on retailers which are interested in objective customers [5].

The description of the official informative sources of modern tendencies shows that the majority of agencies and companies creating trend-information and situated in the world-fashion cities are aimed at to make contacts and to expand the prognostic information. Companies and agencies dealing with and prognosis of fashion tendencies base their works offering the high stylish and street fashion analysing the scientific and technical progress, cultural aspects of the social development, including mass culture. The information, systemized and carefully collected about prognostic parameters of fashionable tendencies is presented visually by manufacturers of mass style (the basic drafts or the main silhouettes and forms' fragments of clothing and garment accessories, coloured palette, the samples of fabric texture and materials both for not numerous and numerous fashionable production as for the masses) in the forms of magazines, journals and so-called "trend-books" These trend-books are usually produced according to specific field and extend among fashionable clothing' manufacturers for particular consuming (men's, women's, child clothing, underwear or outer clothing). Many firms dealing with the prognostication of fashion tendencies present their publications to constant clients and give the renewed information according to the specific directions [6]. Among them "Promostyl" France and "Nelly" Netherlands in this direction are considered to be the leading and the most successful ones.

3 OBSERVATION AND DISCUSSION

3.1 Prognostic observation of fashion-market

The results of prognosis of fashionable clothing for high next season are very often realized in detailed trend-books, which accumulate the most successful images and fashionable clothes presented in professional modern publications. The numerous images and fashionable items presented in trend-books for next season are based with aims and tasks of fashionable clothing's' production for particular group of customers and usually vary from four to six but more often it's limited to five variants. The experience of successful trends and trade-marks' activities in the industry of fashion confirms that five new tendencies and the designing of fashionable clothes models in its direction - is thought to be an essential number which can be presented in the shopping centers of the one retail-trend of fashionable clothes [7]. Traditionally, these five directions have got such artistic and framed images as: three modern, classical one and ethnical image. Classical image (can be, the retro one) and ethnical imaginable subjects can afford to create the great number of combinations of sharply-pointed ideas which is believed to be an extra way for designers being inspired to create fashionable clothes for masses, especially in the fast fashion' conception [8].

Each of fashionable tendencies or directions, as a rule, is provided with imaginable motto which can then relieve the work as for mass-media and mechanism of expansion as for the sellers and agents' instructing. [9].

Besides, artistic images and framed modern items, as a rule, trend-books contain information about coloured palette of each modern tendency. The coloured palette usually prognosticates and performs closely interacting with materials' consuming. And at the moment trend-books' formation the coloured palette is presented too like that new samples of output in textile industry (fabric, materials, and specials items). But in the retailer-trends' activity in the conception of immediate response the creating of fashionable coloured palette is practiced due to the machine projection (CAPR) [10].

As a rule, the realization of modern tendencies by means of drafting trend-boards is performed by designers or by suppliers, but with the exception of presentation to be operated with purchase's section collaborators in the leading fashion industry's organizations. When designers and suppliers cooperate at the same time with several trade-marks, and, in this case they are dealing with fashionable brands' performance apart from of each company. But if these trade-marks conduct its activity in the same of segment of clothes or work for special group of customers, they are given single summarizing information about short-term modern tendencies. In future when selecting the current tendencies for clothing's manufacturing of each trade-mark, the other buyers of this trend join to its concern to follow the individual peculiarities of its fashionable output [11-13].

3.2 Review of conduction of participants of fashion process in the conditions of fashion industry

More mobile and available source of information to a wide range of participants in the fashion industry can be specialized professional publications such as International Textiles [14] or Textile Intelligence [15]. These publications give information on fabrics to be popular, materials, coloured palette and items in the context of its realization in the fashionable clothing's models. These magazines are published long before to the beginning of high season than other trend-books of famous agencies. Besides, the information presented there is not so similar to as different. However, the most designers of the famous trade-marks dealing with the segment of mass market accept this because they are able to sell their products when conducting the fashionable models of clothing's selection (especially in the context of the fast fashion conception).

