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Full Length Research Paper

Examining the effects of mercerization process applied under different conditions to dimensional stability

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In this study, mercerization processes were performed on cotton fabrics with three different weaving patterns in chain mercerizer at 60°C by applying three different time periods and three different processes under factory conditions. The fabrics, which were weaved from 20/1 open-end and 100% cotton yarns, were used in the tests. The fabrics used in the tests were applied singeing, desizing, bleaching and drying processes before the mercerization process. The mercerization processes were applied to the fabrics by using three different processes and times. The effect of the mercerization operation, which was applied in three different conditions, on the dimension stability of the samples was examined.

Key words: Mercerization, finishing, dimensional stability, shrinkage, cotton fabric.

INTRODUCTION

The finishing operations performed on weaving fabrics include all the operations carried out to provide a fabric with those properties that the customer desires after the fabrics leave the textile factories.

With the modern textile finishing operations that are applied today, it is possible to provide cotton fiber with a structure similar to the superior properties of synthetic fibers. One of the finishing operations that change the physical and characteristic properties of cotton fiber and the most important of these is mercerization. Mercerization is the treatment of cotton yarns, fabrics and knitgoods with cold, strong caustic soda liquor under tension. Mercerizing is an important operation for cotton finishing to achieve a resistant silk shine and good handle without all the fundamental processes being understood. Cross section of mercerized cotton fibers becomes larger and assumes perfectly circular forms as shown in Figure 1 (Routte, 2000).

In mercerization, the process is based on treating the threads or fabrics with a caustic soda (sodium hydroxide) solution of 15 - 20%. The threads or fabrics are rinsed a number of times after it has been subjected to sodium hydroxide. The fabrics are subjected to tension on a stenter on which most of the caustic is removed with hot water and then the remainder of base is neutralized in cold acid bath. Then the remainder of the acid is removed from the fabric by washing. The process is continuous. The threads or fabrics are subjected to tension during the finishing process for conventional mercerization. Good results are obtained through proper saturation, sufficient tension and complete washing. In addition, the same results can be obtained for knitted products in the shape of a tube through special equipment (Marjory, 1966; Corbman, 1983).

The reactions that take place in mercerization

Since concentrated sodium hydroxide flotte (operational solution that includes chemicals) is used in mercerization process, the reactions that take place with the cellulose fibers are intramicellar reactions. That is, the sodium hydroxide flotte that is concentrated this much, penetrates inside the micelles (crystallites) and a structure called hydrate cellulose emerges (Aniş, 2005).

$$\text{Cell} - \text{OH} \longrightarrow \underset{75\ \%}{\text{Cell} - \text{OH} + \text{NaOH}} \rightleftarrows \underset{25\ \%}{\text{Cell} - \text{ONa} + H_2O}$$

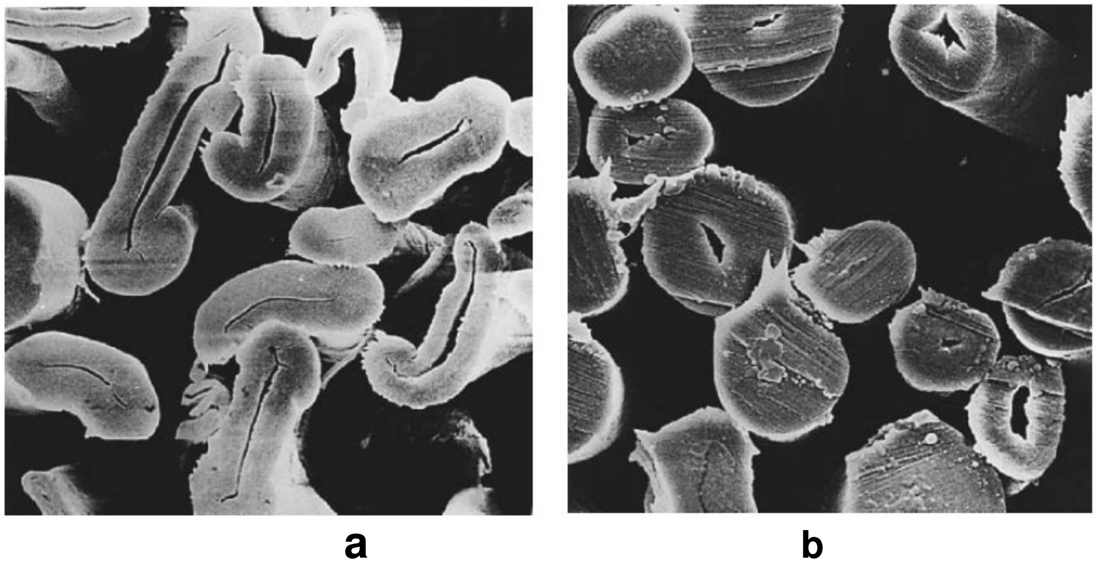

Figure 1. Electron microscope image of cotton fibers (x2200), a, natural; b, mercerized cotton.

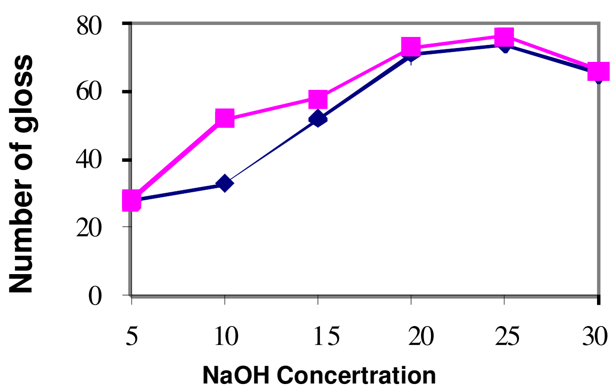

Figure 2. The relationship between the caustic soda concentration and the number of gloss [Tarakçıoğlu, 1979].

