(REFEREED RESEARCH)

THE EFFECT OF CAUSTICIZING, WASHING AND DRYING PROCESSES ON SHRINKAGE AND CREASE RESISTANCE PROPERTIES OF VISCOSE FABRIC

KOSTİKLEME, YIKAMA VE KURUTMA İŞLEMLERİNİN VİSKON KUMAŞIN ÇEKME VE BURUŞMAZLIK ÖZELLİKLERİNE ETKİSİ

Özlenen ERDEM İŞMAL
Dokuz Eylül Ü. Güzel Sanatlar Fakültesi Tekstil Bölümü
e-mail: ozlenen.ismal@deu.edu.tr

ÖZET

Bu makalede ön ve ard işlemlerin viskon kumaşın özellikleri üzerindeki etkileri incelenmiştir. Kostiklemenin, kesiksiz (açık en) ve kesikli (halat) yıkama işlemlerinin kontakt ve konveksiyon kurutmaların etkisi beyazlık, boyut stabilitesi, buruşmazlık özelliği ve kopma dayanımı açılarından incelenmiştir. Yıkama çekmesi ve buruşmazlık özelliğini arttırmak üzere buruşmazlık bitim işlemi yapılmıştır. Sonuçlar istatistiksel analiz yapılarak değerlendirilmiş ve kumaş özellikleri arasındaki ilişkinin eğilimi belirlenmeye çalışılmıştır. Buruşmazlık bitim işlemi buruşmazlık açılarını ve yıkama çekme değerlerini önemli ölçüde iyileştirmiştir. Ancak, özellikle çözgü yönündeki boyut stabilitesi tatmin edici değildir ve kostikleme işlemiyle desteklenmesi gereklidir. Kostiklemenin buruşmazlık özelliği ve boyut stabilitesi üzerinde iyileştirici etkisi vardır. Kopma dayanımında ise istatistiksel olarak önemli olmayan bir azalmaya yol açmıştır. Halat halde kesikli yıkama ve konveksiyon kurutma buruşmazlık özelliği açısından yarar sağlamıştır. Ancak kopma dayanımını olumsuz yönde etkilemiştir. Buruşmazlık özelliği ile yıkama çekmesi ve kopma dayanımı arasında istatistiksel olarak önemli negatif korelasyon olduğu belirlenmiştir. Yıkama çekmesi ve kopma dayanımı arasında pozitif ve bağıl olarak daha düşük bir korelasyon olmakla birlikte istatistiksel olarak anlamlı bir bağıntı kurulamamıştır. Kostikleme işlemi sayesinde, kopma dayanımında önemli bir azalma yaratmaksızın, viskon kumaşın boyut stabilitesini ve buruşmazlık özelliklerini iyileştirmek olasıdır.

Anahtar Sözcükler: Viskon, Çapraz bağlama, Kostikleme, Buruşmazlık açısı, Yıkama çekmesi, Kurutma.

ABSTRACT

In this paper the effects of pretreatment and post treatments on the properties of viscose fabric were investigated. Effect of causticizing, continuous (open-width) and discontinuous (rope) washings, contact and convection dryings were assessed in terms of dimensional stability, whiteness, crease resistance and breaking strength properties. The crease resist finish was applied to enhance crease resistance and washing shrinkage properties. Results were evaluated by statistical analysis and it was tried to determine the tendency of relations among fabric properties. The crease resist finish enhanced dramatically crease recovery angles and washing shrinkage values. However dimensional stability especially in warp direction was not satisfactory and it needs to be supported by causticizing process. Causticizing has an improving effect on both crease resistance and also dimensional stability. It resulted in breaking strength loss that was not statistically significant. Discontinuous washing in rope form and convection drying were beneficiary on crease resistance. However this affected breaking strength negatively. It was identified statistically significant negative correlation between crease resistance, washing shrinkage and breaking strength. Although a positive and relatively lower correlation was detected between washing shrinkage and breaking strength it could not be established a statistically significant relation. It is possible to improve the dimensional stability and the crease resistance properties of viscose fabric through causticizing process without a significant breaking strength loss.

