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STUDYING VARIATION IN LOOP LENGTH IN A COTTON INTERLOCK FABRIC AFTER THE WEAVING AND DYEING PROCESS

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Abstract: *The 100% cotton interlock structure has been widely used to produce winter garments thanks to its thermal properties and comfort. However as with all weft-knitted fabrics, it presents much dimensional instability. For a long time now, companies have attempted to minimise this problem by optimising production processes and implementing quality controls to obtain more dimensionally stable fabrics. The dimensional instability of knitted fabrics from their production stage until a finished fabric is formed is subject to wide variability and, therfore, needs to be minimised. One of the variables that intervenes in fabric shrinkage is loop length.The process followed to analyze this in accordance with regulation UNE-EN 14970 is somewhat bothersome as it is necessary to identify wales and the direction samples unravel 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 this 10 times to then calculate its mean. This study proposes finding the relationship between loop length and the variables wales/cm, courses/cm, stitch density/cm^2, weight, tightness factor, K_c, K_w* and *K_r to obtain knitted fabrics with an optimum dimensional stability to thus guarantee end product quality.*

Key words: *Interlock fabrics, skrinkage, knitted fabric, loop length, cotton.*

1. INTRODUCTION

At the beginning of the 20th century, Chamberlain [1] attempted to discover the loop shape of a knitted fabric.

Doyle and Hurd [2] found that the knit density in plain-knitted fabrics in a dry relaxation state depends only on loop length and is independent of other knitted fabric variables.

Munden [3,4] showed that the natural loop shape is determined by minimum energy conditions, which mean t only similar loops, and the following equations were proposed: ($K_c = c \times l$, $K_w = w \times l$, $K_r = K_c/K_w$), where c and w are courses/length unit and wales/length unit. These equations have been applied for many years to plain-knitted fabrics.

Nutting and Leaf [5] introduced another variable, called count, and proposed making a minor modification to the basic equation.

Knapton [6] not only demonstrated that dimensional stability in plain-knitted fabrics can be achieved by mechanical means, relaxation techniques or chemical treatments, but stable loop geometry is almost identical for wool and cotton in plain-knitted fabrics.

By way of conclusion, almost all the found studies refer to the variable *loop length* as one of the most important factors that intervenes in the dimensional variation of knitted fabrics. The objective of the present study was to find the existing relationships between the variable *loop length* and the variables *wales/cm*, *courses/cm*, *stitch density/cm²*, *weight*, *tightness factor*, K_c, K_w and K_r.

2. MATERIALS AND METHODS

2.1 Description of the fabric manufacturing process

The linear yarn density used to manufacture the fabrics with an interlock structure (I1 and I2) was 30 Ne (combed cotton). The machines employed to make pieces are shown in *Table 1*.

Table 1: *The circular machines used to make fabrics I1 and I2.*

MODEL	DIAMETER (inches)	GAUGE	NEEDLES	No. SETS
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

To undertake this study, 15 pieces were manufactured of each fabric (I1, I2), which weighed no more than 15 kg, for each machine diameter. Thus 270 pieces were produced in all. The difference between the two fabrics produced for each machine diameter is loop length. Fabrics were obtained whose mean loop length in I1 was 0.331 cm and 0.356 cm in I2 after the weaving process.

After weaving, the following relaxation state was differentiated: *"Weaving and dry relaxation (WDR)"*

Next lots were submitted to an exhaustion bleaching process in overflow machines. To analyse the obtained fabric, two relaxation states in fabrics I1 and I2 were differentiated after the dyeing process:

- ***Dyed and dry relaxation (DDR)***. The dyed fabric was submitted to a conditioning environment until a constant mass was obtained
- ***Dyed and wash relaxation (DWR).*** The fabric was dyed and conditioned until a constant mass was obtained to be then submitted to a dimensional stability analysis according to procedure 4N of Standard UNE EN ISO 6330, of September 2012. This status is considered a completely relaxed one.

