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Research Article

A Study of the Contraction Behaviour of Woven Wool Fabrics

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Abstract: Textile materials generally pass through wet processes during pre-treatment, colouring and finishing operations. The process conditions and chemical and physical medium of a particular process are varied. Consequently, the dimensional stability of the fabrics exposed to heat and humidity depends on many factors. In this study, the contraction behaviour of woven wool fabrics in different structures are investigated with an analytical approach as they go through various wet processes. It is observed that the weave type and weft density parameters affect the contraction behaviour in weft and warp direction. The effect of hygral expansion in wool fibre stability is great. The fixation effect obtained through the decatizing of the wool fabrics as a pre-treatment operation, directly affects the hygral expansion rates and hence the dimensional stability behaviour of the fabric in subsequent wet processes.

Keywords: *Crimp, Dimensional stability, Hygral expansion, Wet process, Woven wool fabric.*

Yün Dokuma Kumaşların Çekme Davranışları Üzerine Bir Çalışma

Özet: Tekstil malzemeleri terbiye, renklendirme ve bitim işlemleri sırasında genelde yaş süreçlerden geçerler. Uygulanacak işlemin süreç şartları ile kimyasal ve fiziki ortamı da çok büyük farklılıklar gösterir. Doğal olarak; kumaşların ısı ve nem etkisi altında boyutsal çekmesi pek çok faktöre bağlıdır. Bu çalışmada, farklı yapılardaki yün dokuma kumaşlarda yaş işlem sonrası ortaya çıkan kumaş çekmeleri analitik bir yaklaşımla incelenmiştir. Yapılan çalışma sonucunda örgü cinsi ve atkı sıklığı parametrelerinin atkı ve çözgü yönündeki çekme davranışlarına etkisi olduğu görülmüştür. Yün lifinde higral genleşmenin boyutsal stabilite üzerine etkisi büyüktür. Yün kumaşlara ön işlem olarak uygulanan dekatür işlemi ile elde edilen fiksaj etkisi, daha sonraki yaş işlemlerde higral genleşme oranlarını ve dolayısıyla kumaşın çekme davranışını doğrudan etkilemektedir.

Anahtar kelimeler: *Boyutsal stabilite, Higral genleşme, Kıvrım, Yaş işlem, Yün dokuma kumaş.*

1. Introduction

The dimensional stability of textile fabrics has always been a problem for both textile manufacturers and apparel makers. In most cases, shrinkage may be tolerated or even desired but the amount of shrinkage which occurs during making-up should be capable of being controlled. The behaviour of contraction is varied depending on the fibre type. In case of wool, hygral expansion and relaxation shrinkage are decisive on the dimensional properties of the fabric. The dimensional stability of wool fabrics mostly depends on the finishing treatments of which operational settings are quite important, in addition to the effect of cloth construction. Therefore, it has always been difficult to define a universal shrinkage ratio for wool fabrics. The purpose of this study is the provision of a systematic guide for estimating shrinkage rates in wet treatments in order for the efficient uses of manufacturing resources in commercial production.

1.1. Literature Review

When wool fibres absorb water there occurs radial swelling. This effect is reversible and the change in the size of the wool fabrics is due to these reversible changes. This phenomenon is called as the hygral expansion. While the moisture recovery is below 15%, many of the wool fabrics show dimensional increase in the increasing moisture rates (Baird 1963) [1]. Lindberg (1971) explained this by comparing wool fibres with an elastic arc. In the phenomenon of radial expansion or shrinkage, the crimp diameter of this arc changes in order to reduce the increase in

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strain. While this diameter increases with swelling, the opposite situation called deswelling causes a decrease in the diameter of the crimp [7].

Shiloh M. et al. (1982) reported that woven fabric geometry is very important on hygral expansion. Accordingly, as the weaving crimps increase, the hygral expansion of the yarns increases. The effect of the weaving crimps on the hygral expansion is greater than the effect of the properties of the fibres forming the yarns [2].

