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New Insight into Compressive Shrinkage Finishing in a Garment Company: The Effects on Physical, Mechanical and Colorimetric Properties of Cotton Woven Fabrics

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Abstract: Compressive shrinkage or compressive shrinkage finishing is one of the most important finishing procedures in the textile industry to improve the dimensional stability of cotton fabrics. Study of the physical and mechanical properties of compressive shrinkage finished fabrics could be useful for optimizing the treatment conditions. This research was carried out in a production line of a recognized garment company on cotton woven fabrics with two different woven patterns (twill and plain). The samples were first dyed with reactive and sulfur dyes in a jigger dyeing machine and finished with a silicone softener. The dried fabrics were then processed in a compressive shrinkage machine. Several physical and mechanical properties of the samples were evaluated including area shrinkage, crimp percentage, thickness, abrasion resistance, drapeability, mechanical and colorimetric properties. The results showed that the thickness of all treated samples increased due to compressive shrinkage. The fabrics were analyzed with a Martindale Abrasion Tester to determine the abrasion resistance. Interestingly, we noted an increase in the abrasion resistance. After the compressive shrinkage process, the strength of the plain woven fabrics decreased in the warp direction, but increased for twill woven cotton fabrics. On the contrary, the strength of all samples increased in the weft direction. Colorimetric evaluation of the samples showed that the effect of compressive shrinkage on the color of all samples was negligible.

Keywords: Compressive shrinkage, Cotton, Dyes, Woven fabrics, Crimp

Introduction

Cotton is one of the most important raw materials—it forms about half of all fiber usages in the textile industry [1]. However, shrinkage of cotton fabrics during washing is a problem that has existed long before the production of man-made fibers [2,3]. There are two types of shrinkage in a cotton fabric including *relaxation* and *washing shrinkage*. During spinning, weaving, bleaching, dyeing and the various finishing processes, cotton yarns and clothes are under continuous tension. The amount of relaxation shrinkage depends on the amount of stretching the fibers undergo during manufacturing. The warmth and moisture of the washing processes is an ideal relaxation environment [4,5].

The second is washing shrinkage. This shrinkage is caused by physical adjustments in the fabric brought about by swelling of the fibers and yarns when wet. This allows them to return to their true dimensions and relax, resulting in shrinkage [4,5]. It has been previously demonstrated that the total garment shrinkage occurs at the fabric, yarn and fiber level and that cotton shrinks the most of all fabrics. Knitted cotton goods tend to stretch more than woven ones during manufacture, and therefore knit goods shrink more than woven goods after washing [6-8]. For this purpose, controlled compressive shrinkage treatments were discovered during the 1930s by Sanford Cluett. In compressive shrinkage control processes, the cotton fabric is dampened and carried by the rubber sleeve. It is then compressed between the rubber sleeve and a large roller and is finally heated to set the compressed fabric. The resulting product is shrinkage-free and wrinkle resistant. Different weave patterns for the cotton fabrics have different shrinkage potential such that fabric testing is an essential part of treatment [9-11].

Significant research has been devoted to the study of finishing processes on textiles including mechanical and chemical finishing. These procedures include calendering [12], pressing [13], compressive shrinkage treatment [14], heat-setting [15], bio-polishing [16], crease-resist finishing [17], anti-microbial finishing [18], anti-pilling finishing [19], softening [20-32], stiffening [33], hydrophobic finishing [34,35], stain resistance finishing [36], UV-protective finishing [37,38], anti-static finishing [39], flame retardant finishing [40,41], as well as conductive and electromagnetic shielding [42-44]. However, as far as we know, only one research programexplains the effects of compressive shrinkage treatment on pilling performance of polyester/viscose-blended fabrics [14]. In this regard, only the work by Hussain *et al*. is worthy of mention. They found that this procedure results in an increase in the pilling behavior of blended samples.

In this research, some physical and mechanical properties of twill and plain-woven cotton fabrics dyed with sulfur and reactive dyes after compressive shrinkage process were investigated. The results are very important for understanding the properties of the final textile products for quality control purposes and optimizing the process condition. All studies and experiments were carried out in a garment factory.