2.2 Description of the variables to be analysed

The variables analysed for relaxation states *WDR*, *DDR* and *DWR* were: wales/cm (*P*), courses/cm (*C*), Stitch density/cm² (*DM*), weight (*G*), loop length (*LM*), tightness factor *(TF)* and Munden's constants (K_c, K_w and K_r).

To determine the variables *P*, *C* and *DM*, Standard UNE-EN 14971 was followed. *G* was calculated according to Standard UNE-EN 12127, while Standard UNE-EN 14970 was followed to determine *LM*.

To calculate the constants (K_c, K_w and K_r), Munden's equations were used. To calculate the variable *TF*, the equation below was used:

$$TF = \frac{\sqrt{Dl}}{LM} \quad \textbf{(1)}$$

3. RESULTS AND DISCUSSION

The mean, standard deviation and the 95% confidence interval (CI) of the results from the analysis done of the obtained pieces made from fabrics I1 and I2 in relaxation states *WDR*, *DDR* and *DWR* are provided in Tables 2 and 3.

Table 2: *The experimental results of fabrics I1 and I2 after weaving.*

Sample No.	Variable	WDR Relaxation state		
		M	s_i	CI
	P	27.4	0.4128	[27.2;27.6]
	C	11.7	0.3750	[11.5;11.9]
	DM	321.8	8.7182	[317.1;326.4]
	G	216.4	4.3756	[214.0;218.7]
I1	LM	0.341	0.0088	[0.336;0.345]
	TF	13.032	0.3394	[12.851;13.213]
	K_c	4.00	0.1191	[3.94;4.06]
	K_w	9.34	0.3062	[9.18;9.51]
	K_r	0.43	0.0181	[0.42;0.44]
	P	23.6	0.6418	[23.4;23.9]
	C	11.9	0.6002	[11.7;12.2]
	DM	281.9	13.7145	[276.6;287.2]
	G	198.7	7.3539	[185.8;201.5]
I2	LM	0.365	0.0123	[0.360;0.370]
	TF	12.166	0.4046	[12.010;12.323]
	K_c	4.36	0.1855	[4.29;4.43]
	K_w	8.62	0.3527	[8.48;8.76]
	K_r	0.507	0.0327	[0.49;0.52]

Table 3. *The experimental results of fabrics I1 and I2 after the dyeing process.*

Sample No.	Variable	Relaxation States					
		DDR			DWR		
		M	s_i	CI	M	s_i	CI
	P	27.4	1.6821	[27.1;27.7]	29.2	1.4390	[28.9;29.4]
	C	14.5	0.5668	[14.4;14.6]	13.7	0.5071	[13.6;13.8]
	DM	396.8	24.5142	[392.9;400.7]	398.5	24.9974	[394.6;402.5]
	G	251.3	8.7335	[249.9;252.6]	262.4	11.3890	[260.6;264.2]
I1	LM	0.331	0.0082	[0.330;0.333]	0.331	0.0118	[0.329;0.333]
	TF	13.40	0.3297	[13.35;13.46]	13.42	0.4622	[13.35;13.49]
	K_c	4.80	0.1785	[4.79;4.83]	4.52	0.2007	[4.49;4.55]
	K_w	9.08	0.5728	[8.99;9.17]	9.65	0.3996	[9.58;9.71]
	K_r	0.53	0.0446	[0.52;0.54]	0.47	0.4694	[0.46;0.47]
	P	24.6	0.7250	[24.4;24.7]	26.2	0.9654	[25.9;26.4]
	C	14.2	0.4743	[14.0;14.3]	13.4	0.4457	[13.3;13.5]
	DM	348.2	13.8521	[345.2;351.3]	351.8	19.474	[347.5;356.1]
	G	239.0	6.4395	[237.5;240.4]	251.8	7.0314	[250.2;253.3]
I2	LM	0.356	0.0082	[0.354;0.358]	0.356	0.0097	[0.354;0.358]
	TF	12.46	0.2937	[12.39;12.52]	12.47	0.3459	[12.39;12.54]
	K_c	5.05	0.1497	[5.02;5.08]	4.78	0.1615	[4.75;4.82]
	K_w	8.76	0.3417	[8.68;8.83]	9.33	0.3888	[9.24;9.42]
	K_r	0.58	0.280	[0.57;0.58]	0.51	0.0206	[0.51;0.52]

