Modelling loop length in weft-knitted fabrics with an interlock structure after the dyeing process with a stitch density, wales and courses per centimetre analysis

J. Llinares Berenguer[a], P. Miró-Martínez[b] & P. Díaz García[a]*

[a]*Dpto. Ingeniería textil y papelera, Universitat Politècnica de València, Alcoi, Spain;*
[b]*Dpto. Estadística, Universitat Politècnica de València, Alcoi, Spain.*

*corresponding author: pdiazga@txp.upv.es

Modelling loop length in weft-knitted fabrics with an interlock structure after the dyeing process with a stitch density, wales and courses per centimetre analysis

One of the variables that we need to know in knitted fabrics in order to explain variations in dimensions in their different relaxation states, which might occur during the production process, is the yarn length that a loop forms, known as *loop length*. To experimentally calculate it, quite a lengthy process is required and the following need to be identified: direction of wales, direction that samples unreave in, counting the number of loops in the fabric length, separating and measuring yarn with specific measuring equipment, and repeating these 10 times, according to regulation UNE-EN 14970. Thus, depending on the structure type to be analysed, the whole process can take a relatively long time to do this calculation. This study proposes a calculation system that simplifies the process, for which the yarn length absorbed by an estimated interlock structure was modelled, as was loop length, without having to follow such a time-consuming process.

Keywords: Knitted fabrics, loop length, Stitch density, wales per centimetre, courses per centimetre.

Introduction

The 100% cotton interlock structure has been widely used to produce winter garments thanks to its thermal and comfort properties. However, it also presents considerable dimensional instability, as all weft-knitted fabrics do. Since this drawback implies many problems for textile industries, attempts have long since been made to define the parameters needed to obtain dimensionally stable fabrics. In order to understand how the dimensional stability problem can be overcome, companies have to seek an efficient reproducible method to leave all knitted fabrics in an equivalent relaxation state to be able to compare them. This method would thus be a reference for all measurements and comparisons for fabrics with the above-defined characteristics.

Searches made to dimensionally control cotton-knitted fabrics date back to the beginning of the 20th century when the first mathematical model was presented by Chamberlain (1926), which attempted to determine the loop configuration of knitted fabrics.

K factors are the basis of the system employed to predict the performance of knitted fabrics, and constants are obtained using empirical data. The bigger the database, the more reliable the predictions.

Since then, other research works have undertaken relevant studies which conceptualise, define and mathematically formulate the dimensional behaviour of knitted fabrics.

According to Münden (1959), with Equations (1) to (3) it is possible to verify if K factors are related with courses, gauge and loop length**.** The relevance of Münden’s equations lies in the fact that the dimensions of plain-knitted fabrics, which are produced with discontinuous fibre yarns and continuous filament yarns, are defined by the length of yarns in the loop, provided that the fabric is always measured in the same relaxation state.

$$\boldsymbol{K_C = SL\ x\ CPCM} \tag{1}$$

$$\boldsymbol{K_W = SL\ x\ WPCM} \tag{2}$$

$$\boldsymbol{K_r = \frac{K_c}{K_w}} \tag{3}$$

where: K_c and K_w are constants and represent the fabric dimension.

K_r: is the factor that gives the loop its format.

SL: is loop length.

These equations have been applied to plain-knitted fabrics for many years.

For plain-knitted fabrics, Doyle (1953) later found that knit density depended only on loop length, and was independent of yarn and knitted fabric variables. Münden (1959) suggested that a loop would take a natural form when freed from mechanical strains, and would be independent of yarn properties.

Münden (1960) demonstrated that, if in a minimum energy status, the fabric dimensions of plain-knitted wool fabrics would depend only on loop length. Münden's experimental studies indicate that Equations 1 to 3 can be applied in different relaxations states to give a distinct number of constants.

To conclude, what Münden intended with these equations was that the dimensions of plain-knitted fabrics depended on loop length and no other variable had any influence, provided fabrics were measured in the same relaxation state.

Nutting (1968) introduced another variable, yarn count, and proposed a minor amendment to the basic equation.

Knapton (1968,1975) demonstrated not only that the dimensional stability in plain-knitted fabrics could be accomplished by mechanical means, relaxation techniques or chemical treatments, but also that the stable loop geometry was almost identical for both wool and cotton in plain-knitted fabrics.