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Experimental

Materials

We used bleached/mercerized twill and plain-woven cotton fabrics (Table 1).

Sodium chloride, sodium hydroxide and levegal RDL were applied for sulfur and reactive dyeing. Sodium hydrosulphite was used for sulfur dyeing. Hydrogen peroxide and acetic acid were employed for oxidation of sulfur dyed samples. All materials were supplied by Bayer AG, Germany. The sulfur and reactive dyes used along with their properties are listed in Table 2.

We used a jigger-dyeing machine supplied by Mezerra (1985). A Monfortsstenter (1995) was utilized for fabric softener finishing. A compressive shrinkage machine supplied by Cibitex (1994) was used for processing of dyed fabrics. It involves steaming cylinder spraying, rubber sleeve shrinkage, 4 felt calendars and weft straightener units. All experiments were carried out at PatanJameh Garment Company, Tehran, Iran.

Methods

The dyeing procedures were carried out on bleached and mercerized cotton fabrics in a jigger-dyeing machine. For dyeing with sulfur dyes, the dye bath was prepared by adding a mixture of sulfur dyes (2 % owf) (according to Table 1), levegal RDL (1 % w/w), sodium chloride (20 g/*l*), sodium hydrosulphite (2 % owf) and sodium hydroxide (1 % owf). The initial pH of the bath was 10-11. The dyeing process was started at 40 °C, and the temperature was raised to 85 °C over 20 min and then held at that temperature for 1 h. The oxidation of dyed fabrics was carried out after dyeing by adding hydrogen peroxide (1 % w/w) and acetic acid (1 %) at pH 5 for 15 min at 50 °C. For reactive dyeing, baths were prepared by adding a mixture of reactive dyes (2 % owf) (according to Table 1), leveling agent (1 % w/w) and salt (20 g/*l*). The initial pH of the dye-baths was 7. The dyeing process was started at 40 °C. The temperature was raised to 85 °C over 20 min and sodium hydroxide was added to the bath at 85 °C. Dyeing was held at that temperature for 1 h.

The dyed fabrics were then dried at 120 °C with a Monforts stenter (1995) after padding the silicone softener. The fabrics were then subjected to the compressive shrinkage process as shown in Table 3.

The number of warps and wefts per centimeter as well as the area density of the fabrics were assessed before and after compressive shrinkage.

The crimp percentage of warps after processing was evaluated using a Crimp tester M004 (SDL Technologies) according to ASTM D3883-99.

Fabric thickness was assessed by Thickness tester J-200 (SDL Technologies). The area shrinkage of fabrics before and after processing was measured at warp and weft directions. The percent shrinkage was evaluated after washing and stone washing and defined with the following:

$$\text{Shrinkage \%} = \Delta L / L_0 \times 100 \qquad (1)$$

where ΔL is change in length in cm and L_0 is the original length in cm.

Table 3. Conditions of the compressive shrinkage machine

Fabric	sleeve pressure (psi)	Fabric speed (m/min)
1	7	27
2	10	27
3	8	27
4	7	27

Table 1. Cotton fabrics and dyes used in this study

Fabric	Area density (g/m^2)	Number of warps (1 cm)	Number of wefts (1 cm)	Warp count (Ne$_c$)	Weft count (Ne$_c$)	Woven patterns	Dyes used in dyeing	Chemical type of dyes
1	199	45	19	40/2	40/2	Plain	A, B, C	Sulfur
2	430	26	18	20/3	20/3	Twill	A, B	Sulfur
3	207	32	20	30/2	30/2	Plain	D, E, F	Reactive
4	270	45	20	20/1	20/1	Twill	F, G	Reactive

Table 2. Sulfur and reactive dyes used in this study

Dye	Commercial name	Chemical type	C.I. Constituents	Supplier
A	Hydrosol black B	Sulfur	C.I. Solubilised sulfur black 1	Dystar
B	Hydrosol brown BT	Sulfur	C.I. Solubilised sulfur brown 16	Dystar
C	Sulfur brodeauxe 3B	Sulfur	C.I. sulfur red 6	Sinochem
D	Remazol red RB	Reactive	C.I. Reactive red 198	Dystar
E	Remazol brilliant blue BB	Reactive	C.I. Reactive blue 220	Dystar
F	Remazol golden Yellow RNL	Reactive	C.I. Reactive orange 107	Dystar
G	Remazol black B	Reactive	C.I. Reactive black 5	Dystar

The abrasion resistance of all cotton fabrics was evaluated using a Martindale M235 (SDL Technologies) according to ASTM D4966-96.