Professional and specialized publications (journals) are thought to be an additional source for prognostication of modern tendencies. They present information about specialized exhibitions performed, in particular the textile sphere, sewing equipment, fashionable clothes, etc. The most famous publications are: “Drapers” (Great Britain), «Индустрия моды» (Россия) etc. The results of the specialized exhibitions which are very important for those who can't visit them are believed to be very valuable and can be found in publications above-mentioned. Specialized exhibitions and shows take place as a rule twice a year showing achievements of all spheres of fashion. Festival KievFashion [16] is considered to be an excellent and exciting example of such kind of events. Besides, many exhibitions of special directions of the fashion industry can be said are regularly held, the specialized textile named Premiere Vision (PV) must be particularly mentioned. During the exhibitions the main participants present their prognosis in the sphere of coloured palette and textural or raw materials' peculiarities for fashionable clothes performance, accompanying them with music and video about stylish and imaginable features of modern tendencies in future.

As a rule in different market's sectors of fashionable clothes the specialized exhibitions as modern output are held together with exhibitions of materials for this clothes' production. The specific nature of this cooperation lies in the timeliness of modern tendencies that presented in the exhibitions of raw materials and fabrics that leave behind the novelty of presented samples of clothes. And performing the exhibitions at the same time causes to close business contacts of the various participants in fashionable clothing's manufacturing as the product of fashion [17]

Taking into account that the notion “fashionable clothes” is very common one and consists of many kinds and can be classified according to its segment (outer clothing, smart, underwear, men's, child clothing, sporting, etc.), and even (pret-a-porter, bridge, clothes for masses etc.) in the world of fashion industry many specialized exhibitions are held, devoted to the prognosis, creating and fashionable clothing's producing.

The regular rotation of these exhibition's performance is considered to be the specific feature of these exhibition's performance - many of them despite the good reputation and popularity stop their existence or change the basic nature of their structure, when the others systematically appear and expand its activity, depending on the specific of modern tendencies' development and the industry of fashion in some segments [2, 18, 19]. In addition to the Internet development and other reliable electronic resources the prognosis is becoming to be more and more efficient and available to all participants of fashion industry, that promotes to the more global expansion and mobilize the output's manufacturing [20].

Despite the fact that the designing trends work out the fashionable clothes of various directions including mass clothing (above-mentioned), the notion “designer clothes” traditionally refers to the fashionable output of the most expensive segment in the fashion-market.

Being above-mentioned the collections of designers made in “haute couture” direction are considered to be reliable way of information about fashionable images and tendencies for companies and trade-marks, that work in the mass-clothing's segment [21]. As a rule, the representatives of mass-market's clothing especially working in fast fashion conception [22], they are not allowed to the presentation of “haute couture” collections. The invitations to catwalks and fashion shows are given only to constant clients (reputation), to the public (the prestige to be promoted), to media officials (to be widely light up in the press) and to buyers, that dealing with trade segment in realization of pret-a-porter collections (to rise the popularity of any fashion brand).

Moreover, soon after new collection's presentation of fashionable clothes some brands organized so-called ‘media day’ when stylists and journalists have the possibility to know more about the collections. As a rule, these ‘media days’ devoted not only to the collection presenting in Fashion Week, but to the period of new fashion journals' publications for the next season (from two to eight long after catwalks and shows).