Sodium hydroxide reacts with the hydroxyl groups inside the macromolecule in such a way that it either produces sodium cellulosate or it links to the molecules through the pulling forces. Although both of them take place in mercerization, 75% is on linking's side through the force of pull. As the mercerization process can be done on raw fabrics before the desizing, it can also be done after the desizing, after boiling, after bleaching or after painting (Aniş, 2005)

The factors that affected the mercerization operation

1. Temperature: Temperature has a great effect on swelling Optimum swelling takes place at around 10 - 15°C. However, the swelling speed of fiber at low temperatures falls due to the high viscosity of caustic soda. The heat that emerges during the reaction prevents swelling and therefore, flotte is cooled in order to achieve the best mercerization effect. The temperature of the solution must be uniform (Aniş, 2005; Ekmekçi, 1994).

2. Concentration: The gloss that was obtained as a result of the mercerization processes applied on the same type of fabric with caustic soda at various concentrations at 8 and 18°C is shown in Figure 2. As seen in the Figure 2, the best gloss is obtained with flotte of 27 – 30°B (Tarakçıoğlu, 1979).

3. Time period: It has been determined that when a scoured fabric is dipped into the mercerization flotte, the time required for completely swelling of fibers is 60 s. However this period is getting less with the aid of mechanical effects as is in the mercerization machines. In a good mercerization machine without chain, the time period required for the full impregnation of fibres with the caustic soda flotte is 12 s for dry fabrics and 20 s for wet fabrics. Meanwhile, the role of wetting substances is great in the mercerization of raw fabrics especially. When the work is done without using a wetting substance, the wetting of the fabric would be insufficient even if the mercerization period is increased to 2 - 3 min. For this reason, full impregnation cannot be obtained (Tarakçıoğlu, 1979)

4. Mechanical Effects: During the mercerization process, the thread or fabric is tightened and the crystals get into the parallel to the axis of the fiber inside of fiber and

Table 1. Raw characteristics of the fabrics used in the thesis study.

	Plain weave	Twill	Dobby weave
Warp thread (Ne)	20/1 OE	20/1 OE	20/1 OE
Weft thread (Ne)	20/1 OE	20/1 OE	20/1 OE
Warp frequency	38.3	39.7	41.4
Weft frequency	16.5	21	21
Raw width (cm)	159.5	160	159.5
Raw weight (g/m^2)	181	202	207
Raw warp resistance (kgf)	86.25	96.65	94.25
Raw weft resistance (kgf)	28.75	37.25	37
Raw % of Resistance to shrinkage in the warp	- 14.5	- 14.5	- 14
Raw % of resistance to shrinkage in the weft	- 4	- 4.5	- 4.5

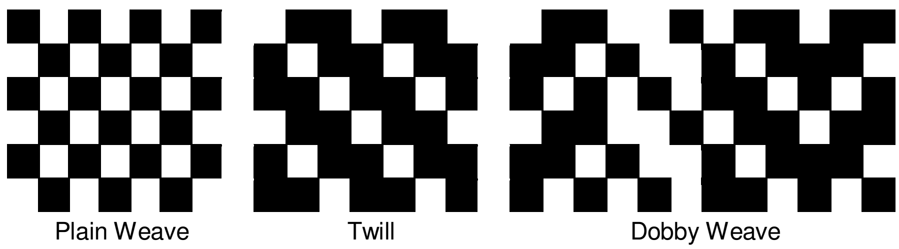

Figure 3. Weave reports of the fabrics used in the thesis study.

consequently, the links among the macromolecule chains (H Bridges, Van Der Wall's forces) increase even more. However, flexibility decreases since the links among macromolecule chains, crystallites and fibrils are even stronger (Lewın and Sello, 1983)

MATERIALS AND METHODS

Materials

In this study, fabrics, that were woven by using 20/1 Open-end 100% cotton thread and three different weaving pattern, were chosen. These fabrics have medium weights and approximately same construction. The characteristics of these fabrics are given in Table 1. Weave reports of the fabrics used in this study are shown in Figure 3. The trials of fabrics were carried out using the machinery and equipment in Kipaş Textiles Painting Finishing Enterprise. The machines and equipments used in the processes were as follows:

1. OSTHOFF burning and desizing machine in which the operations of burning and desizing are combined.
2. KUSTERS combined bleaching machine that makes hot bleaching and also has 2 prewashing and 4 final washing chambers.
3. BENINGER mercerization machine that has stabilization section after the caustic chamber, chain frame and a 5 final washing chamber.
4. WUMAG drying machine with contact drying system in which exit humidity control is carried out with Pleva equipment and which consists of 20 cylinders that work with steam.
5. KUSTERS pad-batch machine. Painting machine with a single tub in which the fabrics are made to absorb the paint and chemicals according to cold pad batch method.
6. Chemistry laboratory and beaker, measuring tape, pipette, titration apparatus, etc. for chemical tests.

For physical tests, SDL strength test equipment, fully automatic washing machine and drum dryer were used in the product test laboratory in Kipaş. The properties of the chemicals that were used in desizing and bleaching processes and other auxiliary chemicals were given in Table 2, Table 3 and Table 4, respectively.

Methods

Firstly, burning and desizing processes were applied on the fabrics. Then pre-finishing was carried out on the fabrics by applying the conditions and prescriptions indicated below before the mercerization process.