The drape of fabrics at length and width was determined using a Drapometer M003B (SDL Technologies) according to ASTM D1388-96.

The force at breakage of the fabrics before and after compressive shrinkage was evaluated using an Instron TE-500 from Farayab with 20 cm gauge and a cross-head speed of 25 cm/min. This occurred after conditioning the specimen for 24 h at 65 % relative humidity and 20 °C (ASTM D5034).

The reflectance of the fabrics before and after processing was recorded using a Gretagmacbeth COLOREYE 7000A spectrophotometer integrated with an IBM personal computer. The CIELAB color coordinates (L^*, a^* and b^*) were calculated from the reflectance data for a 10 ° observer and illuminant D_{65}.

ΔE as color difference was calculated to evaluate the differences in color coordinate values of fabric samples before and after finishing as following:

$$\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \tag{2}$$

where $\Delta L = L^*$ before finishing - L^* after finishing; $\Delta a = a^*$ before finishing - a^* after finishing; $\Delta b = b^*$ before finishing - b^* after finishing.

All measurements were repeated five times. The coefficient of variation was below 5 % for all cases.

Results and Discussion

Evaluation of the Number of Threads Per Unit and the Area Density

Table 4 shows the number of warp and weft yarns per centimeter as well as the area density (1 m^2) of each fabric sample before and after compressive shrinkage. The number of warps per centimeter did not change after processing but did increase in the weft direction. Furthermore, the area density of all fabric samples increased due to compressive shrinkage. It is important to note that cotton fabrics were exposed to high tension in different procedures before finishing in the warp dimension.

When the fabric is fed into the pressure zone between the steam cylinder and rubber sleeve, the warp yarns were shortened. As a result, weft yarns were packed closer. This is another reason for increasing the area density of fabrics after finishing. Nair *et al.* recently used a scanning electron microscope to show that the yarn spacing and pore areas are reduced after compressive shrinkage process leading to increased air permeability [45]. Their results also reflect the fact that changes in the number of threads per unit and the area density do not depend on the type of woven patterns and the dyes used.

Crimp of Warp Yarns and Fabric Thickness

Table 5 shows the crimp percentage of warp yarns and fabric thickness (mm) before and after compressive shrinkage process. The crimp percentage of warp yarns for fabrics dyed with reactive dyes increased from 6 % to 12 % after compressive shrinkage process; it increased from 12 % to 15 % and 17 % for sulfur dyed samples, respectively. According to Table 5, the thickness value of all fabrics increased after compressive shrinkage. Considering the increase in the fabric density after compressive shrinkage, the samples became more compact—this leads to higher crimp in the warp yarns. In other words, the path of warp yarns will have more curvature due to compressive shrinkage due to a higher fabric thickness [46]. It is also obvious that the crimp percentage is doubled for reactive dyes samples after finishing. This is more pronounced relative to the sulfur dyed samples. It is well known that reactive dyes can diffuse into the fabric structure, while sulfur dyes only deposit on the fabric surface after oxidation. This reduces the ability sulfur-dyed cotton yarns to endure friction and results in a more compact structure. On the other hand, less friction between yarns in the reactive dyed fabrics contributes to easier movement of yarns during compressive shrinkage

Table 5. Crimp percentage of warp yarns and fabric thickness (standard deviations in parentheses)

Fabric	Crimp % of warp yarns		Fabric thickness (mm)	
	Before processing	After processing	Before processing	After processing
1	12 (0.3)	17 (0.3)	0.36 (0.1)	0.39 (0.1)
2	12 (0.2)	15 (0.1)	0.74 (0.2)	0.77 (0.2)
3	6 (0.1)	12 (0.2)	0.37 (0.1)	0.42 (0.1)
4	6 (0.2)	12 (0.1)	0.47 (0.1)	0.51 (0.1)