Another study (Ulson de Souza, Cabral Cherem & Guelli U.Souza (2010)) is based on the principle that each industry must determine its own K factors, which are calculated per processing line; e.g., the factor differs for a knitted fabric that has undergone either a continuous bleaching or an exhaustion bleaching process. So these factors differ as they provide distinct combinations of fabrics with several weights, shrinkages and widths. Conversely when cotton-knitted fabrics have the same structure and working, and also the same yarn count, and they are processed by the same dyeing and finishing process, they will have the same K factor**.** This study was conducted with five distinct processes. All the used fabrics came from a circular plain-knitting machine, but had been dyed and finished differently. A process was followed that included five domestic washing steps to see the change in dimensional stability that took place during each washing. The following conclusions were drawn:

Loop length: a minor, but significant, variation was observed throughout the process for the five different processes

The changes or variations in yarn were non-significant for the five different processes

The geometry factor (K_r): for all four analysed structures, a dimensional change was confirmed in the knitted fabric owing to changes in the loop's geometric forms.

In their study, Ulson de Souza, Cabral Cherem and Guelli U. Souza (2010) developed a computational algorithm to help develop fabrics by obtaining fit parameters for the process. To this end, it was necessary to establish a K factor for each production process.

Saravana and Sampath (2012) predicted the knitted fabric's dimensional properties with a double cardigan structure by an "artificial neural network system". In their study, these authors demonstrated the existing relationship that linked courses per centimetre, wales per centimetre and stitch density, and the inverse of loop length in a double cardigan fabric.

Mobarock Hossain (2012) established some mathematical relations to predict the weight (GSM), width and ultimately shrinkage of a finished cotton knitted fabric.

Eltahan, Sultan and Mito (2016) determined the loop length, tightness factor and porosity of a single jersey knitted fabric using mathematical equations.

Sitotaw (2017, 2018) studied the dimensional characteristics of five knitted structures made from 100% cotton and 95% cotton/5% elastane blended yarns. He concluded that the loop length, wales per centimetre, courses per centimetre, stitch density, the tightness factor, the loop shape factor and the take-up rate of single jersey, 1x1 rib, interlock, single pique, and two-thread fleece-knitted fabrics made from 100% cotton and cotton/elastane yarns were significantly influenced by the presence of an elastane yarn. The loop length of single jersey, 1x1rib and interlock knitted fabrics made from elastane yarns reduced, while the single pique and fleece increased. Similarly, other dimensional properties were significantly influenced by the yarn types used during knitting.

Objectives

Nearly all the studies we found referred to the loop length variable as one of the most important factors to intervene in the dimensional variation of knitted fabrics. The process followed to analyse this in accordance with regulation UNE-EN 14970 is somewhat bothersome as it is necessary to identify wales and the direction that samples unreave in, cut all along a course, count the number of loops along a given length, remove yarn from the fabric, place the measuring machine pincers by foreseeing loss of twist to measure its length, and repeat all these 10 times to then calculate its mean.

Therefore, the main objective of this study was to predict the loop length of a knitted fabric with the interlock structure using other variables that are simpler to calculate, such as courses, wales or stitch density. This considerably speeds up the process to calculate the K factors that Münden proposed in his studies.

Experimental

Materials and Methods

The present study was conducted on fabrics knitted with an interlock structure. Fabrics were produced under three knitting conditions: slackly knitted fabrics (SL_1), tightly knitted fabrics (SL_3) and intermediately knitted fabrics/neither slackly or tightly knitted fabrics (SL_2). The linear yarn count employed to produce these fabrics was 30 Ne of combed cotton. The machines employed to make these knitted fabrics are shown in table 1.

Table 1. The circular machines used to produce fabrics knitted under conditions SL_1, SL_2, SL_3.

Model	Diameter (inches)	Gauge	Needles	No. feeders
Mayer IHG II	12	E20	2x756	20
Mayer IHG II	14	E20	2x876	36
Jumberca DVK	16	E20	2x1008	32
Mayer IHG II	17	E20	2x1056	32
Jumberca DVK	18	E20	2x1128	36
Mayer IHG II	20	E20	2x1260	40
Jumberca DVK	22	E20	2x1380	44
Jumberca DVK	24	E20	2x1512	48
Mayer OV 3,2 QC	30	E20	2x1872	96

On all the nine machines cited in Table 1, 45 pieces were produced, which corresponded to 15 pieces under the SL1 condition, 15 under the SL2 condition and 15 under the SL3 condition, which totalled 405 pieces. We obtained knitted fabrics whose average loop length after the knitting process was 0.365 cm for SL1, 0.341 cm for SL2 and 0.339 cm for SL3. Then all the samples were placed in a conditioning atmosphere to reach a constant weight. Next one sample each piece was cut to be analysed. This analysis consisted in determining the number of number of loops in the fabric length and the area unit (wales per centimetre, courses per centimetre and stitch density) according to Standard UNE-EN 14971, and also in determining loop length and laminar weight according to Standard UNE-EN 14970 and factors (Kc, Kw and kr), by applying

Münden's equations.

The mean, standard deviation and 95% confidence interval of the results obtained in the analysis done with the samples, following the knitting process for each knitting condition (SL_1, SL_2, SL_3), are provided in table 2.

