Investigation of knitted fabric dimensional characteristics

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Physical-mechanical properties of knitted fabrics affect the appearance, use and wear comfort of clothing. The mentioned properties become more important for the decision of purchase as the living standard rises. The aim of this paper is to investigate the influence of different knitting yarns (cotton, cotton/elastane) and finishing treatments on physical-mechanical properties of knitted fabrics. The investigation has been carried out on cotton yarns of the counts 12, 14 and 20 tex and on raw and finished single jersey fabrics knitted from 100% cotton yarns and 100% cotton yarns and elastane. The tensile, shear, bending, compression and surface properties of knitted fabrics have been measured using the KES-FB system.

Key words: *knitted fabrics, physical-mechanical properties, KES-FB measured system*

1. Introduction

Knitting is a complex process. The unwanted changes of knitted garment shape can be minimised and optimal physical-mechanical properties kept if the fabrics are carefully engineered [1]. Traditional methods of fabric mechanical properties testing have mostly been focused on tensile, bursting and investigations alike. The mentioned properties become more important for the decision of purchase as the standard of living rises.

The achievement of the synergy between fabric characteristics and garment comfort is one of the basic requirements [2]. **F.T. Peirce** [3] pointed out the importance of the investigation of fabric hand properties and mechanical properties for garment designing in the year 1930. The objective method of fabric hand evaluation was developed in 1972 by **S. Kawabata** and **M. Niwa** in collaboration with the experts from Japanese textile and apparel industry. The method has been in use in industry since 1975 [4]. The first standards of hand subjective evaluation were defined the same year, while the development and application started in 1980. There are a number of factors influencing the production of high quality fabrics and apparel. These factors are optimal selection of fibre, accurate engineering and production of yarn and fabric and optimisation of the finishing process, all shown in Fig.1 [5].

The impact of physical-mechanical properties of knitted fabrics on appearance and garment end-use is unquestionable. Therefore, the aim of the paper is to investigate the influence of different knitting yarns (cotton, cotton/elastane) and finishing treatments on physical-mechanical properties of knitted fabrics.

2. Samples and methods

2.1. Samples

Dimensional characteristics of ten single jersey knitted fabrics were investigated.

The fabrics were divided into the following three groups, according to the differences in raw material and yarn count:

- fabrics knitted from single cotton yarns of the count 20 tex,
- fabrics knitted from single cotton yarns of the count 14 tex and 5-7% elastane yarns of the counts 33 and 44 dtex,
- fabrics knitted from single cotton yarn of the count 12 tex and 8-11% elastane yarns of the counts 33 and 44 dtex.

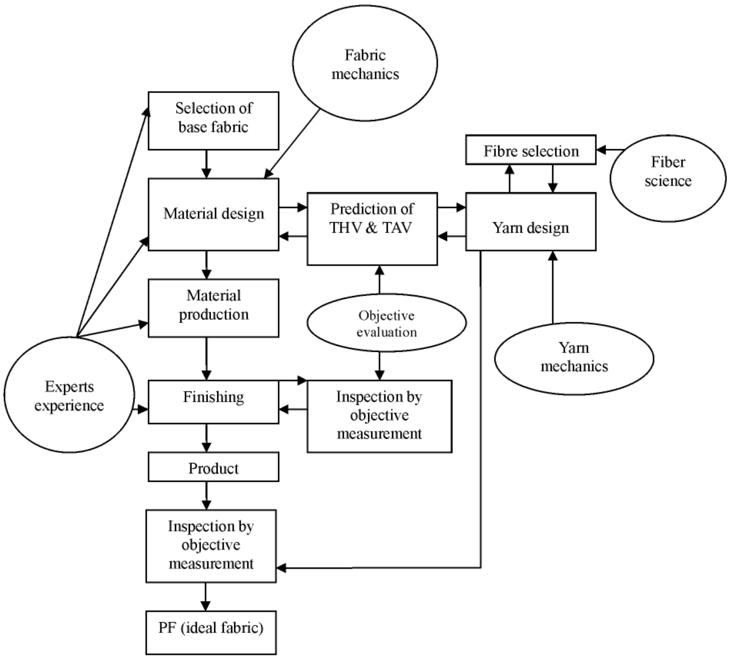


Fig.1 Factors that influence the production of high quality fabrics; modified from [5]