Table 4. Number of warp and weft yarns per centimeter and the area density (1 m^2) of fabrics before and after compressive shrinkage process (standard deviations in parenthesis)

Fabric	Number of warps (1 cm)		Number of wefts (1 cm)		Area density (1 m^2)	
	Before processing	After processing	Before processing	After processing	Before processing	After processing
1	43 (1.5)	43 (1.6)	21 (1)	24 (1)	206.5 (4.2)	223.8 (5.0)
2	26 (0.7)	26 (0.8)	19 (0.5)	20 (0.8)	432.7 (9.1)	445.7 (8.3)
3	30 (0.9)	30 (1.2)	19 (0.4)	20 (0.5)	203.8 (3.5)	219.3 (3.1)
4	45 (1.1)	45 (1.5)	23 (0.9)	25 (1)	283.8 (4.7)	291.3 (6.2)

finishing and more crimping [47,48].

Fabric Shrinkage and Abrasion Analysis

Table 6 shows the shrinkage percentage of fabrics after washing and stone washing in the warp direction as well as the abrasion resistance of samples before and after compressive shrinkage.

Researchers have stated that the fabrics in yarns swell during shrinkage by increasing their diameter and shortening their length [49]. In our compressive shrinkage-treated samples, there was no shrinkage in the warp direction due to washing. Stone-washing was also carried out on twill and plain woven sulfur dyed fabrics. It is necessary to evaluate any possible shrinkage of sulfur dyed fabrics after stone washing as a common procedure for garment finishing. These samples showed a higher decrease in shrinkage percentage after stone washing versus regular washing. This result is incidentally consistent with the results obtained from the crimp percent measurement of sulfur dyed fabrics. The shrinkage percentage of all the fabrics was negligible in weft direction before and after compressive shrinkage.

The compressive shrinkage process increased the abrasion resistance of all fabric samples. This result has a direct relationship to crimp percent and thickness of samples because they increased after the compressive shrinkage process. This could be due to the fact that an increase in the crimp percent increases the contact points and crowns of finished fabric. As a result, the abrasive requires more force to destroy the fabric structure. Note that weft yarns protect crimped warp yarns from abrasion forces and prevent them from being pulled out during analysis. On the other hand, the fabrics became thicker and heavier—this increased their resistance to rubbing and improved their wear [50,51].

We also found that plain-woven cotton fabrics have less improvement in abrasion resistance after finishing relative to twill woven samples. Two research groups have demonstrated that twill woven fabrics generally have higher abrasion resistance and cover factors due to a harder structure and less removal of fibers during rubbing. This pattern has more contact points and less pattern loss against rubbing relative to twill woven fabrics [52,53].

Drapeability and Mechanical Properties

Table 7 shows the drapeability and force at breakage for all fabric samples before and after compressive shrinkage process. The ability to drape for all fabrics increased in the warp direction after processing. However, a reverse trend in drapeability is observed in the weft direction confirming bending rigidity.

It has been reported that the area of density, crimp percent and thickness of fabrics are pivotal factors in evaluating their drapeability. An increase in the crimp of cotton fabrics in the warp threads is generally confirmed by decreasing the bending length [54,55]. On the other hand, the increased thickness and number of threads in the weft direction result in more interactions between yarns in the fabric and more resistance to deformation. This is the main reason for less drapeability of yarns in the weft direction versus the warp threads [56,57].

It can also be seen that different weave patterns show differences in drapeability as a result of changes in thread interactions and shear properties [54,55].

