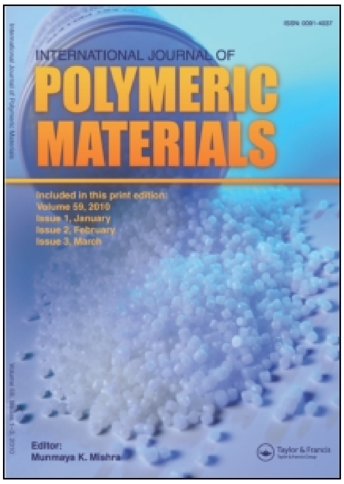

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Optimization of the Cotton/Lycra Plain Knitted Fabric Parameters

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The investigation objective was to reduce the area density of a cotton/Lycra plain knitted fabric according to the product specification. The knitting and after-treatment process parameters were optimized. Simultaneously, knitted fabric parameters were monitored and knitted fabric performance properties like shrinking and laundering and elastic properties: breaking extension, maximum extension at cyclic loading upto defined load/extension and residual extension were assessed.

Keywords: Knitting; knitted fabrics; elastic properties; cyclic loading; maximum extension

1. INTRODUCTION AND INVESTIGATION OBJECTIVE

Knitting is a complex dynamic process. To produce a quality product, an accurate production planning and a continuous control of knitting parameters, which influence the final performance properties of the knitted fabric are required [1]. The changing situation on the textile market often presses knitting producers to substitute yarn suppliers. Consequently, changes of the basic yarn parameters *e.g.*, yarn linear density, thickness, coefficient of friction, breaking tenacity and elastic properties essentially influence the production of a certain knitted product.

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Area density is a basic parameter defining knitted fabric offer. Its specification is inseparably attached to the purcheser's order. Knitted fabric area density is determined by both yarn and knitted fabric parameters on one hand and knitting and after-treatment process parameters on the other. When the yarn linear density is changed, an adequate change of the knitted fabric area density can be expected. To keep the area density in accordance with the order specification, knitting process parameters have to be adjusted. Yet, noticeable changes of the performance properties like dimensional stability, extensibility, elasticity, curling or tearing up can occur.

The investigation objective was to optimize the area density of a cotton/Lycra plain knitted fabric and simultaneously examine the possible change of its performance properties.

2. THEORETICAL

2.1. Plain Knitted Structure Parameters

Basic parameters of a knitted fabric are: stitch width A, stitch height B, stitch length l and yarn thickness d (Fig. 1). The stitch width A is inversely proportioned to the horizontal density of the knitted fabric D_h and similarly, the stitch height B is inversely proportioned to the vertical density of the knitted fabric D_v.

The ideal single jersey stitch length can be calculated as follows [2]:

$$\ell = 1.57A + 2B + \pi d \tag{1}$$

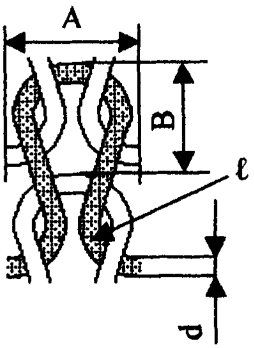

FIGURE 1 Knitted stitch parameters.

where l is stitch length [mm], A is stitch width [mm], B is stitch height [mm] and d is yarn thickness.

The stitch length is influenced by the yarn input tension, knitted fabric take-down tension, knitting velocity, friction in the knitting zone, yarn structure and properties, yarn linear density, *etc.*

On the other hand, the knitted fabric area density depends on the vertical and horisontal density of the fabric, stitch length and yarn linear density [2]:

$$M = D_h D_v \ell T_{\text{tex}} 10^{-2} \tag{2}$$

where M is the knitted fabric area density [gm^{-2}], D_h is the horizontal density of the fabric [cm^{-1}], D_v is the vertical density of the fabric [cm^{-1}], T_t is the yarn linear density [tex] and l is the stitch length [mm].

