Enric Carrera-Gallissà[1,*],
Xavier Capdevila[1],
Josep Valldeperas[2]

Influence of Silk-Like Finishing Process Variables on Fabric Properties

DOI: 10.5604/01.3001.0010.2778

[1] **Polytechnic University of Catalonia, Textile and Paper Department,**
Terrassa, Spain
* E-mail: enric.carrera@upc.edu

[2] **Polytechnic University of Catalonia, Terrassa Institute of Textile Research and Industrial Cooperation,**
Terrassa, Spain

Abstract
A 100% PES woven fabric was subjected to a silk-like finishing treatment using a two-factor (soda concentration and vaporisation time), three-level experimental design on a pilot plant in order to examine the influence of process variables on fabric drape and hand, and also to relate weight loss to the properties of the finished fabric. Weight loss in the fabric was significantly related to the process variables studied. By contrast, the vaporisation time affected no drape indicator, even though it interacted significantly with the soda concentration, which influenced three of the five indicators examined. Also the vaporisation time affected no FAST property, but its interaction with the soda concentration had a significant effect on all drape-related FAST parameters. Regression equations accurately predicting drape indicators and physico-mechanical properties of the fabric studied from its weight loss are proposed.

Key words: *silk-like finishing, drape, FAST.*

Introduction

Silk-like finishing, which is used to make 100% PES fabrics similar to natural silk in drape and hand, has been a common industrial treatment for a long time [1]. Essentially the process involves treating polyester fabrics with an aqueous solution of caustic soda under variable conditions of concentration, temperature and exposure time. As a result, polyester fibres undergo nucleophilic substitution and hydrolysis by reaction with alkali metal hydroxides, hydroxyl ions in the hydroxides attacking the electron-deficient carbon atoms of carbonyl groups in the polyester. to form an intermediate anion. This is followed by chain scission and leads to the formation of terminal hydroxyl and carboxyl groups [2].

Hot soda solutions hydrolyse polyester fibre surfaces, thereby gradually reducing their thickness and weight. The hydrolysis rate depends on the alkali concentration and temperature used. Some studies have revealed a linear relationship between the treatment time and square root of the residual fibre weight [2, 3], while others have found a non-linear relationship between fibre weight loss and alkali concentration and temperature at each treatment time [1]. Industrial and research evidence suggests that the temperature has an even stronger effect than alkali concentration on the reaction rate, the latter variable in turn being more influential than the treatment time [2].

An appropriate combination of alkali concentration and temperature can be used to obtain very interesting finishing effects. In fact, removing the outer layer of fibres leaves a slightly grainy, wavy surface that confers a softer touch and increased drape to fabrics.

Some authors have investigated the hydrolysis of polyester fibre with various bases in non-aqueous media as well as in aqueous sodium hydroxide [4, 5]. Fabric weight loss resulting from the silk-like finishing process has been the subject of several studies since the 1980s, which have revealed that treating fabric with soda has no effect on the fibre cross-section [2, 6] but alters fibre and yarn thickness [7, 8]. The process has also been studied in relation to the mechanical properties of fabric yarns [2, 7], loss of tensile strength [9]; specific structure energy [7], bending stiffness [10], drop properties [11], air permeability [7]; water vapour and liquid water transfer [12], the contact angle and wicking [7, 12], hand properties [6] and the effects of weight loss in polyester microfibre-based fabrics on their physical and mechanical properties [13]. Other authors have examined the influence of silk-like finishing variables and their effects on polymer surfaces [2].

There have also been several studies on the action of sodium hydroxide in alcoholic media (methanol, ethanol, propanol and butanol) on polyester fabrics and its influence on fabric weight loss, tensile strength, density, crystallinity, thermal properties, surface properties (under an electron microscope) and the dielectric constant [14]. A study on the dielectric constant revealed that weight loss by the effect of polyester fabric hydrolysis differs for treatments with sodium hydroxide and those with a sodium alkoxide in a non-aqueous medium.

Objectives

Industrially the silk-finishing process is controlled mainly via fabric weight loss through the effect of soda treatment. The loss, however, is merely a means to an end rather than the aim. The pri-

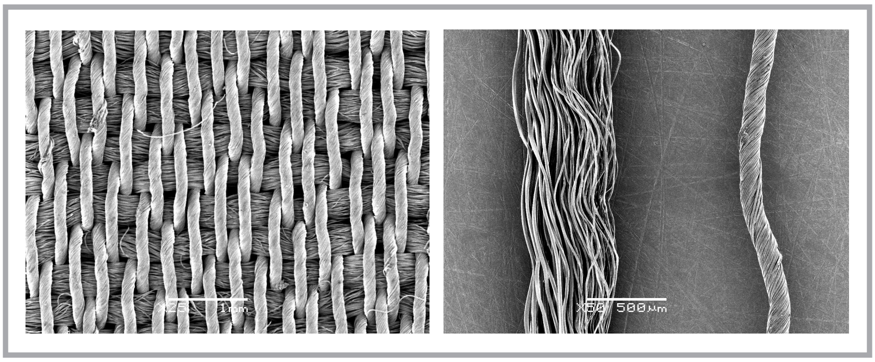


Figure 1. Left: woven fabric consisting of twisted continuous polyester filaments (warp) and untwisted continuous polyester filaments (weft). Right: magnified view of a weft filament (left) and warp filament (right).