Tab.1 Fabric samples and their characteristics

Raw material and yarn count	Finishing	Fabric designation
100% cotton, 20 tex	raw	P1S
100% cotton, 20 tex	raw	P2S
100% cotton, 20 tex	raw	P3S
100% cotton, 14 tex, Lycra 44 dtex	raw	E1S
100% cotton, 14 tex, Lycra 44 dtex	raw	E2S
100% cotton, 14 tex, Lycra 33 dtex	raw	E3S
100% cotton, 12 tex, Lycra 33 dtex	raw	E4S
100% cotton, 12 tex, Creora 44 dtex	raw	E5S
100% cotton, 12 tex, Lycra 44 dtex	raw	E6S
100% cotton, 12 tex, Lycra 44 dtex	raw	E7S
100% cotton, 20 tex	finished	P1D
100% cotton, 20 tex	finished	P2D
100% cotton, 20 tex	finished	P3D
100% cotton, 14 tex, Lycra 44 dtex	finished	E1D
100% cotton, 14 tex, Lycra 44 dtex	finished	E2D
100% cotton, 14 tex, Lycra 33 dtex	finished	E3D
100% cotton, 12 tex, Lycra 33 dtex	finished	E4D
100% cotton, 12 tex, Creora 44 dtex	finished	E5D
100% cotton, 12 tex, Lycra 44 dtex	finished	E6D
100% cotton, 12 tex, Lycra 44 dtex	finished	E7D

The samples were knitted on a single needle circular machine Relanit, count E 28, produced by Mayer & Cie.

The fabrics were optically bleached at 98 °C (receipt: Persoftal L 2,0 g/l, Foamaster 340 0,2 g/l, Ruco-wet WS 1,5 g/l, Tannex geo 2,0 g/l, NaOH 4,0 ml/l, $H_2O_2$10,0 ml/l, Uvitex CF 200% 0,7 %, Plexene APR 1,0 g/l, citric acid 0,4 g/l), dyed with reactive dyes and softened (acetic acid 0,5 ml/l, TC-ecostabil 100 1,0 g/l, Perrustol WO 1132 3,0 %).

The raw material and the count of the yarn used for single fabric knitting with assigned fabric designation to be used onward are shown in Tab.1.

2.2. Investigation of the yarn

The following yarn properties were investigated: count, twist, evenness, breaking force and elongation. Yarn count was determined according to the standard HRN ISO 2060 [8]. Torsiometer Twist tester produced by Mesdan lab, Italy was used for the measurement of yarn twist. According to the standard HRN ISO/DIS 17202 [9], the capacitive method was used. The investigation of yarn evenness was carried out using the Japanese measuring device Keisokki evenness tester, model KET – 80. Dynamometer Statimat M produced by the German company of Textechno was used for the investigation of yarn breaking force and elongation. The investigation was carried out according to the standard HRN ISO 2062:2003 [10].

2.3. Investigation of the knitted fabrics

Knitted fabrics were conditioned and laid straight in the chamber under standard conditions prior to testing. The relaxation process was observed within 120 h. The fabric shrinkage in that period was up to 3%. The values of fabric structural parameters that refer to horizontal density Dh (cm^{-1}), vertical density

Tab.2 The results of the yarn count, twist and evenness investigation

Yarn property		Cotton yarn count (tex)		
		12	14	20
Count	Measured value, tex	12,2	13,9	19,6
	Standard deviation, tex	0,3	0,3	0,5
	Coefficient of variation, %	2,1	2,5	2,3
Twist	Measured value, m^{-1}	1007,5	969,3	1032,5
	Standard deviation, m^{-1}	23,2	7,4	21,6
	Coefficient of variation, %	2,3	2,6	2,1
Evenness	CV_{mass} , %	12,5	12,3	11,2
	Number of thin places/1000 m	0	0	0
	Number of thick places/1000 m	9	10	10
	Number of neps/1000 m	48	38	118

Dv (cm^{-1}), tightness factor C and mass per unit area m_p ($g\ m^{-2}$) were measured on relaxed fabrics. The knitted fabric properties - tensile, shear, bending, compression and surface (friction and roughness) were measured by the KES-FB system (Kawabata Evaluation System). Fabric tensile properties were evaluated by means of tensile energy WT that is determined as the area under the F/Í curve, tensile resilience RT, linearity of load LT that is the measure of the F/Í curve deflection in relation to the straight line and stretching EMT.