Knitted fabric horizontal density D_h is defined by the knitting machine gauge and the yarn input tension; it changes only slightly with the change of the yarn input tension. Vertical density D_v of the knitted fabric changes with the couliering depth change. With the couliering depth increase, the loop length increases and simultaneously the vertical density is reduced. Since the area density of the knitted fabric depends on both, vertical density and loop length, the area density change finally depends on the predominating one of the two parameters.

2.2. Elastic Properties of the Plain Knitted Fabric

The final use of the knitted fabric is usually determined by its elastic properties. The residual extension depends on the yarn composition and structure, the knitted fabric structure and properties, the tension, the atmosphere *etc.* [3].

Elastic properties of knitwear, namely stretch and recovery have a noticeable impact on comfort, adding flexibility and freedom of movement. Gymnastics knitwear requires a stretch rating over 35%, while for everyday garments, 15–25% is sufficient to add comfort. To improve elastic properties of cotton plain knitted fabrics, usually Lycra is fed into the fabric. The degree of stretch and recovery depends on the amount and type of Lycra incorporated and on the construction of the fabric [4].

An ideal plain knitted fabric extends more in the course direction as follows [5]:

$$A_{\max} = 2B_{\max}, \tag{3}$$

where $A_{\max}$ is the maximum stitch width at loading in the course direction and $B_{\max}$ is the maximum stitch height at loading in the wale direction.

2.3. Breaking Tenacity and Extension of the Plain Knitted Fabric

The breaking tenacity and extension of the plain knitted fabric depend on yarn tenacity and breaking extension, and on vertical and horisontal density of the knitted fabric respectively. The strength of the yarn must be sufficient to resist tensile strain occurring during the knitting process. It must also contribute to the required stability of the fabric [6]. Closed knitted fabric exhibits increased breaking tenacity compared to the open one, because more loops/unit length resist the load.

Tenacity of the knitted fabrics can be examined uniaxially: in the course or the wale direction respectively.

In the case of the loading in the wale direction, the breaking tenacity is [5]:

$$\sigma_d = \frac{2qD_h}{100}(N) \tag{4}$$

where σ_d is breaking tenacity in the wale direction $[N]$, q is yarn breaking tenacity [cN] and D_h is horizontal density of the knitted fabric $[(5\,\mathrm{cm})^{-1}]$, if the width of the investigated specimen is 5 cm.

In the case of the loading in the course direction, the breaking tenacity is [5]:

$$\sigma_{\check{s}} = \frac{qD_v}{100}(N) \tag{5}$$

where $\sigma_{\check{s}}$ *is* breaking tenacity in the course direction $[N]$, q is yarn breaking tenacity [cN] and D_v is vertical density of the knitted fabric $[(5\,\mathrm{cm})^{-1}]$, if the width of the investigated specimen is 5 cm.

2.4. Dry and Wet Relaxation of the Knitted Fabric

The relaxation process comprises shrinking or in some cases growing of the knitted fabric. Dry relaxation begins immediately after exiting the knitting zone when the tension applied to the loops during the knitting process is reduced. The relaxation takes some time, depending on the material composition of the yarn, density and structure of the knitted fabric and loads applied to the fabric.

At the beginning of the relaxation, the dimensional changes are visible: the fabric shrinks fast and tends to attain the stable relaxed state. The relaxation process continues 5–20 days after knitting. The knitted fabric is relatively stable if it was not strained during the relaxation, *e.g.*, piled up or winded up to a roll. The relaxation in the course direction takes place immediately after leaving the spreading zone and is less visible after the taking-down zone. The shrinking after knitting and relaxation comes to 10–30%, mostly 20% [1,7–9].

Knitted fabric is wet relaxed during wet after-treatment processes like bleaching and dyeing and also additionally during the care process, *e.g.*, laundering and steaming.

Theoretically, the knitted fabric changes continually and perpetually tends to attain more stable state than the previous one. The changes are also influenced by the factors like temperature, relative humidity, pressure *etc.* As the changes are not visible anymore the state is considered to be balanced.