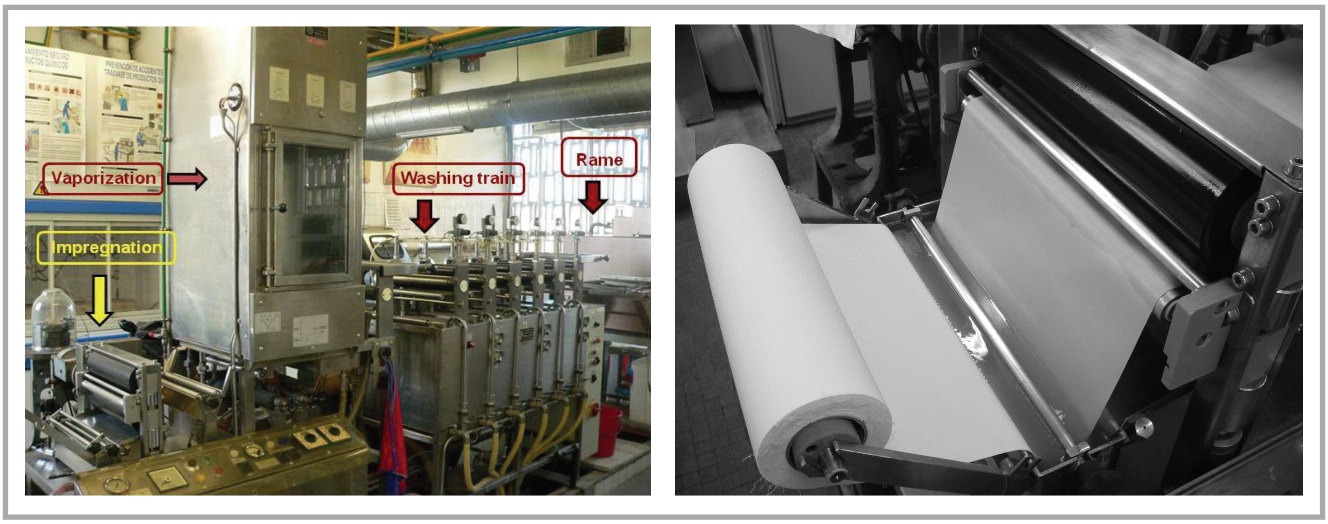


Figure 2. *Pad-Steam pilot plant used in the fabric finishing treatment.*

mary aim of this work was to examine the influence of process variables of the silk-like finishing treatment on fabric drape, as well as the relationship between weight loss and the properties of the finished fabric.

Material and methods

The present study was conducted on a 100% PES fabric (see ***Figure 1***), the characteristics of which are summarised in ***Table 1***. The fabric was subjected to a silk-like finishing treatment on a Pad-Steam pilot plant, comprising an impregnation vat, vaporisation zone, washing train and drying zone (see ***Figure 2***). The plant is located at the Chemical Textile Technology Laboratory of the Textile Research and Industrial Cooperation Institute of Terrassa (INTEXTER), Universitat Politècnica de Catalunya (UPC).

Table 2 summarises characteristics of the experimental set-up used. The study was conducted in accordance with a two-factor (soda concentration and vaporization time), three-level experimental plan (see ***Figure 3***). The nine experiments needed bounded an experimental region consistent with the usual industrial conditions for this fabric and aerial weight. Using a 3^2 factorial design allowed not only linear effects and interactions but also curvature effects to be examined. The design comprised only 8 degrees of freedom, and hence it precluded assessing experimental error. The principal effects possessed 2 degrees of freedom each and interactions 4. With two replications, the total number of degrees of freedom would have been (2·3^2) – 1 = 17 and that for experimental error 9.

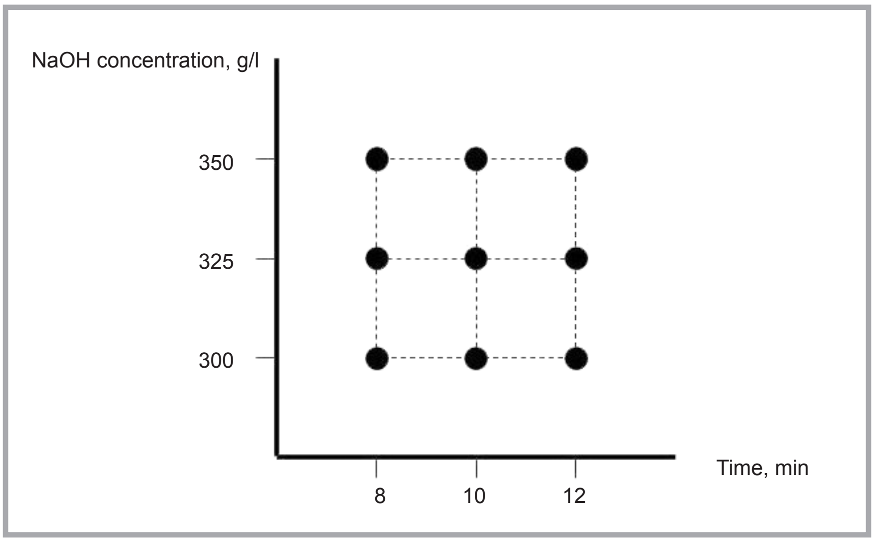


Figure 3. *Experimental design used. Each dot represents a response measured.*

Table 1. *Properties of the woven fabric studied.*

Property	Crude, washing and stabilisation at 120 °C
Composition	100% PES
Weave	Satin (3e^2, b. 2,2,1) (***Figure 1***)
Warp titre, tex	Twisted continuous filament, 19 400 tex
Weft titre, tex	Untwisted continuous filament, 43 800 tex
Aerial weight, g/m^2	260.540
Thickness at 2 g/cm^2, mm	0.497