Table 2. The experimental results of the fabrics under conditions SL_1, SL_2 and SL_3 after knitting.

Sample	Variable	DDR Relaxation state		
		$\overline{X}$	s_i	CI
	WPCM	23.61	0.64	[23.358;23.856]
	CPCM	11.95	0.60	[11.714;12.180]
	SD	281.90	13.71	[276.586;287.221]
	W	198.66	7.35	[185.803;201.507]
SL_1	SL	0.365	0.012	[0.3605;0.3700]
	TF	12.17	0.40	[12.010;12.323]
	K_c	4.36	0.19	[4.287;4.431]
	K_w	8.62	0.35	[8.484;8.758]
	K_r	0.51	0.03	[0.494;0.519]
	WPCM	27.41	0.41	[27.197;27.637]
	CPCM	11.74	0.38	[11.540;11.939]
	SD	321.79	8.72	[317.139;326.430]
	W	216.39	4.38	[214.054;218.717]
SL_2	SL	0.341	0.009	[0.3361;0.3455]
	TF	13.03	0.34	[12.851;13.213]
	K_c	4.00	0.12	[3.936;4.063]
	K_w	9.34	0.31	[9.181;9.508]
	K_r	0.43	0.02	[0.419;0.438]
SL_3	WPCM	27.39	0.86	[27.030;27.750]

CPCM	11.71	0.42	[11.530;11.887]
SD	320.55	12.19	[315.403;325.699]
W	214.16	8.36	[210.631;217.393]
SL	0.339	0.010	[0.3353;0.3437]
TF	13.08	0.38	[12.924;13.245]
K_c	3.97	0.14	[3.912;4.034]
K_w	9.30	0.44	[9.115;9.386]
K_r	0.43	0.024	[0.4180;0.4381]

WPCM: Wales/cm; CPCM: Courses/cm; SD: Stitch density/cm2; W: Weight (g/m2); SL: Loop length (cm); TF: Tightness factor; Kc, Kw, Kr: Munden's factors; $\bar{X}$: Mean; si: Standard deviation; CI: 95% Confidence interval.

Next batches underwent a machine exhaustion dyeing process. The dyeing conditions and the added products are respectively indicated in figure 1 and table 3.

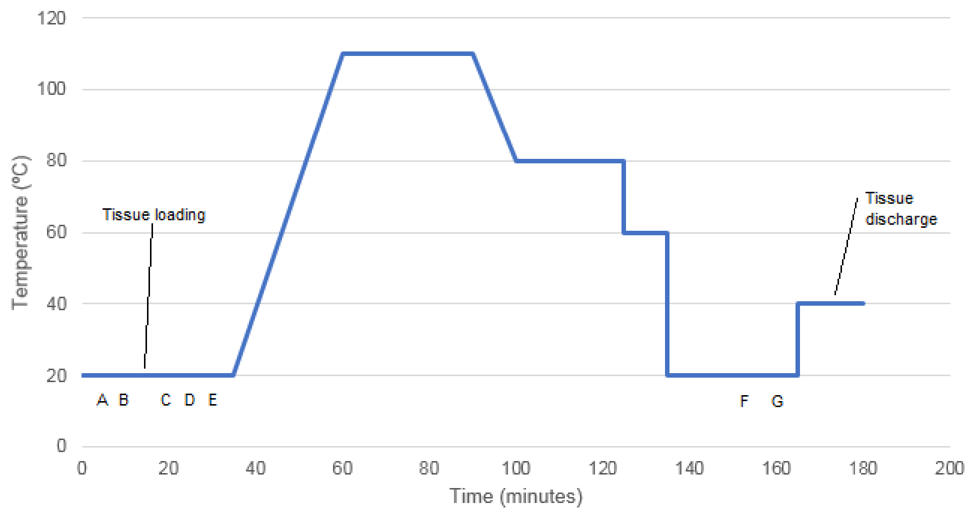

Figure 1. Dyeing curve to optimally bleach the processed fabrics

Table 3. Products employed for optimum bleaching.

Process	Product
A	Tannex Noveco

B	Procuest ND
C	Liquid Soda Lye
D	Hydrogen Peroxide
E	Ledeblanc
F	Dianix violet BTE
G	Formic acid

After completing hydroextraction and then drying the pieces, those to be analysed were identified, a sample of them was taken and they were left in a conditioning atmosphere.

Two relaxation states for the fabrics under knitting conditions SL_1**,** SL_2 **and** SL_3 were distinguished after the dyeing process:

- Dyed and dry relaxation (DDR). The dyed knitted fabric was left in a conditioning atmosphere until a constant weight was obtained.
- Dyed and wash relaxation (DWR). The dyed and conditioned knitted fabric was left until a constant weight was obtained. Then a dimensional stability test was run with it according to regulation UNE EN ISO 6330, of September 2012, procedure 4N.