The processes of burning and desizing were done with OSTHOFF brand burning-desizing machine in which a multi-functional burning machine is combined with a tub where the fabric is made to absorb the desizing solution. The technical data and prescriptions are as follows:

Prescription: 2.5 g/l Torozym NT, 2 g/l Schnellnetzer KE, 1 g/l Emulgator BE-O, 1 g/l Entlüfter BK.
Speed: 70 m/min.

Table 2. The properties of the chemicals that were used in removing dressing.

Name	Torazym NT	Schnellnetzer KE	Emulgator BE-O	Rotta Entlüfter BK
Property	Enzyme	Defoaming, wetting	Emulsifying agent, washing substance	Deculator, wetting
Chemical Structure	Alpha amylase enzyme	Mixture of phosphoric acid esters and oil alcohol polyglicol ether	Special mixture of Ethylenoxide condensation products	Organic hydroxyl compound
Color	Brown	Colorless	Colorless	Colorless
Appearance	Liquid	Liquid	Liquid	Liquid
pH	6.5	7	7	5.5±1
Ion State		Non-ionic	Non-ionic	Non-ionic
The firm it was obtained from	-	Textile Color	Textile Color	Rotta

Table 3. The properties of the chemicals that were used in the bleaching process.

Name	Sodium hydroxide	Hydrogen peroxide	Gemsol WA	Sevalin D	Rohstoff ST/OS
Property				Special substance that increases hydrophility	Bleaching stabilizator
Chemical Structure	48-50^{0}Be NaOH	50% H_2O_2	Balanced and synergic composition of surface active materials	Oil aminopolyglicother	Organic acid
Color	Colorless	Colorless	Colorless	Yellowish	Brown
Appearance	Liquid	Liquid	Liquid	Liquid	Liquid
pH			7-8	9-10	8.5-9.5
Ion State			Non-ionic	Non-ionic	
The firm it was obtained from	Likit Kimya	Hidrojen Peroksit	Gemsan	Textile color	Rotta

Burner position: Vertical – double side
Burner distance: 8 mm
pH: 6 - 7
Temperature: 60 - 65°C
Holding: It was held and continuously rotated in the dock for 6 h.

In the textile enterprise, the fabric was made to absorb the prescription above in order to be able to make it capable of dissolving in the water that has sizing which is in those fabrics that have been sized with the CMC sizing substance. It was inserted into a rotation machine for balance and to prevent it from filtering on one side. It was bleached after the rotation period of 6 h ended.

Bleaching process was carried out in a Mega-Bleach machine which belongs to the firm KÜSTERS, which has two pre-washing chambers, a Flexnip in which the solution is made to absorb to the fabric, a steam chamber which is appropriate for accumulation type working and four washing chambers at its exit. The technical data and the prescription are as follows:

Prescription: 35 ml/l H_2O_2 50%, 15 ml/l NaOH 480Be, 2 ml/l Gemsol WA, 2 ml/l Rohstoff ST-OS, 1 ml/l Sevalin D.
Speed: 60m/min.
Steam chamber: Accumulation type
Holding: 20 min in saturated steam at 98°C

The temperatures of the pre-washing and final washing chambers were fixed at 90 - 95°C. The fabrics that were taken from the rotation station were passed from the prescription and working conditions above in the bleaching machine and they were bleached. Then they were dried or mercerized according to the process stage.

They were dried in the WUMAG drying machine, which works with contact drying method and which consists of 20 cylinders that are heated with steam. The exit humidity of the fabrics was measured with Pleva humidity measurement device in a controlled way. The technical data are as follows:

Speed: 40m/min.
Temperature: In cylinder drier machine at 140°C.
Humidity: % 8 ± 2

The fabrics were mercerized after the drying process. They were mercerized according to the plan indicated in Table 5 by using BENINGER chain fabric mercerization machine at 60°C and 30°Be NaOH. The fabrics were applied with 3% tension along the warp and mercerization was carried out by stretching the +1 cm width at the needle frame section after the stabilization part along the weft.

The fabrics were painted with reactive dyestuff after the

Table 4. The properties of the other chemicals that were used.

Name	Floranit 4028	Erkantol AS	Silicate
Property	Wetting agent for mercerized material	Wetting agent	38-40^{0}Be
Chemical structure	Alcohol derivative	Inorganic acid ester	
Color	Yellow	Yellowish	Colorless
Appearance	Liquid	Liquid	Liquid
pH	10-11	6-9	12
Ion State	Anionic	Anionic	
The firm it was obtained from	Spot (Henkel)		

Table 5. Mercerization trial plan of the fabrics.

Trial No	Mercerization conditions	
	Process phase	**Time period for staying in the caustic tub (s)**
1st Trial	With drying after bleaching (Dry)	15
2nd Trial	With drying after bleaching (Dry)	10
3rd Trial	With drying after bleaching (Dry)	7.5
4th Trial	Mercerization after bleaching (Wet)	15
5th Trial	Mercerization after bleaching (Wet)	10
6th Trial	Mercerization after bleaching (Wet)	7.5
7th Trial	Mercerization with wetting agent after bleaching (Wet + with wetting agent)	15
8th Trial	Mercerization with wetting agent after bleaching (Wet + with wetting agent)	10
9th Trial	Mercerization with wetting agent after bleaching (Wet + with wetting agent)	7.5

mercerization process. The fabrics were made to absorb the dyestuff and chemicals in pad-batch painting machine, which is KÜSTERS brand and which works with single dipping and wringing method, and they were rotated during the fixed period in order to avoid filtration at the rotation stations. The technical data and the prescription are as follows:

Prescription: 14.8 g/l Cibacron Blue CR, 5.6 g/l Cibacron Deep Red CD, 12.1 g/l Cibacron yellow CRG, 1 g/l Erkantol AS, 4.84 g/l Caustic 48 0Be, 50 g/l Silicate.
Fixed period: after the dyeing, they were held by rotating at the dock for 14 h. After fixing, the fabrics were washed with hot-boiling water and then dried at 120℃.