Table 2. *Specifications of the Pad-Steam system used.*

Pilot plant width	33 cm
Foulard pressure	10 kg
NaOH concentration	300, 325 and 350 g/l + 2 g/l Sandopan DTC
Vaporisation temperature	105 °C, saturated vapour
Vaporisation time	8, 10 and 12 min
Washing	2 washing vats containing water at 60 °C and 1 at room temperature
Neutralisation	2 vats containing a 2 g/l concentration of 80% acetic acid
Rame temperature	90 °C
Rame drying time	1 min

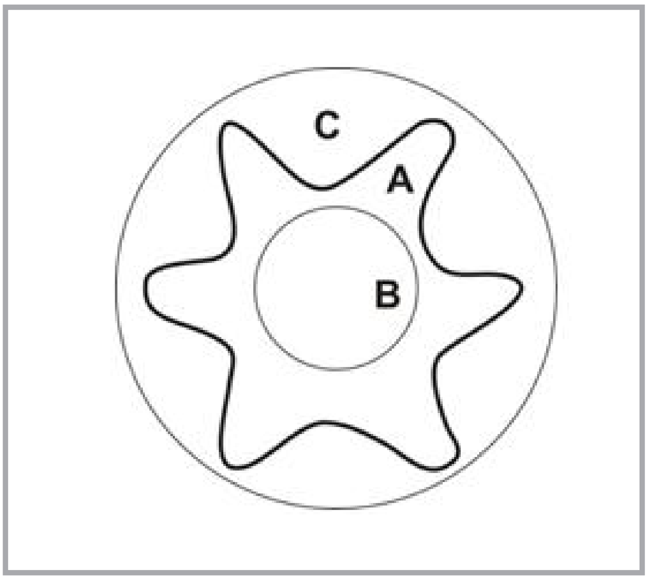


Figure 4. *Area of simple fall. A = area of simple fall, B = base blade area, C = specimen area.*

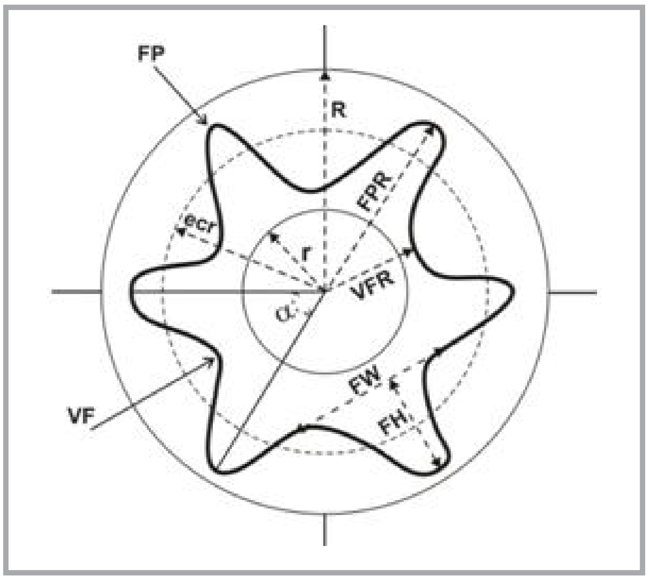


Figure 5. *FP = fold peak, VF = valley fold, FPR = fold peak radius, VFR = valley fold radius, FW = fold width, FH = fold height, r = support disc radius, R = specimen radius, ecr = equivalent circle radius, α = angle between consecutive folds.*

The 3^2 plan used is depicted schematically in ***Figure 3***. The null hypothesis (H_0) was that the properties of the target fabric would be insensitive to differences in the process variables and, hence, that the factors examined would have no effect. The alternative hypothesis was that the fabric properties studied would be influenced by changes in the process variables.

The finished fabric specimens obtained were subjected to a series of analyses in order to determine the specific physico–mechanical properties typically used to assess fabric drape industrially.

A literature search for the period 1950-2013 retrieved 36 different reported drape indicators. Despite the large number of indicators currently available, the drape ratio (%DR) continues to be the most widely used even though it has proved ineffective to explain drape shape. In order to assess the accuracy of the 36 indicators, we used a digital Cusick drape meter to calculate them for a total of 37 commercial drapery, woolmaking, shirtmaking and lining woven fabrics, spanning a wide range of composition, aerial weight and weave type [15]. A correlation analysis between indicators and subsequent suppression of duplicity and collinearity revealed that seven were mutually correlated. Also a principal component analysis of the results revealed an underlying structure consisting of three common factors which allowed the indicators to be classified into three different groups according to drape intensity, severity, and shape symmetry and variability. Cluster analysis, which was additionally used to examine the results in graphical form, singled out three clusters that coincided with the three factors in the underlying structure. A criterion for distinguishing fabrics with an identical drape ratio in terms of drape shape based on sequential application of four of the seven initially selected indicators was developed and experimentally validated.