Key Words: Viscose, Cross-linking, Causticizing, Crease recovery angle, Washing shrinkage, Drying.

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1. INTRODUCTION

Nowadays textiles made of viscose fibres which have a pleasant handle, drape and lustre are becoming increasingly popular. The process of making viscose yarn was discovered by C.F.Cross and E.J.Bevan-two chemists who brought about a much better understanding of chemistry of cellulose. The process was discovered in 1891, and patented by Cross, Bevan and Beadle in 1892, but took some considerable time to establish itself. Viscose rayon is generated cellulose. The cellulose comes from wood, of which it is the major constituent. It is purified, treated with caustic soda, which converts it into alkali cellulose, then treated with carbon disulphide, which converts it into sodium cellulose xanthate and then dissolved in a dilute solution of caustic soda. This solution is then "ripened", the solution becoming at first less viscous and then increasing nearly to its original viscosity; it is then spun into an acid coagulating bath, which precipitates the cellulose in the form of viscose filament (1).

Viscose rayon is one of the most absorbent of all textiles. It has a very high shrinkage potential and tend to shrink more than cotton fabrics of similar construction (2). For this reason it needs to apply much compression in finishing to give appropriate end-use washing shrinkage values and some problems related to extention and measure deviations of viscose fabrics during cut and sewing processes could be experienced. In case of having a very high initial shrinkage, it needs an excessive compression to get final reduced shrinkage values during sanforazing. Enforcing the fabric can generate a deformation and a tendency to extension. In this connection, it can be a good solution to reduce initial washing shrinkage as possible as can be to avoid from inconveniences. Conventional viscose fibres exhibit less strength, higher water absorption capacity, creasing and flexibility properties than that of cotton (3).

Dimensional stability is a crucial factor for the fabric quality. Cellulose fibres and regenerated fibre types in particular absorb relatively high amounts of water and swell to a lesser or greater extent. In order to stabilise woven and knitted goods made of cellulose fibres and to increase the utility values of the fibres it is necessary to reduce the water absorption capacity of the fibres. This can be achieved with the help of cellulose cross linkers. To achieve a good dimensional stability remember that a final sanforisation process can only be effective up to a certain extent since the relatively flat surface and already cross-linked regenerated cellulose fibres can not be compacted to the same extent as cotton (4). The chemical method leading to cross-linking of the cellulose macromolecules through the introduction of different products is one of the most widely used. In this way, the current state of the fabric is fixed and subsequent shrinkage is hindered (5). Some researchers investigated the effects of various cross-linking agents (5-12). Dimethyldihydroxyethylene urea is produced with the reaction of dimethylurea and glyoxal. It has two reactive hydroxyl groups and combines with cellulose by means of ether bonds (13). Fibres having great deals of amorphous regions and weak molecular bonds tend to crease more. The purpose of crease resist finish is to reduce swelling of fibre and to improve crease resistance properties. If water hardly diffuses into the gaps among fibre crystallites, then swelling and consequently shrinkage values are reduced. Similarly if fibre units are made difficult to slide mutually, crease resistance is improved. Causticizing is also an useful process to enhance dimensional stability in addition to improve the crease resistance properties. It also partly recovers the interior stress of the fibres and results in a better dimensional stability (14). It is reported that cellulosic fibres treated with alkaline solutions were become considerably more activated and accessible to their hydroxyl groups (15,16).

2. EXPERIMENTAL

Fabric

Experiments were conducted by using a 100 % viscose raw fabric with a weight of 145 gr/m^2, yarn count of 20x20 Ne, count of 25 warp and 20 weft thread/cm and width of 102 cm.