Table 7 shows the force at the breaking point for twill woven fabrics. This force increased in the warp direction

Table 6. Shrinkage percentage of warp yarns and abrasion resistance of fabrics before and after compressive shrinkage (standard deviations in parentheses)

Fabric	Shrinkage % after washing		Shrinkage % after stone washing		Abrasion resistance (number of cycles)	
	Before processing	After processing	Before processing	After processing	Before processing	After processing
1	4 (0.12)	0	6 (0.13)	1 (0.05)	6500 (15)	7000 (12)
2	4.4 (0.14)	0	6.5 (0.14)	3 (0.07)	17000 (23)	20000 (25)
3	5.2 (0.14)	0	-	-	9000 (14)	9500 (13)
4	2 (0.11)	0	-	-	7000 (20)	12000 (22)

Table 7. Drape length and force at breaking of all the fabric samples before and after compressive shrinkage processing (standard deviations in parentheses)

Fabric	Drape length in warp direction (cm)		Drape length in weft direction (cm)		Force at break in warp direction (kgf)		Force at break in weft direction (kgf)	
	Before processing	After processing	Before processing	After processing	Before processing	After processing	Before processing	After processing
1	5.91 (0.1)	5.8 (0.1)	4.62 (0.1)	5.75 (0.1)	125.7 (2)	120.1 (3)	57.8 (1)	60.9 (2)
2	10.5 (0.2)	10.1 (0.2)	8.7 (0.1)	9.9 (0.1)	143.8 (3)	145 (3)	100 (3)	111.2 (2)
3	4.94 (0.1)	4.71 (0.1)	4.62 (0.1)	4.71 (0.1)	90.4 (2)	77.2 (2)	56.7 (1)	58.2 (2)
4	8.7 (0.1)	8.37 (0.1)	7.53 (0.1)	7.74 (0.1)	95.02 (3)	101.4 (2)	80.2 (2)	81.9 (1)

Table 8. CIELAB color coordinates of fabric samples after processing

Fabric	Color coordinates						
	L^*		a^*		b^*		ΔE
	Before processing	After processing	Before processing	After processing	Before processing	After processing	-
1	20.2	20.1	2.34	2.36	3.02	2.85	0.19
2	47.7	48	-0.01	-0.05	4.78	4.93	0.33
3	35.6	34.9	2.18	2.37	9.42	9.76	0.80
4	15.7	15.9	1.13	1.12	-2.51	-2.71	0.28

after compressive shrinkage but decreased for plain-woven fabrics. The force at the breaking point of all samples increased in the weft direction after processing. During measurement of mechanical properties, the crimp is removed from the yarn threads. The data suggests that compressive shrinkage finishing increases the binding between fibers and reduces the wasting effect in twill woven fabrics. In plain-woven textiles, the fibers themselves in warp threads were subjected to a high rate of abrasive action after finishing [54]. Thus, we concluded that the mechanical properties of the finished fabrics depend on the weave pattern, the number of threads per unit, crimp percent and thickness.

Increases in the mechanical properties of fabrics in the weft direction could be due to increasing number of weft yarns per unit after compressive shrinkage processing.

Colorimetric Properties

Table 8 shows CIELAB color coordinates of fabric samples after processing. There was no considerable change in L^* a^*, b^* and ΔE values after compressive shrinkage.

Conclusion

Compressive shrinkage processing changed some physical and mechanical properties of woven cotton fabrics dyed with sulfur and reactive dyes. The number of warps per unit did not change after processing but it did increase in the weft direction. The rubber belt pressure decreased the drapeability of fibers in the warp direction. This can be due to passing the fabrics through the pressure zone between the steam cylinder and the rubber sleeve, which changed the thickness, crimp percentage and drapeability of fabrics. Interestingly, the crimp percentage of warp yarns for twill and plain-woven fabrics dyed with reactive dyes increased more than sulfur dyed samples. This is perhaps because of the diffusion properties of the dyes.

There was no remaining shrinkage for any fabric in the warp direction after compressive shrinkage due to washing. The results also showed that stone washing caused the sulfur dyed fabrics to change dimension even after finishing. It is thus very important to increase the sleeve pressure for sulfur dyed fabrics relative to the reactive dye samples. This will inhibit any possible shrinkage during stone washing of garments. Finally, compressive shrinkage finishing did not change the colorimetric properties of fabrics—this is another key benefit of this approach.