In this study, drape was assessed using five of the seven indicators selected by the authors in a previous work on the evaluation of fabric drape [15].

The specific indicators used were as follows:

Drape ratio (*%DR*) [17], which was calculated from

$$\%\mathrm{DR} = \left(\frac{\mathrm{A-B}}{\mathrm{C-B}}\right) \cdot 100 \qquad (1)$$

the parameters of which are illustrated in ***Figure 4***.

Fold Number (*FN*) [18]. A fold was taken to be the maximum projection of the drape profile on a plane. Geometrically folds are roughly triangles of width *FW* and height *FH,* with a peak *FP* and two adjacent valleys *FV* as vertices (see ***Figure 5***).

Mean fold height (*FH*) [19], in mm, as measured from the line used to calculate *FW* (see ***Figure 5***).

Table 3. *Experimental tests conducted on the fabric.*

Parameter	Units	Equipment	Reference
Weight loss	%	Balance	UNE 339-76
Drape ratio, %DR	%	UPC digital drape meter	[15]
Fold number, FN	Folds	UPC digital drape meter	[15]
Fold height, FH	mm	UPC digital drape meter	[15]
Drape unevenness, %DU	%	UPC digital drape meter	[15]
Folding distribution, %Gp	%	UPC digital drape meter	[15]
Overall formability, F	mm^2	FAST	[16]
100% Warp stretching, Wp E100	%	FAST	[16]
100% Weft stretching, We E100	%	FAST	[16]
Bias elongation, Be	%	FAST	[16]
Overall bending stiffness, BS	mN·m	FAST	[16]
Shear stiffness, G	N/m	FAST	[16]
Thickness at 100 g/cm^2, GT 100	mm	FAST	[16]

$$FH = \sum_{i=1}^{n} \frac{FHi}{n} \qquad (2)$$

Drape unevenness (*%DU*) [20]. This is the coefficient of variation between consecutive folds and accounts for drape symmetry in each specimen, but not for drape shape. This indicator is expressed as a percentage and can range from 0% (maximum symmetry) to 100% (minimum symmetry).

$$\%\mathrm{DU} = \frac{\sqrt{\frac{\sum_{i=1}^{n}(\alpha i - \bar{\alpha})^2}{n-1}}}{\bar{\alpha}} \times 100 \qquad (3)$$

Fold distribution (*%Gp*) [21]. This is the percent coefficient of variation for the peak length (*FPR*, ***Figure 4***), and provides a measure of variability in the fold shape and symmetry in each specimen.

$$\%\mathrm{Gp} = \frac{\sqrt{\frac{\sum_{i=1}^{n}(\mathrm{FPRi} - \overline{\mathrm{FPR}})^2}{n-1}}}{\overline{\mathrm{FPR}}} \times 100 \qquad (4)$$

The physical and mechanical properties of the fabrics related to the drape were examined using FAST equipment [16].

Table 3 shows the tests, equipment and methodology used. All specimens were conditioned in accordance with UNE 40-139-75 and all tests conducted at the Textile Physics Laboratory of the Textile and Paper Engineering Department of the Universitat Politècnica de Catalunya.

Results and discussion

Table 4 shows the figures of merit of the regression between weight loss as a response variable and process variables at the three levels examined. Using multiple linear regression to fit the relationship between weight loss and process variables led to a second-order linear model containing no quadratic terms and providing the response surface of ***Figure 6***.

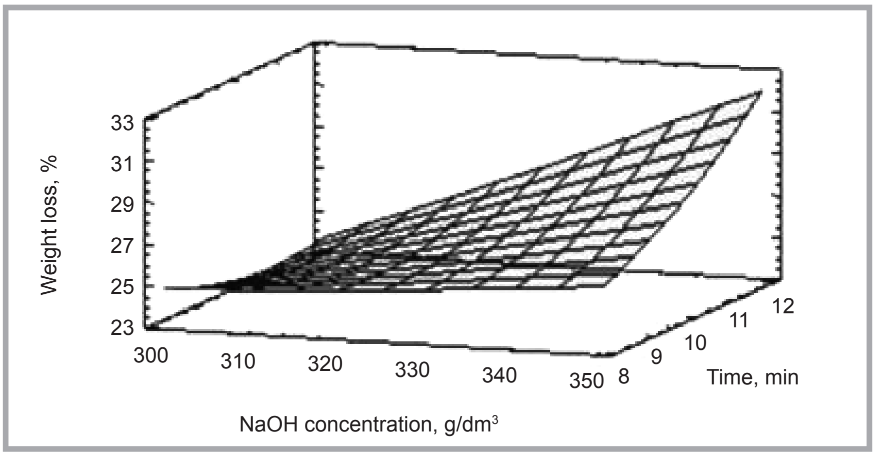


Figure 6. *Estimated response surface for fabric weight loss as a function of NaOH concentration and vaporisation time.*

The regressors accounted for 86.173% of the variability in the response ($R^2 = 86.173$). The equation can thus be used to predict weight loss at different values of the process variables.

Since all *p* values in ***Table 4*** are less than 0.05, the finishing process variables studied were statistically significantly related to fabric weight loss at the 95.0% confidence level.