The plan of the trials to be applied on the fabrics in the mercerization machine

The fabrics that have the properties in Table 1 were passed from the mercerization machine according to the plan below and they were tried. Mercerization details of these fabrics were given in Table 5. At 1st, 2nd and 3rd trials, the fabrics were dried after the bleaching process before the mercerization and entered into the caustic chamber as dried. At 4th, 5th and 6th trials, they entered the caustic chamber as wet without being dried after bleaching. As for 7th, 8th and 9th trials, they entered the caustic chamber as wet without being dried after bleaching and wetting agent of 5 g/l was given to the caustic chamber.

After the finishing processes, the sample fabrics were applied the dimension stability test in order to observe the change in their dimensions. Six measurements were done on each sample according to the standard of BS EN 26330 and the average of them was taken. Household type washing machines indicated in standard of TS 5720 EN ISO 6330 were used in the measurements (Annonim, 2002). In the measurements, the fabrics were marked with permanent marker with 35*35 cm gaps (in the direction of wefts and warps) and they were washed in the washing machine at 60℃. After washing they were dried in drum drier and their shrinking percentage values were measured.

The results of resistance to shrinkage obtained in this study were analyzed with SPSS 12.0 statistical data analysis program in the computer and their statistical significance was calculated. Two-way ANOVA test was used in the statistical analysis. 5% margin of error (95% confidence interval) was taken as a basis in all the calculations and the results that are upper than P=0.050 value do not have an effect that has statistical significance. The results that are smaller than this value have a statistically significant effect (Kalaycı, 2005).

RESULTS AND DISCUSSIONS

In dimension stabilization, what is desired is not high swelling in the fibers, but their homogeneity, because the fibers at the outside of yarns swell more than the fibers at the inside of yarns in mercerization at low temperatures and internal tension emerges as a result of the difference between the swellings inside and outside which has a detrimental effect on stabilization.

Table 6. Results of SPSS analysis related to resistance to shrinkage in the warp. (Tests of between-subjects effects).

Source	Dependent variable	Type III sum of squares	df	Mean square	F	P
Corrected Model	Plain weave	11.933[a]	8	1.492	20.719	0.000
	Twill	14.467[b]	8	1.808	92.297	0.000
	Dobby weave	8.565[c]	8	1071	8.629	0.000
Intercept	Plain weave	1977.140	1	1977.140	27463.810	0.000
	Twill	1475.802	1	1475.802	75324.471	0.000
	Dobby weave	2065.852	1	2065.852	16650.149	0.000
Process	Plain weave	6.350	2	3.175	44.100	0.000
	Twill	11.338	2	5.669	289.338	0.000
	Dobby weave	5.481	2	2.741	22.090	0.000
Time period	Plain weave	3.419	2	1.709	23.746	0.000
	Twill	2.671	2	1.336	68.166	0.000
	Dobby weave	2.287	2	1.144	9.216	0.000
Process * Time period	Plain weave	2.164	4	0.541	7.516	0.000
	Twill	0.458	4	0.114	5.841	0.001
	Dobby weave	0.796	4	0.199	1.604	0.190
Error	Plain weave	3.240	45	0.072		
	Twill	0.882	45	0.020		
	Dobby weave	5.583	45	0.124		
Total	Plain weave	1992.313	54			
	Twill	1491.150	54			
	Dobby weave	2080.000	54			
Corrected total	Plain weave	15.172	53			
	Twill	15.348	53			
	Dobby weave	14.148	53			

[a] R^2 = 0.786 (Adjusted R^2 = 0.749).
[b] R^2= 0.943 (Adjusted R^2= 0.932).
[c] R^2= 0.605 (Adjusted R^2= 0.535).

A homogeneous swelling is produced in mercerization at 60℃, but the shrinkage in the fibers changes with the changing of the application time, thus stabilization will also change. As seen in Table 6, all the P values of plain, twill and dobby weave fabrics occurred 0.000 in terms of statistical significance in resistance to shrinkage in the warp except for the process*time interactions of the dobby weaving fabric. The process, time period and process *time period interactions, have a statistically significant effect on the resistance to shrinkage of the warps of the fabrics except for the process*time interactions of the dobby weaving fabric.

However the P value of dobby weave fabric appeared to be 0.190, which is higher than 0.050 in the process*time period interaction, so process*time period interaction does not have a statistically significant effect on the resistance to shrinkage of dobby weave fabric. As seen in Table 7, the P values of plain weave, twill and dobby weave fabrics in the resistance to shrinkage of the weft appeared to be 0.000. Process, time period and process*time period interactions have a statistically significant effect on the resistance to shrinkage of the weft. As seen in Table 8, 50 - 60% improvement was seen in the direction of warp compared to the raw fabric. We see the best results at the conclusion of the trials with dry process. The reason for that is that, they gather a little bit in drying. The resistance to shrinkage values gave better results as the time period for application increased in the direction of the warp.

25 - 75% improvement was observed in the direction of the weft depending on the time period. We observed the best results at the conclusion of the trials with wet process. Since the shrinkage in the fibers increase as the time period increases, the resistance to shrinkage in the weft appears to be higher. Changes in the resistance to shrinkage in the directions of warp and weft in plain weaving fabrics depending on process *time period are shown in Figure 4 and 5, respectively.

As seen in Table 9, 60 - 70% improvement was seen in the direction of the warp compared to the raw fabric. We observed the best results at the conclusion of the trials with dry process. The reason for that is that the fabrics

Table 7. Results of SPSS analysis related to resistance to shrinkage in the weft. (Tests of between-subjects effects).

