NC STATE
College of Textiles
JTATM
Journal of Textile and Apparel, Technology and Management

Volume 9, Issue 2, Spring2015

Modelling Heat-Setting of Cotton/Elastane Knitted Fabrics for Optimum Dimensional Stability

Ahsan Nazir[1,2], Tanveer Hussain[1], Aisha Rehman[1], Affan Abid[1]
[1]Department of Textile Processing, National Textile University Faisalabad, Pakistan
[2]Laboratoire de Physique et Mécanique Textiles, ENSISA, UHA, Mulhouse France

ABSTRACT

Cotton/elastane fabrics are popular for their excellent stretch and recovery properties. However, the optimization of dimensional stability of such fabrics is quite challenging for the textile manufacturer. Heat-setting is one of the most common methods used to improve the dimensional stability of cotton/elastane fabrics. The aim of this study was to model the heat-setting process of cotton/elastane knitted fabrics using response surface methodology. Heat-setting time, temperature, fabric width extension (%) and overfeed (%) were taken as predictor variables while length- and width-way fabric shrinkage, and fabric areal density were taken as response variables. The developed response surface regression models can be used for predicting and optimizing the dimensional stability properties of cotton/elastane fabrics. It could be concluded by statistical analysis that all the predictor variables used in this study have significant effect of the dimensional stability of cotton/elastane knitted fabrics.

Keywords: Elastane, modeling, dimensional stability, heat-setting, knitted fabrics

Introduction

Stretchable knitted cotton fabrics find numerous applications in outer and inner wear due to the exceptional comfort characteristics of cotton fiber. Although 100% cotton knitted fabrics have substantial stretchability, poor recovery in these fabrics elicits the need to add an elastic component in these fabrics (Matsuo & Yamada, 2009; Shanahan & Postle, 1974). Polyurethane-based elastane fibers can be added in suitable percentage in cotton fabrics to enhance their stretch and recovery properties (Marmarali, 2003; Sadek, El-Hossini, Eldeeb, & Yassen, 2012; Senthilkumar, Anbumani, & Hayavadana, 2011; Tezel & Kavuşturan, 2008). Elastane is a copolymer of alternating soft and hard molecular segments. The elastic properties of elastane fiber are owing to the presence of soft molecular segments, consisting of coiled aliphatic polyesters and polyethers, which uncoil to render it stretchability under load (Salem, 2001).

Addition of elastane fiber in cotton knitted fabrics substantially improves their 'stretch-recovery' properties (Abdessalem, Abdelkader, Mokhtar, & Elmarzougui, 2009). Such fabrics offer better resilience, extension and immediate recovery as compared to 100% cotton knitted fabrics (Mukhopadhyay, Sharma, & Mohanty, 2003). Despite these advantages, elastane containing fabrics have poor dimensional stability and they tend to crease and curl extensively. So, they have to be subjected to heat setting treatment that rearranges and relaxes the molecular chains, thus significantly improving the dimensional stability of cotton/elastane blended knitted fabrics (Karmakar, 1999).

The heat-setting of cotton/elastane blended fabrics is carried out above the glass transition temperature and below the melting temperature of elastane, for a suitable time. Fabric width and overfeed are also important factors that decide the effectiveness and efficiency of the heat-setting process. Other factors include type of impurities added during yarn and fabric manufacturing, wetting ability of padding solution and the moisture in heat-setting chambers (Desai, 2011; Karmakar, 1999). The heat-setting process is strongly dependent on these parameters and a small variation in these parameters may cause a large effect on fabric properties. So, these parameters must be selected, optimized and monitored carefully. Nevertheless, no significant study in the field of modeling and optimization of heat-setting parameters of cotton/elastane knitted fabrics has been reported. This study focuses on optimization of heat-setting parameters of cotton/elastane knitted jersey fabric for better dimensional stability. Response surface optimization methodology has been used in this study, which has already been used by different researchers for modeling and optimizing various textile processes.

Experimental

This study was accomplished on knitted single jersey fabric with 5% elastane and 95% cotton. The elastane was added from all feeders on knitting machine to obtain the above mentioned composition. The fabric samples were knitted on Mayer and Cie single knit machine using 30/1 cotton yarn and 22 denier elastane filament yarn, at needle gauge and stitch length of 9.44 needles/cm and 0.3 cm respectively. The resulting fabric had 65 course/inch, 38 wales/inch and accrue fabric density of 246 g/sq. m.