The NaOH concentration only influenced those indicators related to drape intensity (%DR and FN) (***Figures 7*** and ***8***) or to geometric isometry in the drape shape (%DU) (***Figure 9***). However, it had no effect on the node severity or roughness (FH), nor on the evenness of the drape profile shape (%Gp) because these indicators are the result of specific interactions between physico-mechanical properties of fabrics which did not occur in this case. The time-concentration interaction had no effect on drape intensity (%DR) but influenced the fold number (FN) (***Figure 10***); this is usually the case with fabrics of identical drape (%DR) but differing in the fold number (FN) [15]. This interaction influences the node severity or roughness – a phenomenon explained by the indicator FH, which thus allows one to discriminate between drape shapes and confirms the results of a previous study [15].

The results obtained using the experimental plan proposed are shown in ***Table 5***. As noted earlier, fabric weight loss was strongly influenced by the soda concentration, vaporisation time and their mutual interaction.

As with drape, the vaporization time had no influence on FAST properties. On the other hand, the NaOH concentration was related to all the physico-chemical properties measured by FAST equipment that were previously shown to affect fabric drape [22] (***Figures 11-13*** and ***15-16***). Also the time–concentration interaction was closely associated to the shear stiffness (G) and bias elongation (Be) (***Figures 14*** and ***17***). One should bear in mind that FAST methodology uses Be to calculate G (see ***Table 6***).

The silk-like finishing treatment results in a weight loss in polyester fibres as a consequence of a decreased diameter rather than of changes in the inner structure. The

Table 4. *Results of the multiple regression analysis.*

Parameter	Estimate	Standard error	T	p	R^2, %
Constant	102.411	26.382	3.881	0.001	
Concentration	-0.252	0.081	-3.117	0.007	
Time	-10.717	2.603	-4.116	0.001	86.173
Concentration-time interaction	0.034	0.007	4.360	0.000	

Table 5. *p value for each condition.* ***Note:*** * *p < 0.05.*

Loss (%)	Vaporisation time	NaOH concentration	Time + concentration
Weight, aerial	0.001*	0.000*	0.002*
%DR	0.319	0.012*	0.432
FN	0.769	0.028*	0.018*
FH	0.882	0.087	0.033*
%DU	0.572	0.042*	0.074
%Gp	0.372	0.663	0.806