The shrinking in the course direction (horizontally) can be calculated [10]:

$$K_s = 100\left(\frac{S_1 - S_2}{S_1}\right)(\%), \tag{6}$$

where the S_1 is width of the fabric before shrinking, S_2 is width of the fabric after shrinking and K_s is horizontal shrinking in (%).

The shrinking in the wale direction (vertically) can be calculated [10]:

$$K_d = 100\left(\frac{D_1 - D_2}{D_1}\right)(\%), \tag{7}$$

where the D_1 is length of the fabric before shrinking, D_2 is length of the fabric after shrinking and K_d is vertical shrinking in (%).

The determination of the shrinking is very important when planning the quantity of the fabric to be knitted to comply with the order. Relaxation shrinking can easily be monitored by the changes of the vertical and horizontal density and the area density repeated measurements, until the balanced state is attained.

The change of the area density of the fabric can be calculated as follows [10]:

$$S_m = 100\left(\frac{M_1 - M_2}{M_1}\right)(\%), \tag{8}$$

where M_1 is area density immediately after knitting, M_2 is area density after shrinking and S_m is the change of the area density.

The more porous is the knitted fabric and the longer is the distance between the loops, the bigger is the shrinking possibility. More compact and tightly knitted structures also tend to shrink, but less extensively than the slacky ones, because the distance between loops is shorter. Simultaneously, the shrinking in the course and wale direction results in the thickness increase.

3. EXPERIMENTAL

3.1. Sampling

3.1.1. Yarn

The examined knitted fabrics were made out of cotton yarn with Lycra in a plated structure. The yarn properties are shown in Table I.

3.1.2. Knitted Fabrics

The examined knitted fabrics were produced on the MAYER & Cie RELANIT 4,28 E circular knitting machine, with the 30″ diameter and 96 yarn feeders. Plain knitted fabric with plated Lycra was produced. The process parameters of the knitted fabrics are shown in Table II.

TABLE I Knitting yarns

Yarn	*Sample*	*Material composition*	*Specified linear density Tt (dtex)*
COTTON	B	100% cotton	118
LYCRA	L	100% Lycra	33

TABLE II Knitting process parameters of the investigated fabrics

			Process parameters-knitting machine Setting			
			Yarn feeding		*Yarn feeding load (cN)*	
Sample	*Yarn*	*Couliering*	*B*	*L*	*B*	*L*
30-1	B+L	8-9	145	165	4-5	2-3
30-2	B+L	10-11	163	200	6-7	3-4

The 30-1 investigated fabric is the product, regularly produced by Inplet Sevnica. The 30-2 is the 30-1 product with the altered knitting and after-treatment process parameters in order to achieve lower area density of the 30-2 product comparing to the 30-1 area density.

The regular product 30-1 was optimized by the couliering depth increase. Simultaneously the vertical density decreased. Several preliminar samples knitted at different couliering depth were produced. Vertical density and area density of the grey fabric immediately after knitting were measured. The optimal couliering depth was defined on the basis of the grey samples area density measurements. The optimised samples were marked 30-2. The loop length increase was supposed to be the predominating factor contributing to the expected vertical density and simultaneous area density decrease (Eq. (2)).

3.2. Research Methods End the Results Evaluation

3.2.1. Yarns

Prior to knitting, the following yarn properties were investigated: linear density on the basis of the SIST EN ISO 2060 : 1996 standard, breaking tenacity and extension on the basis of the SIST ISO 2060 : 1996 standard, yarn twist on the basis of the SIST EN ISO 2061 : 1995 and SIST ISO 2 : 1995 standard and yarn evenness on the basis of the SIST DIN 53817-1 : 1981 and SIST DIN 53817-2 : 1981 standard. The results of the investigation are shown in Tables III and IV.