Cookson (1990), in his study, examined the inter-fibres forces in unset, low and high set values of wool fabrics, under different moisture regains. Since the warp yarns have a high crimp rate due to the weaving, as the result of the permanent set, the tendency to increase the hygral expansion in the warp direction is higher, and the tendency to increase the hygral expansion is less in the weft yarns as a result of low crimp rate. When the moisture regain of wool fibres is low during drying of fibres, the inter-fibre forces decrease, replacing the cohesive forces. In this way, the set effect is obtained through cohesive forces. The unset wool fabrics have high inter-yarn forces. This causes an increase in the wavelength of the crimp and in the fabric dimensions [3].

Wemmyss and Boss (1991), in their study, examined the effect of fabric structure and finishing treatments on the mechanical and dimensional properties of wool fabrics. As a result, it was observed that the bending stiffness and shrinkage hysteresis increased in all types of weave and the percentage of hygral expansion and elongation decreased. The effect of the cover factor on the dimensional and mechanical properties is related to the interaction between the yarns (pressure applied to each other). It was observed that the shrinkage hysteresis and interaction between the yarns were lower in the 2/2 twill fabric than the plain fabric with the same cover factor. Also, it was concluded that the shrinkage hysteresis was lower in the fabrics treated with high set values and not much affected by the cover factor [4].

Dodd et al. (1997) examined the effect of dyeing process on the dimensional stability and set values of 100% wool fabrics. In fabrics decatized and treated with alkali, the ones with high set values also have high hygral expansion values at the end of dyeing. Although in some dyeings, it was observed that the maximum hygral expansion value of the fibres containing dyestuff in the fabrics with same set values may decrease. This shows that the low hygral expansion values at the end of the dyeing are not due to the low set values. In the case of prior to dyeing, the presence of hydrophobic groups increases the dimensional instability of the fabric at low moisture regains [5].

Li et al. (2009) studied the relationship between the change in swelling and fabric dimensions in wool fibres at different pH values. The change of fibre swelling owing to pH is due to the ionic repulsion and tensile forces between the amphoteric protein chains. The swelling values of the fibres at pH 2.1 were higher and the fabric dimensions were smaller than that in pH 7.2. Since the intersections of the yarns and the interaction between yarns are higher in the plain fabric, the differences between the dimensions of the wet and dryed-conditioned fabrics are more pronounced and variations in dimensional changes in increasing fibre swellings have been observed [6].

2. Material and Methods

2.1. Material

In this study a selection of twelve 100% wool woven samples in four basic weaves were used, which each weave type with three different pick densities (Table 1).

Warp yarn number: 80/2 Nm

Warp density: 26 ends / cm

Weft yarn number: 80/2 Nm

Table 1. Weave type and weft densities of samples.

Weave type	Weft density (picks/cm)
Plain	18
	21
	24
Twill 2/1	23
	26
	29
Panama 3/3	30
	33
	36
Warp satin 5	28
	31
	34

2.2. Methods

In this study, the most suitable one of the different sample sizes and measurement intervals were selected and the experiments were carried out according to AATCC 135: 2004 (dimensional change in fabrics after domestic washing) and ASTM D 3883: 04 (measurement of crimp and shrinkage values of woven fabrics) standards. Samples prepared in 22 * 22 cm dimensions were conditioned in standard atmosphere conditions (20°C ± 2 temperature, 65 ± 4% relative humidity). After conditioning, the markings were placed on the samples in the direction of weft and warp at 20 cm intervals. The wet processes were carried out in laboratory machines. After the process, squeezing was performed under 2 bar pressure between the laboratory type squeezing cylinders. Lengths between marks were measured with a ruler before drying. In the experiments, the following equation (1) was used to calculate the linear shrinkage value resulting from the wet treatments.

$$\% \text{ Shrinkage} = \frac{L1-L2}{L1}\ 100 \quad (1)$$

L1 : Length of material prior to wet treatment

L2 : Length of material after wet treatment

All of the samples as mentioned Table 1 were exposed to four different treatments, namely prewashing, drying, decating and dyeing at two different temperatures. Acid dyes were used at the pH 4 with a liquor ratio of 1:10. Dyeing process was also repeated at neutral conditions without using of any dyestuff and chemicals. Prewashing was carried out at 40°C for 20 minutes, drying at 110°C for 15 minutes, decating at 108°C with 1,2 bar steam for 3 minutes. Treatments and their conditions, applicated on wool fabric samples, grouped and mentioned below.