Thirty samples of the cotton-elastane single-jersey fabric were subjected to heat-setting treatment at different process parameters. Based on the previous studies (Desai, 2011; Karmakar, 1999) and industrial experience of the authors, the process parameters or factors selected for this study were temperature (T), time (t), fabric width extension (E_w) and overfeed (OF) at the stenter. The coded and actual values of the factor levels are mentioned in Table 1. The experiments were designed using the central composite design of response surface methodology on Minitab® 16 software.

Table 1. Coded and actual levels of design factors

Factor Symbol	Factor	Coded and Actual Levels				
		- 2	- 1	0	+ 1	+ 2
X_1	T, (C)	160	170	180	190	200
X_2	t, (sec.)	50	70	90	110	130
X_3	E_w (%)	6	9	12	15	18
X_4	OF (%)	2.5	15	27.5	40	52.5

T : heating-setting temperature, t : heat-setting time, E_w : extension % in width with respect to grey width, OF - overfeed %.

Table 2. Testing results of heat setting experiments

No.	Factors				Responses			
	X_1: T, °C	X_2: t, sec	X_3: E_w, %	X_4: OF, %	S_L, %	S_W, %	ΔD_R, %	ΔD_W, %
1	170	70	9	15	13.0	10.4	2.03	24.80
2	190	70	9	15	8.5	7.5	-0.81	16.06
3	170	70	15	15	13.0	11.4	-0.16	25.00
4	190	70	15	15	9.1	8.1	-2.31	11.79
5	170	110	9	15	12.2	9.1	3.4	22.0
6	190	110	9	15	6.1	4.7	-1.79	4.67
7	170	110	15	15	13.2	9.4	-2.60	19.72
8	190	110	15	15	5.5	5.5	-8.13	-0.41
9	170	70	9	40	13.2	11.4	5.5	31.3
10	190	70	9	40	9.3	9.1	3.25	19.11
11	170	70	15	40	13.0	11.2	6.91	27.03
12	190	70	15	40	7.1	9.1	-2.44	8.13
13	170	110	9	40	10.6	9.4	5.8	23.6
14	190	110	9	40	5.5	4.5	-5.57	3.05
15	170	110	15	40	11.2	9.3	3.66	21.75
16	190	110	15	40	4.1	4.9	-6.10	2.85
17	160	90	12	27.5	12.6	12.4	6.91	33.74
18	200	90	12	27.5	3.3	4.5	-10.85	-7.52
19	180	90	6	27.5	9.1	8.1	1.46	17.89
20	180	90	18	27.5	9.1	9.1	-0.28	15.04
21	180	50	12	27.5	12.6	12.2	7.15	39.63
22	180	130	12	27.5	8.7	7.7	-0.28	13.62
23	180	90	12	2.5	10.0	9.4	-2.03	17.28
24	180	90	12	52.5	9.3	8.5	0.53	18.50
25	180	90	12	27.5	12.4	10.8	-3.53	18.50
26	180	90	12	27.5	11.2	9.6	-2.32	19.51
27	180	90	12	27.5	11.4	10.2	-2.44	16.06
28	180	90	12	27.5	11.0	10.8	-1.10	20.33
29	180	90	12	27.5	11.0	10.9	-1.50	16.87
30	180	90	12	27.5	9.5	9.1	-1.10	16.26

T : heating-setting temperature, t : heat-setting time, E_w : extension % in width with respect to grey width, OF : overfeed %, S_L : length-way shrinkage (%) after washing, S_W : width-way shrinkage (%) after washing, ΔD_R : difference % between grey fabric density and that after dry-relaxation after heat-setting, ΔD_W : difference % in grey fabric density and that after 5 laundering and tumble drying cycles

Each fabric sample was first padded in a solution of wetting agent (2 g/L Falosan RGN, CHT, Pakistan) on a lab-scale padder at 75% pickup. It was then heat-set on a lab-scale stenter according to the experimental plan given in Table 2. After heat-setting, the samples were conditioned in standard atmospheric conditions (20°C ±2, 65% ±4 relative humidity) and then tested for the response variables. The width of samples was determined according ASTM D3774. The dimensional stability of samples was determined in accordance with AATCC 135 standard test method using Whirlpool washing machine (Model: 3LWTW4840YW) and drier (Model: 3DWGD4800YQ) completing five washing and drying cycles. The areal density (grams per square meter) of washed and unwashed fabric samples was determined according to ASTM D 3776. Statistical data analysis and modeling was done using Minitab® 16 software package.

