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The Effect of Finishing upon Textile Mechanical Properties at Low Loading

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The paper deals with the experimental investigation of flax fabrics' mechanical and surface properties at low loads, as well as their formability and the influence of different finishing treatments upon these properties. The KES-FB (Kawabata Evaluation System for Fabrics) is used for the measurements of low stress tensile, shear, bending, compression and surface properties. Fabric formability as it's sustainability of in-plain compression before buckling in principle directions is investigated before and after finishing. Nine most important parameters are extracted from the standard measured parameters and presented in circular charts for the comparison of overall changes induced into fabrics after different finishing treatments. The obtained results revealed that any kind of softening treatment makes the greatest influence on shear and bending properties of fabrics, while dyeing of fabric makes negligible changes upon fabric behavior.

Keywords: low stress mechanical properties, KES-FB, finishing.

INTRODUCTION

The tailoring quality of fabrics, the design of garments as well as automated handling are greatly influenced by the fabric physical and low stress mechanical properties such as bending, tensile, shear, compression and surface properties. Objective measurement of these characteristics leads to making rational decisions in choice of fabrics in order to minimize the tailoring problems and improve the quality of finished garment [1 – 3].

As living standards have raised and the consumer market increasingly become sophisticated, the investigations of overall performance of garments related to its service and wearing properties became more popular than traditional strength oriented mechanical tests [4, 5]. The KES-FB (Kawabata Evaluation System for Fabrics) [6] system that was primarily developed for an objective evaluation of fabric handle was widely accepted as a system for the investigation of low stress mechanical and surface properties [7].

During tailoring a plain textile fabric is shaped into a spatial stable garment. Textile formability is defined as its ability to cover surfaces of various curvatures that no wrinkles or folds are formed. Formability is usually defined as a product of bending rigidity and longitudinal compressibility (compressional strain per unit applied load) sustained by fabric before it buckles and it is crucial factor in obtaining a smooth fabric surface during seaming and shaping. Compressibility could be changed into initial fabric extensibility that was proved by Lindberg [8] to be of the same magnitude as compression load.

When a three dimensional surface must be covered by textile fabric the out-of-plain and in-plain deformations occur. The in-plain deformation requires the distortion of the surface elements and one of the dominating deformations is shear deformation, when rotation of warp and weft threads occurs and the angles between threads change [8 – 11].

In textiles raw material, yarn structure, planar structure and finishing affect the fabric hand and its overall performance. During finishing, internal stresses stored during spinning, warping and weaving are removed and fabrics attain an almost fully relaxed state. The amount of changes (e. g. in thickness, density, cover factor and mechanical parameters) that occur in fabric during finishing makes the subject complicated. By using various finishing treatments different kinds of end products in a sense of aesthetic and utility properties can be produced from the same unfinished textile fabric [12 – 14].

The present paper is concerned with the experimental investigation of the influence of different finishing upon low stress mechanical properties such as tensile, shear, bending, compression and surface properties measured by KES-FB system as well as formability of textile fabrics.

MATERIALS AND TEST METHODS

Six fabrics were chosen for the investigation: three plain weave flax fabrics of the same yarns, very similar in warp, weft and area densities with different finishing applied on them, one thick plain weave flax fabric, one flax fabric of weft rib weave type and one basket weave cotton fabric. Different finishing was applied on the selected fabrics: washing, dyeing, chemical and mechanical softening or their combinations. The specifications of investigated materials are presented in Table 1.

Various fabric properties especially drape and hand can be altered by finishing, thus the KES-FB system [6] consisting of traditional four test instruments for conducting surface, bending, compression, tensile and shear tests was used for the investigation of the fabrics before and after finishing. The investigated parameters, properties and apparatus are presented in Table 2.