Processes

Trials were performed at mill conditions and repeated three times. Viscose fabrics were pretreated according to the following procedures:

- Washing in a bath containing 2 g/L soda, 1 g/L wetting agent at a liquor ratio of 1:7 in an overflow at 70 °C for 60 minutes.
- Washing at 80 °C for 15 minutes, neutralization with 0.5 g/L acetic acid at 30 °C for 10 minutes, cold rinsing for 10 minutes.
- Drying in a stenter at 120 °C
- Fabric was divided in two parts and causticizing process was applied to one of them. Causticizing was carried out in continuous washing machine by using 9 Baumé (62.5 g/L-5.86 %) sodium hydroxide solution at the first box and at 30 °C. Treatment time of the fabric with the alkaline solution was 20 seconds.

Causticized and not causticized fabrics were printed with reactive dye. Then they were steamed and divided in four parts. One part of the causticized fabric was washed in an open width continuous washing machine with seven boxes and dried at drums (16 cylinders) by contact drying method at 120 °C. Fabrics were run with minimum tension adjustments. Other part of the causticized fabric was washed in overflow machine and dried in a stenter by convection method at 120 °C. These different washing and drying cycles were repeated for not causticized fabric.

Fabrics were coded and finished in the following way:

A: Not causticized, continuous washing, contact drying (Crease resist finish)

A': Causticized, continuous washing, contact drying (Crease resist finish)

B: Not causticized, discontinuous washing, convection drying (Crease resist finish)

B': Causticized, discontinuous washing, convection drying (Crease resist finish)

C: Not causticized, continuous washing, contact drying (Silicone finish)

C' Causticized, continuous washing, contact drying (Silicone finish)

D: Not causticized, discontinuous washing, convection drying (Sili-cone finish)

D': Causticized, discontinuous washing, convection drying (Silicone finish)

Crease resist finish and silicone finish were applied in a stenter. Crease resist finish was performed by padding with a bath containing 80 g/L Dimethyldihydrox-yethylene urea, 16 g/L catalyst, 20 g/L polyethylene dispersion, 0.5 g/L acetic acid and 15 g/L silicone micro emulsion (amino functional polysiloxane) at 80 % wet pick-up. Drying was followed at 120 °C and curing was performed at 150 °C for 4 minutes. Other parts of fabrics were padded with a bath containing 15 g/L silicone micro emulsion (amino functional polysiloxa-ne) at 80 % wet pick-up and dried at 120 °C.

Testing Procedures

Fabrics were conditioned for one day at 20 °C and 65 % relative humidity before testing. Test results are the averages of three measurements belong to test specimens which were taken from three different places of the fabrics. Whiteness measurements were performed by using X-Rite SP78 spectrophotometer. (stens-by formula) Dry crease recovery angles were determined according to AATCC 66-1984. Dimensional stability tests were conducted with full width of fabric in warp and weft directions according to ISO 6330-1984 (Testing procedure 2A) and samples were dried flat (Procedure C). Breaking strenght measurements were carried out according to ASTM D5035-90. All the test results related to crease resistance, breaking strength and dimensional stability were evaluated by statistical analysis based on significance level of α=0.05 (ANOVA-oneway, regression and correlation). Variance analysis (ANOVA) was performed to identify the significant differentces between processses and to deter-mine the significancy of regression. If $p< 0.05$, $F>F_c$; it was decided that statistically significant differences among processes and regression between variants were existed. Correlation analysis was conducted to see existence, degree and direction of relationship among fabric properties (variables). Regression analysis was applied to define the rank and significancy of these relations and coefficients.

3. RESULTS AND DISCUSSIONS

Whiteness

Causticizing resulted in insignificant decrease of whiteness. It is also reported that whiteness decrease of viscose fabric through causticizing process in some cases (15). In this study, it was not detected a significant difference between continuous or discontinuous post treatments in terms of whiteness (Table 1).