Figures 1-8 represent the mean of the variables *P, C, DM, G, TF*, K_c, K_w and K_r for fabrics *I1* and *I2* The average loop length of fabric I1 was 0.331 cm and it was 0.356 cm of fabric I2.

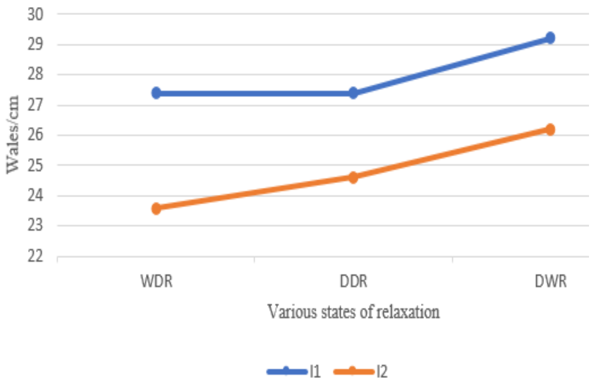

Fig.1. *Relationship between the loop length (LM) of fabrics I1 and I2 and wales/cm (P) in relaxation states WDR, DDR and DWR.*

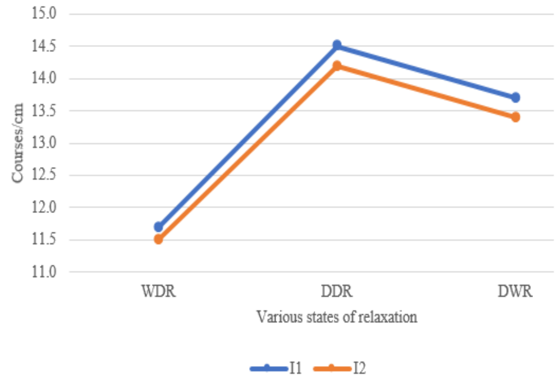

Fig. 2. *Relationship between the loop length (LM) of fabrics I1 and I2 and courses/cm (C) in relaxation states WDR, DDR and DWR.*

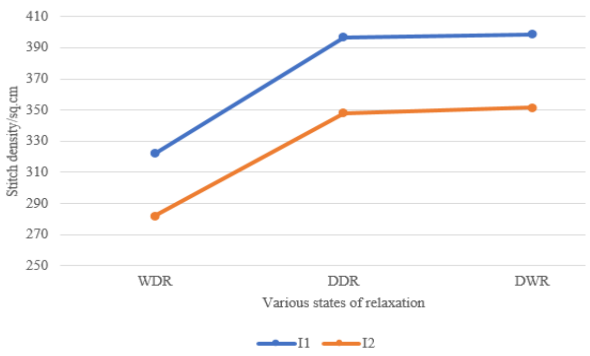

Fig. 3. *Relationship between the loop length (LM) of fabrics I1 and I2 and stitch density (DM) in relaxation states WDR, DDR and DWR.*

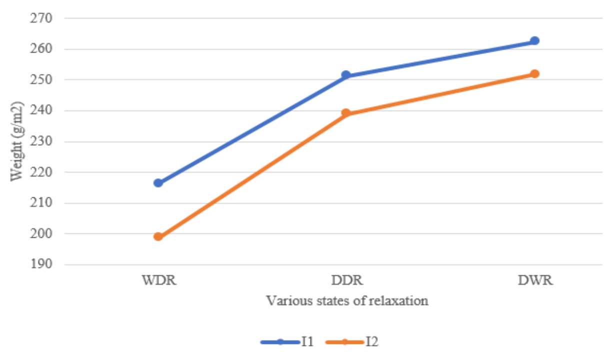

Fig.4. *Relationship between the loop length (LM) of fabrics I1 and I2 and weight (G) in relaxation states WDR, DDR and DWR.*