Specimen preparation, pre-conditioning, and testing involved standard atmospheric conditions of 20 °C ±2 °C

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Table 1. The characteristics of investigated materials

Fabric	Finishing*	Fiber composition	Weave	Area density, g/m^2	Linear density, tex		Density, cm^{-1}		Thickness, mm
					Warp	Weft	Warp	Weft	
IM_1	–	100% LI	plain	151.8	38.5	38.5	20.0	18.0	0.53
	D + Ch			158.7			20.8	18.0	0.41
IM_2	–	100% LI	plain	169.5	38.5	38.5	22.0	18.0	0.56
	M			161.3			23.6	17.2	0.48
IM_3	–	100% LI	plain	169.9	38.5	38.5	21.6	19.0	0.54
	D + M			170.2			22.0	19.6	0.49
IM_4	–	100% LI	plain	354.8	105	416.7	6.2	5.4	1.30
	D + M			433.6			7.2	5.4	1.31
IM_5	–	100% LI	weft rib	207.9	105	105	8.4	9.4	0.90
	Ch + M			216.6			9.6	9.6	0.93
IM_6	–	100% CO	basket	379.9	64*2	64*2	8.2	5.4	1.33
	D + W			368.8			8.4	5.4	1.12

Note: * D – dyeing; W – washing; M – mechanical softening; Ch – chemical softening.

Table 2. The parameters investigated with KES-FB system

Properties	Parameters	Description	Units	Apparatus
Tensile	*LT*	linearity of tensile curve	–	KES-FB1
	WT	tensile energy	gf·cm/cm^2 (N·m/m^2)	
	RT	tensile resilience	%	
Shear	*G*	shear modulus	gf/cm·° (N/m·°)	
	2HG	shear hysteresis at 0,5°	gf/cm (N/m)	
	2HG5	shear hysteresis at 5°	gf/cm (N/m)	
Bending	*B*	bending rigidity	gf·cm^2/cm (N·m^2/m)	KES-FB2
	2HB	hysteresis of bending moment	gf·cm/cm (N·m/m)	
Compression	*LC*	linearity of compression curve	–	KES-FB3
	WC	compressional energy	gf·cm/cm^2 (N·m/m^2)	
	RC	compressional resilience	%	
	T_0	thickness at pressure 0.5 gf/cm^2	mm	
	T_m	thickness at pressure 50 gf/cm^2	mm	
Surface	*MIU*	coefficient of friction	–	KES-FB4
	MMD	mean deviation of MIU	–	
	SMD	geometrical roughness	mm	

temperature and 65 % ±2 % relative humidity. Standard size samples of 200 mm × 200 mm were tested in warp and weft directions. Four replicate measurements were made for each property.

Mechanical properties were measured according to standard KES-FB specifications except for shear test. For the investigation of shear properties maximum shear angle was set to 5 degrees, because investigated fabrics were prone to buckle before 8 degrees angle (typical for KES-FB) was reached.

A non-standard parameter – formability – was also calculated from KES-FB test results. Fabric formability in principle warp and weft directions in mm^2 is calculated as a product of initial extensibility and bending rigidity [2]:

$$F = E \cdot B,$$

where: B – bending rigidity in N·m^2/m; E – extensibility, calculated as ratio of tensile deformation divided by tensile stress:

$$E = \frac{\varepsilon_{20}}{100} \cdot \frac{1}{20},$$

here, ε_{20} – fabric extension at 20 N/m.

Pan and Zeronian [4] were combining principal component analysis with D-Optimal method and have proved that 16 parameters measured by KES-FB system give data overlap. They have extracted nine parameters that give sufficient characterization of fabric. As proposed by Pan and Zeronian [4] for overall fabric performance evaluation circular charts are used that consist of circle and nine radii evenly distributed over the whole circumference each representing one parameter. The scales of the axis are kept unchanged for all investigated fabrics. Overall influence of finishing is represented by the changes of area defining fabric in a circular chart.

RESULTS AND DISCUSSION

Tensile behavior

Linearity of tensile curve *LT*, tensile energy *WT* and tensile resilience *RT* values were obtained from the tensile experiment increasing tensile load up to 490 N/m and are presented in Table 3. In Fig. 1 an example of tensile curves of gray and finished fabrics is presented.