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References

1. H. H. Htike, J. Kang, H. Yokura, and S. Sukigara, *J. Text. Sci. Eng.*, **5**, 223 (2015).
2. I. C. Sharma, S. Ghosh, and N. K. Gupta, *Text. Res. J.*, **55**, 149 (1985).
3. S. C. Anand, K. S. M. Brown, L. G. Higgins, D. A. Holmes, M. E. Hall, and D. Conrad, *Autex Res. J.*, **2**, 84 (2002).
4. I. Y. Lee, G. E. Jeong, S. R. Kim, C. Bengelsdorff, and S. D. Kim, *Color. Technol.*, **131**, 192 (2015).
5. M. G. Uddin and M. R. Islam, *J. Fashion Technol. Text. Eng.*, **3**, 2 (2015).
6. L. Quaynor, M. Takahashi, and M. Nakajima, *Text. Res. J.*, **70**, 28 (2000).
7. L. Quaynor, M. Nakajima, and M. Takahashi, *Text. Res. J.*, **69**, 285 (1999).
8. A. S. Bagwan, A. Rajput, S. Dalal, and A. Aakade, *J. Text. Sci. Eng.*, **5**, 213 (2015).
9. M. Sumithra and V. N. Raaja, *J. Fashion Technol. Text. Eng.*, **3**, 1 (2014).
10. H. S. Mohapatra, N. Singh, P. Shukla, and S. K. Pal, *J. Text. Sci. Eng.*, **5**, 203 (2015).
11. M. Q. Tusief, N. Mahmood, N. Amin, and M. Saddique, *J. Text. Sci. Eng.*, **4**, 160 (2014).
12. G. S. Bhat, P. Gulgunje, and K. Desai, *Express Polym. Lett.*, **2**, 49 (2008).
13. C. V. Le, N. G. Ly, and R. Postle, *Text. Res. J.*, **63**, 88 (1993).
14. T. Hussain, S. Ahmed, and A. Qayum, *Color. Technol.*, **124**, 375 (2008).
15. D. Phillips, J. Suesat, M. Wilding, D. Farrington, S. Sandukas, J. Bone, and S. Dervan, *Color. Technol.*, **119**, 128 (2003).
16. A. Sadeghian Maryan, M. Montazer, T. Harifi, and M.