Source	Dependent variable	Type III sum of squares	df	Mean square	F	P
Corrected Model	Plain weave	31.586[a]	8	3.948	32.121	0.000
	Twill	22.788[b]	8	2.849	98.603	0.000
	Dobby weave	18.593[c]	8	2.324	8.339	0.000
Intercept	Plain weave	203.196	1	203.196	1653.117	0.000
	Twill	219.212	1	219.212	7588.103	0.000
	Dobby weave	350.116	1	350.116	1256.229	0.000
Process	Plain weave	3.898	2	1.949	15.857	0.000
	Twill	4.327	2	2.164	74.891	0.000
	Dobby weave	5.565	2	2.782	9.983	0.000
Time period	Plain weave	20.259	2	10.130	82.411	0.000
	Twill	14.505	2	7.252	251.045	0.000
	Dobby weave	6.704	2	3.352	12.027	0.000
Process * Time period	Plain weave	7.428	4	1.857	15.108	0.000
	Twill	3.956	4	0.989	34.237	0.000
	Dobby weave	6.324	4	1.581	5.673	0.001
Error	Plain weave	5.531	45	0.123		
	Twill	1.300	45	0.029		
	Dobby weave	12.542	45	0.279		
Total	Plain weave	240.313	54			
	Twill	243.300	54			
	Dobby weave	381.250	54			
Corrected total	Plain weave	37.117	53			
	Twill	24.088	53			
	Dobby weave	31.134	53			

[a] R^2= 0.851 (Adjusted R^2= 0.824).
[b] R^2= 0.946 (Adjusted R^2= 0.936).
[c] R^2= 0.597 (Adjusted R^2= 0.526).

Table 8. Resistance to shrinkage in fabrics with plain weave.

Conditions for mercerization (s)		Experiment No	Resistance to shrinkage %	
			Warp	Weft
Raw fabric			- 14.5	- 4.00
Dry	15	1	- 5.13	- 3.04
	10	2	- 5.96	- 1.25
	7.5	3	- 5.38	- 1.00
Wet	15	4	- 6.13	- 2.00
	10	5	- 6.50	- 1.88
	7.5	6	- 6.96	- 1.33
Wet + wetting agent	15	7	- 5.88	- 3.00
	10	8	- 5.96	- 2.67
	7.5	9	- 5.83	- 1.21

gather a little bit in drying. Depending on the time period, the resistance to shrinkage of those fabrics whose application time period is higher appears to be lower.

In the direction of the weft, an improvement of 25 - 75% was observed depending on the time period similar to the plain weave. We observed the best results at the

Table 9. Resistance to shrinkage in twill fabrics.

Conditions for mercerization (s)		Experiment no	Resistance to shrinkage %	
			Warp	Weft
Raw fabric			- 14.50	- 4.50
	15	1	- 4.25	- 3.00
Dry	10	2	- 4.52	- 1.25
	7.5	3	- 5.00	- 1.50
	15	4	- 5.50	- 2.43
Wet	10	5	- 5.97	- 1.00
	7.5	6	- 5.92	- 1.75
	15	7	- 4.85	- 2.75
Wet + Wetting agent	10	8	- 5.28	- 2.42
	7.5	9	- 5.52	- 2.03