Table 1. Whiteness measurements of pretreated fabrics

Sample	Whiteness (Stensby)
A	83.74
A'	81.97
B	84.34
B'	81.74

A: Not causticized, continuous washing, contact drying

A': Causticized, continuous washing, contact drying

B: Not causticized, discontinuous washing, convection drying

B': Causticized, discontinuous washing, convection drying

Dimensional stability evaluation of crease resist finish

Washing shrinkage of raw fabric was -23.3 % in warp and -12 % in weft direction. Markings were given in warp and weft directions on the fabric before entering alkaline solution to determine

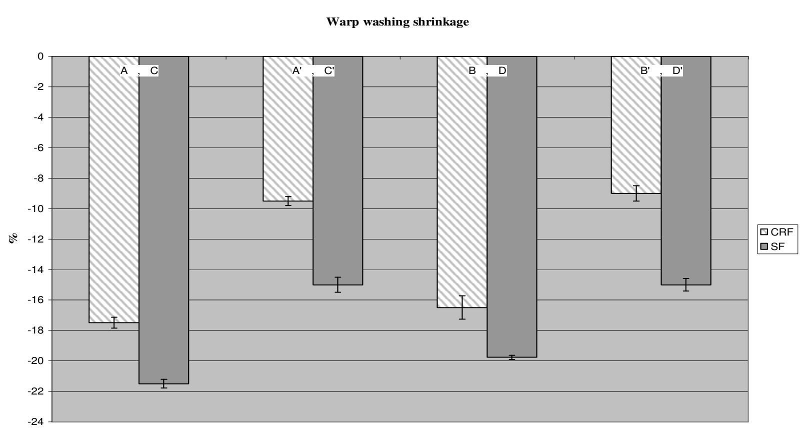

Figure 1. Washing shrinkage in warp direction

CRF: Crease Resist Finish

SF: Silicone Finish

* Warp shrinkage of pretreated white fabric (not causticized) was -20 %.

* Warp shrinkage of pretreated white fabric (causticized) was -14.2 %.

A: Not causticized, continuous washing, contact drying (crease resist finish)

A': Causticized, continuous washing, contact drying (Crease resist finish)

B: Not causticized, discontinuous washing, convection drying (Crease resist finish)

B': Causticized, discontinuous washing, convection drying (Crease resist finish)

C: Not causticized, continuous washing, contact drying (Silicone finish)

C' Causticized, continuous washing, contact drying (Silicone finish)

D: Not causticized, discontinuous washing, convection drying (Silicone finish)

D': Causticized, discontinuous washing, convection drying (Silicone finish) shrinkage ratios during alkaline process. These markings were measured at the end of causticizing process subsequently. Shrinkage values were determined as +1 % in warp and -5.2 % in weft direction. It shows that relaxation occurs in warp direction through alkaline process due to swelling. Statistical analysis showed that there was a significant difference among trials (Fig.1 and Fig. 2, Table 2 and Table 3). Crease resist finish generated a reduction in terms of washing shrinkage by limiting the diffusion of water to the gaps among the fibre units due to crosslinking. However these values were still higher degrees of shrinkage. Causticizing treatment generated obviously a better dimensional stability than that of not causticized specimens. It also revealed a tendency of extension in weft direction. These are possibly due to the results of relaxation and better removal of interior stresses of the fabric. Discontinuous process provided a lower washing shrinkage (A-B, A'-B'). However it can be observed from the graphs and error bars that the differences among them were not statistically significant. An alkaline process with a concentration of above 5 % creates a remarkable looseness in crystalline structure of viscose. Structure of viscose fibres was affected by causticizing process due to its low proportion of crystalline regions. It was observed through X-ray analysis and SEM photographs that causticizing resulted in a significant increase in terms of crystalline index and improved the fibre surface smoothness and swelling (15). It can be assumed that viscose fabric becomes more stable by causticizing process through the increase of swelling ratio and crystalline regions.