The following shear properties of knitted fabrics were determined: bending rigidity G and hysteresis of shearing moment 2HG and 2HG5 at 0.5° or 5° shear angle. The fabric bending properties were determined using the values of bending rigidity B and hysteresis of bending moment 2HB. The parameters of compressional energy WC, which stands for the energy generated during fabric compression and is a measure of fabric compressibility, compressional resilience RC, linearity of compression LC and minimal and maximal thickness TO and TM were determined in the course of testing fabric compressional properties. The values of friction coefficient MIU, mean deviation of the coefficient of friction MMD and geometrical roughness SMD, which stands for the divergence of existing bumps from the imagined straight line, were determined when testing fabric surface properties.

3. Results and discussion

The results of the cotton yarns investigation are shown in Tab.2 and 3.

The measured values of the knitted fabric structural parameters are shown in Tab.4.

The values of tensile, bending and shear properties are shown in Fig. 2-10, while the values of compressional and surface properties, both of raw and finished fabrics, are shown in Tab.5 and 6.

Tab.3 The results of the tensile properties investigation

Property	Cotton yarn count (tex)		
	12	14	20
Breaking force (cN)	217	280	281
Standard deviation of breaking force (cN)	19,3	19,5	20,4
Coefficient of variation (%)	8,8	6,9	7,3
Breaking elongation (%)	3,9	4,5	3,4
Standard deviation of break. elong. (m^{-1})	0,3	0,3	0,2
Coefficient of variation (%)	7,6	6,8	7,0
Work to rupture (cNcm)	236	333	279
Standard deviation of work to rupt. (cNcm)	34,9	41,9	36,1
Coefficient of variation (%)	14,8	12,6	12,9
Tenacity (cN/tex^{-1})	17,7	20,1	14,3

Tab.4 Knitted fabric structural parameters

Sample	Dh (cm^{-1})	Dv (cm^{-1})	C	m_p ($g\ m^{-2}$)
P1S	12,8	18,0	0,71	145
P2S	13,5	18,5	0,73	150
P3S	13,8	18,0	0,77	148
E1S	16,0	27,0	0,59	186
E2S	16,2	26,2	0,62	184
E3S	18,0	30,2	0,60	244
E4S	18,5	30,0	0,62	220
E5S	18,8	32,8	0,57	262
E6S	18,0	32,0	0,56	230
E7S	18,2	30,4	0,60	261
P1D	13,0	18,2	0,71	140
P2D	13,8	18,8	0,73	140
P3D	13,9	18,2	0,76	139
E1D	16,2	27,5	0,59	160
E2D	16,0	26,4	0,61	157
E3D	18,2	30,4	0,59	200
E4D	18,7	30,4	0,62	170
E5D	19,2	32,9	0,58	220
E6D	18,2	32,2	0,57	196
E7D	18,4	30,4	0,61	232

Tab.5 The compressional properties of knitted fabrics

Sample	WC ($cN\ cm/cm^{-2}$)	RC (%)	LC	TO (mm)	TM (mm)
P1S	0,399	39,89	0,323	0,979	0,485
P2S	0,422	33,64	0,368	1,105	0,646
P3S	0,345	37,09	0,344	0,939	0,538
E1S	0,569	38,79	0,347	1,320	0,711
E2S	0,568	34,01	0,340	1,587	0,877
E3S	0,558	40,51	0,389	2,087	1,501
E4S	0,646	32,61	0,352	1,483	0,700
E5S	0,612	38,40	0,220	1,870	0,924
E6S	0,585	34,39	0,309	1,450	0,676
E7S	0,667	39,78	0,351	1,617	0,842
P1D	0,389	42,07	0,386	2,236	1,834
P2D	0,369	40,49	0,390	2,190	1,813
P3D	0,305	50,59	0,381	2,508	2,188
E1D	0,294	37,19	0,373	2,138	1,822
E2D	0,363	36,60	0,367	2,267	1,870
E3D	0,356	44,25	0,369	2,979	1,597
E4D	0,254	36,08	0,353	2,138	1,851
E5D	0,371	38,92	0,377	2,327	1,932
E6D	0,348	33,80	0,406	2,225	1,881
E7D	0,277	41,47	0,301	2,256	1,882