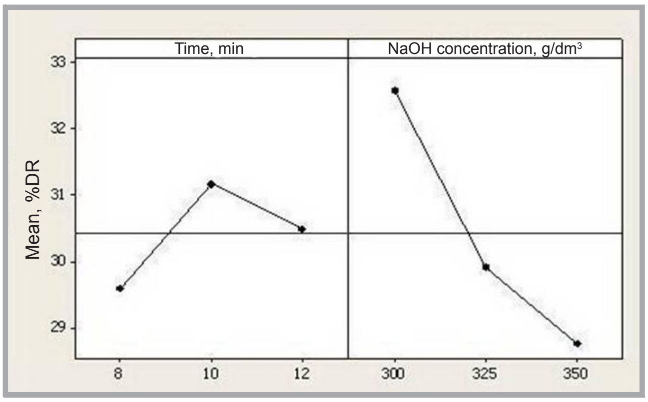


__Figure 7.__ Main effect plots for %DR.

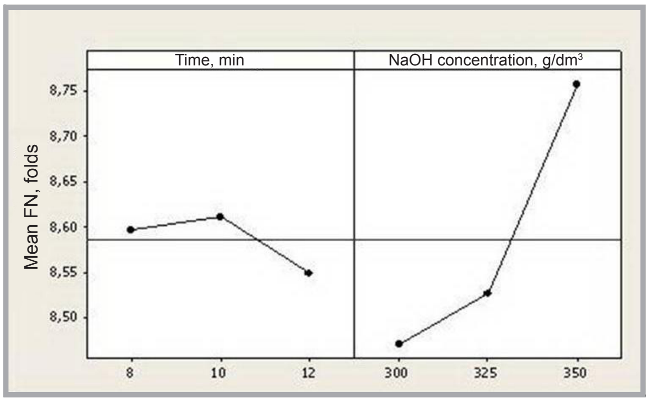


__Figure 8.__ Main effect plots for FN.

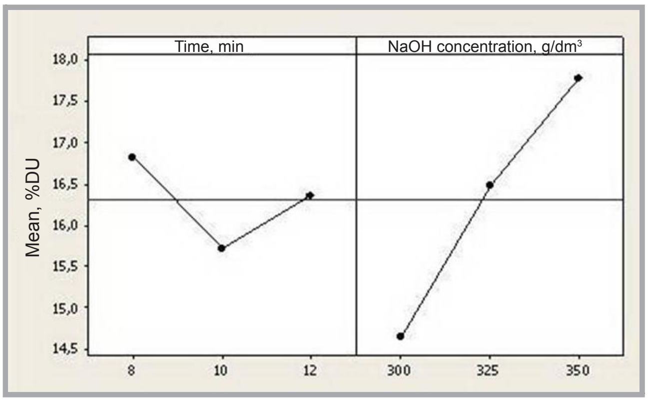


__Figure 9.__ Main effect plots for %DU.

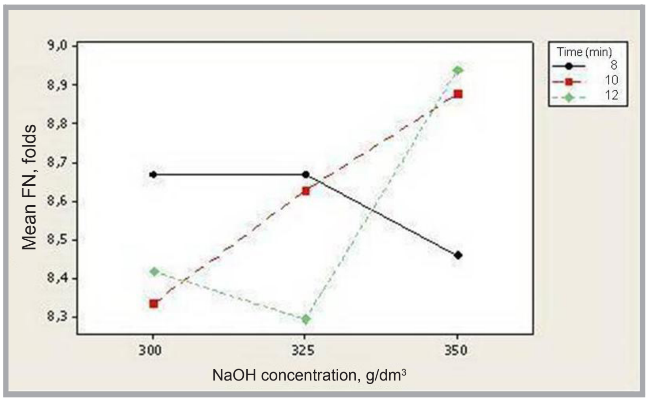


__Figure 10.__ Interaction plot for FN.

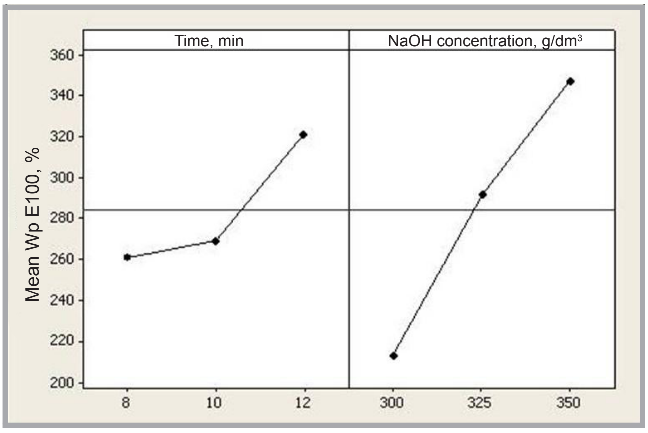


__Figure 11.__ Main effect plot for Wp E100.

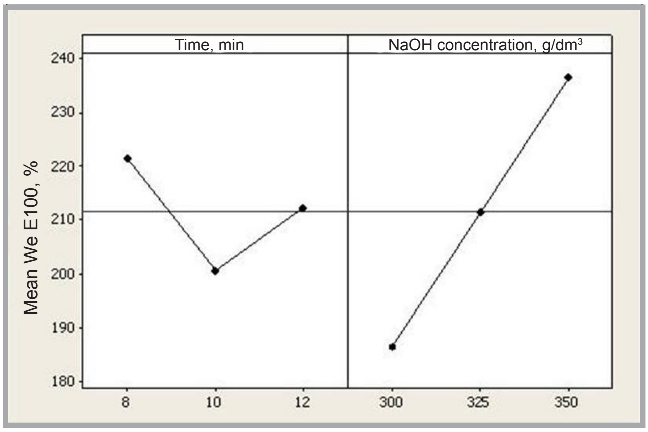


__Figure 12.__ Main effect plot for We E100.

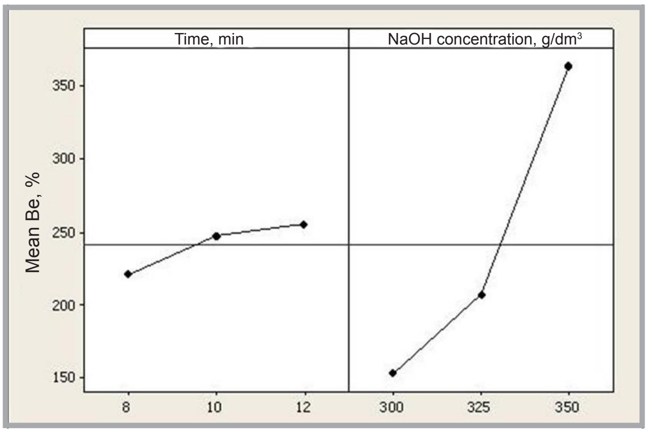


__Figure 13.__ Main effect plot for Be.

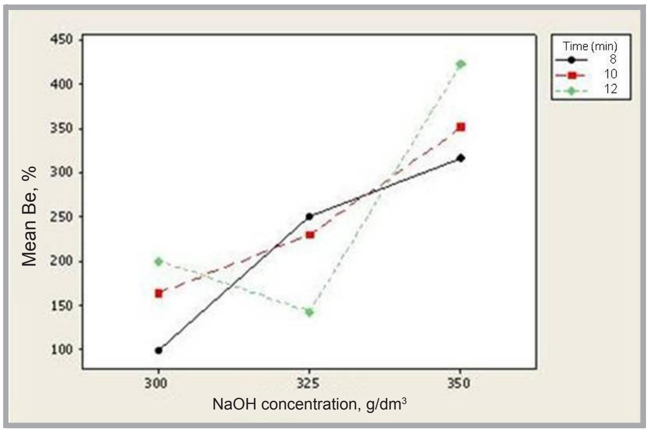


__Figure 14.__ Interaction plot for Be.

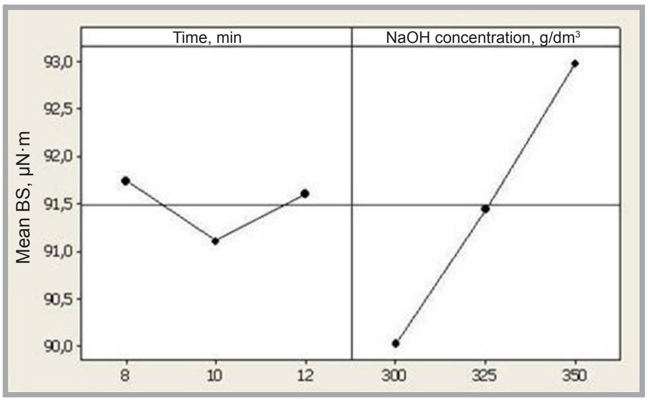


Figure 15. *Main effect plot for BS.*

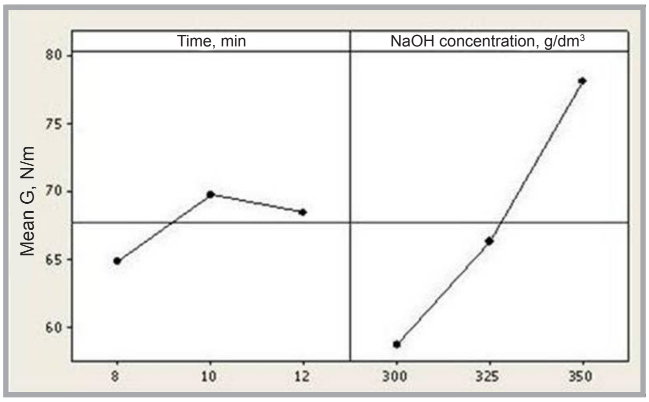


Figure 16. *Main effect plot for G.*

decreased diameter reduces the bending stiffness and improves drape as a result [23]. Our results for fabric weight loss, physico-mechanical properties and drape are quite consistent with these assertions.

Table** 7* shows the regression models for the weight loss and different drape indicators and ***Table 8 those for the different FAST parameters. The weight loss was inversely related to the %DR and linearly related to FN and %DU. The relations with FAST regressors were all linear. However, the variables were transformed in order to obtain equations with high coefficients of determination – and hence low mean square errors. Because none of the coefficients exceeded 75%, the equations cannot be used as predictive models; however, they are useful to explain the process in terms of drape and FAST parameters.

Conslusions

As in several previous studies, a statistically significant relationship at the 95.0% level between the fabric weight loss and process variables of silk-like finishing treatment was found here. The linear model proposed accounts for 86.173% of the variability in weight loss. Therefore the response surface model proposed can be used for predictive purposes.