Group A: The samples in this group were treated same as shown in the process diagram in Figure 1, in neutral medium (pH 7), without using of any chemical and dyestuff, with a liquor ratio of 1:10, at the temperature of 98°C, for 45 minutes. At the end of the process squeezing was performed under 2 bar pressure between the laboratory type squeezing cylinders. Lengths between marks were measured with a ruler before drying.

Group B: Firstly, prewashing was carried out at 40°C for 20 minutes, at pH 7, with a liquor ratio of 1:10, squeezing was performed under 2 bar pressure, before drying at 110°C for 15 minutes in relaxed form, lengths between marks were measured with a ruler. Then decating at 108°C with 1,2 bar steam for 3 minutes was performed. After decating, lengths between marks were measured. Finally, the samples were treated same as illustrated in the process diagram Figure 1, in neutral medium (pH 7), without using of any chemical and dyestuff, with a liquor ratio of 1:10, at the temperature of 98°C, for 45 minutes. At the end of the process, squeezing was performed under 2 bar pressure and lengths between marks were measured with a ruler before drying.

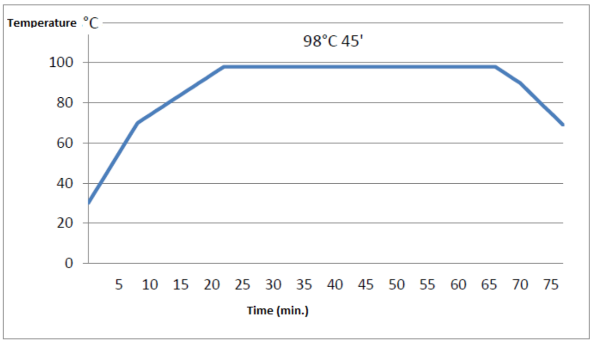

Figure 1. Wet treatment diagram for Group A and B.

Group C: Firstly, prewashing was carried out at 40°C for 20 minutes, at pH 7, with a liquor ratio of 1:10, squeezing was performed under 2 bar pressure, before drying at 110°C for 15 minutes in relaxed form, lengths between marks were measured with a ruler. Then decating at 108°C with 1,2 bar steam for 3 minutes was performed. After decating, lengths between marks were measured. Finally, the samples were dyed with acid dyes, at pH 4, with a liquor ratio of 1:10, at the temperature of 98°C, for 45 minutes as shown in Figure 2. At the end of the process, squeezing was performed under 2 bar pressure and lengths between marks were measured with a ruler before drying.

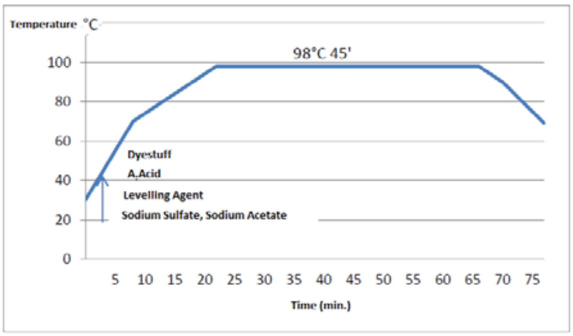

Figure 2. Dyeing process diagram for Group C.

Group D: Firstly, prewashing was carried out at 40°C for 20 minutes, at pH 7, with a liquor ratio of 1:10, squeezing was performed under 2 bar pressure, before drying at 110°C for 15 minutes in relaxed form, lengths between marks were measured with a ruler. Then decating at 108°C with 1,2 bar steam for 3 minutes was performed. After decating, lengths between marks were measured. Finally, the samples were dyed with acid dyes, at pH 4, with a liquor ratio of 1:10, at the temperature of 110°C, for 45 minutes as illustrated in Figure 3. At the end of the process squeezing was performed under 2 bar pressure and lengths between marks were measured with a ruler before drying.