But, the information about trendy goods, presented in such shows can be received long before as it appears in commercial network [11]. Many professional trendy journals (Collezioni or L"Officiel), women's journals such as Vogue, Elle and others, are considered to be the reliable sources of information. Electronic resources are too very popular nowadays, some of them buy the rights to provide live broadcast of high fashion (WGSN.com, firstview.com, mgsn.com and others) [3]. Thus, the performance of trendy clothes' pret-a-porter collections is directed towards the fashion-calendar of haute-couture showing, though the collections of haute couture have now less influence on the creating and realization of mass clothes. From the other side, they play the role of outdoor advertising, and the pret-a-porter collections are provide with high artistic and stylistic features, but from another side they promote these artistic images to the mass-consuming. In another words, they form and create the fashion trend [23]. As these shows are held twice a year, it helps to preserve the seasonal functioning in the fashion industry, despite the mentioned activity of changing in selected collections of fast fashion direction [24]. Despite the fact that the live broadcast information about fashion shows of high fashion is quite valuable for the production of trendy clothes as fashion industry production, it is considered to be a source of knowledge of world fashion trends for customers being the subjects of fashion industry [25, 1]. In particular, mass customers, having no possibility to buy haute couture or pret-a-porter clothes, get the additional goods and garment accessories of these designers as well as fashionable clothes, produced by license, realizing at the same time their own ambitions and reputation in society.

So, analysing the sources of information about fashion trends as objects in the fashion industry among all subjects of industry it must be mentioned that both manufacturers and customers realize the necessity of this information through different sources. The expansion of information about modern directions in current or next season can be seen in a model (Figure 1). The information gathered by sectors working with the public of modern tendencies and made on its basis fashionable goods is thought to be very essential for designers. The designer brands having the beneficial cooperation with mass-media, supply them with new information about its activity and mass-media, in its turn, gives them a general publicity, providing themselves with high rating through the readers and the great popularity through the customers.

Among the obligations of PR-sector officials of trade-marks and designer's companies are the development and expansion of press-dossier (in some cases they are called press-files), which are devoted to the beginning of new modern product made by trade-mark in current season.

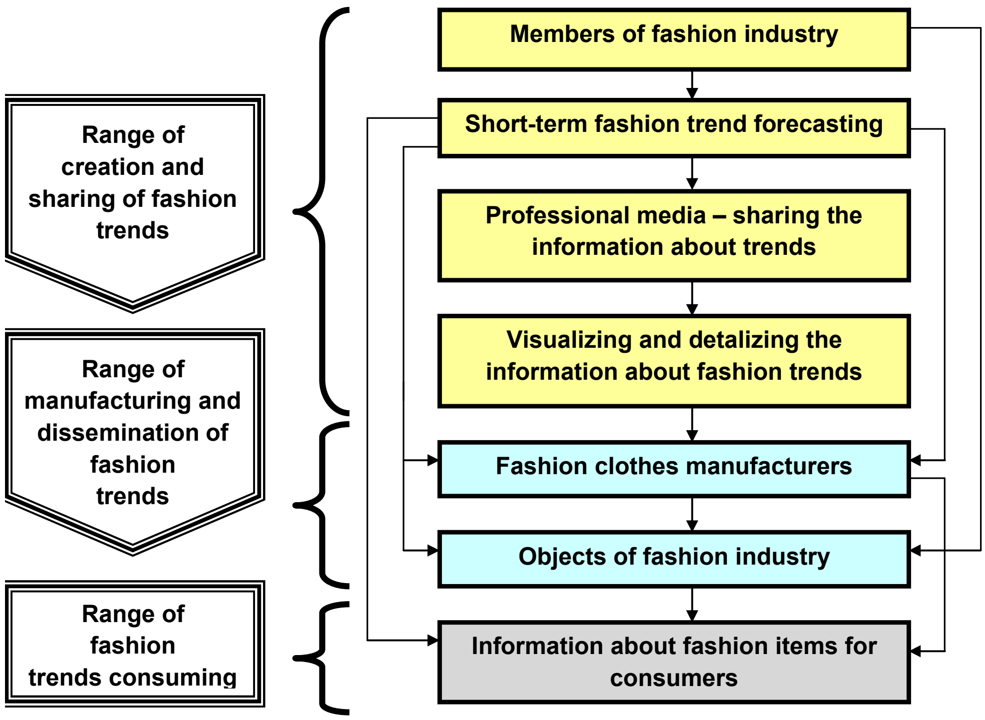

Figure 1 Implementation model of fashion industry participants` needs in the fashion information