Table 3. Analysis of variance for effect of input variables on response variables

Terms	**S_L**		**S_W**		**ΔD_R**		**ΔD_W**	
	Coeff.	*P-Value*	*Coeff.*	*P-Value*	*Coeff.*	*P-value*	*Coeff.*	*P-value*
X_1	-5.233	0.000*	-3.675	0.000*	-6.998	0.000*	-17.69	0.000*
X_2	-2.133	0.000*	-2.510	0.000*	-3.184	0.000*	-9.841	0.000*
X_3	-0.183	0.557	0.393	0.161	-2.209	0.006*	-2.86	0.034*
X_4	-0.667	0.045*	0.066	0.807	2.215	0.005*	-1.304	0.305
X_1^2	-2.917	0.000*	-2.130	0.001*	-0.163	0.902	-6.309	0.015*
X_2^2	-0.217	0.71	-0.680	0.191	5.244	0.001*	7.207	0.007*
X_3^2	-1.767	0.007*	-2.030	0.001*	2.399	0.085	-2.956	0.218
X_4^2	-1.217	0.050	-1.640	0.005*	1.057	0.430	-1.533	0.515
$X_1 X_3$	-1.250	0.115	0.196	0.768	-1.281	0.464	-3.099	0.319
$X_1 X_2$	-1.950	0.020*	-1.670	0.021*	-3.801	0.041*	-5.945	0.067
$X_1 X_4$	0.050	0.948	0.193	0.771	-4.269	0.024*	-2.795	0.368
$X_2 X_3$	0.350	0.646	0.003	0.995	-1.748	0.321	2.489	0.421
$X_3 X_4$	-1.05	0.181	-0.687	0.309	2.256	0.205	-1.474	0.632
$X_2 X_4$	-1.15	0.145	-0.980	0.153	-1.890	0.285	-0.661	0.829
*Statistically significant term with 95% confidence								

Results and Discussion

The results of the experiments performed for the optimization of heat setting parameters are summarized in Table 2. The statistical significance of the effect of each factor, as a function of p-value (at 95% confidence) based on the analysis of variance (ANOVA) of the data, is shown in Table 3. The regression equations for all the response variables, including the statistically significant factors, are given in Table 4.

Table 4. Regression equations for each response variable in uncoded units

Response	Regression Equation	R-Sq (%)
S_L	$– 203.85 + 2.42 X_1 + 0.38 X_2 + 1.02 X3 – 0.027 X_4 – 0.01 X_1^2 – 0.04X_3^2 – 0.01X_1X_2$	93.45
S_W	$–163.72 + 1.86X_1 + 0.33X_2 + 1.33X_3 + 0.14X_4 – 0.01X_1^2 – 0.05X_3^2 – 0.01X_4^2 – 0.01X_1 X_2$	94.08
ΔD_R	$-23.66 + 0.31X_1 + 0.22X_2 – 0.36X_3 + 1.62X_4 – 0.01X_2^2 – 0.01X_1 X_2 – 0.01 X_1 X_4$	87.74
ΔD_W	$-222.31 + 4.28 X_1 – 1.12 X_2 – 0.48 X_3 – 0.01 X_1^2 + 0.01 X_2^2$	90.30

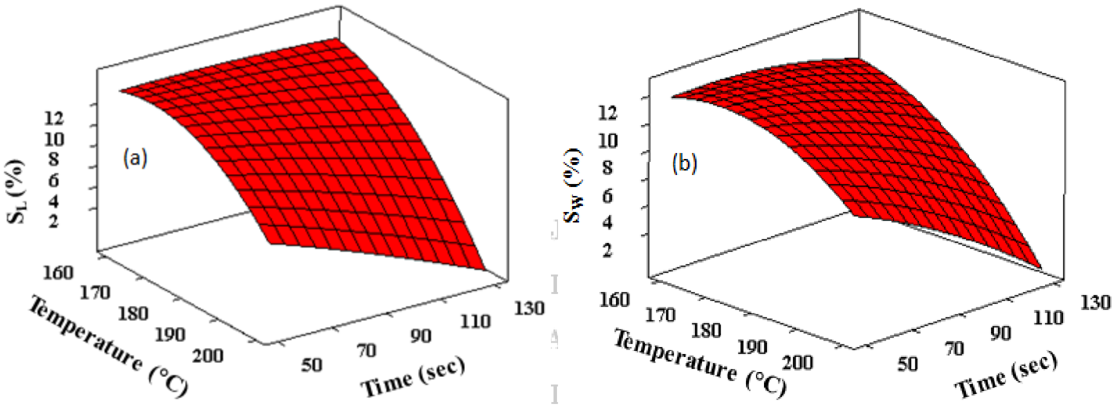

Figure 1. Effect of heat-setting time and temperature on fabric shrinkage in laundering,