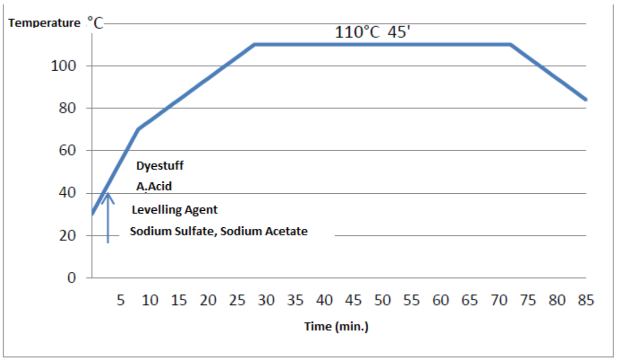

Figure 3. Dyeing process diagram for Group D.

3. Results and Discussion

Results for Group A: At 80°C, in the satin weave, where the most floating yarns exist, the shrinkage of the weft yarns are at the lowest level compared to the other weaves. This finding is contrary to the findings of the previous studies. It might be due to the high crimp rates in warp yarns rendered by weaving process to this weave, so as the result of the permanent set given by wet treatment at high temperature, the tendency to increase the hygral expansion is higher. Plain and twill weave fabrics which have a tighter structure than others have the highest shrinkage ratio. The panama weave follows them. As the temperature increases, the shrinking rates of plain and twill fabrics with the minimum weft density and panama fabrics are at the same level. In the same weave type, at 80°C, in plain and twill fabric samples, the shrinkage ratio has increased at increasing densities, and at the end of the process, in these types of weaves, the effect of weft density on the shrinking behaviour has been seen. It has been observed that in loose textured panama and satin weaves, there is no effect of weft density on the tendency of shrink from 80°C. The shrinkage ratios of the warp yarns in the panama and satin fabrics are not related to the weft density, too. When the weft density is increased in the plain and twill fabrics, the shrinkage ratio of the warp yarns increases in parallel with the increase in temperature and time. At the end of the process, while the shrinkage values have been observed to be highest in plain weave, it has been followed by twill sample. The reason for this is the desire to return to the more curved structure from the less curved one that these weaves gained in the weaving, due to the effect of the hygral expansion. The shrinkage ratios in panama and satin weaves with loose texture structure where the relaxation in the warp yarns are higher, are close and lower. Results are depicted in Figures 4 and 5.

