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IMPROVING KNITTED FABRICS BY A STATISTICAL CONTROL OF DIMENSIONAL CHANGES AFTER THE DYEING PROCESS

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Abstract: *One of the most important problems that cotton knitted fabrics present during the manufacturing process is their dimensional instability, which needs to be minimised. Some of the variables that intervene in fabric shrinkage are related with its structural characteristics, use of fiber when producing yarn, the yarn count used or the dyeing process employed. Conducted under real factory conditions, the present study attempted to model the behaviour of a fabric structure after a dyeing process by contributing several algorithms that calculate dyed fabric stability after the first wash cycle. Small-diameter circular machines are used to produce garments with no side seams. This is the reason why a list of machines that produce the same fabrics for different widths needs to be made available to produce all the sizes of a given garment. Two relaxation states were distingued for interlock fabric: dyed and dry relaxation, and dyed and wash relaxation. The linear density of the yarn employed to produce sample fabric was combed cotton Ne 30. The machines used for optic bleaching were Overflow. To obtain knitting structures with optimum dimensional stability, different statistical tools were used to help us to evaluate all the production process variables (raw material, machines and process) responsible for this variation. This allowed to guarantee product quality without creating costs and losses.*

Key words: *Dimensional stability, shrinkage, knitted fabric, prediction, relaxed fabrics.*

1. INTRODUCTION

The considerable interest in studying the dimensional stability of cotton fabrics is shown by the publications found on this theme. One of the most highlighted publications talks about predicting dimensional changes in circular knitted cotton fabrics [1]. Along these lines, Ulson de Souza, Cabral Cherem and Guelli U.Souza produced a database for the relaxation processes for knitted cotton products for all production phases. In parallel, a development system is required that simulates all the process variables. This study is based on the principle that each industry must determine its own ***K*** dimensional factor, calculated for each processing line. According to Munden [2], with their equations it is possible to check that the factors which represent fabric dimensions are related with courses, gauge and loop length. Later for plain weave knitted fabrics, Doyle [3] discovered that stitch density depended only on loop length, and is independent of yarn variables and knitted fabric. Another study by Münden [4] showed that, in a minimum energy state, the dimensions of plain weave wool knitted fabrics depend only on the yarn length in each loop. Nutting [5] introduced another variable, yarn count, and proposed making a minor modification to the basic equation. Knapton [6] demonstrated that dimensional stability in plain weave knitted fabrics can be accomplished by mechanical means, relaxation techniques or chemical treatments. This work also showed that the stable loop geometry for wool and cotton in plain weave knitted fabrics is almost identical.

The "Starfish" Project [7] [8] is a research programme that attempts to provide a rigorous working method and a sufficiently complete database to predict shrinkage and weight per square metre of cotton knitted fabric based on knowing only some parameters (machine, yarn, knit density), the end process and the final nominal dimensions. This project defines a ***"reference relaxation state for fabric",*** like that obtained after a wash and dry cycle by centrifuging, followed by four rinse cycles and tumble drying. Then it builds a database that describes a wide range of structure qualities According to this database, it generates some equations by linking the finished fabric parameters to the dimensions of the aforementioned state.

Conducted under real factory conditions, the present study attempted to model the behaviour of a fabric structure after a dyeing process by contributing several algorithms that calculate dyed fabric stability after the first wash cycle. It also attempted to calculate weight, stitch density and fabric performance with two variables: variation in tubular fabric width between the first wash and its initial stage after dyeing ***(ΔA)*** and wales/cm.

2. MATERIALS AND METHODS

2.1 Description of the fabric manufacturing process

Small-diameter circular machines are used to produce garments with no side seams (vests, bed covers, underwear, etc.). This is the reason why a list of the machines that produce the same fabric for different widths needs to be made available to produce all the sizes of a given garment because this tube width corresponds to the garment's girth.