WC - compressional energy, RC - compressional resilience; LC - linearity; TO - maximal thickness at 0.5 cN/cm^{-2}; TM - maximal thickness at 5 cN/cm^{-2}

Tab.6 Surface properties of knitted fabrics

Sample	MIU			MMD			SMD (μm)		
	N	R	x	N	R	x	N	R	x
P1S	0,177	0,253	0,215	0,0071	0,0125	0,0098	2,518	13,096	7,807
P2S	0,202	0,240	0,221	0,0109	0,0125	0,0117	3,369	12,174	7,771
P3S	0,201	0,248	0,224	0,0159	0,0139	0,0149	2,557	13,840	8,199
E1S	0,256	0,262	0,259	0,0090	0,0119	0,0105	6,863	5,186	6,025
E2S	0,260	0,309	0,285	0,0079	0,0119	0,0101	6,669	8,047	7,358
E3S	0,203	0,220	0,212	0,0059	0,0083	0,0071	3,084	3,618	3,351
E4S	0,227	0,219	0,223	0,0060	0,0207	0,0134	2,632	5,485	4,058
E5S	0,196	0,190	0,193	0,0099	0,0219	0,0159	2,419	5,277	3,848
E6S	0,200	0,212	0,206	0,0106	0,0180	0,0143	2,732	4,783	3,757
E7S	0,206	0,216	0,211	0,0092	0,0098	0,0095	2,760	2,565	2,662
P1D	0,206	0,239	0,222	0,0079	0,0106	0,0092	3,377	5,727	4,552
P2D	0,184	0,241	0,212	0,0144	0,0127	0,0135	3,083	4,411	3,747
P3D	0,185	0,228	0,206	0,0089	0,0081	0,0085	3,535	4,135	3,853
E1D	0,236	0,245	0,240	0,0196	0,0068	0,0132	7,230	2,911	5,070
E2D	0,221	0,225	0,223	0,0090	0,0050	0,0070	8,760	2,240	5,500
E3D	0,242	0,232	0,237	0,0065	0,0080	0,0073	2,655	3,588	3,122
E4D	0,217	0,224	0,221	0,0065	0,0097	0,0081	5,175	3,884	2,594
E5D	0,254	0,205	0,230	0,0079	0,0099	0,0089	4,746	8,087	6,412
E6D	0,224	0,218	0,221	0,0058	0,0093	0,0076	2,198	5,121	3,659
E7D	0,208	0,196	0,202	0,0056	0,0082	0,0069	2,122	4,128	3,125

N – direction of wales, R – direction of rows, MIU – coefficient of friction, x – mean value, MMD – mean deviation of MIU, SMD – geometrical roughness

Tab.7 Trends of the measured parameter's changes

Property	Parameter	Cotton fabrics				Cotton fabrics with elastane			
		wale*	row*	x*	trend**	wale*	row*	x*	trend**
Tensile properties	WT	3	3	3	↓	3 3	5 1	4 3	↓
		↓	↓	↓		↓ ↑	↓ ↑	↓ ↑	
	RT	2 1	1 1	2 1	↓	2 4	3 4	3 4	↑
		↓ ↑	↓ ↑	↓ ↑		↓ ↑	↓ ↑	↓ ↑	
	LT	3	2 1	2 1	↓	4 3	5 2	6 1	↓
		↓	↓ ↑	↓ ↑		↓ ↑	↓ ↑	↓ ↑	
Shear properties	G	3	3	3	↑	6 1	5 1	6 1	↓
		↑	↑	↑		↓ ↑	↓ ↑	↓ ↑	
	2HG	3	1 2	3	↑	6 1	4 3	6 1	↓
		↑	↓ ↑	↑		↓ ↑	↓ ↑	↓ ↑	
	2HG5	3	1 2	3	↑	5 2	4 3	4 2	↓
		↑	↓ ↑	↑		↓ ↑	↓ ↑	↓ ↑	
Bending properties	B	3	3	3	↓	6 1	7	7	↓
		↓	↓	↓		↓ ↑	↓	↓	
	2HB	3	2 1	2 1	↓	7	7	7	↓
		↑	↓ ↑	↓ ↑		↓	↓	↓	
Compressional properties	WC	-	-	3	↓	-	-	7	↓
		-	-	↓		-	-	↓	
	RC	-	-	3	↑	-	-	3 4	↑
		-	-	↑		-	-	↓ ↑	
	LC	-	-	3	↑	-	-	2 5	↑
		-	-	↑		-	-	↓ ↑	
	TO	-	-	3	↑	-	-	7	↑
		-	-	↑		-	-	↑	
	TM	-	-	3	↑	-	-	7	↑
		-	-	↑		-	-	↑	
Surface properties	MIU	2 1	2 1	2 1	↓	4 3	3 4	4 3	↓
		↓ ↑	↓ ↑	↓ ↑		↓ ↑	↓ ↑	↓ ↑	
	MMD	2 1	2 1	2 1	↓	5 2	6 1	5 2	↓
		↓ ↑	↓ ↑	↓ ↑		↓ ↑	↓ ↑	↓ ↑	
	SMD	1 2	3	3	↓	3 4	6 2	5 3	↓
		↓ ↑	↓	↓		↓ ↑	↓ ↑	↓ ↑	