3.2.2. Knitted Fabrics

The properties of the grey and after-treated knitted fabrics were investigated. The width, horizontal and vertical density, area density and elastic properties of the grey samples were measured. The

TABLE III Cotton yarn properties

	Sample	x	σ	CV
linear density		11,8 tex		
twist		1013 m^{-1}		
breaking force	B	176,7 CN	204,1	11,55%
extension at break		5,930%	1,003%	16,92%
number of neps		1378/1000 m		14,09%
number of thin places		31/1000 m		

TABLE IV Lycra properties

	Sample	x	σ	CV
linear density		33 dtex		
breaking force	L	373.6 cN	9.32 cN	24.69%
extension at break		400.5%	77.34%	91.31%

investigated parameters were measured in different time intervals: immediately after knitting, after 1 hour, 2 and 5 days. The density coefficient was calculated as follows:

$$C = \frac{D_h}{D_v}. \tag{9}$$

(a) The results of the **vertical and horizontal density** measurements and the calculated **density coefficients** are shown in Tables V and VI.

(b) The **width** and **area density** of the after-treated samples were investigated. On the basis of the measurements it was concluded

TABLE V Basic grey and finished 30-1 knitted fabric parameters

	1	2	3	4	G
30-1	*Immediat.*	*After* 1 *h*	*After* 2 *days*	*After* 5 *days*	*Finished fabric*
FABRIC WIDTH (cm)	149,00	148,20	146,40	146,20	154,00
AREA DENSITY (gdm^{-2})	219,77	217,64	226,58	232,60	167,55
VERT DENSITY D_v (cm^{-1})	35,6	34,6	37,4	37,4	31,0
HORIZ DENSITY D_h (cm^{-1})	17,6	17,4	18,2	18,0	16,0
DENSITY COEFF C	0,49	0,50	0,49	0,48	0,52
*MAX. wales	190,0	×	207,5	212,5	150,0
MANUAL courses	162,2	×	180,0	175,0	163
EXT.R_r(%)					

* the method is described in Chapter 3.2.2.

× for the time limitation, maximum extension 1 h after knitting was not measured.

TABLE VI Basic grey and finished 30 – 2 knitted fabric parameters

30 – 1	1 Immediat.	2 *After 1 h*	3 *After 2 days*	4 *After 5 days*	*G* *Finished fabric*
FABRIC WIDH (cm)	149,40	146,40	144,20	143,80	155,00
AREA DENSITY (gdm^{-2})	207,26	214,82	224,75	230,05	159,85
VERT DENSITY D_v (cm^{-1})	30,2	31,0	33,2	33,2	27,6
HORIZ DENSITY D_h (cm^{-1})	17,4	17,6	17,8	18,0	16,3
DENSITY COEFF C	0,58	0,57	0,54	0,54	0,59
*MAX. wales	195,0	×	215,0	217,5	163,0
MANUAL courses	207,0	×	250,0	247,5	210,0
EXT.R_r(%)					

* the method is described in Chapter 3.2.2.

× for the time limitation, maximum extension 1 h after knitting was not measured.

that the examined samples of the after-treated fabrics met the relaxed state a few hours after the finished after treatment. The relaxed fabric area density and fabric density only changed in the case of the changed clima including humidity, temperature and the mechanical factors like transport and storage. Area density was investigated on the basis of the SIST ISO 3801 : 1996 standard. The results are shown in the Tables V and VI.

(c) The **material composition** of the samples was investigated: the Lycra share depends on the knitting and after-treatment process parameters. After the optimising the process parameters of the 30 – 1 product, the material composition change of the 30 – 2 sample was expected. The results of the material composition investigation is shown in Table VII.

(d) The **shrinking of the samples during laundering** on the basis of the SIST EN 25077 standard was evaluated. The results of the shrinking evaluation after 1st laundering cycle is shown in Table VIII.

(e) The **elastic properties** of the fabric were also investigated.