The linear density of the yarn employed to produce sample fabric A was combed cotton Ne 30**.** The present study focused on knitted weft fabrics with an interlock structure. The machine used to produce pieces was a E20 gauge "Mayer IHG II", 12 inch diameter, 20 feeders, and 756 x 2 needles. The working speed was 70 rpm. Twenty pieces produced on this machine, which corresponded to different batches, were selected. Once they had been identified, they were each included in their batch, which meant 20 batches with 25 pieces each.

Next batches were submitted to an exhaustion dyeing process. The machines used for optic bleaching were Overflow. After completing hydroextraction and then drying pieces, those to be analysed were identified by taking one sample of them and placing it in a conditioning atmosphere.

Two relaxation states were distinguished for interlock fabric sample A:

- ***Dyed and dry relaxation (DDR).*** The dyed fabric was placed in a conditioning atmosphere until a constant mass was obtained.
- ***Dyed and wash relaxation (DWR).*** The fabric was dyed and conditioned until a constant mass was obtained, and it was submitted to a dimensional stability analysis according to Standard UNE EN ISO 6330, of September 2012.

2.2 Description of the variables to be analysed

The variables analysed for each relaxation state were: wales/cm (***P***), courses/cm (***C***), stitch density/cm^2 (***DM***), weight (***G***), width (***A***), loop length (***LM***), performance (***R***), shrinkage length (***EL***) and shrinkage width (***EA***). The variables that corresponded to relaxation state ***dyed and dry relaxation (DDR)*** are shown with subscript ($_i$), while those that corresponded to relaxation state ***dyed and wash relaxation (DWR)*** are shown with subscript ($_f$).

Standard UNE-EN 14971 was followed to determine variables ***P***, ***C*** and ***DM***. ***G*** was calculated according to Standard UNE-EN 12127, and ***EL*** and ***EA*** according to Standard UNE EN ISO 6330.

Variable ***ΔA*** represented variation in the existing width between the width obtained after relaxation state ***DWR*** *(A_f)* and that obtained from relaxation state ***DDR*** *(A_i).*

3. RESULTS AND DISCUSSION

The average, standard deviation and 95% confidence interval of the results obtained in the analysis with the 20 pieces included from distinct batches for relaxation states ***DDR*** and ***DWR*** are shown in ***Table 1***.

Table 1: *The experimental results of each variable in relaxation states DDR and DWR.*

PROPERTIES		Relaxation							
		Dry (DDR)				Wash (DWR)			
		Variable	Result	S_i	95% Confidence interval	Variable	Result	S_i	95% Confidence interval
Wales/cm		P_i	26.0	2.8243	[24.6-27.4]	P_f	28.1	2.5362	[26.9-29.3]
Courses/cm		C_i	14.1	0,5487	[13.9-14.4]	C_f	13.9	0.7039	[13.5-14.2]
Stitch density/cm^2		DM_i	368.42	50,2365	[344.21-392.63]	DM_f	390.68	48.597	[367.26-414.11]
Weight, g/m^2		G_i	254.66	16.5123	[246.70-262.62]	G_f	267.79	18.0656	[259.08-276.50]
Width, cm		A_i	26.3	0.8932	[25.84-26.70]	A_f	26.7	1.0879	[26.2-27.3]
Loop length, mm		LM_i	3.44	0.2045	[3.34-3.53]	LM_f	3.40	0.2214	[3.29-3.51]
Performance, m/kg		R_i	7.501	0.3466	[7.334-7.668]	R_f	7.008	0.2506	[6.887-7.129]
DC %	Length		-	-	-	EL	-7.05	0.0242	[-8.22--5.89]
	Width		-	-	-	EA	+1.74	0.0182	[+0.86-+2.61]

Table 1 shows a marked variation between the performances of the two relaxation states, where ***R_f*** was greater than ***R_i***, which implies that the fabric was submitted to stretchings during the dyeing process. The dimensional stability in the longitudinal sense ***(EL)*** confirmed that the fabric had relaxed after the first wash, had shrunk by -7.05% longitudinally, while wales (***P_f)*** and weight had increased. Fabric width also increased and, consequently, so did the dimensional stability to width ***(EA)*** by +1.74%, while courses (***C_f***) were lost.