The mean, standard deviation and 95% confidence interval of the results obtained in the analysis done of the samples after the dyeing process for each knitting condition (SL_1, SL_2, SL_3), and in the DDR and DWR relaxation states, are shown in table 4.

Table 4. Experimental results of the fabrics under knitting conditions SL_1, SL_2 and SL_3 after the dyeing process.

Sample No.	Variable	Relaxation States					
		DDR			DWR		
		$\overline{X}$	s_i	IC	$\overline{X}$	s_i	IC

	WPCM	24.57	0.73	[24.412;24.732]	26.19	0.97	[25.98;26.40]
	CPCM	14.17	0.47	[14.070;14.280]	13.43	0.45	[13.327;13.525]
	SD	348.23	13.85	[345.171;351.297]	351.77	19.48	[347.462;356.076]
	W	238.95	6.44	[237.527;240.375]	251.76	7.03	[250.203;253.313]
SL_1	SL	0.356	0.008	[0.3546;0.3583]	0.360	0.010	[0.354;0.358]
	TF	12.46	0.29	[12.394;12.524]	12.47	0.35	[12.391;12.544]
	K_c	5.05	0.15	[5.018;5.084]	4.78	0.16	[4.746;4.817]
	K_w	8.76	0.34	[8.683;8.835]	9.33	0.39	[9.244;9.416]
	K_r	0.58	0.03	[0.571;0.584]	0.51	0.02	[0.509;0.518]
	WPCM	27.41	1.68	[27.15;27.68]	29.17	1.44	[28.944;29.399]
	CPCM	14.49	0.57	[14.40;14.57]	13.66	0.51	[13.580;13.741]
	SD	396.80	24.51	[392.920;400.680]	398.53	25.00	[394.57;402.48]
	W	251.25	8.73	[249.869;252.631]	262.38	11.39	[260.580;264.183]
SL_2	SL	0.331	0.008	[0.3300;0.3332]	0.331	0.012	[0.3293;0.3330]
	TF	13.40	0.33	[13.352;13.456]	13.42	0.46	[13.347;13.493]
	K_c	4.80	0.18	[4.769;4.826]	4.52	0.20	[4.490;4.554]
	K_w	9.08	0.57	[8.991;9.172]	9.65	0.40	[9.587;9.713]
	K_r	0.53	0.04	[0.524;0.538]	0.47	0.03	[0.465;0.474]
	WPCM	26.89	1.11	[26.727;27.049]	29.30	0.99	[29.153;29.442]
	CPCM	14.77	0.68	[14.667;14.865]	14.17	0.50	[14.101;14.245]
	SD	397.13	25.81	[393.395;400.863]	415.34	22.29	[412.117;418.565]
	W	247.92	6.80	[246.931;248.898]	261.69	7.07	[260.668;262.713]
SL_3	SL	0.323	0.013	[0.3209;0.3247]	0.319	0.010	[0.3170;0.3201]
	TF	13.77	0.54	[13.694;13.850]	13.95	0.43	[13.885;14.008]
	K_c	4.76	0.15	[4.738;4.782]	4.51	0.15	[4.490;4.534]
	K_w	8.67	0.37	[8.619;8.726]	9.33	0.35	[9.279;9.380]
	K_r	0.55	0.03	[0.545;0.555]	0.48	0.02	[0.481;0.487]

WPCM: Wales/cm; CPCM: Courses/cm; SD: Stitch density/cm^2; W: Weight (g/m^2); SL: Loop length (cm); TF: Tightness factor; Kc, Kw, Kr: Munden's factors; $\overline{X}$: Mean; s_i: Standard deviation: CI: 95% Confidence interval

Results and Discussion

After completing the analysis of the knitted fabrics under conditions SL_1, SL_2 and SL_3 to obtain the variables DDR and DWR relaxation states, we intended to observe the existing relationship between these variables and to obtain models with which to predict loop length (SL). The models obtained by linear regression are shown in tables 5 and 6.

Table 5. The models proposed by linear regression for each knitted fabric under knitting conditions SL_1, SL_2 and SL_3.

