Mielicka et al., J Fashion Technol Textile Eng 2015, S1
http://dx.doi.org/10.4172/2329-9568.S1-006

Journal of Fashion Technology & Textile Engineering

Review Article

A SCITECHNOL JOURNAL

Imparting Flame-Retardant and Antistatic Properties to Two-Layer Knitted Fabrics

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Abstract

A technology of multi-functional two-layer knitted fabrics with barrier properties was developed on the basis of design works within the scope of both material-structural and technical-technological parameters. The barrier properties of knitted fabrics were imparted to them by using the following yarns to make their top layers:

- Yarns of 100% metaaramide fibers and blended (metaaramide + viscose FR) fibers imparting protective properties against hot thermal conditions,
- Yarns of blended metaaramide and antistatic fibers imparting to the knitted fabrics protective properties against hot thermal factors and static electricity, while for the bottom layers the following were used: Blended cotton and wool yarns with the addition of viscose FR fibers or modacryl Protex fibers, imparting to the knitted fabrics protective properties against hot thermal conditions and beneficial physiological properties.

The comprehensive tests carried out to determine structural, physico-mechanical, chemical and functional barrier properties as well as physiological comfort of the knitted fabrics allowed us:

- To design fabric structures in two-layer and plating system,
- To choose optimal knitted fabrics for the technology development of multi-functional protective fabrics on the basis of knitting and finishing processes,
- To work out design and structural assumptions and to make protective fabrics on the basis of the analysis and properties of the fabrics.

The knitted fabrics designed can find their use as individual protective measures for workers exposed to work conditions such as: hot thermal conditions and static electricity.

Keywords

Two-layer knitting materials; Antistatic; Flame retardant; Physiological properties

Introduction

Both the textile and clothing industry belong to the economy sectors that are initiators of new products for various market segments competing in quality and functionality. Owing to manufacturing and processing technologies based on a wide knowledge, especially in the field of chemistry, biotechnology and physics, textiles become more and more versatile. Works using this knowledge aim at the development of functional textiles most frequently combining barrier properties with the comfort of use. The reports of the European Textiles and Apparel Organization (EURATEX), comprising market research in the recent decade, have shown that there is a growing demand for multi-functional, health protecting and environmentally friendly textiles. Within the wide range of fabrics offered in this group, protective clothing seems to be of practical importance. Textile fabrics designed for clothing gain protective properties by using appropriate raw materials, structures and special finishing treatments. The users' expectations in relation to offered protective clothing indicate the multi-functionality of fabrics whose functional properties should combine protective features to the largest extent with functionality and physiological comfort.

There are known many published reports describing the individual protection measures for use in specific work places and presenting the legal basis of use and introduction of the individual protection measures on the market, the principles of hazard identification and professional risk evaluation in the context of protection choice and use of safety marks on work stands [1-9].

The competition on the clothing market forces improvements in the production of textiles including protective fabrics. Following through manufacturers' offers, one can notice that these comprise highly specialized products directed to various work environments. Information about their properties indicates good qualities meeting users' expectations. They are mostly manufactured with the use of new generation fabrics made of highly efficient raw materials, using special finishing techniques [10-12].

From the literature review made [10-15] it follows that the most frequently used raw materials in the production of fabrics for protective clothing are: cotton, anilana (acrylic fiber), polyester-cotton blends, polyester, polyamide, conductive fibers, wool, glass, nomex, kevlar, kermel and neoprene. In many cases, fabrics are made as multi-layer products or products modified by chemical treatments through the deposition of coatings, among others, metallized, rubber, polyethylene, polyethylene containing silver ions, poly(vinyl chloride), and butyl coatings. In view of the conditions occurring on work stands, there are very often required protective fabrics characterized by multi-functional features, e.g. protective properties against hot thermal conditions and static electricity, providing at the same time the function of physiological comfort including antibacterial protection. Imparting the multi-functionality to textiles is connected with their modification that has been long dynamically developed [11-14]. The development of protective fabrics with multi-functional properties, in addition to the use of appropriate raw materials, requires one to design materials with specified structural and technological parameters [11-15].

Recently, this subject matter has been taken up in research works realized at the Textile Research Institute, and the studies carried out previously have shown that it is possible to carry out comprehensive studies and to obtain positive results [16-19], which is presented in this paper.

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Received: March 11, 2015 **Accepted:** April 16, 2015 **Published:** April 14, 2015

Technological Experiments

The aim of the research undertaken was to develop new ranges of knitted fabrics designed for clothing with the following barrier properties:

- Protection against hot thermal conditions and static electricity,
- Biological activity in relations to antibacterial effects.

The study was headed for the multi-functionality of knitted fabrics by imparting barrier properties to a specified fabric range that would simultaneously show improved physiological comfort features and the aesthetic value expected by users. Imparting flame-retardant properties and antistatic features to knitted fabrics was possible by making them with the use of yarns with required features, while antibacterial properties were obtained by finishing them with a chemical agent containing silver nanoparticles.