Effect of Heat-setting Parameters on Fabric Shrinkage

The effect of heat-setting temperature and time on length- and width-way fabric shrinkage is depicted in Figure 1. The analysis of variance (ANOVA) results showed that the effect of both the heat-setting temperature and time was statistically significant on fabric shrinkage in both ways (p-values <0.05 for X_1 and X_2, Table 3). It is evident from Figure 1 that the effect of temperature is more pronounced than that of the time. It is also clear that when the heat setting temperature is higher than the softening temperature of elastane (175-180°C), the fabric shrinkage decreases sharply. Below the elastane softening temperature, polymeric chains in the fiber do not undergo significant movement and rearrangement to form a more stable orientation of the molecular chains.

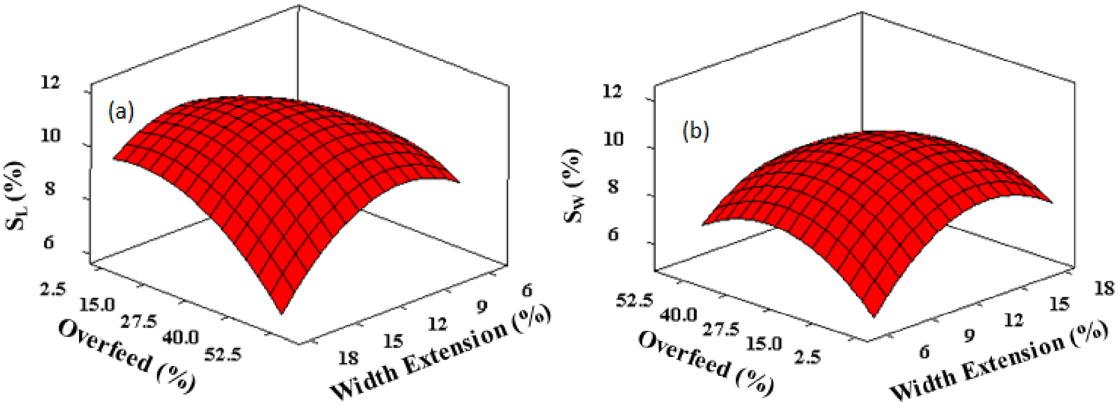

Figure 2. Effect of width extension and overfeed during heat-setting on fabric shrinkage in laundering,

This leads to higher shrinkage in fabric when the chains relax during laundering. However, when the fabric is heat-set at temperatures above the elastane softening temperature its shrinkage on laundering decreases. There is a statistically significant interaction between heat-setting time and temperature. The effect of heat-setting time is less noticeable at low temperatures and it becomes more prominent when the fabric is heat-set at higher temperatures. Above the elastane softening temperature, the fabric shrinkage decreases with increase in time.

The effect of fabric width extension and overfeed during heat-setting on the fabric shrinkage after laundering is shown in Figure 2. It can be noticed that at higher width extension, the fabric length-way shrinkage decreases with increase in fabric overfeed. However, the effect of increasing fabric overfeed on length-way shrinkage is less significant when the fabric is heat-set at lower width extension. The effect of overfeed is less significant on width-way fabric shrinkage as compared to that in length-ways.

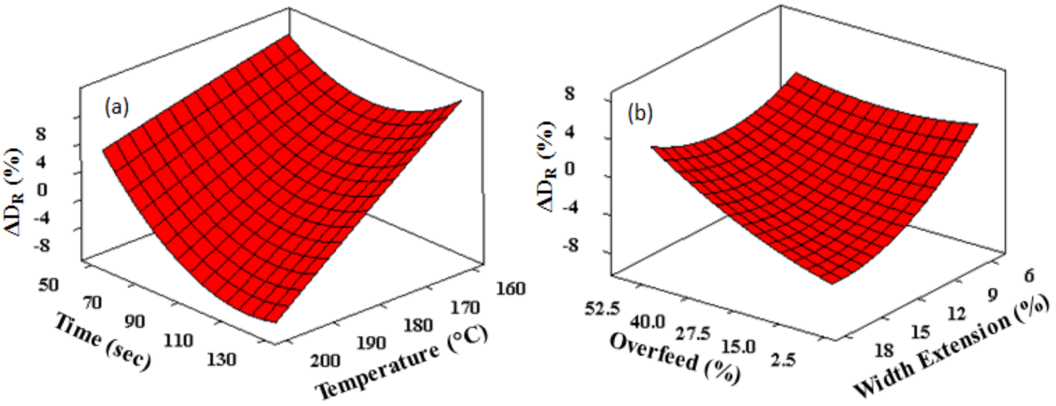

Figure 3. Effect of heat-setting parameters on density of the dry-relaxed fabric,