After analysing the variables in each relaxation state, the intention was to see the relationship that existed between them and to obtain models that can predict variables ***EL, EA***, ***G_i DM_i*** and ***R_i***. The models obtained by linear regression are found in ***Table 2.*** For dimensional stability in the longitudinal sense ***(EL),*** the selected model showed a linear relationship with variation in the width between both relaxation states ***(ΔA)***, while ***EL*** shrank as ***ΔA*** increased. However, the relationship between ***ΔA*** and ***EA*** in the proposed model acted in the opposite way as ***EA*** increased as ***ΔA*** did. A model was proposed to predict variable ***G_i*** from the existing increasing relationship with variable ***Pi***, and ***G_i*** increased as ***P_i*** did. Variable ***DM_i*** presented an increasing linear relationship compared to ***G_i***, while the relationship between ***R_i*** and ***G_i*** diminished in the models proposed in *Table 2*.

Table 2: *Models proposed by linear regression.*

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	LINEAR RELATIONSHIP	R^2
EL	ΔA	***EL=-0.0444888-0.055558·ΔA***	87.9356%
EA	ΔA	***EA=-0.002208+0.0417924· ΔA***	87.8229%
G_i	P_i	***G_i=110.68+5.5375·P_i***	89.9707%
DM_i	G_i	***DM_i=-359.95+2.86017·G_i***	88.3814%
R_i	G_i	***R_i=12.1763-0.0183587·G_i***	76.4545%

Of the models proposed in ***Table 2,*** it can be stated that from knowledge about dependent variables ***ΔA*** and ***P_i***, dependent variables ***EL***, ***EA***, **G_i**, ***DM_i*** and ***R_i*** are predicted. ***Figures 1-6*** graphically represent the proposed models.

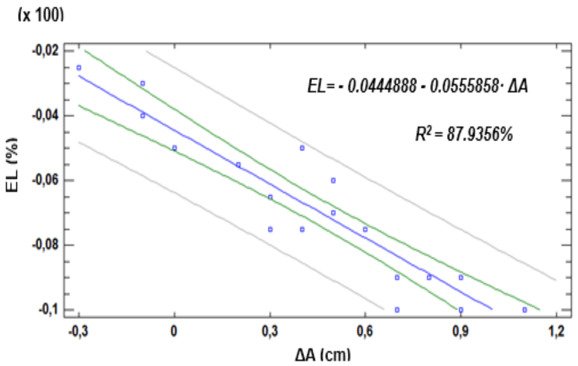

Fig.1: *Graph of the adjusted linear regression model that describes the relationship between longitudinal shrinkage **(EL)** and the width differential **(ΔA).***

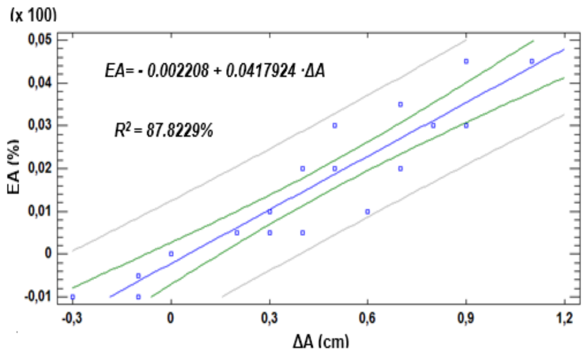

Fig.2: *Graph of the adjusted linear regression model that describes the relationship between shrinkage at width **(EA)** and the width differential **(ΔA)**.*