Novelty is considered to be the required element of each press-dossier, connected with modern product's promotion to the market, but also with contact information about manufacturer and seller of this fashion product. Such review is accompanied with visual information about of its own product, but also about modern trends and artistic images, when it was made. This information gives to the mass-media editions, which prefer the special consuming one or another trade-mark. Moreover, for the last time the conducting of different PR-steps, devoted to the collections' presentation made by designers and trade-marks but also commercial or charitable steps and events.

Another important aspect of grounding and information' expansion about modern product of trade-marks is look-book made by designers in PR-sections. Look-book is stylistically visually designed material about modern clothes' collections and accessories of trade-mark, which is sent to the mass-media editions for being used in publications. In another words, look-book – it is a catalogue of trendy product of any trade-mark, designed for press in general and in particular for being used by journalists in future information promotional articles of given publication. The catalogues of modern model's clothes differ from look-book as they are sent to potential customers not for being advertised but for selling, so the accents are made mainly on coloured palette, and the possibility to be compiled with other products of fashion or accessories and other peculiarities of consumption.

3.3 Channels of information about fashion trends in the fashion industry

The fashion industry as one of the most developed areas in the world economy has its own specifics. Its activities are directly related to the constant attention to the satisfaction of social, aesthetic, functional consumer problems ahead of their desires, tastes and requests [26]. This has contributed to the formation of multi-functional system of PR-communications, which cover the whole spectrum of interaction with the media at all stages of the development, distribution and consumption of fashion as a product of the fashion industry, as represented in Figure 2.

Thus, information about fashion trends for the consumer is an essential component of advertising because advertising always performs a function of non-personal information. On the other hand, the transience and regular turnover of fashion trends and fashion designs determines informative nature of advertising in the fashion industry. Therefore, all sources of information about fashion trends for the consumer as the widest range of participants of the fashion industry serve advertising and informational purposes only. For example, for information and advertisements about fashion trends and fashion products in printed media it is accepted to use photographs provided by the manufacturer or trained editorial staff as well as targeted advertising of certain design firms and brands (advertorial). Magazines, on the pages of which information about fashion trends and products is published, can be divided into groups depending on the editorial policy and the target consumer information (mutually influencing criteria). The first group, the most often referred to as glossy magazines, are some of the creators of fashion and fashion information, called "Consumer Magazines". They are endowed with the highest authority in the fashion world because on the one hand, on a professional level, they disseminate information about fashion and fashion trends among a wide range of customers (educational function), and on the other hand, they are analysing the activities of the subjects of fashion-market (arbitral function) [27]. Specificity of glossy magazines is that they have a network structure that is promoting a unified editorial policy (and with it the information about fashion) in different regions of the fashion-market, but for each region edition revision corrects the information provided in accordance with the peculiarities of the industry development fashion and consumer requirements. Most influential in this area are the editions of L'Officiel, Vogue, ELLE, Harper's Bazar, etc.

In order to expand the channels providing information about fashion and the fashion industry, fashion industry subjects seek to promote other types of periodicals, i.e. so lifestyle magazines. The basic directions of their editorial policy should be regarded as a reflection of socio-cultural norms, traditions and trends in the life and activity of various social groups, demographic and subcultural formations. The main features of the periodicals of this type are:

- the predominance of the visual illustrations above the text;
- description of the chronicles of social life;
- review of the consumer fashion victim fashion shows and in retail networks;
- small issue and limitations in the availability, which adds such publications an extra weight in consumer circles.

In this segment of the media such magazines as Vanity, Cosmopolitan, Glamour, The Face are popular.

Another area of operation of the fashion industry is a business apparel and accessories, which could not but affect the interaction of this industry sector with business magazines and weekly analytical and overview newspapers, in particular Forbes, The Economist, Business Week, The New York Times, etc.