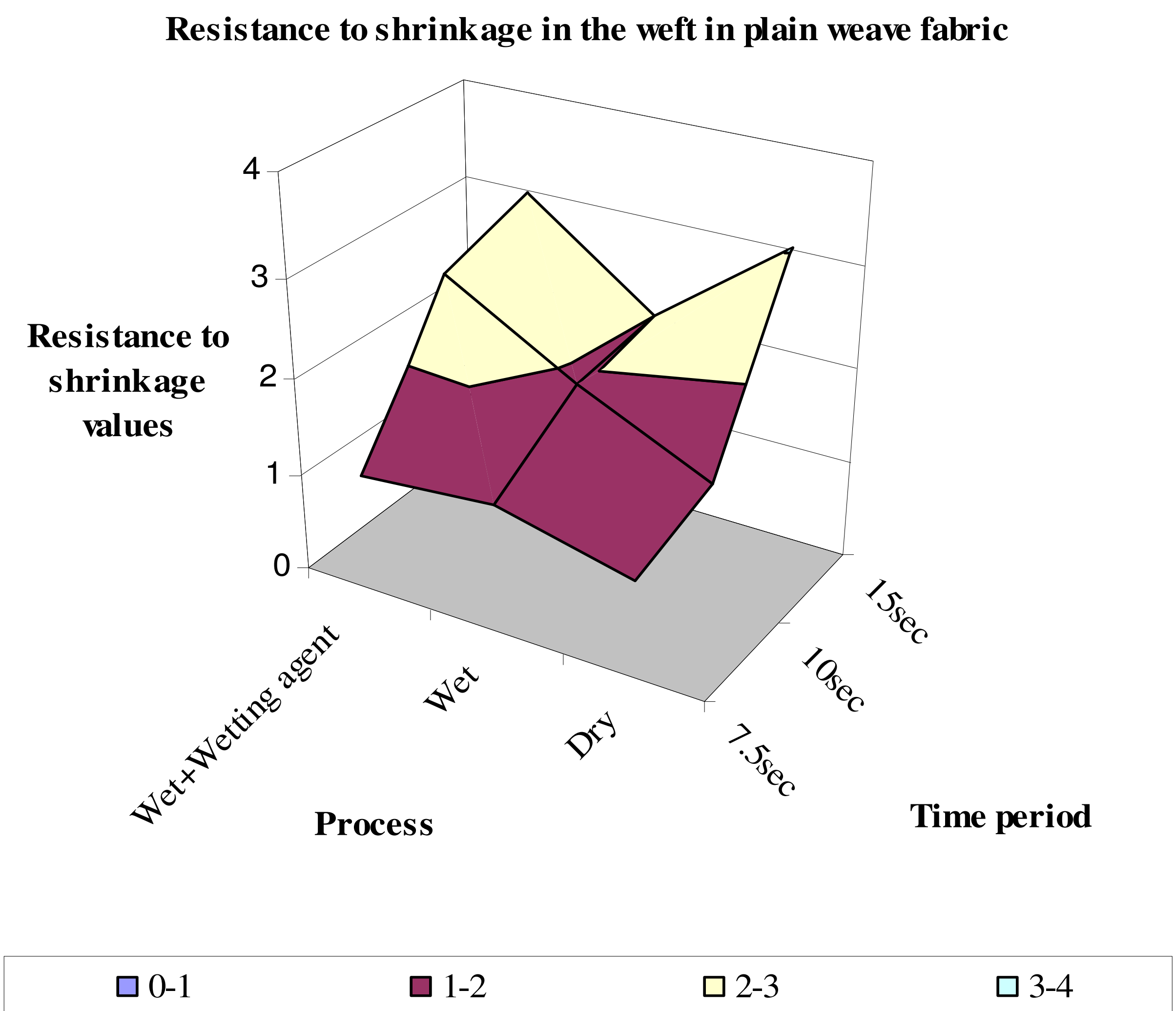

Figure 4. Changes in the resistance to shrinkage in the warp in plain weave fabric depending on process*time period.

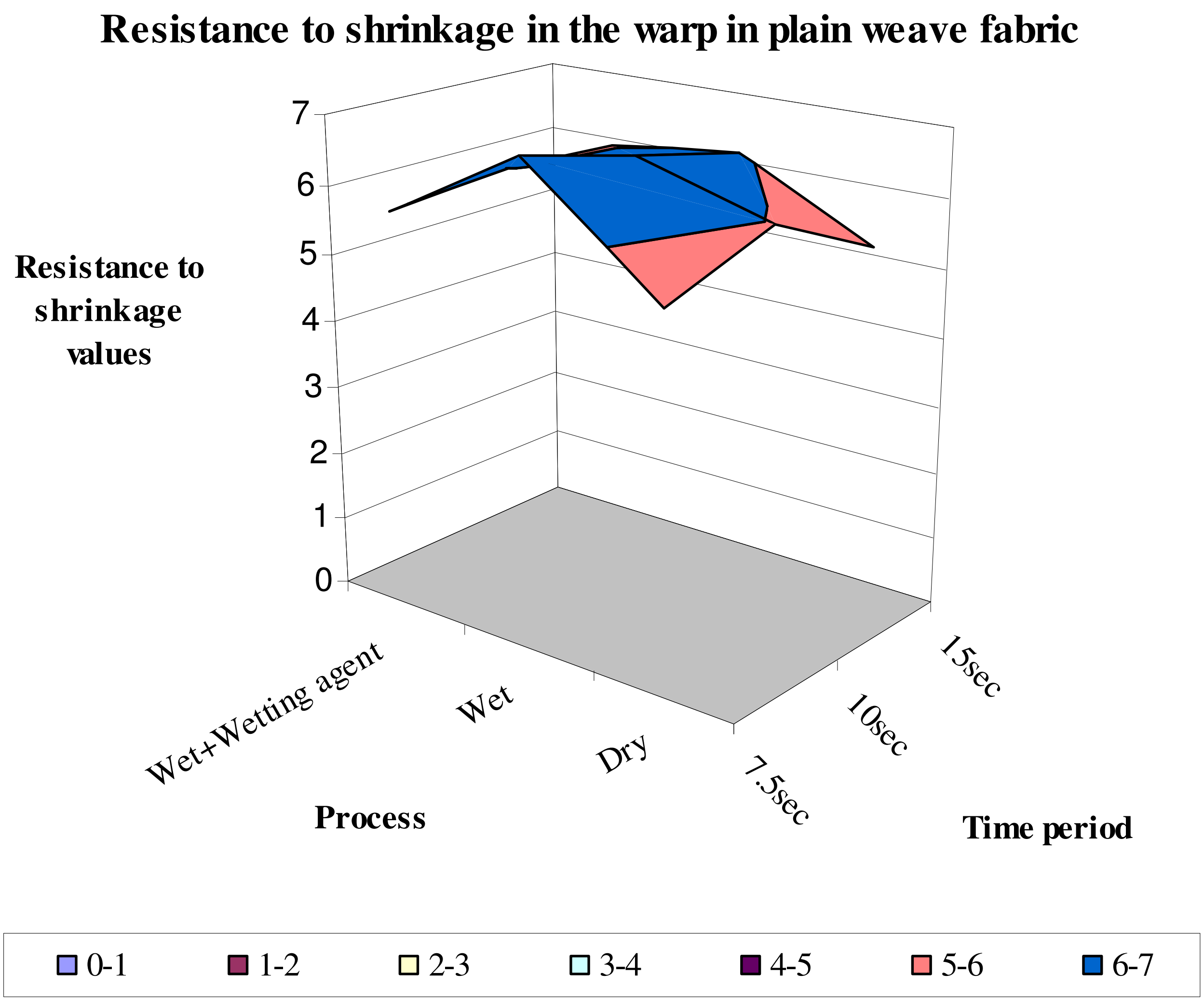

Figure 5. Changes in the resistance to shrinkage in the weft in plain weave fabric depending on process*time period.

conclusion of the trials with wet process. Since the shrinkage in the fibers increases as the time period increases, the resistance to shrinkage in the weft appears to be higher. Changes in the resistance to shrinkage in the directions of warp and weft in twill fabrics depending on process*time period are shown in Figure 6 and 7, respectively.