Mahmoudi Rad, *Carbohydr. Polym.*, **95**, 338 (2013).
17. M. Parvinzadeh Gashti, A. Elahi, and M. Parvinzadeh Gashti, *Compos. Pt. B-Eng.,* **48**, 158 (2013).
18. F. Alimohammadi, M. Parvinzadeh Gashti, and A. Shamei, *Prog. Org. Coat.*, **74**, 470 (2012).
19. K. Millington, *Text. Res. J.*, **68**, 413 (1998).
20. M. Parvinzadeh, *J. Surfactants Deterg.*, **10**, 219 (2007).
21. M. Parvinzadeh and H. Najafi, *Tenside Surfactants Deterg.*, **45**, 13 (2008).
22. M. Parvinzadeh and R. Hajiraissi, *J. Surfactants Deterg.*, **11**, 269 (2008).
23. M. Parvinzadeh and R. Hajiraissi, *Tenside Surfactants Deterg.*, **45**, 254 (2008).
24. M. Parvinzadeh, *Tenside Surfactants Deterg.*, **46**, 335 (2009).
25. M. Parvinzadeh, N. Memari, M. Shaver, B.Katozian, S. Ahmadi, and I. Ziadi, *J. Surfactants Deterg.,* **13**, 135 (2010).
26. I. Ebrahimi, A. Kiumarsi, M. Parvinzadeh Gashti, R. Rashidian, and M. Hossein Norouzi, *Eur. Phys. J. Appl. Phys.*, **56**, 10801 (2011).
27. M. Parvinzadeh and I. Ebrahimi, *Appl. Surf. Sci*., **257**, 4062 (2011).
28. M. Hossein Rahimi, M. Parvinzadeh, M. Yousefpour Navid, and S. Ahmadi, *J. Surfactants Deterg.*, **14**, 595 (2011).
29. M. Parvinzadeh and I. Ebrahimi, *Radiat. Eff. Defects Solids*, **166**, 408 (2011).
30. M. Parvinzadeh Gashti, M. Yousefpour Navid, and M. Hossein Rahimi, *J. Appl. Polym. Sci.*, **125**, 1430 (2012).
31. M. Parvinzadeh Gashti, M. Yousefpour Navid, and M. Hossein Rahimi, *Pigm. Resin. Technol.*, **42**, 34 (2013).
32. M. Parvinzadeh Gashti and H. Adibzadeh, *Fiber. Polym.*, **15**, 65 (2014).
33. S. Majid Mortazavi and P. Esmailzadeh Boukany, *Iran. Polym. J.*, **13**, 213 (2014).
34. M. Parvinzadeh Gashti, F. Alimohammadi, and A. Shamei, *Surf. Coat. Technol.*, **206**, 3208 (2012).
35. M. Parvinzadeh Gashti, A. Pournaserani, H. Ehsani, and M. Parvinzadeh Gashti, *Vacuum*, **91**, 7 (2013).
36. M. Parvinzadeh Gashti and A. Almasian, *Compos. Pt. B-Eng.,* **52**, 340 (2013).
37. E. Pakdel, W. A. Daoud, L. Sun, and X. Wang, *Appl. Surf. Sci.*, **321**, 447 (2014).
38. E. Pakdel, W. A. Daoud, L. Sun, and X. Wang, *J. Colloid Interf. Sci.*, **440**, 299 (2015).
39. K. K. Samanta, M. Jassal, and A. K. Agrawal, *Fiber. Polym.*, **11**, 431 (2010).
40. M. Parvinzadeh Gashti and A. Almasian, *Compos. Pt. B-Eng.,* **45**, 282 (2013).
41. M. P. Gashti, *J. Textile Sci. Eng.*, 4: e120. doi:10.4172/2165-8064.1000e120 (2014).
42. M. Parvinzadeh Gashti, A. Almasian, and M. Parvinzadeh Gashti, *Sens. Actuator A-Phys.*, **187**, 1 (2012).
43. F. Alimohammadi, M. Parvinzadeh Gashti, and A. Shamei, *J. Coat. Technol. Res.*, **10**, 123 (2013).
44. M. Parvinzadeh Gashti, S. Tajzadeh Ghehi, S. Valipour Arekhloo, A. Mirsmaeeli, and A. Kiumarsi, *Fiber. Polym.*, **16**, 585 (2015).
45. A. U. Nair, B. A. Patwardhan, and R. P. Nachane, *Ind. J. Fibre Text*., **38**, 366 (2013).
46. J. G. Frick Jr. and G. B. Verburg Jr., *Text. Res. J.*, **46**, 227 (1976).
47. M. Maqsood, T. Hussain, Y. Nawab, K. Shaker, and M. Umair, *J. Text. Inst.*, **106**, 1180 (2015).
48. G. Sule, *Text. Res. J.*, **82**, 810 (2012).
49. M. Topalbekiroğlu and H. Kübra Kaynak, *Int. J. Cloth. Sci. Technol.*, **20**, 281 (2008).
50. O. Shurkian, J. Amirbayat, and R. H. Gong, *J. Text. Eng.*, **48**, 1 (2002).
51. F. Khedher, S. Dhouib, S. Msahli, and F. Sakli, *Autex Res. J.*, **9**, 93 (2009).
52. A. Seyam and A. El-Shiekh, *Text. Res. J.*, **65**, 14 (1995).
53. H. K. Kaynak and M. Topalbekiroğlu, *Fibres Text East Eur.*, **16**, 54 (2008).
54. Y. J. Jeong and D. G. Phillips, *J. Text. Inst.*, **89**, 70 (1998).
55. N. Kenkare and T. May-Plumlee, *Int. J. Cloth. Sci. Technol.*, **17**, 109 (2005).
56. C. V. Le, D. H. Tester, N. G. Ly, and S. De Jong, *Text. Res. J.*, **64**, 61 (1994).
57. N. Alkadi and A. Karnoub, *J. Text. Sci. Eng.,* **5**, 191 (2015).