The load-extension curves of textile materials are never linear and this effect appears due to the weave

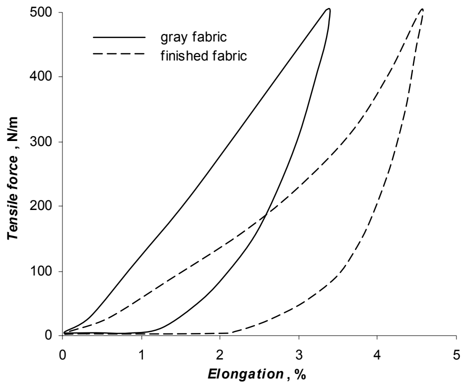


Fig. 1. Tensile curves of fabric IM_1 in warp direction before and after finishing

Table 3. Parameters obtained by tensile test of gray and finished fabrics

Fabric	Treat-ment*	*LT*		*WT*, N·m/m^2		*RT*, %	
		Warp	Weft	Warp	Weft	Warp	Weft
IM_1	–	0.91	1.08	8.30	1.45	36.49	57.72
	D + Ch	0.71	0.88	8.75	11.50	35.72	30.44
IM_2	–	0.97	0.94	8.50	3.23	56.02	50.86
	M	0.65	0.74	8.60	7.25	40.48	32.05
IM_3	–	1.05	0.95	6.08	1.25	51.87	67.82
	D + M	0.68	0.81	10.58	8.48	38.34	35.99
IM_4	–	0.99	1.32	4.78	2.58	55.75	31.30
	D + M	0.72	0.55	9.88	18.25	36.95	26.77
IM_5	–	0.99	1.32	2.20	12.95	38.91	43.00
	Ch + M	0.72	0.55	6.68	21.23	39.74	34.50
IM_6	–	0.69	0.78	14.75	6.58	46.62	41.83
	D + W	0.73	0.77	8.33	8.73	38.75	33.43

Note: * Treatment characters are described under the Table 1.

structure and non-linear nature of constituent material [10]. The higher is the linearity the lower is tensile strain and the lower is the tensile energy. In all cases, investigated fabrics with softening treatment show reduced linearity *LT* by 18 % – 58 % after treatment in both warp and weft directions, this is associated with reduction in fabric stiffness. The linearity of fabric IM_6 increased negligibly after treatment due to slight increase in stiffness induced by dyeing and washing.

Tensile energy *WT* or the work done by the extension up to maximum force (490 N/m) has increased after softening treatment for all fabrics in warp and weft directions, this means that fabrics became more stretchable and more energy is needed to reach the same tensile load. After dyeing and washing treatment fabric IM_6 exhibit decrease of *WT* by 43 % in warp direction, because fabric became stiffer and less stretchable.

As cloth deformation is non elastic, it exhibits a considerable amount of visco-elasticity and hysteresis. Finishing quite markedly influences resilience behavior of fabrics. Decreasing tendency of the tensile resilience *RT* (2 % – 47 %) is observed for most of the investigated fabrics after finishing treatment except for the fabric IM_5 in warp direction, where negligible increase of 2 % is observed. The highest reduction in resilience – 37 % – 47 % exhibit thinner fabrics IM_1, IM_2 and IM_3 in weft direction.

Shear behavior

Shear rigidity *G* and shear hysteresis values at 0.5° *2HG* and at 5° *2HG5* were obtained from shear experiment. In Fig. 2 an example of shear curves of gray and finished fabrics is presented.

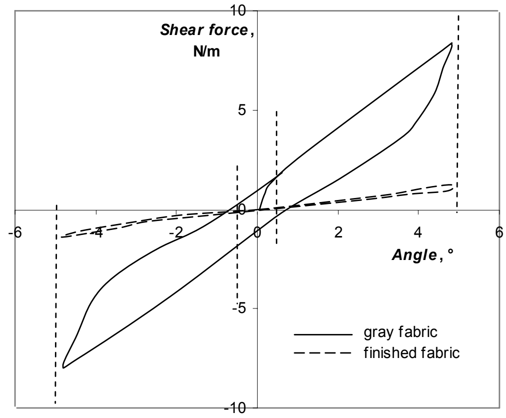


Fig. 2. Shear curves of fabric IM_5 in weft direction before and after finishing

The biggest influence of finishing is obtained on share properties, an average reduction of 81 % – 94 % in shear rigidity *G* of the fabrics with softener treatment is observed, while dyeing almost doubly increases shear modulus (Fig. 3). The same tendency is observed in both warp and weft directions for shear rigidity *G* as well as for shear hysteresis *2HG* and *2HG5*.