Breaking strength evaluation of crease resist finish

Crease resist finish exhibited a considerable breaking strength loss by limiting the movement of the fibre units mutually through crosslinking. Table 4 shows the comparision of relative breaking strength. It was concluded that causticizing did not create a supporting effect in terms of breaking strength loss. Causticizing resulted in a breaking strength loss both in warp and weft direction that was not statistically significant (Figure 3, Figure 4 and Table 6). However Table 5 shows significant differences between continuous and discontinuous processes in terms of warp breaking strength. It is also reported that causticizing leaded to a some strength loss due to its sensitiveness to alkaline solutions (15). It is known that viscose swells very rapidly. It was not experienced any damage or breaking/ tearing of fabric during continuous washing process thanks to minimum tension adjustment and short treatment time with alkaline solution. Fabric weight also could be efficient on this observation. It must be considered that viscose fibre is sensitive to mechanical action especially when it is wet. Water facilitates the slippage of macromolecules mutually resulting in strength loss and breaking/ tearing of viscose fibres. Discontinuous post treatment as washing in overflow and convection drying caused more breaking strength loss both in warp and weft direction. It may be the result of the mechanical action and longer time

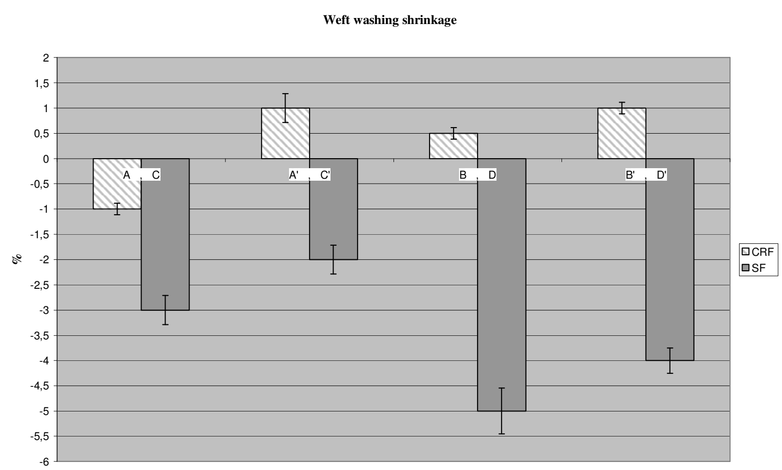

Figure 2. Washing shrinkage in weft direction

* Weft shrinkage of pretreated white fabric (not causticized) was +2.5 %.

* Weft shrinkage of pretreated white fabric (causticized) was +6.7 %.

Table 2. Variance analysis for dimensional stability in warp direction. (crease resist finish)

Source of variance	Sum of squares	df	Mean of squares	F	P	F c
Among groups	182.0625	3	60.6875	77.30892	3E-06	4.066181
Within groups	6.28	8	0.785			
Total	188.3425	11				

Table 3. Variance analysis for dimensional stability in weft direction (crease resist finish)

Source of variance	Sum of squares	df	Mean of squares	F	P	F c
Between groups	8.0625	3	2.6875	29.05405	0.000119	4.06618
Within groups	0.74	8	0.0925			
Total	8.8025	11				