At lower fabric overfeed, the fabric length-way shrinkage appears to increase with increase in fabric width-extension. However, at higher fabric overfeed, the trend seems to reverse. Similarly, at lower fabric overfeed, the fabric width-way shrinkage also appears to increase with increase in fabric width extension. However, at higher fabric overfeed, the width-way fabric shrinkage first appears to slightly increase then decrease.

Although there is no statistically significant interaction between the fabric width extension and overfeed, the optimum percentage of both the factors is essential for achieving minimum fabric shrinkage simultaneously in both the fabric directions.

Effect of Heat-setting Parameters on Fabric Density after Heat Setting

From the analysis of variance results given in Table 3, it is evident that the relaxed fabric density after heat-setting is significantly affected by all of the heat-setting parameters. It can be observed in Figure 3 (a) that at lower heat setting times, increase in fabric density was found to be higher without being influenced much by the temperature. However, as the heat-setting time increases the effect of temperature becomes stronger. At higher process times, the increase in fabric density drops with increase in temperature. This could be attributed to better stabilization of fabric at higher heat-setting temperature and time, resulting in less relaxation shrinkage after the heat-setting process to cause any increase in fabric areal density. Since the fabric is not well-set at low temperature and time, it tends to relax after the heat-setting process resulting in increase in fabric areal density. Effect of width extension and overfeed during heat-setting on change in density of the dry-relaxed fabric is shown in Figure 3(b). Increase in fabric density on dry relaxation after heat-setting is minimum when the fabrics are heat-set at high width-extension and lower overfeed. When heat-setting is done with higher fabric width extension the elastane filaments, which run mainly along the width, get better heat-set because of their better exposure to heat. Dry relaxation remains low when the elastane gets better heat-set, leading to less increase in fabric density on relaxation. In case of higher length-way fabric overfeed and less width-way fabric extension during heat-setting, the elastane is not better heat-set. Hence, the fabric undergoes greater dry relaxation resulting in higher gain in the fabric areal density on relaxation.

Effect of Heat-setting Parameters on Fabric Areal Density after Laundering

The effect of heat-setting time and temperature on difference in grey fabric areal density and that after five laundering and tumble drying cycles (ΔD_w %) is shown in Figure 4(a). It is clear that the increase in fabric density on laundering is lower when the fabric is heat set at higher temperature and time. Since, the fabric gets better heat-set at higher temperature and time, it tends to shrink less in laundering resulting is less increase in fabric density.

The effect of fabric-overfeed and width extension on the increase in density of the fabric after laundering is depicted in Figure 4(b). It can be noticed that the effect of fabric overfeed and width extension during heat-setting is not as much pronounced as that of heat-setting time and temperature. Increase in fabric density after laundering is lower when the fabric is heat-set at higher width extension. At higher width extension, elastane filaments get better heat-set due to better exposure to heat. The effect of fabric overfeed during heat-setting was not found to be statistically significant on change in fabric areal density after laundering (p-value > 0.5, Table 3). The results imply that the stability of cotton/elastane fabric to laundering is better in terms of fabric areal density, if the fabric is heat-set at sufficiently higher temperature and time with higher width extension.

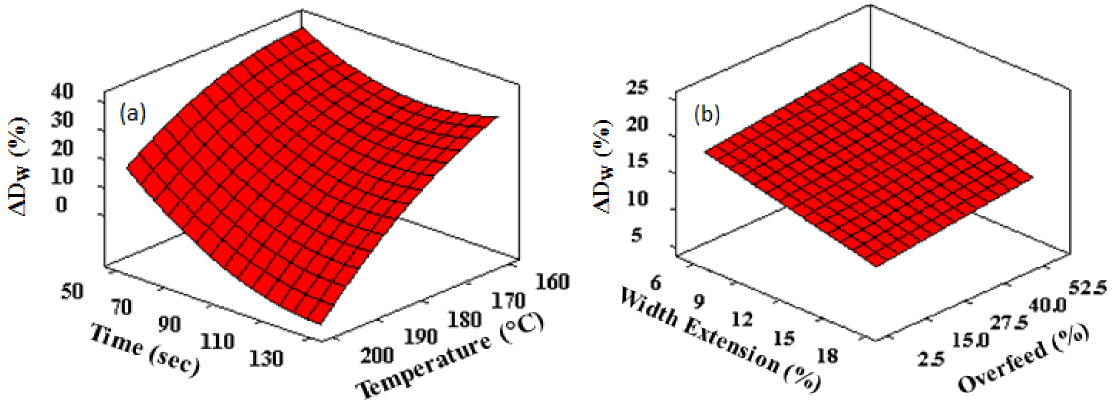

Figure 4. Effect of heat-setting parameters on density of the fabric after laundering,