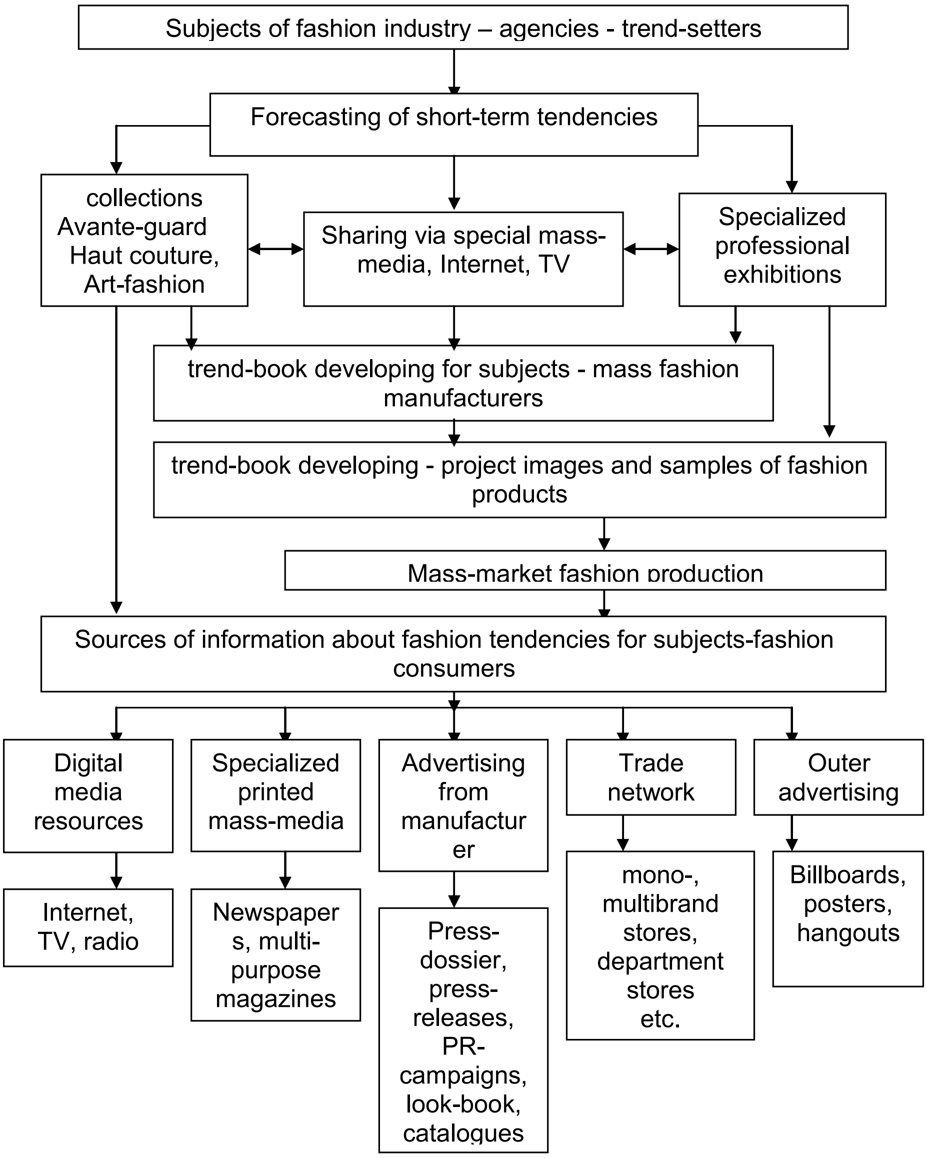

Figure 2 Channels of information about fashion trends in the fashion industry (system of PR-communications)

It is not by chance that many brand designers, whose sphere of production is the business clothes and everything connected with it, make extensive use of advertising-information capabilities of these publications to inform the target audience about fashion trends and products of the current season. Drawing attention of the business elite to development of fashion in the business outfit, such fashion houses (as Hugo Boss, Giorgio Armani, Nino Cerutti) form a new level of fashion product consuming [28].