Sample No.	DV	IV	Relaxation states: DDR Linear relation	DDR R^2	DWR Linear relation	DWR R^2
SL_1	SL	CPCM	$SL = \frac{1}{0.197885 \cdot CPCM}$	99.913	$SL = \frac{1}{0.209063 \cdot CPCM}$	99.887
	SL	WPCM	$SL = \frac{1}{0.114132 \cdot WPCM}$	99.842	$SL = \frac{1}{0.107122 \cdot WPCM}$	99.828
	SL	SD	$SL = \frac{1}{0.00805089 \cdot SD}$	99.8591	$SL = \frac{1}{0.00796533 \cdot SD}$	99.730
SL_2	SL	CPCM	$SL = \frac{1}{0.208244 \cdot CPCM}$	99.862	$SL = \frac{1}{0.221106 \cdot CPCM}$	99.806
	SL	WPCM	$SL = \frac{1}{0.109768 \cdot WPCM}$	99.907	$SL = \frac{1}{0.103499 \cdot WPCM}$	99.835
	SL	SD	$SL = \frac{1}{0.00758624 \cdot SD}$	99.678	$SL = \frac{1}{0.00756708 \cdot SD}$	99.748
SL_3	SL	CPCM	$SL = \frac{1}{0.209966 \cdot CPCM}$	99.897	$SL = \frac{1}{0.221546 \cdot CPCM}$	99.886

SL	WPCM	$SL = \frac{1}{0.115291 \cdot WPCM}$	99.827	$SL = \frac{1}{0.107166 \cdot WPCM}$	99.862
SL	SD	$SL = \frac{1}{0.0077963 \cdot SD}$	99.829	$SL = \frac{1}{0.0075501 \cdot SD}$	99.791

DV: Dependent variable; IV: Independent variable; WPCM: Wales/cm; CPCM: Courses/cm; SD: Stitch density/cm^2; SL: Loop length (cm).

Of the models proposed in Table 5, by knowing the independent variables courses/cm (CPCM), wales/cm (WPCM) and stitch density/cm2 (SD), it is possible to predict the loop length (SL) variable for each studied knitted fabric under knitting conditions (SL_1, SL_2, SL_3). Almost all these models have an R2 that exceeds 99%, and variability is well accounted for by the linearity that exists with the independent variables CPCM, WPCM and SD. Figures 2-4 illustrate the linear regression models adjusted for the fabric knitted under knitting condition SL_3, and a relation was found among the variables courses/cm, wales/cm, stitch density, and the inverse of the loop length in the DWR relaxation state.

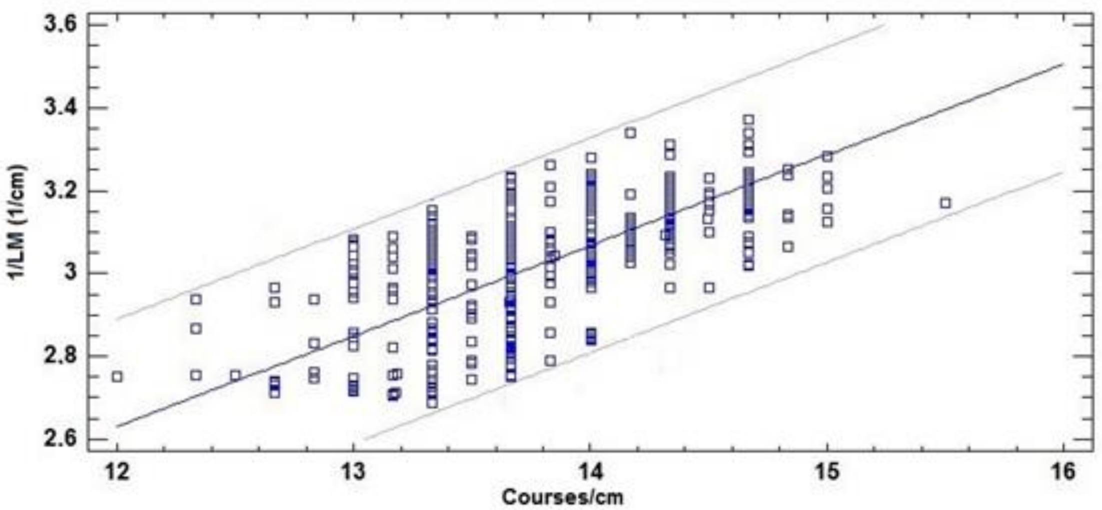

Figure 2. Graph showing the linear regression model adjusted for knitted fabric SL_3 that describes the relation between the inverse of loop length and courses/cm for the DWR relaxation state.