The trends of the parameters changes after finishing are shown in Tab.7, in order to facilitate the monitoring of fabric properties. The number of cotton samples or samples with elastane on which refers the trend of the increase (↑) or decrease (↓) of the value after finishing, is defined for each parameter and direction of investigation (row or wale).

An average trend of increase/decrease of the value of single parameter is given for cotton knitted fabrics and fabrics with elastane (Tab. 7). The results of the yarn investigation indicate that there are no significant differences in the properties among the investigated yarns. All the fabrics were knitted on the same machine and under nearly same conditions. The knit was the same for all the samples (single jersey), but the horizontal and vertical density, as well as the mass per unit area, differed.

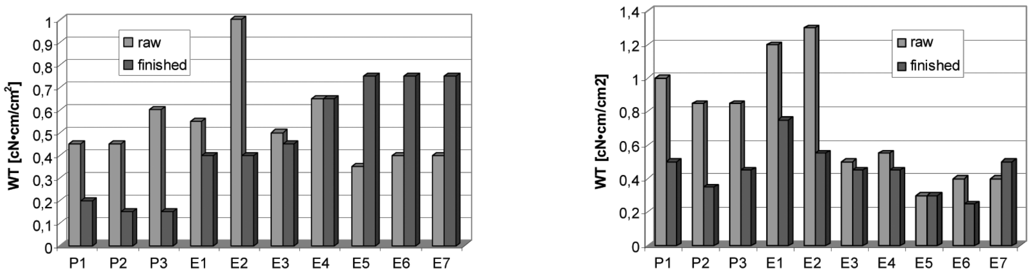
3.1. Knitted fabric tensile properties

The higher values of tensile energy of cotton fabrics (P1-P2) was noticed during the measurement in the direction of the courses, respectively the fabric width (Fig.2a, 2b). It has reconfirmed the fact known from the literature, according to which the single jersey fabrics are two times more stretchable in the direction of width than the length (i.e. the stretchability ratio of knitted fabrics $A_{max}/B_{max} = 2$).

The comparison of the results for cotton raw and finished fabrics measurement indicates that the work needed for the fabric reshape decreases up to 60% after finishing.

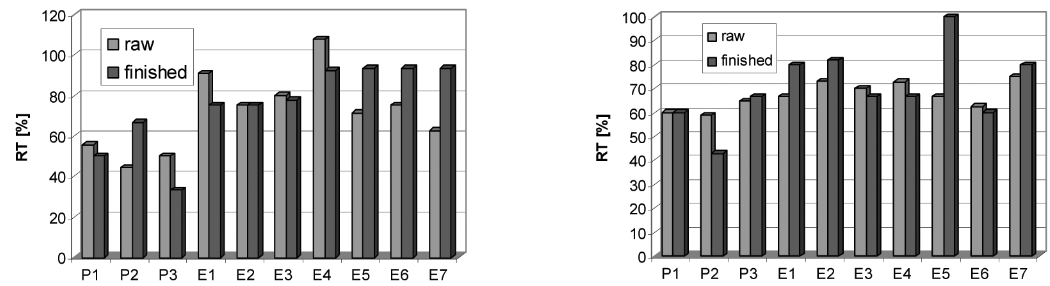
* number of knitted fabric samples for which a single parameter increases/decreases (↑/↓) and a trend of the sample group in the direction of wales/rows