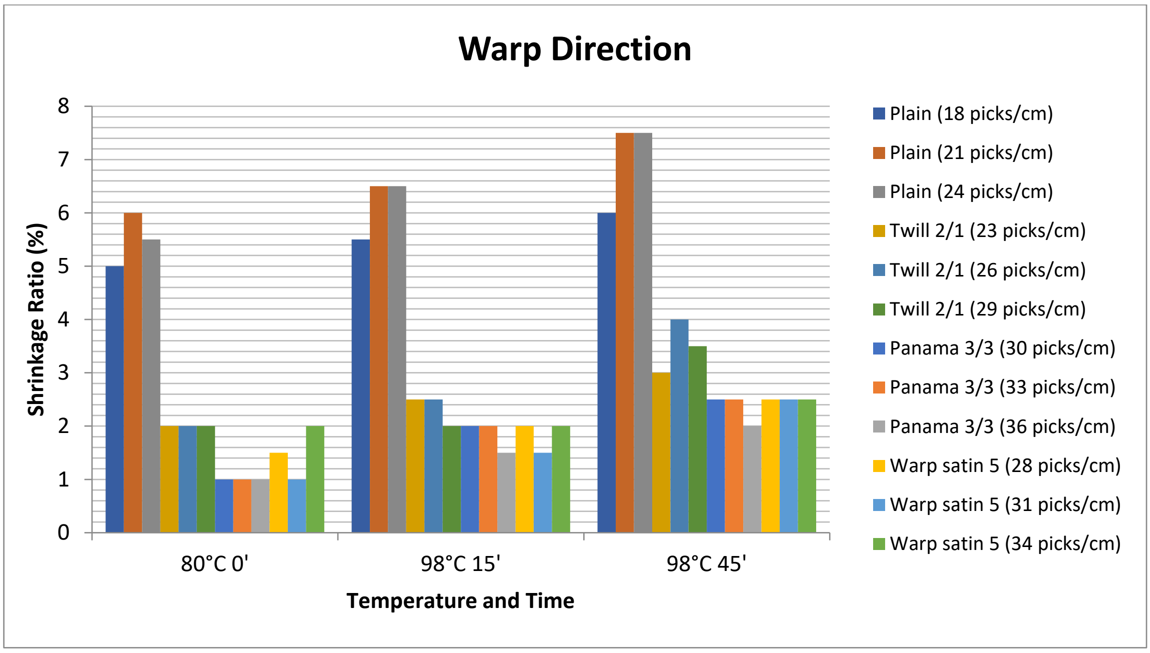

Figure 4. Results for Group A in warp direction.

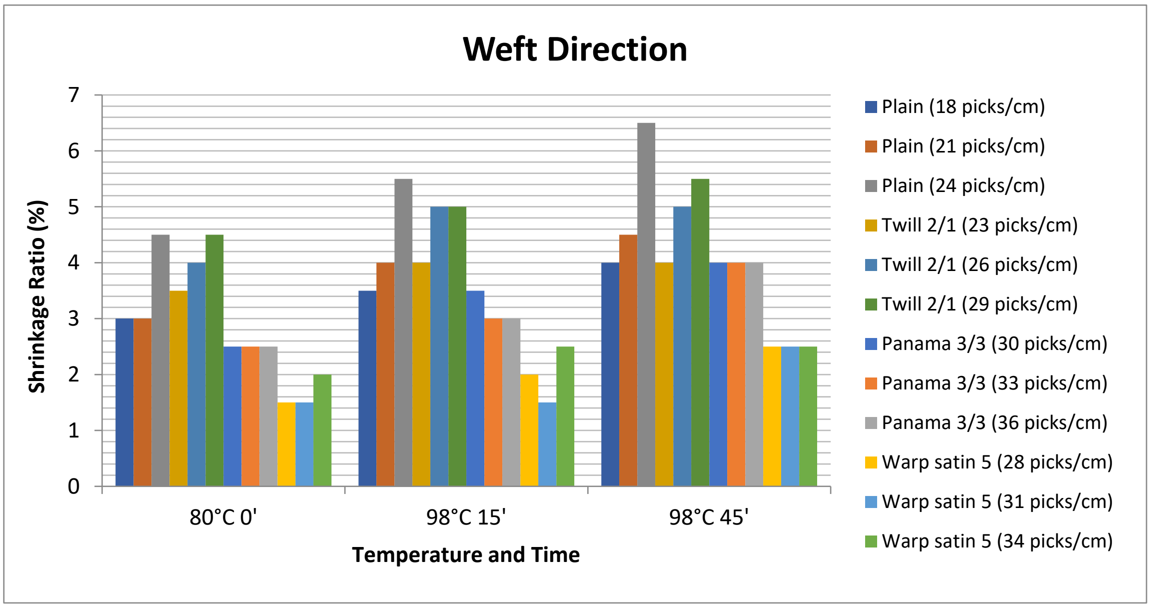

Figure 5. Results for Group A in weft direction.