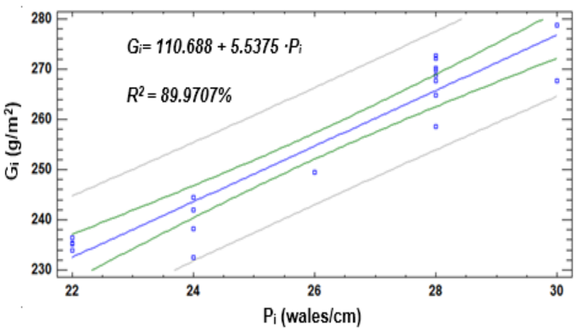

Fig.3: *Graph of the adjusted linear regression model that describes the relationship between variables weight **(G_i)** and wales/cm **(P_i).***

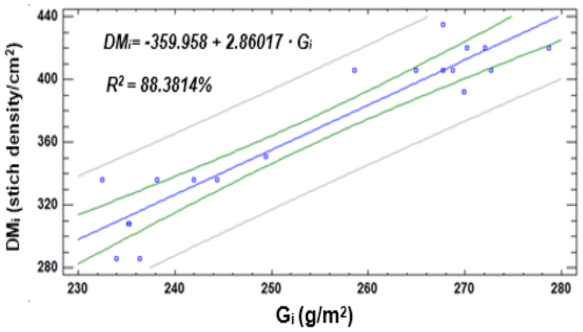

Fig.4: *Graph of the adjusted linear regression model that describes the relationship between variables stitch density/cm^2 **(DM_i)** and weight **(G_i).***

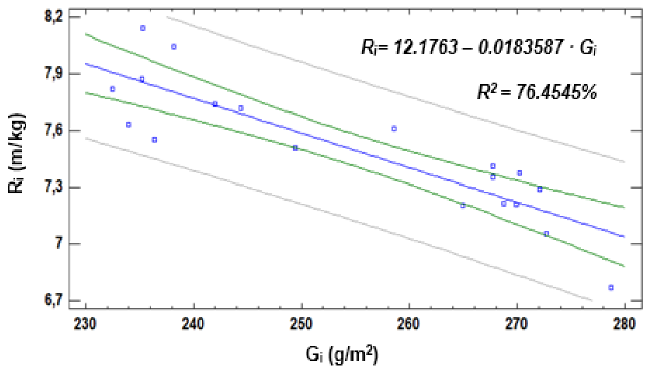

Fig.5: *Graph of the adjusted linear regression model that describes the relationship between variables performance **(R_i)** and weight **(G_i).***

Figures 1-5 represent the models proposed for variables ***EL***, ***EA***, G_i, DM_i and R_i. They all had a high R^2, which would explain the very good variability from the linearity that existed with independent variables ΔA (in the models about dimensional stability), P_i (in the dependent model of G_i) and G_i (in the models dependent on DM_i and R_i).

4. CONCLUSIONS

This study has modelled the dimensional properties of the interlock fabric under study by linear regression models. Therefore, these models help us to predict the variability of the fabric's dimensional stability in a longitudinal sense and width-wise (***EL*** and ***EA)*** from the variation in the width of the tubular structure obtained after the first wash cycle (***Dyed and Wash Relaxation)*** and its initial state (***Dyed and Dry Relaxation)***. Despite having to run a wash test to know variation in fabric width with these proposed models, there is no need to run the sample marking and measuring process to determine dimensional variations, which evidently optimises the analysis process.

In parallel, by knowing the fabric's wales/cm values in relaxation state ***Dyed and Dry Relaxation,*** weight can be estimated without having to necessarily run an analysis in the laboratory as only a balance and sample cutter are required. Indeed simply using a thread counter suffices. Once this variable is known, it is possible to predict stitch density/cm^2 and fabric performance in parallel. By knowing fabric performance, we can deduce if a fabric has been considerably stretched or not, and can decide if it is re-operated to obtain the desired performance before running further analyses.

Improving the variability obtained in the different analysed results from each batch is proposed to optimise the dyeing process to, thus, avoid as much as possible any stretching that might take place during this process and overfeeding fabric in the drying place so it better recovers.

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