** trend of the sample group in the direction of rows and wales for a single measured property



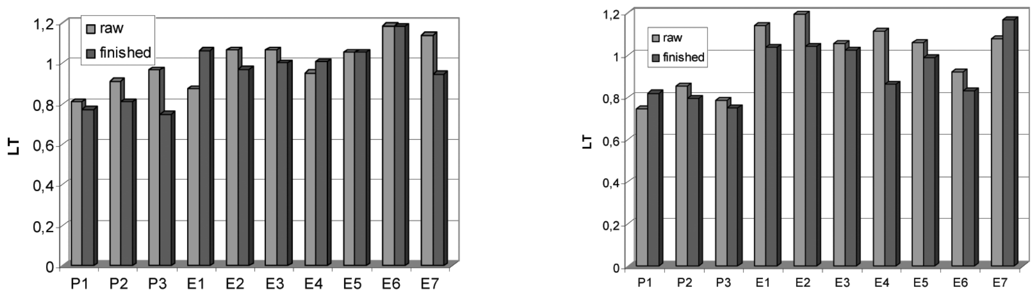
a) b)

Fig.2 Tensile energy of knitted fabrics in the direction of wales a) and raws b)



a) b)

Fig.3 Tensile resilience of knitted fabrics in the direction of wales a) and raws b)



a) b)

Fig.4 Linearity of knitted fabrics in the direction of wales a) and raws b)

The samples E1S and E2S sort out among the samples with elastane because of significantly higher values of tensile energy. Higher values are due to big difference between the structural parameters of the samples E1S and E2S, as compared to the samples E3S-E7S.

Namely, the two mentioned samples have significantly lower horizontal and vertical density.

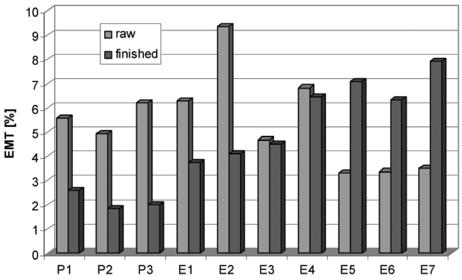
Raw cotton fabrics relax equally after the termination of the force and the ability of resilience changes from +6 to -13%. The influence of the yarn raw material on the ability of resilience is well seen if the results of the samples P1-P3 are compared to E1-E7 (Fig.3a, 3b).

The ability of resilience of the samples E1-E7 is in the range 68-90% and of the samples P1-P3 51-57%. The main reason for the increased ability of resilience of the samples E1-E7 in comparison to the samples P1-P3 is different raw material of the yarns used in knitting, where the elastane yarn increases the ability of resilience in the knitted fabric structure. It is known from the literature related to the investigation on the KES-FB system that the higher values of linearity LT are characteristic for resilient knitted fabrics. The fact was confirmed during this investigation, too (Fig.4a, 4b).

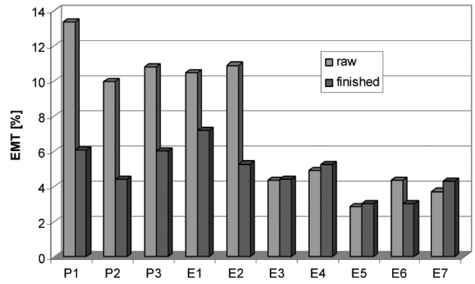
3.2. Knitted fabric shear properties

The stretching of cotton knitted fabrics after shear (EMT) is significantly lower for the finished fabrics (Fig.5a, b5).