Results for Group B: In the prewashing process at 40 °C for 20 minutes, the weft and warp yarns begin to get rid of their internal stresses and the yarn lengths shortened. Since the water molecules between the fibres and the yarns will be removed by the drying process, the free movements of the yarns are getting easy and the yarns are largely relaxed, in the spaces formed. In satin and panama fabric samples having loose texture structure, the large differences between the shrinkage values at the end of pre-wash and at the end of drying processes are due to the higher gaps in these weaves. In samples with the lowest weft density (i.e. looser structure) in the same type of weaves, the differences between the values of the wet shrinkage and after drying shrinkage values verify this, too. As the weft density decreases, the wet shrinkage values decrease, but these values become almost equal with subsequent tensionless drying process. Contrary to the values obtained at the end of the wet process, the changes in the weft density have no effect on the shrinkage values of the relaxed yarns obtained with tensionless drying. Since the weft and warp yarns in satin and panama weaves float each other more than that in plain and twill weaves, the internal stresses occurring during weaving are also lower at a certain rate. So satin and panama weaves are relaxed priorly. Therefore, at the end of the wet process, the shrinkage values of these weaves are lower than the plain and twill ones with tighter structure. This difference is also observed in relaxed priorly, looser structures with less weft density in the same weave type. At the end of decating process, a slight change occurs in the yarn lengths compared to the values at the end of tensionless drying. This result shows that the pressure and steam have no significant effect on the increase of the shortening the yarn lengths of the relaxed woolen fabrics. When samples are treated again in aqueous medium, it is detected that at 80°C shrinkage values are lower than that of at the end of decating.

In other words, the shortening ratio of yarn lengths decreased. The difference between these values is the lowest in the plain weave with the tightest structure. Due to the loose structure in satin and panama weaves, the difference in shrinkage values between the end of decating and the end of wet process is the highest. Initially, at 98°C, in the weft and warp directions there is not much change observed in the shrinkage values, and the results obtained are close to these values at the end of 45 minutes. It is thought that this is due to the fixing effect given to the yarns by pre-decatization process. Results are depicted in Figures 6 and 7.

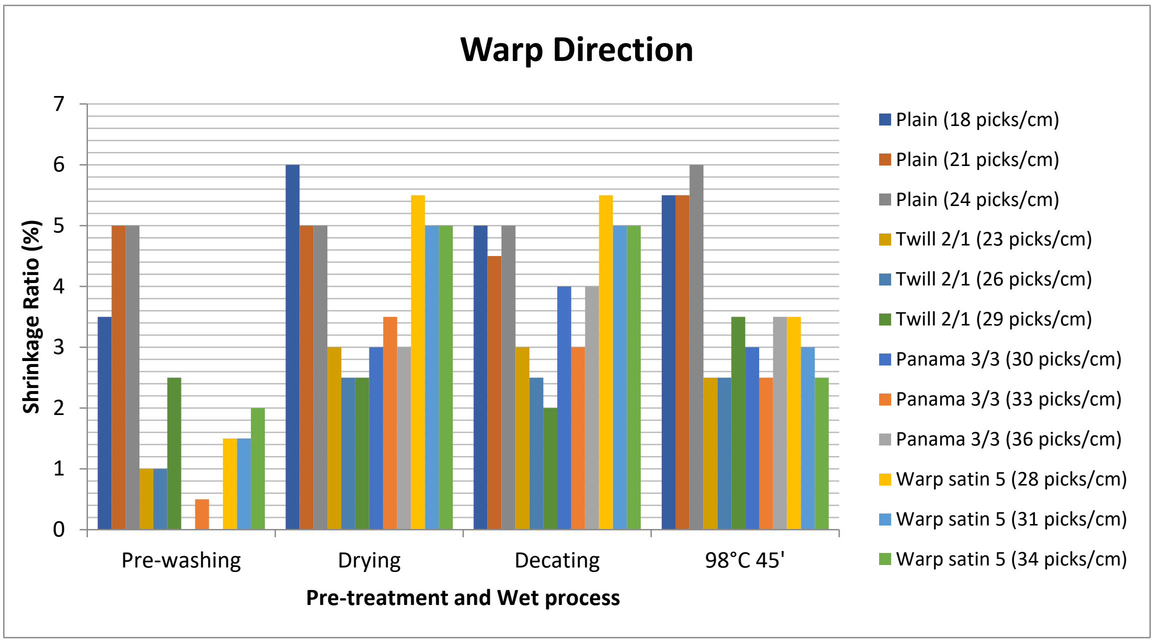

Figure 6. Results for Group B in warp direction.