In order to obtain a specified physiological comfort with the given barrier capability, there were designed weft-knitted fabrics with two-layer stitch structures based on rib stitch (RR) and plain stitch (RL). In designing the knitted structures, for particular fabric layers were used such yarn types that the internal layers (being in contact with user's skin) could show good properties of physiological comfort [20].

It was assumed that the knitted fabrics developed could be used to make light outerwear in the form of various ranges of vests, shirts and blouses.

Raw material systems of knitted fabrics

According to the design assumptions, the following raw materials were used for making two-layer knitted fabrics:

1) 100% metaaramide yarn imparting protective properties to knitted fabrics against hot thermal conditions.
2) Blended yarns imparting protective properties to knitted fabrics against hot thermal conditions and static electricity: (metaaramide + antystatic), (Vsc Lenzing + PES + antystatic) under trade name Rezistat,
3) 100% and blended yarns imparting protective properties to knitted fabrics against hot thermal conditions, including beneficial physiological properties: viscose FR, (modakryl Protex + cotton).

The yarns mentioned in the first two groups were used to make external layers, while those from the third group were used for internal layers.

Two-layer knitted fabrics with RR stitches

Technological experiments were carried out with the use of rip knitting machine with needle gauges of 18 and 24. The two-layer knitted fabrics were made using RR derivative stitch.

From among the designed and made knitted fabrics samples, there are presented those that were positively assessed in further tests [20].

Sample 1: Two-layer knitted fabric with tucking RR stitch (pique) and the following raw material composition: metaaramide + Rezistat + Protex/cotton

Sample 2: Two-layer knitted fabric with tucking RR stitch (pique) with the following raw material composition: metaaramide + Rezistat + Protex/cotton

Sample 4: Two-layer knitted fabrics with RR stitch (Punto di Roma) with the following raw material composition: metaaramide + Rezistat + Protex/cotton

Sample 7: Two-layer knitted fabric with RR stitch (Punto di Roma) with the following raw material composition: (metaaramide +antystatic)+ viscose FR

The knitted fabric structures differed in manufacturing parameters and the percentage composition of specified yarns.

Two-layer knitted fabrics with RL stitch

The knitting process was carried out with the use of open top knitting machine with needle gauge of 24. Two-layer knitted fabrics were made using RL plated stitch according to the principle assumed: yarns providing the basic protective features on the fabric face, yarns providing the physiological comfort of use on the fabric back. There are presented two ranges of RL plated knitted fabrics with flame-retardant and antistatic properties having the following raw material characteristics:

Sample 24: (metaaramide + antystatic) + viscose FR,

Sample 26: (metaaramide+antystatic) + metaaramide + (cotton+Protex).

Finishing treatment of knitted fabrics

The main objective of works connected with the finishing treatment was to determine the technological parameters of this process for two-layer knitted fabrics with various raw material compositions in such a way that would provide the stabilization of fabric structure maintaining the protective properties obtained owing to the use selected raw materials. The selected ranges of fabrics were additionally finished with antibacterial agents. The test results of the physical parameters and physiological comfort of two-layer RR and RL knitted fabrics are listed in Table 1.

Assessment of the functional barrier properties concerning flammability, static electricity and biological activity of the knitted fabrics made

All the knitted fabrics [20] were subjected to flammability and antistatic tests, while biological activity was determined for fabric sample 2 (subjected to antibacterial treatment).

The flame-retardant properties of the knitted fabrics were tested for:

- Resistance to fabric ignition according to PN-EN ISO 15025:2005,
- Resistance to heat according to ISO 17493:2000,
- Resistance to heat radiation according to PN-EN ISO 6942:2005,
- Heat penetration parameter under the action of flame according to PN-EN 367:1996.

The test results of the parameters mentioned, their analysis and assessment were referred to the requirements of PN-EN ISO 11612:2011 and presented in Table 2.

The electrostatic properties of knitted fabrics were assessed by testing the following parameters:

- Surface resistance according to PN-EN 1149-1:2008.

- Volume resistance according to PN-EN 1149-2:1999/Ap1:2001.
- Half-decay time and screening coefficient by the induction method according to PN-EN 1149-3:2007.

Assessment of flame-retardant properties in relations to the requirements of PN-EN ISO 11612:2011

1) Knitted fabrics meet the requirements of resistance to ignition for textiles, range A1.
2) Knitted fabrics meet the requirements of resistance to the action of heat at a temperature of 180°C
3) Knitted fabrics meet the requirements of resistance to the action of thermal radiation at the effectiveness level C1.
4) Knitted fabrics meet the requirements of resistance to heat penetration at the effectiveness level B1.

The analysis and assessment of the test results of these parameters were carried out in relations to the requirements of PN-EN 1149-5:2009, as presented in Table 3.

Assessment of antistatic properties

Knitted fabrics show barrier properties concerning static electricity, meeting at least one of the indices required: $t_{50} < 4s$.