The average values of shear rigidity (G) of raw cotton knitted fabrics are unified (Fig.6a, 6b) and rise after finishing. The average values of shear rigidity of raw cotton knitted fabrics are rather low in comparison to the values of the fabrics with elastane (bending rigidity of cotton knitted fabrics is in the range 0.50-0.61 cN/cm and of the fabrics with elastane 0.78-1.78 cN/cm). The values of fabric structural parameters indicate that knitted fabrics with elastane (E1S-E7S) have higher hori-

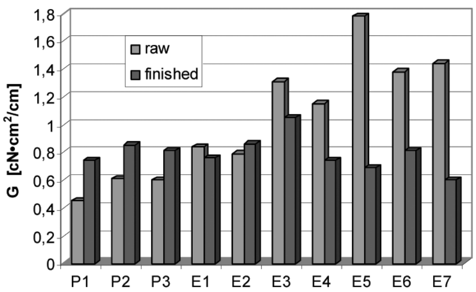


a)

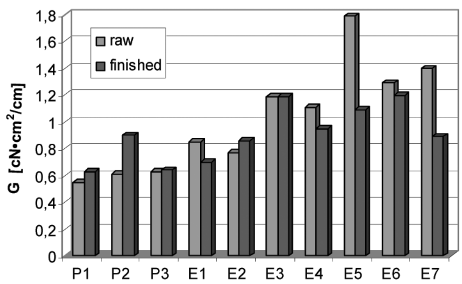


b)

Fig.5 Stretching of knitted fabrics in the direction of wales a) and raws b)

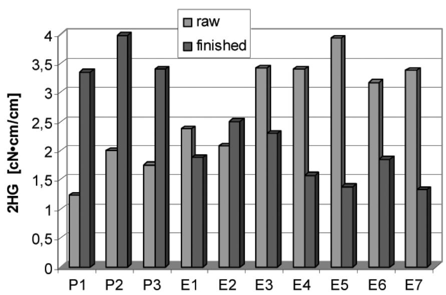


a)

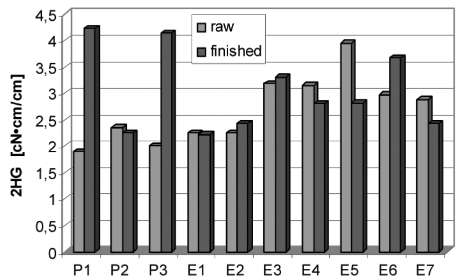


b)

Fig.6 Shear rigidity of knitted fabrics in the direction of wales a) and raws b)

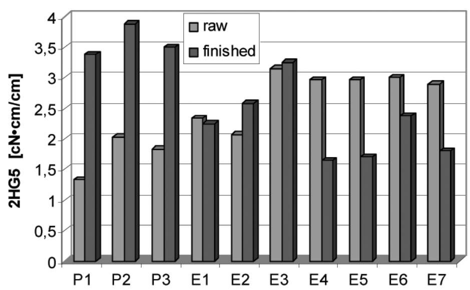


a)

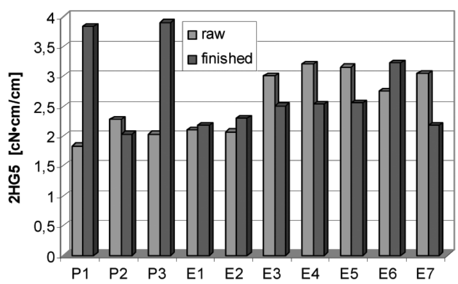


b)

Fig.7 Hysteresis ± 0.5° in the direction of wales a) and raws b)



a)



b)

Fig.8 Hysteresis ± 5° in the direction of wales (a) and raws (b)

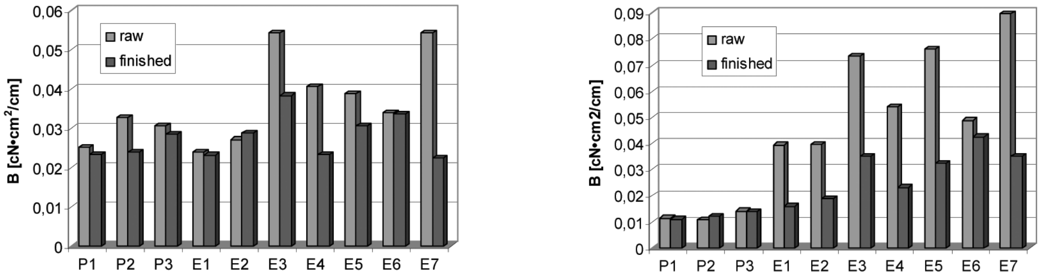


Fig.9 Bending rigidity of knitted fabrics in the direction of wales a) and raws b)