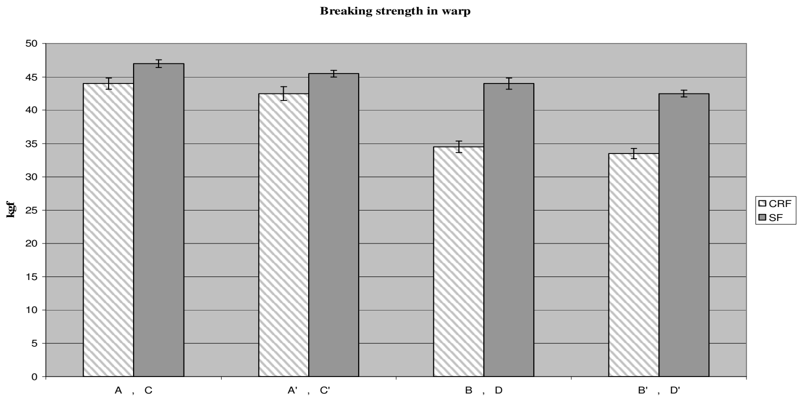

Figure 3. Breaking strength in warp direction

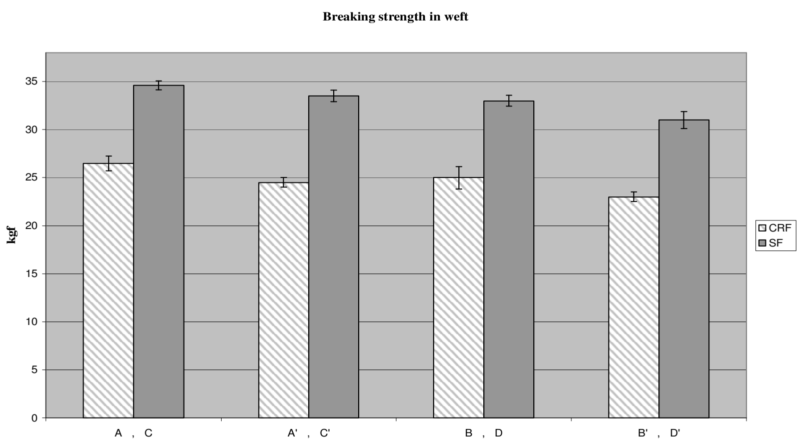

Figure 4. Breaking strength in weft direction

Table 4. Relative breaking strength (crease resist finish)

Trials	Warp (%)	Weft (%)
A	100	100
A’	96.5	92.4
B	78.4	94.3
B’	76.1	86.7

Table 5. Variance analysis for breaking strength in warp direction (crease resist finish)

Source of variance	Sum of squares	df	Mean of squares	F	P	F c
Between groups	289.5	3	96.5	40.63158	3.45E-05	4.066181
Within groups	19	8	2.375			
Total	308.5	11				

Table 6. Variance analysis for breaking strength in weft direction (crease resist finish)

Source of variance	Sum of squares	df	Mean of squares	F	P	F c
Between groups	18.75	3	6.25	3.448276	0.071716	4.066181
Within groups	14.5	8	1.8125			
Total	33.25	11				

during washing in overlow comparing with continuous washing and drying (Table 4). In this connection it was detected a statistically significant difference in warp and not in weft direction between discontinuous and continuous processes. Swelling of viscose fibres is not eliminated during drying process however water retention capacity diminishes through each of drying steps. Water weakens H-bonds of viscose fibres (15). In author’s opinion also, there is possibly an inverse relation between swelling ratio and breaking strength loss of viscose fibre. According to the findings of this study, breaking strength values of the samples continuously washed and contact dried (A, A’) were higher than that of the samples discontinuously washed and convection dried (B, B’). Contact drying is a more severe medium and possibly leaded to a contraction of capillaries of viscose fibres and consequently a decrease of swelling ratio/water retention capacity. It must be considered the effect of fabric rotation and abrasion of fibre surface on breaking strength during discontinuous washing

Crease recovery angle evaluation of crease resist finish

Different pre and post treatments and causticizing exhibited a significant difference in terms of crease recovery angle since $p<0.05$ (Figure 5 and Table 7). Error bars also support this observation. Causticizing has an improving effect in crease recovery angle. It is considered that this finding sources from the increase of crystalline region of viscose thanks to causticizing and it is consistent with some researches. It is also reported that alkaline pretreatment had an improving effect on crease recovery angle of cotton by increasing macromolecular orientation. Cotton and viscose showed similar behaviours through alkaline process (16). Post treatment was efficient in this study. Fabric subjected to hot metal drying drums directly and some stress in case of continuous washing and contact drying. A harsh handle was obtained due to the effect of hot drums. Consequently, these conditions and effects could impair the crease resistance and the dimensional stability