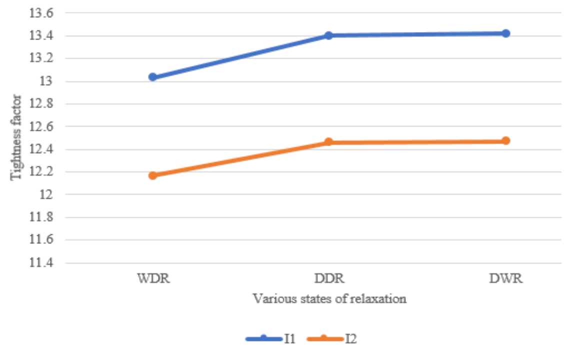

Fig. 5. *Relationship between the loop length (LM) of fabrics I1 and I2 and tightness factor (TF) in relaxation states WDR, DDR and DWR.*

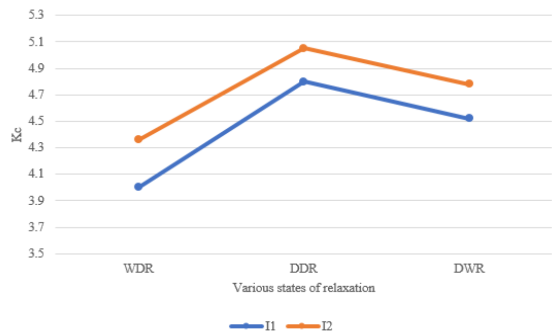

Fig. 6. *Relationship between the loop length (LM) of fabrics I1 and I2 and* K_c *in relaxation states WDR, DDR and DWR.*

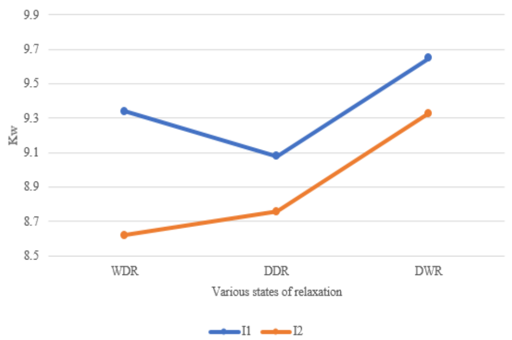

Fig. 7. *Relationship between the loop length (LM) of fabrics I1 and I2 and K_w in relaxation states WDR, DDR and DWR.*

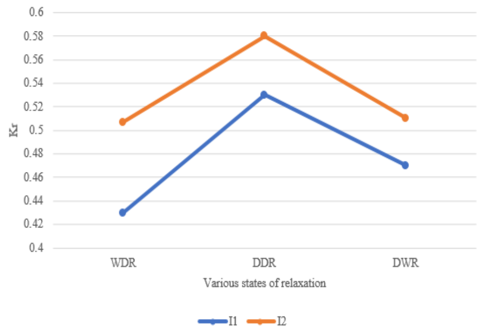

Fig.8. *Relationship between the loop length (LM) of fabrics I1 and I2 and K_r in relaxation states WDR, DDR and DWR*

According to the results shown in *Figure 1* we can see how *loop length* is inversely proportional to wales/cm for all the relaxation states. There is a marginal difference in the variable *wales/cm* for both fabrics: *I1* (with a shorter loop length) and *I2* (with a longer loop length) in all the relaxation states, and the value obtained for fabric *I1* of 3-4 wales/cm is higher than that of fabric *I2*. We can also see how the *wales/cm* value for shorter *loop lengths* tends to be similar between relaxation states *WDR* and *DDR*, while wales/cm vary more with higher *loop length* values. The *wales/cm* value for both fabrics *I1* and *I2* increases proportionally and significantly, and peaks in relaxation state *DWR* in both cases.