Assessment of microbiological properties

Table 4 presents the results of microbiological tests for Sample 2 that, according to the assessment criteria of standard JIS L 1902 (a fabric has bacteriostatic properties if S > 2, and bactericidal properties if L ≥ 0) shows bacteriostatic properties towards bacteria *Staphylococcus aureus* and *Escherichia coli*, while it shows bactericidal properties only towards bacteria *Staphylococcus aureus.*

Conclusion

The research and development works carried out at the Textile Research Institute have shown that it is feasible to impart multi-functional properties to knitted fabrics designed for light ranges of clothing fabrics. The multi-functionality of the knitted fabrics includes protective features against hot thermal conditions and static electricity as well as, for selected types of fabrics, biological activity

Table 1: Test results of physical properties and physiological comfort of two-layer knitted fabrics (determined according to PN-EN IS).

No.	Fabric type and sample no. / Parameter	Two-layer RR knitted fabrics				Two-layer RL plated knitted fabrics	
		Sample 1.	Sample 2.	Sample 4.	Sample 7.	Sample 24.	Sample 26.
1.	Surface weight [g/m²]	297	300	225	355	298	250
2.	Dimension change after laundering, lengthwise [%]	-1,0	-2,0	-2,0	-1,5	-4,0	-3,5
	crosswise [%]	-1,2	-2,0	-1,0	-4,0	-5,5	-4,0
3.	Thermal resistance [m²K/W]	0,044	0,045	0,048	0,038	0,029	0,035
4.	Water vapor resistance [m²Pa/W]	-	-	-	4,32	4,05	4,01
5.	Water vapor permeability [g/m²/day][1] [g/m²Pa h][2]	1064[1]	808[1]	1094[1]	0,344[2]	0,367[2]	0,371[2]
6.	Air permeability[mm/s]	1292	1366	1428	807	505	808

Table 2: Test results of the barrier properties concerning flammability of two-layer knitted fabrics.

Sample number	Resistance to heat at a temperature of 180 °C			Resistance to heat radiation			Heat penetration index under the action of flame		
	Dimension change		Change in appearance	Index of heat radiation transfer RHTI 24	Index of heat radiation transfer RHTI 12	RHTI 24 - RHTI 12	Heat penetration index HTI 24	Heat penetration index HTI 12	HTI 24 – HTI 12
	lengthwise [%]	crosswise [%]							
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
1.	-1,6	-2,4	No	18,0	11,0	7,0	8,0	6,0	2,0
2.	-1,9	-1,9	No	16,5	10,4	6,1	8,0	5,0	3,0
4.	-0,8	-2,4	No	15,6	9,9	5,7	8,0	5,0	3,0
7.	-0,8	-0,8	No	16,5	10,2	6,3	9,0	6,0	3,0
24.	-0,3	-1,6	No	15,1	9,2	5,9	7,0	5,0	2,0
26.	-1,3	-2,7	Slightly darkened	15,3	9,3	6,0	6,0	4,0	2,0

Table 3: Test results of the parameters of static electricity.

Sample no.	Surface resistance R_s[Ω]		Volume resistance R_V[Ω]	Half-decay time t_{50} [s]	Screening coefficient S
	Fabric face	Fabric bottom			
1.	4,27 x 10^5	1,66 x 10^{12}	8,78 x 10^{10}	**< 0,01**	0,70
2.	1,75 x 10^5	1,90 x 10^{12}	8,48 x 10^{10}	**< 0,01**	0,70
4.	1,43 x 10^5	1,44 x 10^{12}	9,02 x 10^{10}	**< 0,01**	0,55
7	1,46 x 10^{12}	1,44 x 10^{12}	8,17 x 10^6	**< 0,01**	0,61
24.	1,78 x 10^{12}	1,66 x 10^{12}	1,04 x 10^7	**< 0,01**	0,580
26.	1,24 x 10^{12}	1,28 x 10^{12}	7,50 x 10^6	**2,7- 1,8**	0,091- 0,090
Requirements according to PN-EN 1149-5:2009	**$R_s \leq 2,5 \times 10^9$ at least on one surface**		**1,66 x 10^{12}**	**t_{50} < 4s**	**S > 0,2**

Table 4: Results of microbiologic test of two-layer knitted fabric (quantitative method).

Tested sample	Microorganisms used in tests according to: AATCC Test Method 100-2004and PN-EN ISO 20743	Parameters determined	
		Bacteriostatic activity S	Bactericidal activity L
Sample 2.	Staphylococcus aureus (ATCC 6538)	3,7	0,3
	Escherichia coli (ATCC 11229)	3,6	-1,7

concerning antibacterial effects. These fabrics are also characterized by good parameters of physiological comfort. The aim of the studies has been achieved by means of:

- The use of yarns with barrier flame-retardant and antistatic properties,
- Designing and making two-layer structures of knitted fabrics, with each layer consisting of different raw materials,
- The use of yarns, in the bottom layers, that beneficially influences the physiological comfort use,
- working out the parameters of the fabric finishing process paying special attention to maintain the barrier features resulting from the use of specified types of yarns,
- Working out the finishing process of the knitted fabrics with the use of appropriate biologically active agents for the raw materials used.

Acknowledgement

The research work were developed within the international project Eureka! BATAN 5799 “Barrier textiles and nanomaterials”, which were co-financed through the National Centre for Research and Development (NCBiR).

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This article was originally published in a special issue, **Proceedings of 47th IFKT 2014 Congress**