Validation

The models developed were validated using the set of parameters mentioned in table 5. For this purpose, a comparison of predicted and actual output variables was made. Figure 5 shows fitted line.

Table 5. Predicted and actual values of outputs

X_1	X_2	X_3	X_4	**SL**			**SW**			ΔD_R			ΔD_W		
				Pred.	Actual	Abs. Error	Pred.	Actual	Abs. Error	Pred.	Actual	Abs. Error	Pred.	Actual	Abs. Error
200	89.2	6	10.4	1.89	1.93	0.03	1.32	1.55	0.23	-4.49	-5.69	1.19	-3.48	-3.72	0.23
186	95	16	20	7.94	8.15	0.20	7.63	7.48	0.15	-5.57	-5.50	0.06	8.03	7.65	0.37
175	100	8	35	10.66	10.98	0.31	9.08	8.79	0.29	2.70	2.21	0.48	20.87	21.60	0.72
165	120	11	10	13.06	14.01	0.95	9.78	9.4	0.38	3.05	3.87	0.82	24.37	26.03	1.65
195	95	10	16	5.00	5.41	0.41	4.94	4.42	0.52	-5.99	-6.38	0.38	0.21	0.19	0.02
				Mean error		0.38	Mean error		0.31	Mean error		0.59	Mean error		0.60

Figure 5 and 6 show fitted line plot for predicted and actual values of shrinkage in length-way and width-way direction respectively. The Pearson correlation for predicted and actual shrinkage in length and width is 0.998 and 0.995 with *p-values* of 0.000 for both. This reflects the accuracy and reliability of models.