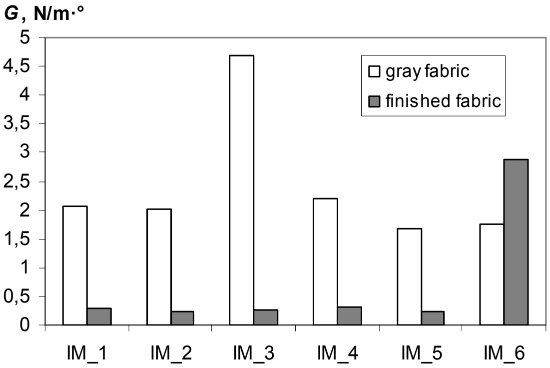


Fig. 3. Shear rigidity *G* changes after finishing in warp direction

The great effect of softening is directly related to the level of inter-yarn pressure and frictional resistance to shear deformation. Finishing results in relaxation of stresses (that were induced into yarns during weaving) leading into reduced inter-fiber and inter-yarn pressure within finished fabric what reduces frictional shear stress. Strain level in warp and weft threads is lowered as well offering comparatively lower resistance to bending during shear deformation. This ease in bending results in comparatively free relative rotation of yarns during shearing, thus reducing shear rigidity *G* [11]. The reduction above 90 % in shear hysteresis *2HG* and 85 % – 93 % in *2HG5* shows that softener finishing substantially reduces inter-fiber and inter-yarn friction, while dyeing treatment of IM_6 increased its shear modulus *G* approximately by

50 % and shear hysteresis *2HG* and *2HG5* close to two times.

Bending

Bending rigidity *B* as well as bending hysteresis *2HB* parameters were obtained by KES-FB2 bending tester, their values are presented in Table 4.

Table 4. Parameters obtained by bending test of gray and finished fabrics

Fabric	Finishing**	*B*, $N \cdot m^2/m \cdot 10^{-4}$		*2HB*, $N \cdot m/m \cdot 10^{-4}$	
		Warp	Weft	Warp	Weft
IM_1	–	0.31	1.05	0.41	1.00
	D + Ch	0.41	0.32	0.28	0.25
IM_2	–	0.94	0.86	1.00	1.00
	M	0.20	0.12	0.13	0.28
IM_3	–	0.57	2.78*	0.28	0.99
	D + M	0.22	0.17	0.11	0.10
IM_4	–	4.13*	5.24*	0.99	0.96
	D + M	0.49	0.51	0.26	0.21
IM_5	–	4.07*	0.43	1.00	0.54
	Ch + M	0.36	0.20	0.29	0.12
IM_6	–	0.48	0.50	0.54	0.52
	D + W	0.77	0.52	1.00	0.55

Note: *Values are calculated manually, because bending curve steepness doesn't reach curvature of 0.5 cm^{-1} and were not recorded by apparatus.
** Finishing characters are described under the Table 1.

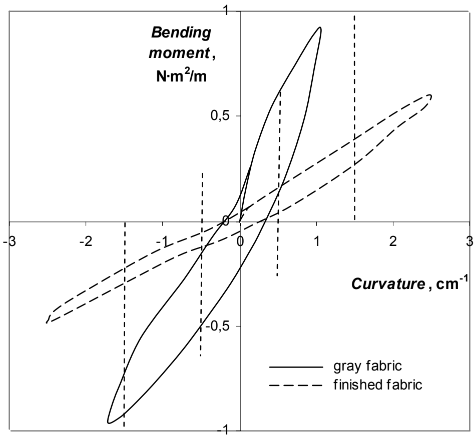


Fig. 4. Bending curves of fabric IM_3 in weft direction before and after finishing

Substantial reduction of bending rigidity *B* by 55 % – 93 % was observed after softening for flax fabrics (Fig. 4).