TABLE VII Material composition of the 30 – 1 and 30 – 2 knitted fabrics

			30 – 1	30 – 2
MATERIAL COMPOSITION (%)	planned	*B*	91,0	91,0
		L_1	9,0	9,0
	actual	*B*	91,4	90,8
		L_1	8,6	9,2

TABLE VIII Shrinking of the finished 30−1 and 30−2 knitted fabrics during 1st laundering cycle

		30−1	30−2
SHRINKING AT	wales	8,0	6,6
LAUNDERING (%)	courses	3,0	3,0

Manually, the elastic properties were investigated by stretching the specimens according to the MANUAL method executed internally at INPLET textile testing laboratory. The specimens 30 × 10 cm were marked as shown in Figure 2. Three specimens in each course and wale direction were prepared for each knitted fabric sample. The specimens were swiftly stretched three times. The maximum elongation at the third stretching was measured. The maximum extension was calculated as follows:

$$R_{r\max} = 100\left(\frac{B_1}{B}\right)(\%), \tag{10}$$

where B is the width between marks before stretching ($B = 10\,\text{cm}$) and $B1$ is the width between marks at third stretching.

The residual extension was calculated as follows:

$$R_t = 100\left(\frac{B_2}{B}\right)(\%), \tag{11}$$

where B is the width between marks before stretching ($B = 10\,\text{cm}$) and $B2$ is the width between marks of the relaxed specimen immediately after third stretching.

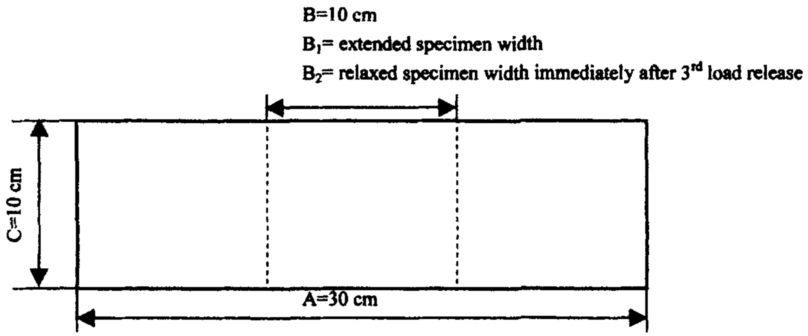

FIGURE 2 Test specimen dimensions for manual tensing of knitted fabric extensibility.

The results of the maximum extension measured by the manual method are shown in Tables IX and X. Grafically, they are shown in Figures 3 and 4.

The manual method of the elastic properties evaluation proves to be subjective, therefore maximum and residual extension were also investigated on the INSTRON 6022 apparatus. Three different methods were used to simulate the manual method. The first method named CYCLES 1 comprised cyclic loading of specimen by gradually increasing the load to 100 N and decreasing the load until clamps were returned to their original position. The specimen were strained three times. During the third cycle, the maximum extension was measured. After the 60s relaxation, the residual extension was measured during the control cycle. Elastic properties in both, course and wale direction were measured respectively.

TABLE IX Elastic properties of the 30–1 knitted fabric

			Wales direction		*Courses direction*	
			ext. (%)	*load* (*N*)	*ext.* (%)	*load.* (*N*)
30-1 grey	BREAK		335,15	211,15	268,26	231,53
	CYCLE 1	maximum extension	293,0067	52,4333	239,2833	77,3083
		resid. ext.	95,5033	–	59,3233	–
	CYCLE 3	**resid. ext.**	51,6433	–	41,0767	–
	MANUAL	maximum extension	210,00	–	250,00	–
		resid. ext.	50,00	–	22,50	–
30-1 finished	BREAK		238,30	166,41	241,33	174,57
	CYCLE 1	maximum extension	212,57	73,67	210,35	61,20
		resid. ext.	71,53	–	78,71	–
	CYCLE 2	maximum extension	156,42	24,97	153,13	21,93
		resid. ext.	49,70	–	50,47	–
	CYCLE 3	**resid. ext.**	57,92	–	60,85	–
	MANUAL	maximum extension	142,50	–	142,50	–
		resid. ext.	25,00	–	24,50	–

CYCLE 1 = cyclic loading – 100 N load.
CYCLE 2 = cyclic loading – 35 N load.
CYCLE 3 = cyclic loading – 150% extension.