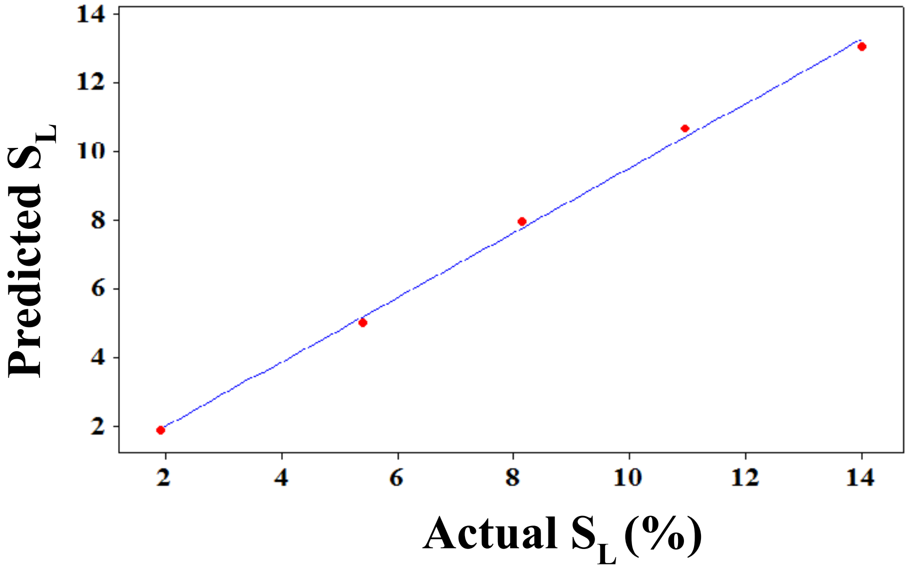

Figure 5. Fitted line plot for actual and predicted S_L (%),

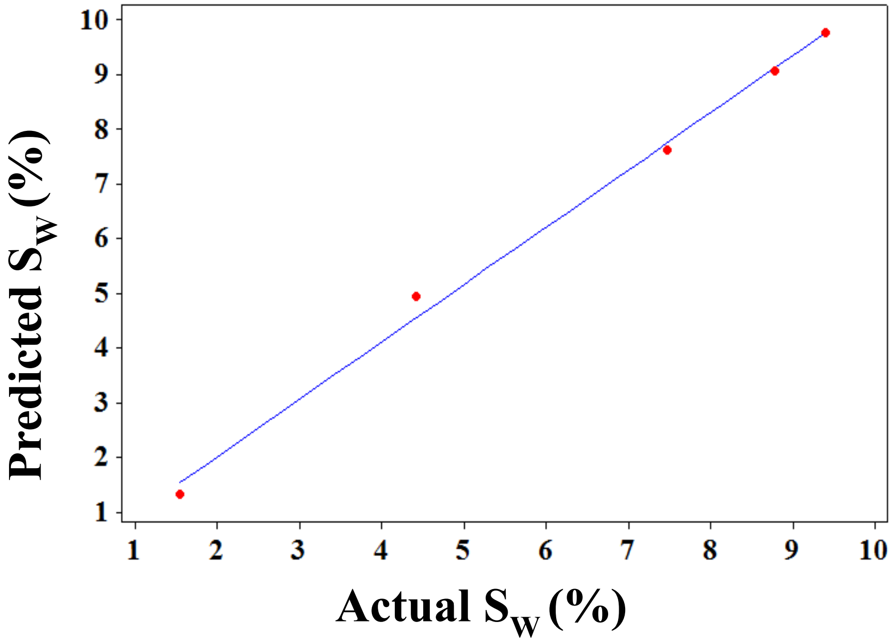

Figure 6. Fitted line plot for actual and predicted S_W (%),

Figure 5 and 6 show fitted line plot for predicted and actual values of fabric density after heat setting and washing, respectively. The Pearson correlation values for these responses are 0.982 and 0.999 with *p-values* of 0.001 and 0.000 respectively. These values show that the models are accurate and can be used reliably.

Conclusions

It can be concluded from this study that maximum stability in the dimensions and areal density cotton-elastane fabrics after laundering can be obtained if the fabrics are heat-set for a sufficient time above the elastane softening temperature. Increase in fabric width extension at higher fabric overfeed results in decrease in fabric length-way shrinkage and better stability of fabric areal density during laundering. Increase in fabric width extension at lower fabric overfeed results in higher width-way fabric shrinkage on laundering. Stability of fabric density to dry relaxation is better when the fabric is heat-set at higher fabric-width extension and lower fabric-overfeed. The response surface regression model developed in current work could be utilized as a useful tool for "right first time" heat setting of elastane/cotton knitted fabrics. Moreover, tools like software may also be developed for industrial heat setting of subjected fabrics.