Although the vaporisation time affected none of the drape indicators studied, drape intensity (FN) and its severity (FH) interacted significantly with the NaOH concentration. However, such a concentration only influenced drape intensity indicators (%DR and FN) and geometric isometry (%DU).

The vaporisation time affected no FAST parameter either; however, it interacted

Figure 17. *Interaction plot for G.*

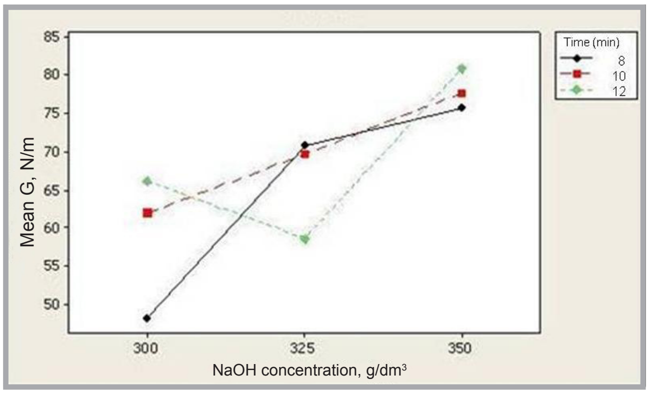


Table 6. *p values of the responses. Note: * p< 0.05.*

Loss, %	Vaporisation time	NaOH concentration	Time + concentration
Wp E 100%	0.275	0.021*	0.195
We E 100%	0.345	0.017*	0.314
Bias elongation, Be	0.335	0.000*	0.023*
Overall bending stiffness, BS	0.493	0.002*	0.816
Shear stiffness, G	0.256	0.000*	0.022*
Thickness at 100 g/cm², GT100	0.454	0.317	0.513

Table 7. *Regression models between weight loss and drape.*

Variable	Model	Coefficients	F	p	R², %
%DR	$Y = \frac{1}{a + \frac{b}{x}}$	a = 0.052 b = -0.503	17.790	0.000	52.650
FN	$Y = \sqrt[2]{a + b \cdot X^2}$	a = 62.579 b = 0.015	8.090	0.011	33.590
%DU	$Y = \sqrt[2]{a + b \cdot \sqrt[2]{X}}$	a = -653.259 b = 180.004	10.130	0.005	38.771

Table 8. *Regression models between weight loss and FAST properties.*

Variable	Model	Coefficients	*F*	*p*	*R*², %
Wp E 100	$Y = \sqrt[2]{a + b \cdot X^2}$	*a* = 15 9567.0 *b* = 350.430	33.990	0.000	67.994
We E 100	$Y = \sqrt[2]{a + b \cdot X^2}$	*a* = 9999.270 *b* = 50.484	8.170	0.011	33.797
Be	$Y = \sqrt[2]{a + b \cdot X^2}$	*a* = -124 668.0 *b* = 273.983	21.020	0.000	56.783
BS	$Y = \sqrt[2]{a + b \cdot \ln X}$	*a* = 1 983 290 *b*= 1 953 470	19.270	0.000	54.641
G	$Y = \sqrt[2]{a + b \cdot \sqrt[2]{X}}$	*a* = -1 1214 900 *b* = 3 097 430	8.870	0.008	35.670

significantly with the NaOH concentration in Be and G. Such a concentration influenced all FAST parameters associated to the drape.