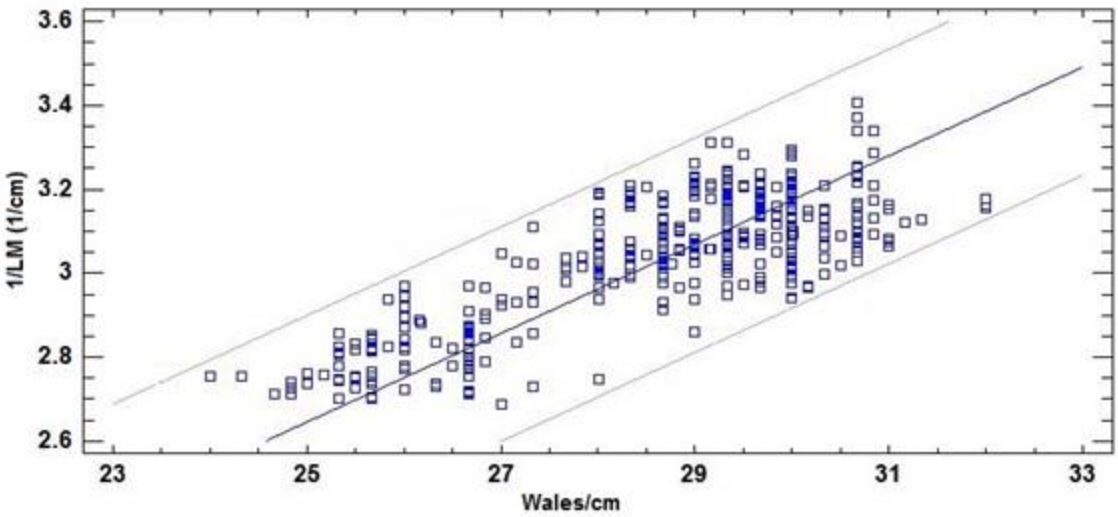

Figure 3. Graph showing the linear regression model adjusted for knitted fabric SL_3 that describes the relation between the inverse of loop length and wales/cm for the DWR relaxation state.

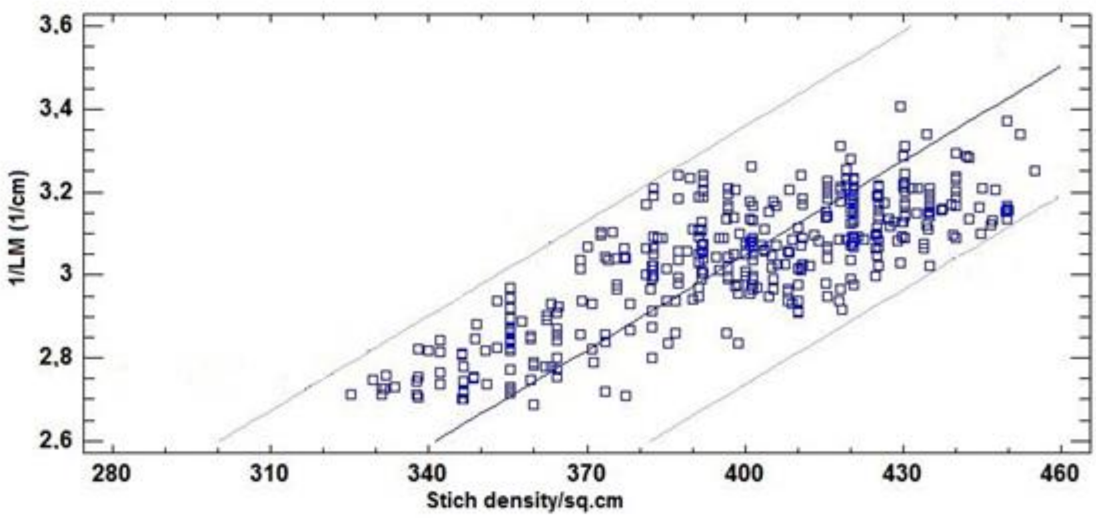

Figure 4. Graph showing the linear regression model adjusted for knitted fabric SL_3 that describes the relation between the inverse of loop length and stitch density for the DWR relaxation state.

Table 6 offers some generic models for the three fabrics knitted under conditions SL_1**,** SL_2 and SL_3 that can be perfectly used to predict variable SL because they optimally explain variability by obtaining an R^2 of around 98%.

Table 6. The proposed generic linear regression models for the three studied fabrics knitted under conditions SL_1, SL_2 and SL_3.

Sample	DV	IV	DDR Linear relation	DDR R^2	DWR Linear relation	DWR R^2
	SL	CPCM	$SL = \frac{1}{0.207143 \cdot CPCM}$	99.841	$SL = \frac{1}{0.21914 \cdot CPCM}$	99.812
$SL_{1,2,3}$	SL	WPCM	$SL = \frac{1}{0.112946 \cdot WPCM}$	99.698	$SL = \frac{1}{0.105759 \cdot WPCM}$	99.818
	SL	SD	$SL = \frac{1}{0.00775448 \cdot SD}$	99.737	$SL = \frac{1}{0.0075501 \cdot SD}$	99.791

DV: Dependent variable; IV: Independent variable; WPCM: Wales/cm; CPCM: Courses/cm; SD: Stitch density/cm^2; SL: Loop length (cm).