It could be explained by removal of sizes what reduces inter-fiber and inter-yarn friction and relaxation of stresses induced during weaving. Approximately 60 % – 90 % reduction in bending hysteresis is observed after softening, what shows the increased yarn mobility within structure.

Dyeing and washing increased bending rigidity *B* of fabric IM_6 by 58 % in warp and 5 % in weft direction, as well as bending hysteresis *2HB* by 80 % in warp and 7 % in weft direction.

Compression

Compression rate *EMC*, linearity of compression curve *LC*, compressional energy *WC* and compressional resilience *RC* were obtained from compression experiment for gray and finished fabrics; typical compression curve is presented in Fig. 5.

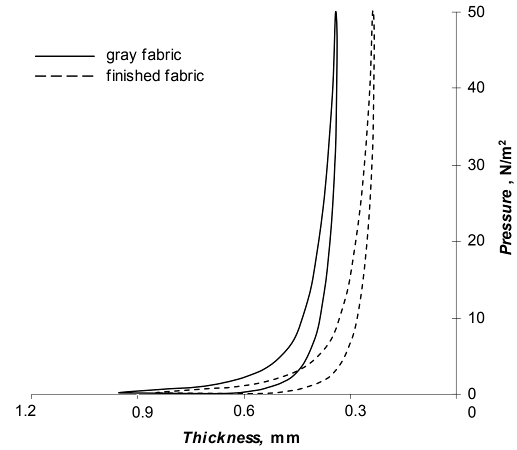


Fig. 5. Compression curves of fabric IM_3 before and after finishing

Compressibility is influenced by a yarn structure that is influenced by finishing. For gray fabrics compression rate *EMC* varies from 23 % to 39 % and for finished fabrics compression rate has increased by 18 % – 73 % except the case of fabric IM_1, where 9 % reduction in compressibility after treatment is observed.

Due to relaxation induced by finishing to fabrics in most cases the linearity of compression *LC* has decreased by 10 % – 22 %, but in fabrics IM_4 and IM_1 linearity increased 30 % and 10 % respectively. The values of compressional energy *WC* for five fabrics is approximately (0.2 – 0.3) $N \cdot m/m^2$ except for fabric IM_4 its *WC* value after finishing increases by 85 % and reaches 0.65 $N \cdot m/m^2$, this effect is obtained due to fabric contraction in weft direction, when the crimp of weft threads has markedly increased.

Finishing had little effect on compressional resilience *RC* of investigated fabrics.

Surface

Coefficient of friction *MIU*, mean deviation *MMD* and surface roughness *SMD* before and after finishing were obtained in surface investigation experiment. Comparing the surface roughness properties in warp and weft direction it is observed that *SMD* values in warp direction tends to be higher than in weft direction and opposite situation is found in a case of friction coefficient where warp values are smaller than in weft direction. This is explained by the higher resistance of work-hardened warp yarns to KES-FB compression load than the non hardened weft yarns. The case of *MIU* is explained by the plastic strain of warp yarns increasing orientation of fibers in a yarn thus it reduces the denting and crushing effect when friction occurs [15].

After softening treatment the coefficient of friction between fabric surface and the slip probe *MIU* is defined as the ratio of the sliding force to the compressional load and it increased in all cases around 6 % – 45 % in warp direction and 7 % – 25 % in weft direction (Fig. 6).

For the fabric that was just dyed the coefficient of friction remained the same in warp direction and decreased by 16 % in weft direction.