As seen in Table 10, an improvement of 50 - 60% was seen in the direction of the warp compared to the raw fabric in the dobby weave. We observed the best results at the conclusion of the trials with dry process. The reason for that is that the fabrics gather a little bit in drying. No change was observed in the direction of the warp depending on the time period.

Changes in the resistance to shrinkage in the direction of warp and weft in dobby weave fabric depending on process*time period was shown in Figures 8 and 9, respectively. In the dobby weave, an improvement of 25 - 65% was observed in the direction of the weft as it was observed in plain weave and twill. We observed the best results at the conclusion of the trials again with wet process. Since the shrinkage in the fibers increases as the time period rises, the resistance to shrinkage in the weft appears to be higher. This clarity was not seen in the wet process and values close to each other were observed.

In general, the dried fabrics provide better stability in resistance to shrinkage in the warp, but this difference disappears when we think of the effect of drying. That is, there is no improvement in the resistance to shrinkage of those fabrics that are dried with an additional process. Moreover, using a wetting agent did not improve the stability.

In the direction of the weft, there was a change depending

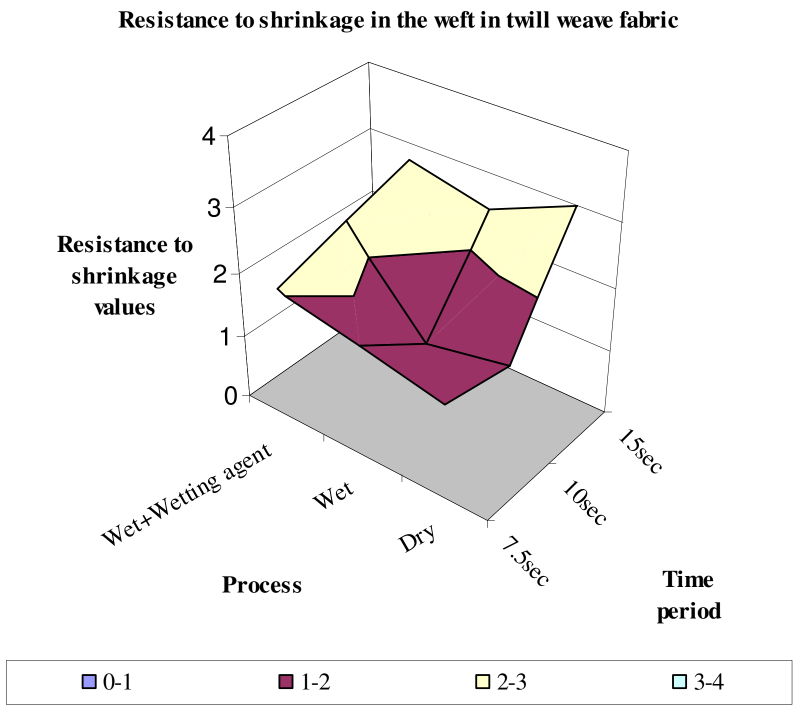

Figure 6. Changes in the resistance in the warp of twill fabric depending on process*time period.

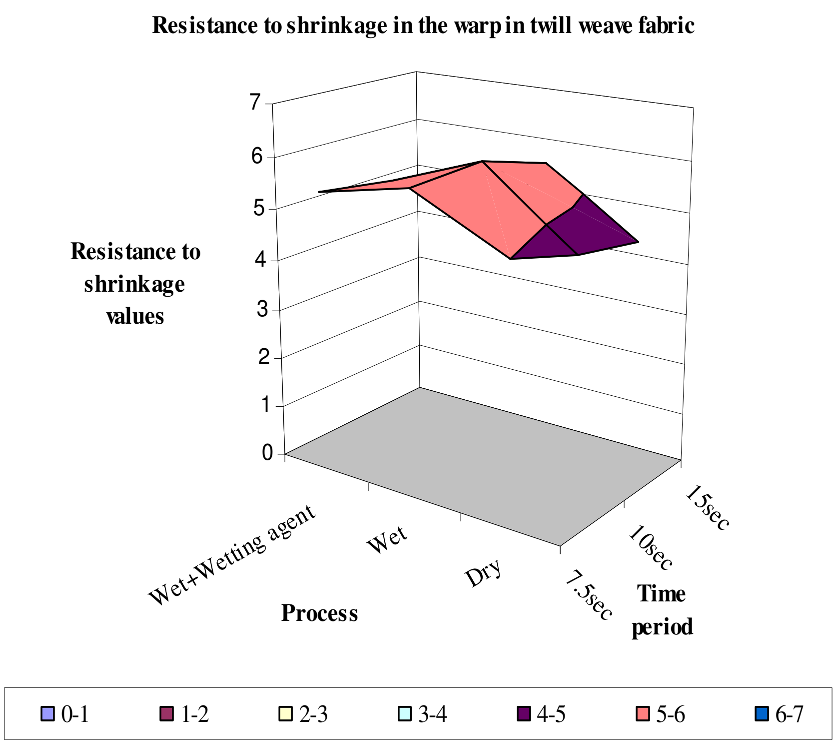

Figure 7. Changes in the resistance in the weft in twill fabric depending on process*time period.

Table 10. Resistance to shrinkage in fabrics with dobby weaves.