To verify the validity of the obtained models, they were all validated by analysing a set of batches that represented all the diameters and each knitted fabric. To analyse them, the loop length of each batch was calculated in the DDR and DWR relaxation states. Next the obtained models were used to calculate the estimated values. The estimated error was the difference between the estimated value and the real value. The estimated errors of the models proposed for each variable are summarised in table 7**.**

Table 7. Summary of the estimated errors made by the proposed models for each fabric knitted under conditions SL_1, SL_2 and SL_3 to estimate loop length (SL).

Sample	DV	IV	DDR Estimated error	DDR s_i	DWR Estimated error	DWR s_i
	SL	CPCM	0.020	0.009	0.022	0.005
SL_1	SL	WPCM	0.010	0.010	0.009	0.012
	SL	SD	0.015	0.011	0.020	0.010
	SL	CPCM	0.004	0.003	0.012	0.006
SL_2	SL	WPCM	0.016	0.005	0.015	0.004
	SL	SD	0.016	0.003	0.015	0.009

	SL	CPCM	0.013	0.010	0.012	0.011
SL_3	SL	WPCM	0.012	0.004	0.005	0.004
	SL	SD	0.010	0.009	0.009	0.005

DV: Dependent variable; IV: Independent variable; WPCM: Wales/cm; CPCM: Courses/cm; SD: Stitch density/cm^2; SL: Loop length (cm).

Table 7 shows how the estimated errors, made when the models proposed for each analysed knitted fabric were used, are minor errors. We conclude that these models efficiently represent the variability obtained with all the proposed knitted fabrics.

Table 8. Summary of the estimated errors made by the generic models proposed to estimate loop length (SL).

			Relaxation states			
Sample	DV	IV	DDR		DWR	
			Estimated error	s_i	Estimated error	s_i
	LM	C	0.012	0.010	0.013	0.008
$SL_{1,2,3}$	LM	P	0.011	0.007	0010	0.008
	LM	DM	0.014	0.010	0.014	0.009

DV: Dependent variable; IV: Independent variable; P: Wales/cm; C: Courses/cm; DM: Stitch density/cm^2; LM: Loop length (cm).

Table 8 summarises the estimated errors made when the generic models proposed to estimate loop length were used. The errors made when these models were used are, in some cases, somewhat greater than those proposed in Table 7, but are still minor errors. Thus we conclude that these models can also efficiently represent the variability of all the fabrics proposed jointly without separating them.

Conclusions

This study proposes linear regression models (Tables 5 and 6) to help predict loop length by knowing only one of the following variables; wales/cm, courses/cm and stitch density/cm^2; in relaxation states Dyed and Dry Relaxation and Dyed and wash relaxation, without having to apply regulation UNE-EN 14970, which is a somewhat bothersome procedure. This work explains how to avoid operations to identify wales, the direction that samples unreave in, cutting a long a column, counting the number of loops along a given length, removing yarn from knitted fabric, placing the measuring machine pincers by foreseeing loss of twist to measure its length, and repeating this whole process 10 times to then calculate its mean.

The loop lengths of the three knitted fabrics were modelled with the interlock structure, and all with different loop lengths, after a dyeing process by linear regression models. They are indicated in Tables 5 and 6. After their validation, we can see that the estimated errors were made when the proposed models (both the specific models for each proposed fabric and the generic ones) were used, which are minor errors. Thus we conclude that these models efficiently represent the variability obtained from each proposed knitted fabric.

After validating the proposed models, we found that they can be suitably used to calculate loop length in the proposed knitted fabrics by knowing only one of these variables: courses/cm, wales/cm and stitch density.

References

Amreeva, G. & Kurbak, A. (2007). Experimental Studies on the Dimensional Properties of Half Milano and Milano Rib Fabrics. *Textile Res. J., 77*, 151-160.

Allan, S., Greenwood, F., Leah, R.D., Eaton, J.T., Stevens, J.C., Keher, P. (1982). Prediction of Finished Weight and Shrinkage of Cotton Knits- The Starfish Project. *Fiifth Annual Natural Fibers Textile Conference, Charlotte, North Carolina*, September 14-16.

Allan, S., Greenwood, F., Leah, R.D., Eaton, J.T., Stevens, J.C., Keher, P. (2011). Prediction of Finished Relaxed Dimensions of Cotton Knits- The Starfish Project. *Textile research Journal,* 040-5175/85/55004-211.

Black, D.H. (1974). Shrinkage Control for Cotton and Cotton Blend knitted Fabrics. *Textile Res. J, 44*, 606-611.

Chamberlain, J. (1926). Hosiery Yarns and Fabrics. Leicester College of Technology and Commerce. *Leiceste ,107.*

Demiroz A. (1998). A Study of Graphical Representation of Knitted Structures. *PhD Thesis, UMIST,* Manchester, UK .

Doyle, D.J. (1953). Fundamental Aspects of the Design of Knitted Fabrics. The *Journal of The Textile Institute, 44,* 561–578.