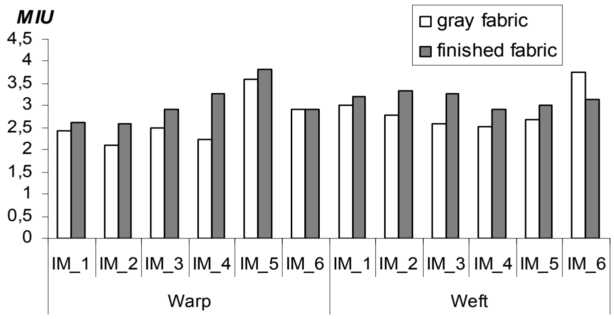


Fig. 6. Friction coefficient *MIU* before and after finishing

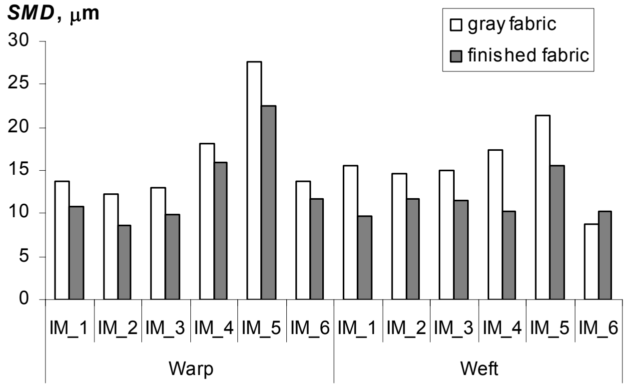


Fig. 7. Surface geometrical roughness *SMD* before and after finishing

The surface roughness that depends on yarn spacing irregularity, fabric design and other fabric geometrical factors *SMD* after softening has decreased about 12 % – 29 % in warp direction and 21 % – 38 % in weft direction because the yarns became softer, fewer spaces were left between them, this way the smoother surface of fabric has more contact with probe tip and this gives the rise in friction coefficient *MIU*. Surface roughness changes after treatment are presented in Fig. 7.

In general light weight fabrics having similar structure i. e. IM_1, IM_2 and IM_3 showed very similar surface properties independently of kind of finishing treatment applied on them. The highest surface irregularities are represented by fabric IM_5 due to unsymmetrical weft rib weave pattern.

Formability

As stated earlier fabric formability is dependent on its bending rigidity and extensibility (extension in fraction divided by applied load per unit width), thus substantial effects of finishing treatment upon these properties causes tangible changes in fabric formability (Fig. 8).

The moderate correlation ($r = 0.48$) between fabric formability in warp and weft directions is not unexpected, because fabric bending rigidity is strongly influenced by yarn linear density and extensibility is influenced by the weave crimp. Good correlation ($r = 0.89$) was obtained between formability and mass per unit area as it directly influences bending rigidity parameter. Light weight fabrics IM_1, IM_2, IM_3, IM_5 exhibit lower formability values than heavier ones IM_4 and IM_6.

The biggest changes in formability after dyeing and mechanical softening are observed in fabric IM_4 in weft direction, formability in this case increased 2.4 times.

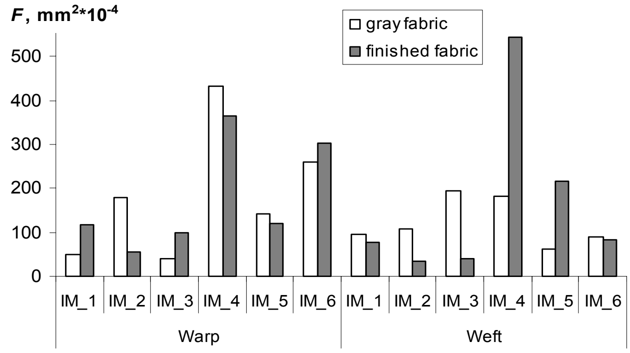


Fig. 8. Fabric formability before and after finishing

The smallest changes in formability are obtained with a dyed fabric IM_6, when no softening treatment was used and finishing treatment just slightly changed its bending and tensile properties.

Overall performance of fabrics

For overall performance of fabrics circular charts proposed by Pan at al. [4] were drawn for fabrics in warp and weft directions (Fig. 9).