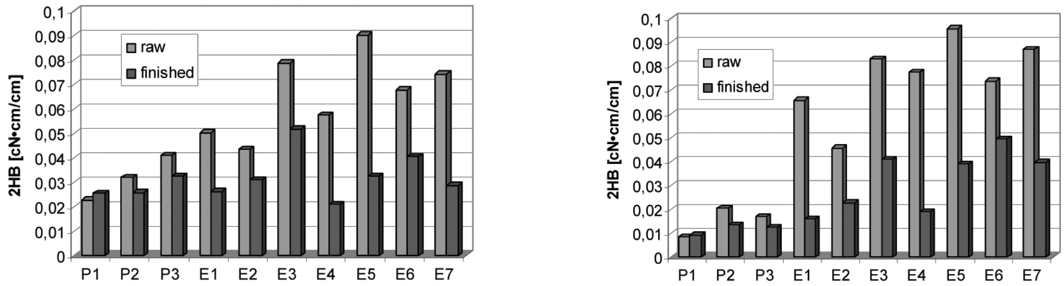


Fig.10 Hysteresis of bending moment of knitted fabrics in the direction of wales a) and raws b)

zontal and vertical density, which is the reason for higher values of shear rigidity, characteristic for tight structures. The average rigidity of the fabrics with elastane mostly decreases after finishing. The hysteresis of shear force (2HG and 2HG5) represents the energy that the knitted fabric looses during shear deformation and is significant for the assessment of garment appearance. The changes of the hysteresis values, according to the trend, are analogue to the changes in shear rigidity (Fig.7a, 7b, 8a, 8b).

3.3. Knitted fabric bending properties

The results of bending rigidity (B), (Fig.9a, 9b) indicate significantly lower values for the fabrics knitted from cotton yarns (P1, P2 and P3), especially if investigated in the direction of the rows. It can be seen that cotton fabrics with elastane have higher resistance to bending, which can be explained by higher structure tightness and the presence of elastane yarns in the knitted fabric. The bending rigidity of cotton fabrics with and without elastane decreases after finishing. The bending hysteresis, as a measure of the energy that knitted fabric looses during bending deformation, is connected to fabric rigidity. If the values of bending rigidity and bending hysteresis are compared, it can be seen that the values of bending hysteresis increase with the increase of bending rigidity (Fig.10a, 10b).

3.4. Knitted fabric compressional properties

The values of compressional energy of raw cotton fabrics are significantly lower than the values of raw cotton fabrics with elastane (Tab. 5). The reasons are tighter structure of the cotton fabrics with elastane and higher values of minimal and maximal fabric thickness. It can be seen that the compressional energy for all the fabrics decreases after finishing. The values of resilience after finishing are higher for all the cotton fabrics (34-40% or 40-51%) and for most of the knitted fabrics with elastane (33-41% or 34-44%).

3.5. Knitted fabric surface properties

Friction coefficients of cotton fabrics with elastane are higher than the coefficients of cotton fabrics (Tab.6). Geometrical roughness (SMD) is the highest for raw cotton fabrics - from 7.807 to 8.199 μm. The roughness is higher for the fabrics with uneven surface and lower density. Among the investigated knitted fabrics, cotton fabrics have the lowest density. Besides, cotton fabrics are knitted from the yarn of the count 20 tex that has the highest number of neps, which increases geometrical roughness. The geometrical roughness of cotton fabrics decreases after finishing. It can be perceived that the average roughness of all cotton fabrics is significantly higher in the direction of the rows than wales. The values of geometrical roughness are for most of the cotton fabrics with elastane higher if the fabrics are investigated in the direction of the rows.

4. Conclusion

According to the investigation of the samples described, obtained results and discussion, it can be concluded that significant characteristics that influence the physical-mechanical properties of the fabrics are yarn count and raw material content, meaning the presence of elastane yarns in knitted fabrics. The presence of elastane component in single jersey fabrics knitted from cotton affects the changes of the following properties of knitted fabrics: increases the tensile resilience after the termination of the force, shear rigidity, bending rigidity and compressional energy during compression. Among the investigated yarn characteristics, yarn evenness significantly affects geometrical roughness so that the yarns of higher evenness increase geometrical roughness. Finishing process applied, including optical bleaching, softening and dyeing, lowers tensile energy during stretching, bending rigidity, compressional energy and average values of geometrical roughness, while it significantly increases fabric thickness and compressional resilience.

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