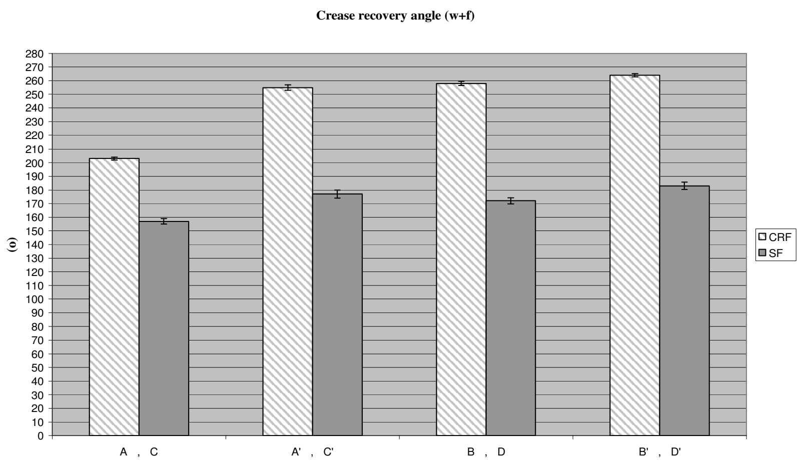

Figure 5. Crease recovery angle

Crease recovery angle of pretreated and not causticized white fabric was 107° (warp+weft)

Crease recovery angle of pretreated and causticized white fabric was 167° (warp+weft)

Table 7. Variance analysis for crease recovery angles (crease resist finish)

Source of variance	Sum of squares	df	Mean of squares	F	P	F c
Between groups	7182	3	2394	342	8.79E-09	4.066181
Within groups	56	8	7			
Total	7238	11				

Table 8. Correlation between crease resistance, breaking strength and washing shrinkage (crease resist finish)

	Crease resistance	Breaking strength	Washing shrinkage
Crease resistance	1		
Breaking strength	-0.75251	1	
Washing shrinkage	-0.76426	0.43646467	1

Table 9. Regression analysis between crease resistance and breaking strength (crease resist finish)

	Sum of squares	df	Mean square	F	p
Regression	249.1916	1	249.1916	13.05551	0.004743
Difference	190.8709	10	19.08709		
Total	440.0625	11			

properties as well. There was a great difference in terms of the crease resistance between causticized and not causticized specimens that were continuously post treated (A, A'). However the difference was less in case of discontinuous post treatment system. It seems that the discontinuous process compensated the stabilizing effect of due to lower stress.

Correlation and regression analysis of crease resist finish

The correlation coefficient (r) is a value between the range of +1 and -1. A positive correlation coefficient means that variables increase simultaneously. A negative correlation coefficient shows that one variable increases while other decreases. No correlation is present if r =0. Determination coefficient (r^2) shows the performance of regression. The regression is more significant and descriptive how r2 is close to 1.

The correlation and regression analysis show that a significant negative correlation between crease resistance and washing shrinkage and breaking strength since $p<0.05$ (Table 8, 9 and 10). It means that the more crease resistance the less washing shrinkage and the less breaking strength. It was seen a positive and relatively lower correlation between washing shrinkage and breaking strength. However this correlation was not statistically significant since $p>0.05$ (Table 11).

A simple linear regression equation (eq-1) was applied as follows:

$y= a+bx$,

b is regression coefficient If b is positive it means a positive linear relation and vice versa.

The regression between crease resistance and breaking strength is given by Eq-2.

X= is the crease resistance

$y= 108.8344-0.18555x$ (Eq-2)

p=6.17E-06 for a

p=0.004743 for b

The coefficients are statistically significant since $p<0.05$.

One unit increase in crease resistance generates a decrease of 18.5 % in breaking strength.

The regression between crease resistance and washing shrinkage is given by Eq-3

$y= 46.93762-0.13954x$, (Eq-3)

x is the crease resistance

p=0.000451 for a

p=0.003799 for b

The coefficients are statistically significant since $p<0.05$.

One unit increase in crease resistance generates a decrease of 13.9 % in washing shrinkage.