The relative changes in area of polygon, obtained in circular chart by connecting values of parameters on the axis, after finishing are presented in Table 5.

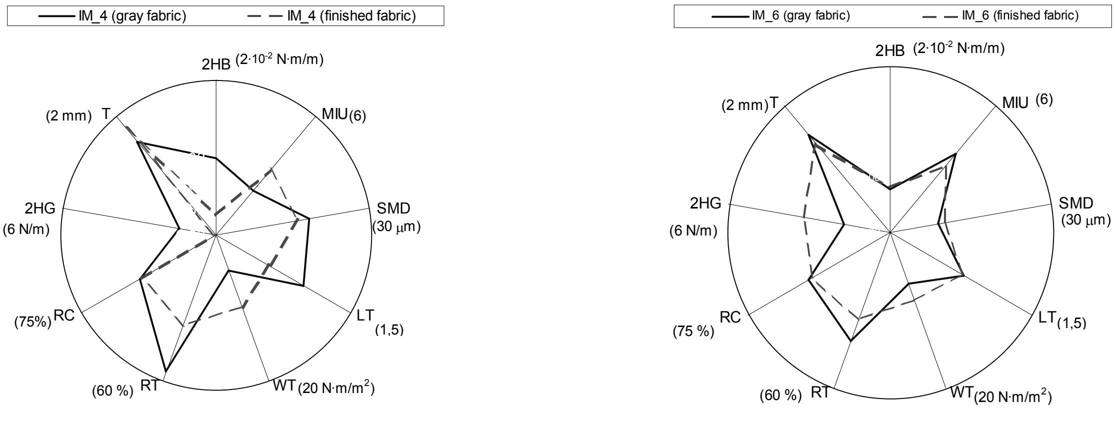
Table 5. Circular chart area (representing fabric) changes after finishing

Fabric	Area changes after finishing, %	
	Warp	Weft
IM_1	23.14 ↓	21.18 ↓
IM_2	43.81 ↓	44.84 ↓
IM_3	43.08 ↓	43.83 ↓
IM_4	36.44 ↓	34.95 ↓
IM_5	25.23 ↓	23.99 ↓
IM_6	1.22 ↓	1.16 ↓

In all cases the reduction in relative area of circular diagram is obtained. It is negligibly small in a case of a fabric IM_6 without softening treatment and varies between 21 % and 45 % for softened fabrics. Calculating relative area i.e. fabric area/ area of a circle, smaller values represent more limp fabrics with a pleasant hand and higher values represent thicker, stiffer, more harsh fabrics. It could be noticed that the percentage area changes in warp and weft directions show very similar values, so it would be enough of area calculations in one direction or to calculate an average value.

CONCLUSIONS

After investigating low stress mechanical properties it is worth noticing that dyeing of fabrics doesn't vitally change low stress mechanical parameters, while any kind of softening treatment i. e. mechanical, chemical or combination of both make substantial effect on fabric behaviour.



a b

Fig. 9. Circular charts before and after finishing for fabrics: a – IM_4 warp direction; b – IM_6 weft direction

The biggest changes due to softening treatment are observed on shear and bending parameters, shear parameters decreased approximately 85 % – 94 %, bending parameters – 55 % – 93 %. Tensile parameters show that any kind of softening treatment makes fabrics more stretchable and more energy is needed to reach the same tensile load. Reduction of 2 % – 47 % is observed in tensile resilience after finishing.

Surface roughness after finishing decreased in all cases due to compaction of yarns and flatter surface gave rise to friction coefficient due to increased contact surface between fabric and a probe.

In most of the cases gray fabrics show higher formability. Dyeing of fabric has a little influence on its formability, while softening treatment by inducing tangible changes in fabric stiffness markedly changes its formability.

Overall performance of fabrics was evaluated using circular diagrams. Softening treatment reduces the fabric representing polygon area markedly (21 % ÷ 45 %). In a circular diagram limp fabrics cover smaller area while thicker, stiffer, more harsh fabrics are represented by bigger area of polygon.

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