Conditions for mercerization (s)		Experiment no	Resistance to shrinkage %	
			Warp	Weft
Raw fabric			- 14.00	- 4.50
	15	1	- 5.67	- 3.42
Dry	10	2	- 5.58	- 2.00
	7.5	3	- 6.25	- 1.58
	15	4	- 6.50	- 2.25
Wet	10	5	- 6.33	- 2.50
	7.5	6	- 6.83	- 2.17
	15	7	- 5.83	- 3.42
Wet + Wetting agent	10	8	- 6.33	- 2.67
	7.5	9	- 6.50	- 2.83

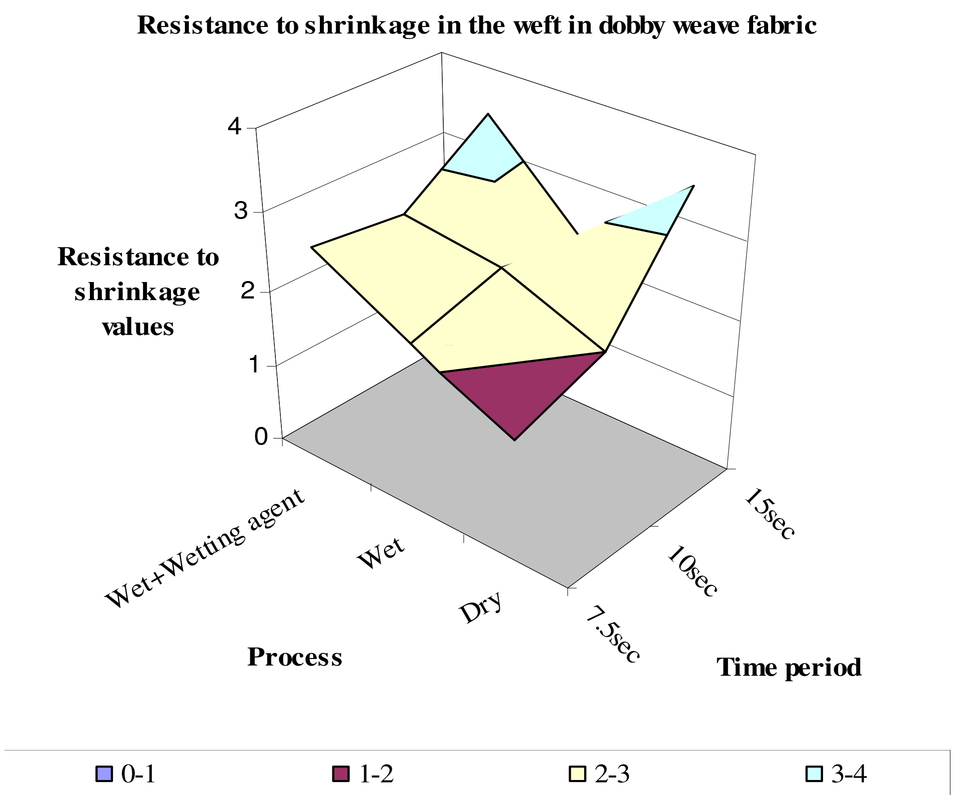

Figure 8. Changes in the resistance to shrinkage in the warp in dobby weave fabric depending on Process*Time Period.

depending on the time period of holding. This dependency is such that the resistance to shrinkage values increases as the period of holding increases. The faster the processes of mercerization, the better are the results of stability in the direction of the weft.

Conclusion

It was observed that three different fabric samples processed at three different time and conditions indicated the best unshrinking values under dry mercerization

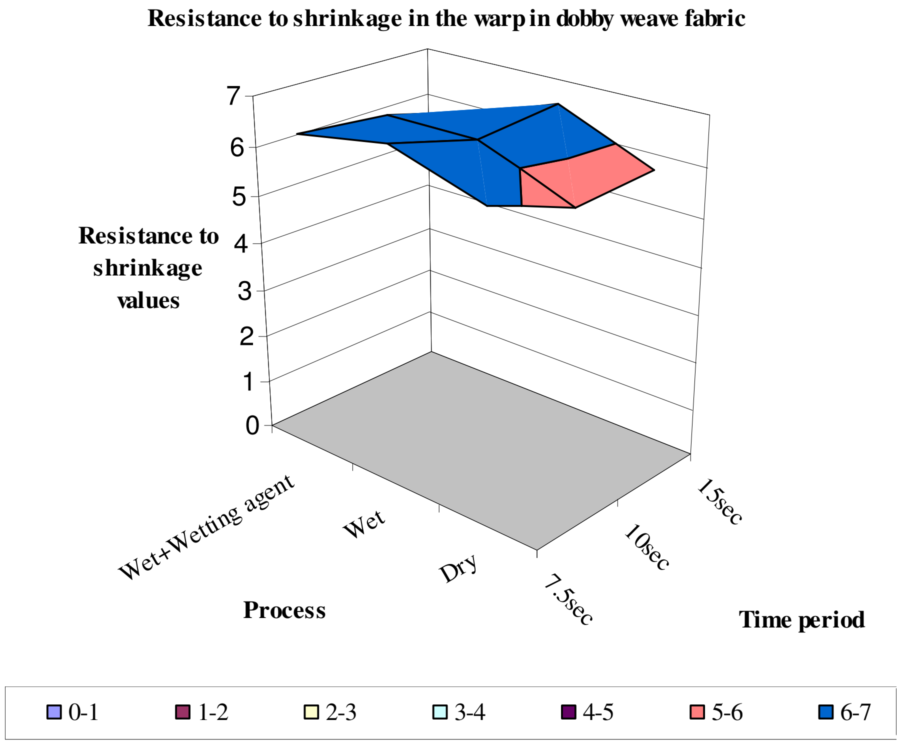

Figure 9. Changes in the resistance to shrinkage in the weft in dobby weave fabric depending on Process*Time Period.

conditions and decreased shrinkage values on warp direction with increasing of processing time. It was obtained that shrinkage values on warp direction were greater than those of weft.

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