Weight loss resulting from the silk-like finishing treatment affected the physico-mechanical properties associated to the drape intensity (%DR and FN) and shape (FH) as well as the geometric isometry (%DU) and drape profile unevenness (%Gp), namely bending stiffness, shear stiffness and stretching.

The equations of the regression models proposed allow fabric weight loss to be explained in terms of drape and FAST parameters. The models, however, only account for part (33-67%) of the shared variability in weight loss.

Our results regarding fabric weight loss, FAST parameters and drape indicators confirm previous conclusions about the consequences of a decreased diameter in polyester fibres through the effect of the silk-like finishing treatment.

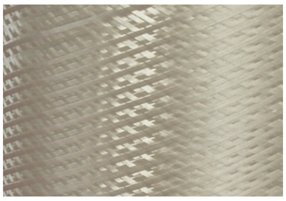
Acknowledgements

Experimental assistance from the staff at the Chemical Textile Technology Laboratory of the Textile Research and Industrial Cooperation Institute (INTEXTER) is gratefully acknowledged.

References

1. Dave J, Kumar R and Srivastava HC. Studies on modification of polyester fabrics I: alkaline hydrolysis. *J. Appl. Pol. Sci.*1987; 33 (2): 445-477.
2. Zeronian S H, Collins M J. Surface modification of polyester by alkaline treatments. *Textile Progress* 1989; 20 (2): 1-34.
3. Gacén J. *Fibras de Poliéster.* 2nd ed. Terrassa: Universitat Politècnica de Catalunya, 1991, p. 331.
4. Namboori CG, Haith MS. *Journal of Applied Polymer Science*, 1968. Vol. 12 (9): 1999-2005.
5. Raslan WM, Bendak A. Changes induced in silk-like polyester properties by alkoxides treatment. *Journal of Applied Polymer Science* 2005; 98: 1829-1837.
6. Soon LJ, Seon RH. Alkaline softening of polyester fabrics treated with aqueous NaOH solutions containing CTAB & EDA. *Proceedings of the 3rd Asian Textile Conference* 1995; I: 256-261.
7. Sanders EM. Zeronian SH. An analysis of the moisture-related properties of hydrolyzed polyester. *Journal of Applied Polymer Science* 1982; 27: 4477-4491.
8. Haghighat Kish M, Nouri M. Effects of sodium hydroxide and calcium hydroxide on polyester fabrics. *Journal of Applied Polymer Science*, 1999; 72: 631-637.
9. Shet RT, Zeronian SH, Needles HL, Siddiqui SA. Modification of polyester and polyester/cotton by alkali treatment. *Textile Chemist and Colorist* 1982; 14: 233-237.
10. Needles HL, Brook DB, Keighley JH. How alkali treatment affect selected properties of polyester, cotton and polyester/cotton fabrics. *AATC;* 1985, 17 (9): 177-180.
11. Davis M, Amirbayat J. The effect of weight reduction on the performance of a polyester fiber satin bending, shear, drape and drop. *Journal of the Textile Institute* 1994; 85(3): 376-382.
12. Needles HL, Brook DB, Keighley JH. How alkali treatment affect selected properties of polyester, cotton and polyester/cotton fabrics. *AATC* 1985; 17 (9): 177-180.
13. Mousazadegan F, Saharkhiz S, Maroufi M. Weight reduction of microfiber polyester fabric and the effect on its physical and mechanical properties. *Journal of the Textile Institute* 2010; 101 (8): 716-728.
14. Raslan WM, Bendak A. Changes induced in silk-like polyester properties by alkoxides treatment. *Journal of Applied Polymer Science* 2005; 98: 1829-1837.
15. Carrera-Gallissà E, Capdevila X, Valldeperas J. Evaluating drape shape in woven fabrics. *The Journal of the Textile Institute* 2017; 108 (3): 325-336.
16. De Boss A, Tester DH. *A system for fabric objective measurement and its application in fabric and garment manufacture.* CSIRO Report No. WT92.02. 1994.
17. Cusick G E. *A Study of Fabric Drape.* University of Manchester, 1962.
18. Chu CC, Milton MP, Hamburguer WJ. Investigation of the factors affecting the drapeability of fabrics. *Textile Research Journal* 1960; 20: 66-67.
19. May-Plumlee T, Eischen J, Kenkare N, Pandurangan P. *Evaluating 3D Drape Simulations: Methods and Metrics*. Edinburgh ed. 22-24 September 2003.
20. Al-Gaadi B, Göktepe F, Halász M. A new method in fabric drape measurement and analysis of the drape formation process. *Textile Research Journal* 2012; 82 (5): 502-512.
21. Jevsnik S. Gersak J. Modelling the fused panel for a numeric simulation of drape. *Fibres & Textiles in Eastern Europe* 2004; 12, 1(45): 47-52.
22. Jedda H, Ghith A, Sakli F. Prediction of fabric drape using FAST system. *The Journal of The Textiles Institute* 2007; 98 (3): 219-225.
23. Mousazadegan F, Saharkhiz S, Maroufi M. Weight reduction of microfiber polyester fabric and the effect on its physical and mechanical properties. *The Journal of the Textile Institute* 2010; 101 (8): 716-728.

Received 08.09.2016 Reviewed 27.03.2017



Multifilament chitosan yarn