TABLE X Elastic properties of the 30–2 knitted fabric

			Wales direction		*Courses direction*	
			ext. (%)	*load* (*N*)	*ext.* (%)	*load.* (*N*)
30-2 grey	BREAK		332,58	168,21	359,68	182,02
	CYCLE 1	maximum extension	282,98	38,12	314,66	50,38
		resid. ext.	70,13	–	95,67	–
	CYCLE 3	**resid. ext.**	39,59	–	28,96	–
	MANUAL	maximum extension	157,50	–	205,00	–
		resid. ext.	27,50	–	37,50	–
30-2 finished	BREAK		244,28	160,28	299,61	120,12
	CYCLE 1	maximum extension	215,29	63,35	28426	42,74
		resid. ext.	72,03	–	109,24	–
	CYCLE 2	maximum extension	165,96	24,08	222,80	31,15
		resid. ext.	46,59	–	64,83	–
	CYCLE 3	**resid. ext.**	43,98	–	45,43	–
	MANUAL	maximum extension	227,50	–	240,00	–
		resid. ext.	40,00	–	42,50	–

CYCLE 1 = cyclic loading – 100 N load.
CYCLE 2 = cyclic loading – 35 N load.
CYCLE 3 = cyclic loading – 150% extension.

The second method named CYCLES 2 comprised cyclic loading (3 cycles) of specimen by 35 N. During the third cycle, the maximum extension was measured. The residual extension was measured immediately after the cyclic loading during the control cycle. Elastic properties in both, course and wale direction were measured respectively.

The third method named CYCLES 3 comprised cyclic loading load by 150% extension, maintaining the extension for 60s and decreasing the load. After two loading cycles the specimen were relaxed for 180s. Through the third (control) cycle, the residual extension was measured. Elastic properties in both, course and wale direction were measured respectively.

The results of the elastic properties evaluation are shown in Tables IX and X. Grafically, they are shown in Figures 3 and 4.

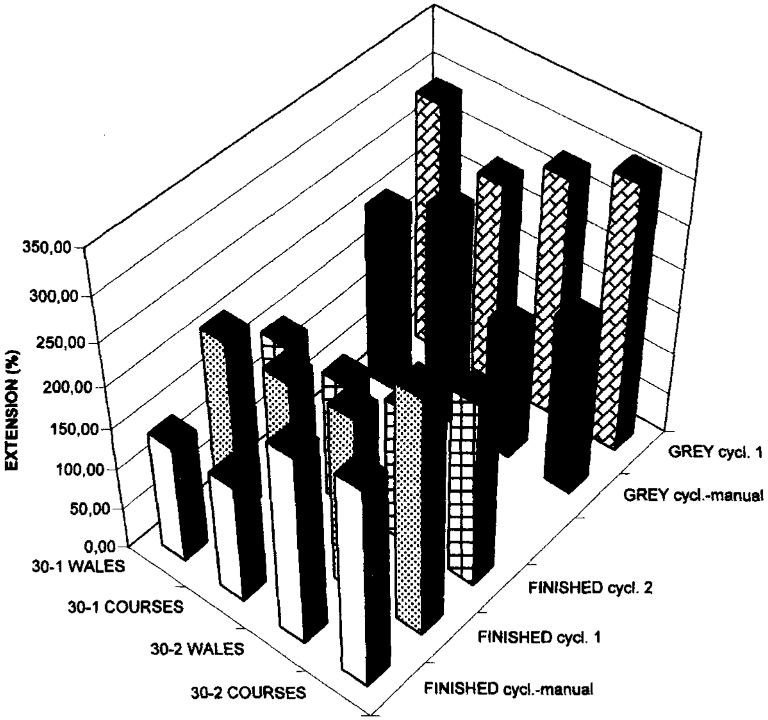

FIGURE 3 Maximal extension of the grey and finished 30 – 1 and 30 – 2 knitted fabrics.

3.3. Results and Discussion

3.3.1. Yarns

According to the final use of the investigated fabrics, the electronic cleaning of the cotton yarn should be introduced due to the yarn unevenness (Tab. III).