Eltahan, Sultan & Mito. (2016). Determination of loop length, tightness factor and porosity of single jersey knitted fabric. *Alexandra Engineering Journal,* 55(2), 851-856.

Eltahan, E. (2016). Effect of Lycra Percentages and Loop Length on the Physical and Mechanical Properties of Single Jersey Knitted Fabrics. *Journal of Composites*; 7.

Gravas,E., Kiekens, P. & Langenhove, L. (2005). An Approach to the 'Proknit' System and Its Value in the Production of Weft-knitted fabrics. *AUTEX Res. J., 5*(4), 220-227.

Growers, C. & Hunter, F.N. (1978). The Wet Relaxed Dimensions of Plain Knitted Fabrics. *The Journal of The Textile Institute. 69,* 108-115.

Heap, S.A, Greenwood, P.F., Leah, R.D., Eaton, J.T., Stevens, J.C. & Keher, P. (1983). Prediction of Finished Weight and Shrinkage of Cotton Knits-The Starfish Project: Part I: Introduction and General Overview. *The Journal of The Textile Institute, 53,* 109–119.

Heap, S.A. (1989). Low Shrink Cotton Knits Textiles Fashioning the Future. *Textile Institute Annual World Conference Proceedings.* Nottingham, United Kingdom.

Heap, S.A. & Stevens, J.C. (1992). Shrinkage, If You Can Predict It You Can Control It. *Cotton Technol. Int.,* 1.

Knapton, J.J.F., Ahrens, F.I., Ingenthron, W.W. & Fong, W. (1968). The Dimensional Properties of Knitted Wool Fabrics, Part I: The Plain Knitted Structure. *The Journal of The Textile Institute, **38**,* 999–1012.

Knapton, J.J.F., Truter, E.V. & Aziz AKMA. (1975). Geometry, dimensional properties and stabilization of the cotton plain jersey structure. *The Journal of The Textile Institute, 66,* 413-419.

Kurbak, A.& Amreeva, G. (2006). Creation of a Geometrical Model for Milano Rib Fabric. *Textile Res. J., 76*(11), 847-852.

Leaf, G.A.V. & Glaskin, A. (1955). Geometry of Plain Knitted Loop. *The Journal of The Textile Institute,46,* T587.

Leong, K.H., Falzon, P.J., Bannister, M.K. & Herszberg, I. (1998). An Investigation of the Mechanical Performance of weft knitted. *Milano Rib Glass/Epoxy Composites, Comp. Sci. Technol., 52,* 239-251.

Mobarok, A.K.M. (2012). Prediction of dimension and performance of finished cotton knitted fabric from knitting variables. *Annals of the University of Oradea: fascicle of Textiles, (2)*; 99-103.

Munden, D.L. (1959). The Geometry and Dimensional Properties of Plain Knit Fabrics. *The Journal of The Textile Institute., 50,* T448-T471.

Munden, D.L. (1960). The Dimensional Behaviour of Knitted Fabrics. *The Journal of The Textile Institute. 51,* 200–209.

Munden, D.L. (1968). Knitting Versus Weaving. *Textile Mercury Int., 12,* 10-13.

Nayak, R., Kanesalingam, S., Houshyar, S., Vijayan, A. & Wang, L. (2016). Effect of Repeated Laundering and Dry-cleaning on the Thermo-physiological Comfort Properties of Aramid Fabrics. *Fibers and Polymers*; 17(6), 954-962.

Nutting, T.S. & Leaf, G.A.V. (1968). A generalised geometry of weft knitted fabrics. *The Journal of The Textile Institute, 55,* 45–53.

Poincloux, S., Adda-Bedia, M. &Lechenault, F. (2018). Geometry and Elasticity of a Knitted Fabric. *Physical Review X*; 8(2).

Saravana, KT. & Sampath, V.R. (2012). Prediction of dimensional properties of weft knitted cardigan fabric by artificial neural network system. *Journal of Industrial Textiles*, *42*(4), 446-458.

Sharma, I.C., Ghosh, S. & Gupta, N.K. (1985). Dimensional and Physical Characteristics of Single Jersey Fabrics. *Textile Research Institute. 0040-5175/85/55003-149*.

Sitotaw, D. & Adamu, B. (2018). Tensile Properties of Single Jersey and 1x1 Rib Knitted Fabrics Made from 100% Cotton and Cotton/Lycra Yarns. *Journal of Engineering*; 7.

Sitotaw, D. (2018). Dimensional Characteristics of Knitted Fabrics Made from 100% Cotton and Cotton/Elastane Yarns. *Journal of Engineering*; 5.

Ulson, A.A., Cabral, L.F. & Souza, M.A.G. (2010). Prediction of Dimensional changes in circular Knitted cotton fabrics. *Textile Research Journal*, *80*(3), 236-252.