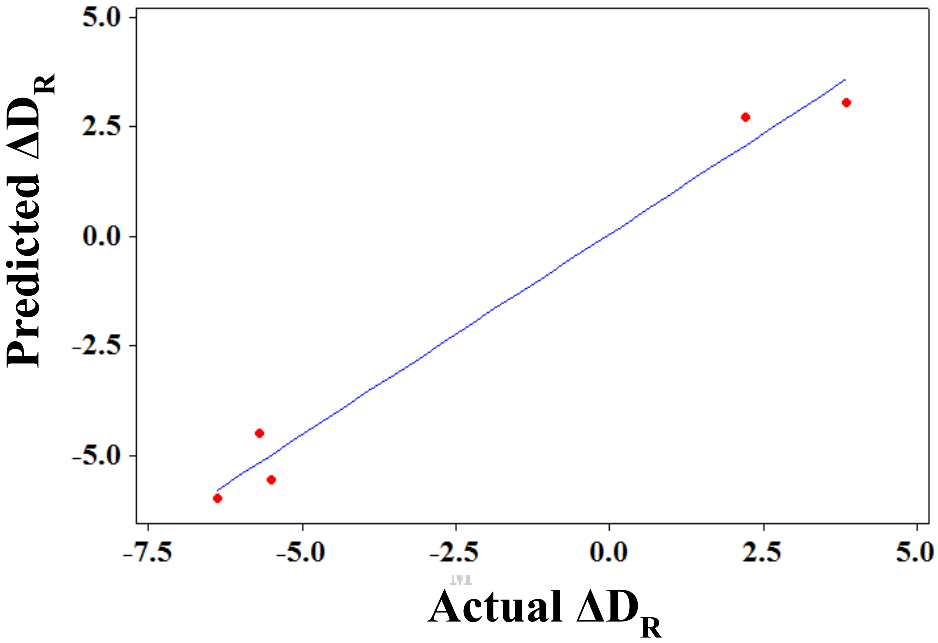

Figure 7. Fitted line plot for actual and predicted ΔD_R (%),

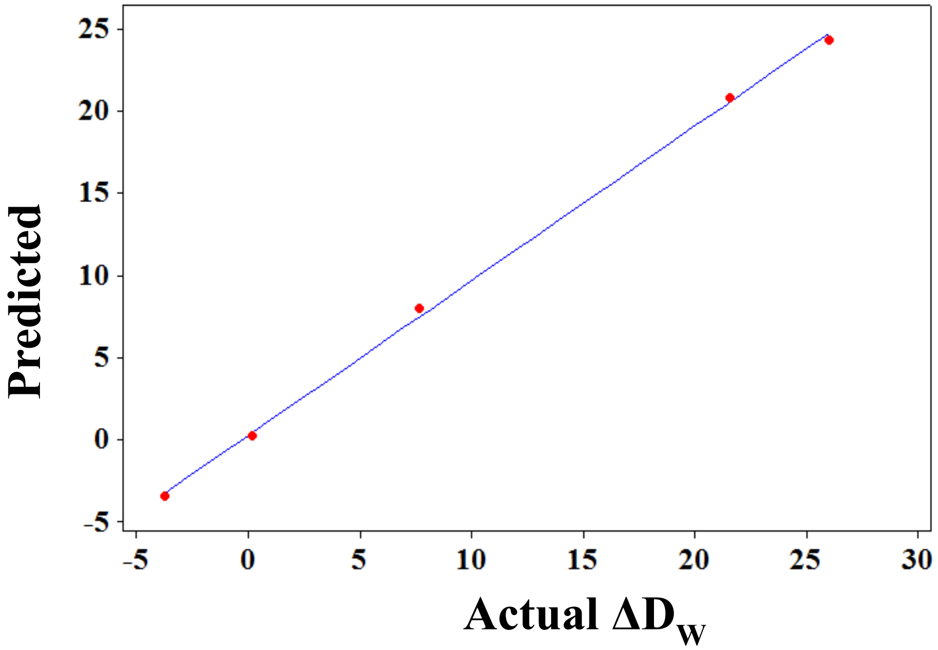

Figure 8. Fitted line plot for actual and predicted ΔD_W (%),

Acknowledgement

The authors are thankful to the management of Masood Textile Mills for providing their services for execution of this research work.

REFRENCES

Abdessalem, S. B., Abdelkader, Y., Mokhtar, S., & Elmarzougui, S. (2009). Influence of elastane consumption on plated plain knitted fabric characteristics. *J. Eng. Fiber Fabr, 4*, 30-34.

Desai, S. M. (2011). Wet processing of cotton and cotton/lycra blended knit fabrics. *Colourage, 58*(7), 79.

Karmakar, S. R. (1999). *Chemical Technology in the Pre-Treatment Processes of Textiles*: Elsevier Science.

Marmarali, A. B. (2003). Dimensional and physical properties of cotton/spandex single jersey fabrics. *Text. Res. J., 73*(1), 11-14.

Matsuo, M., & Yamada, T. (2009). Hysteresis of Tensile load - Strain Route of Knitted Fabrics under Extension and Recovery Processes Estimated by Strain History. *Text. Res. J., 79*(3), 275-284. doi: 10.1177/0040517507090504

Mukhopadhyay, A., Sharma, I., & Mohanty, A. (2003). Impact of lycra filament on extension and recovery characteristics of cotton knitted fabric. *Indian J. Fibre Text. Res., 28*(4), 423-430.

Sadek, R., El-Hossini, A., Eldeeb, A., & Yassen, A. (2012). Effect of Lycra Extension Percent on Single Jersey Knitted Fabric Properties. *Journal of Engineered Fibers and Fabrics, 7*(2), 11-16.

Salem, D. R. (2001). *Structure Formation in Polymeric Fibers*: Hanser Verlag.

Senthilkumar, M., Anbumani, N., & Hayavadana, J. (2011). Elastane fabrics - A tool for stretch applications in sports. *Indian J. Fibre Text. Res., 36*(3), 300.

Shanahan, W. J., & Postle, R. (1974). A theoretical analysis of the tensile properties of plain-knitted fabrics. part i: the load-extension curve for fabric extension parallel to the courses. *J. Text. Ins., 65*(4), 200-212. doi: 10.1080/00405007408630448

Tezel, S., & Kavuşturan, Y. (2008). Experimental investigation of effects of spandex brand and tightness factor on dimensional and physical properties of cotton/spandex single jersey fabrics. *Text. Res. J., 78*(11), 966-976.