The results provided in *Figure 2* show that *loop length* is inversely proportional to *courses/cm*, although the difference obtained with the variable *courses/cm* between the higher and lower *loop length* values is not as marked as it is for the variable *wales/cm*. Very marked growth is seen for fabrics *I1* and *I2* between relaxation states *WDR* and *DDR*, which diminishes in relaxation state *DWR*.

Figure 3 evidences how the relationship between *loop length* and *Stitch density* is inversely proportional. Marked and proportional growth is noted for both fabrics *I1* and *I2* between relaxation states *WDR* and *DDR*, which becomes stable in relaxation state *DWR*.

Figure 4 shows how the relationship between *loop length* and *weight* is inversely proportional. A positive and very pronounced slope that is proportional to both fabrics *I1* and *I2* is observed between relaxation states *WDR* and *DDR*, which diminishes for relaxation state *DWR*.

Figure 5 evidences how *tightness factor* increases when *loop length* is shorter in all the relaxation states. The variable *tightness factor* grows between both relaxation states *WDR* and *DDR*, and becomes stable for relaxation state DWR.

From the results in *Figure 6*, we can see how the relationship between *loop length* and K_c is directly proportional. Marked and proportional growth is observed for fabrics *I1* and *I2* between relaxation states *WDR* and *DDR*, which diminishes for relaxation state *DWR*.

According to the results indicated in *Figure 7*, the relationship between *loop length* and K_w is inversely proportional. The variable K_w is seen to grow in the fabrics with a longer *loop length* (*I2*), while the opposite is true for the fabrics with a shorter *loop length* (*I1*), between relaxation states *WDR* and *DDR*. Yet between relaxation states *DDR* and *DWR*, both fabrics display proportional growth.

Figure 8 indicates a directly proportional relationship between *loop length* and K_r, and the growth of K_r between relaxation states *WDR* and *DDR*, which diminishes between *DDR* and *DWR*.

4. CONCLUSIONS

The present study analysed the relationship between *loop length* and the variables *wales/cm* *courses/cm*, *stitch density/cm*^{2}, *weight*, *tightness factor*, K_c, K_w and K_r for the interlock structure. The variable *wales/cm* displayed better dimensional stability for the *loop length* value of 0.331 cm than for that of 0.356 cm, which was not differentiated in the variable *courses/cm*, and behaved similarly. The reduction in courses/cm in relaxation state *DWR* was due to the fabric reaching its maximum relaxation in this state. Evidently throughout the production process, the fabric was submitted to stretchings and, thus, to transversal shrinkage, which allowed its equilibrium state to be recovered in relaxation state *DWR*. The variables *stitch density/cm*^{2} and *tightness factor* obtained higher values in the fabric with a shorter *loop length*, but were proportional to that with a longer *loop length*, and a notable increase was noted between relaxation states *WDR* and *DDR*, before it stabilised between relaxation states *DDR* and *DWR*. The value of the variable *weight* increased with lower *loop length* values, but they were proportional to the higher loop length values in all the relaxation states. The variables K_c and K_r obtained higher values in the fabrics with longer *loop lengths*, but were proportional to the fabrics with shorter *loop lengths*. Evidently they performed like the variable *courses/cm* as K_c was a dependent variable of *courses/cm*. The variable K_W increased in the fabric with a shorter *loop length*..

Finally, we reached the conclusion that as *loop length* increased for all the relaxation states, *wales/cm*, *courses/cm*, *stitch density/cm*^{2}, *weight*, *tightness factor* and K_w lowered, while K_c and K_r increased, and *vice versa*.

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