Table 10. Regression analysis between crease resistance and washing shrinkage (crease resist finish)

	Sum of squares	df	Mean square	F	p
Regression	140.9367	1	140.9367	14.04406	0.003799
Difference	100.3533	10	10.03533		
Total	241.29	11			

Table 11. Regression analysis between breaking strength and washing shrinkage (crease resist finish)

	Sum of squares	df	Mean square	F	p
Regression	45.96609	1	45.96609	2.353326	0.156024
Difference	195.3239	10	19.53239		
Total	241.29	11			

Table 12. r^2 values (crease resist finish)

	r^2
Crease resistance-breaking strength	0.566264
Crease resistance- washing shrinkage	0.584097
Breaking strength- washing shrinkage	0.190501

Table 13. Correlation between crease resistance and breaking strength (silicone finish)

	Crease resistance	Breaking strength	Washing shrinkage
Crease resistance	1		
Breaking strength	-0.7174	1	
Washing shrinkage	-0.6477	0.311669	1

r^2 values also shows that variance of breaking strength is of 56.62 % crease resistance, variance of washing shrinkage is of 58.40 % crease resistance and variance of washing shrinkage is of 19.05 % breaking strength (Table 12)

Dimensional stability evaluation of silicone finish

It is clearly seen that washing shrinkage values of silicone finish is higher than that of crease resist finish (Figure 1 and Figure 4). Cross-linking agent ensured a remarkable improvement in terms of dimensional stability. Washing shrinkage values of pretreated fabrics proves that silicone finish did not generate any improvement in terms of dimensional stability even it resulted in an increase of initial values. It can be caused by extention forces occured during processes and can be assumed that crease resist finish compensates the shrinkage tendency of fabric by its stabilizing effect. Silicone finish was not comparable with crease resist finish. Differences were statistically significant since $p<0.05$ (p=7.69E-05 for warp and p=0.001101 for weft). Table 13 shows that correlation between crease resistance and washing shrinkage is negative and significant (p=0.022766) similar to the results of crease resist finish. The higher the crease resistance the less washing shrinkage.

Breaking strength evaluation of silicone finish

Silicone finish did not lead to a significant breaking strength loss comparing by initial values. However it occured differences between discontinuous and continuous processes. Unlike crease resist finish, less breaking strength losses occured through discontinuous washing and convection drying comparing with the other system (Figure 3 and Figure 4). Some weakening of facric possibly due to the friction effect of discontinuous washing could lead to more breaking strength loss at the end of the crease resist finish. There was a negative and significant correlation (p=0.008626) between the breaking strength and the crease resistance (Table 13). It was not found a significant correlation between the breaking strength and washing shrinkage (p=0,324051). These findings are in line with the result of crease resist finish.

Crease recovery angle evaluation of silicone finish

It was observed a significant difference among trials (p= 0.000512). Causticizing resulted in a significant increase of crease recovery angle and greater difference was observed between the causticized and not causticized fabrics at continuous processes similar to the crease resist finish (Figure 5). It can source from stabilizing effect of causticizing. Continuous process is of higher stress and could possibly be caused efficiently to reveal the stabilizing effect of causticizing.

4. CONCLUSION

Crease resist finish improved the crease recovery angles and the washing shrinkae values dramatically. However the dimensional stability especially in warp direction was not satisfactory and it needs to be supported by causticizing process. It is possible to improve the dimensional stability and the crease resistance properties of viscose fabric through causticizing process without affecting breaking strength significantly. It provides more reduced washing shrinkage and more improved crease resistance values. Consequently less shrinkage proportions were involved during the sanforisation. It means less total loss in length of fabric and higher cost saving. Otherwise it needs to apply an excessive shrinkage in sanforazing process to set appropriate dimensional stability and fabric deformation was existed. Subsequently, it causes problems at the cut and sewing steps. Under the conditions of this study, post treatments did not exhibit a significant difference except for warp breaking strength and crease recovery angle. Discontinuous process (overflow washing and convection drying) reduced the breaking strength while continuous process (continuous washing and contact drying) impaired crease resistance. It was detected a statistically significant negative correlation between the crease resistance, the washing shrinkage and the breaking strength. However it could not be established a statistically significant relation between the washing shrinkage and the breaking strength.

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