3.3.2. Knitted Fabrics

The width of both grey samples decreased during the relaxation as expected. The vertical and horizontal density of both grey samples increased during the relaxation. The density coefficient of the 30 – 2 sample exceeds the density coefficient of the 30 – 1 sample and

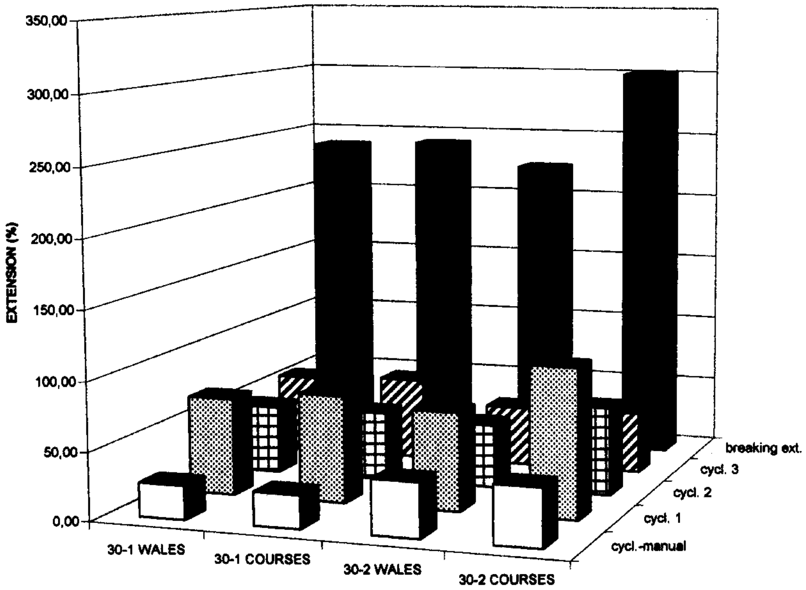

FIGURE 4 Residual and breaking extension of the finished 30 – 1 and 30 – 2 knitted fabrics.

approximates to the coefficient of the ideal plain knitted fabric $C = 0,7 - 0,8$. The area density of both grey samples increased during the relaxation due to fabric shrinking. The area density of the finished samples differs from the grey samples area density because of the biaxial extension of the fabric during the after-treatment. The results show, that the area density of the 30 – 2 sample was optimized as planned.

The 30 – 2 sample includes 2% more Lycra while the 30 – 1 sample includes 0,4% less Lycra than specified. The material composition of both fabrics corresponds to the product specification limits.

The shrinking in the wale direction of both samples exceeds the shrinking in the course direction. The laundering properties of the 30 – 2 sample improved with the process parameters change.

The breaking extension of the finished sample 30 – 2 was improved compared to 30 – 1 finished sample. The maximum extension of the finished sample 30 – 2 exceeds the 30 – 1 maximum extension, which corresponds to the final use of the elastic fabrics. Generally, the residual extension of the 30 – 2 sample, measured by different methods, exceeds the residual extension of the 30 – 1 sample, except in the case of the CYCLES 3 method, where the specimens were twice extended to 150% and relaxed for 180s (Tabs. IX and X).

4. CONCLUSIONS

On the basis of the investigation results the following conclusions can be made:

(1) The relaxation of the grey knitted fabric can be monitored on the basis of the vertical, horizontal and area density measurements. To enable an objective assessment of the process, the measurements should be executed regularly in constant time intervals after knitting, *e.g.*, 10 min. Area density control within knitting department should be organised and knitting coefficient calculation and monitoring should be executed.

(2) Area density of the investigated knitted fabric was reduced according to the investigation objective due to the knitting process parameters optimisation. Simultaneously, density coefficient was improved. Performance properties like shrinking at laundering and maximum extension were improved. Material composition of the optimised fabric remained within the specified limits.

(3) In order to enable objective elastic properties measurement of knitted fabrics, apparatus for uniaxial cyclic loading of the knitted fabrics should be developed for the internal INPLET textile laboratory testing.

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