In contrast to the Internet, which is actively overtaking the functions of printed periodicals, TV and radio broadcasting, information about fashion trends on television (except for specialized channels about fashion) is not very effective both for manufacturers and for consumers, because it does not rely on the particular attention of the target consumer, but requires large budgetary costs. As for the radio as a source of information in the fashion industry the lack of visual imagery makes it impossible to disseminate comprehensive information about fashion trends and therefore shifts the emphasis towards newsroom messages character of promotions, new collections and sales. Another source of information for the fashion industry consumers is outdoor advertising. However, it can be considered effective only for the dissemination of information on tendencies of network and retail brands as has the ability to inform consumers quickly. On the other hand, it is a benefit for the newsroom and advertising messages but not for visual analytic to which belongs the information about fashion trends in the fashion industry. As one of the factors the rate of turnover and the nature of consumer perception of fashion innovation may be regarded. The psychological background of different consumer reactions to innovations in fashion is that any change is observed in the human mind as more or less radical. Therefore, the rate and nature of the consumers' perception of fashion innovation is taken into account by a number of fashion industry members for an adequate segmentation of the consumer market on the basis of relationship to fashion. Thus, it is proved that the sources of information have a permanent impact on the formation and distribution of fashion trends of the modern consumer society. Various sources of information on trends in the fashion industry justify the development of methods for the fashion market of clothes, designed for different purposes. The influence of information sources on the formation of the fashion trends for the target consumer audience is revealed. Sources of information about fashion trends in the fashion industry (PR-communications system) explain the behaviour of the participants in the processes of development of fashion in a fashion industry. Criteria of consumer attitudes to modern standards of fashion products are essential for the fashion industry as well. They were theoretically proved in sociological and marketing research, which also led to creating a model of interaction between the needs of participants in the fashion industry information about fashion trends.

4 CONCLUSIONS

Thus, present review describes the various sources of the modern fashion trends. It mainly characterizes the activities of various members of the fashion industry, involved in the commercial production and distribution of fashion trends. The article is focused in particular on the mass production of clothing, which is usually caused by a tendency of so-called "fast fashion".

It was determined that, in addition to the typical functions of promotion of fashion products and services to the mass market, in the current stage of development of the advertising industry, fashion has acquired another, important for the participants of the fashion process function - consumer tastes modeling, formation of certain fashion trends, and determining the need for fashion innovation.

All these pre-conditions for the development of society of mass consumption (technological, economic and cultural) has led to the fact that members of the elite society, who were the only carriers and consumers of contemporary designs and artistic innovations before, as it turned out, are involved in mass consumption process. We have to constantly sell various fashionable innovations to demonstrate their status and social position.

On the basis of the above arguments and facts the article characterizes and analyses the comparison of the principles of formation of the fashion industry in the context of modern mass consumer society. In addition, the criteria of mutual influence and the reasons for the evolution of these definitions in today's public consciousness are defined.

Thus, if we consider the value of the direct "distributors" of fashionable standards in a society, then their function is obvious. Of particular importance are those members of the fashion process, who in the structure of the fashion industry and trade constitute the auxiliary segments. They, like the fashion industry entities, directly form the consumer’s perception of actuality of a fashion object, and then satisfy their need of possessing the object.

Thus, it is the close interaction between "manufacturers" and "consumers", with the "distributors" who allow the fashion industry to carry out its basic purpose – to meet consumer demand in the fashion standards and fashion products. In this case the result of the complementary activities of all participants in the process should be considered as trendy fashion innovation, the essence of which is to continuously upgrade the standards of fashion and objects under the influence of certain factors.

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