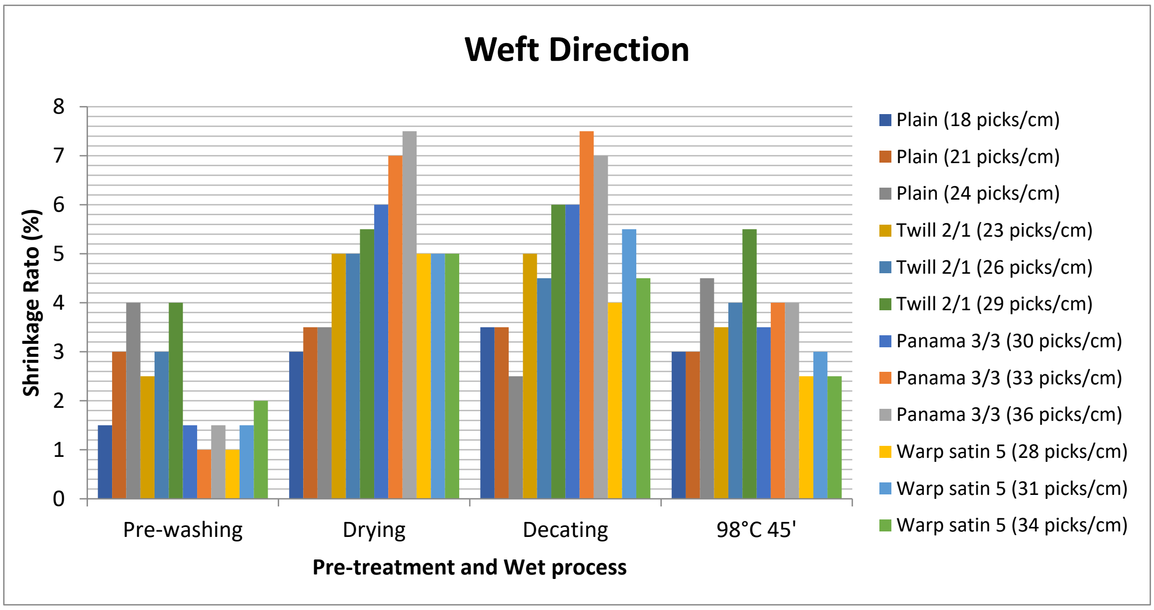

Figure 7. Results for Group B in weft direction**.**

Results for Group C: When warp yarns are examined, it is seen that at the end of prewashing the shortening is the highest in the plain fabric. It is observed that there is no shrinkage in panama weaves and 3% shortening occurs after tensionless drying. As the hygral expansion and the relaxation ratio are directly proportional, also in other weave types the shrinkage ratio of the yarns relaxed with drying, increase. At the end of the decating process, the shrinkage values did not change much and the difference between these values of the different weave types was preserved. It is seen that shortening of plain and satin fabrics before dyeing is close to each other and higher than others. At the beginning of the dyeing, it occured an elongation in the yarn lengths in respect to the decating process. Because, in the temporary fixation process by decating, hydrogen bonds are loaded with tension and in the course of the process, these bonds are broken by the effect of temperature and water, which increases the desire to shorten the yarns. However, since the hygral expansion has a greater tendency to increase the length of the yarn, the shrinkage ratio during dyeing is lower than in the decating. At the end of the dyeing, because of the hollow structure of satin and panama fabrics, the shrinkage ratios remain low compared to the decating process due to the hygral expansion while the plain and twill fabrics with tight structure shorten more because the effect of hygral expansion is decreased on them. No significant relationship could be established between the change in weft density and shrinkage values in warp direction. While the shrinkage values in the weft direction did not change at the beginning of the dyeing temperature, the shortening values increased slightly between 30-45 minutes of the process. At the end of the dyeing, it has seen that the highest shrinking ratios are in the twill and panama fabrics and the lowest ones are in the plain fabrics. This result is due to the different crimp ratios of the weft yarns. In panama and satin fabrics, as in warp yarns, there is a large difference in shrinking ratios between pre-wash and drying in weft yarns, which can be explained by the fact that the penetration of more water between fibers and yarns in these weaves. This case results in increasing the desire of shrinkage in the yarns by increasing the number of broken hydrogen bonds. Results are depicted in Figures 8 and 9.

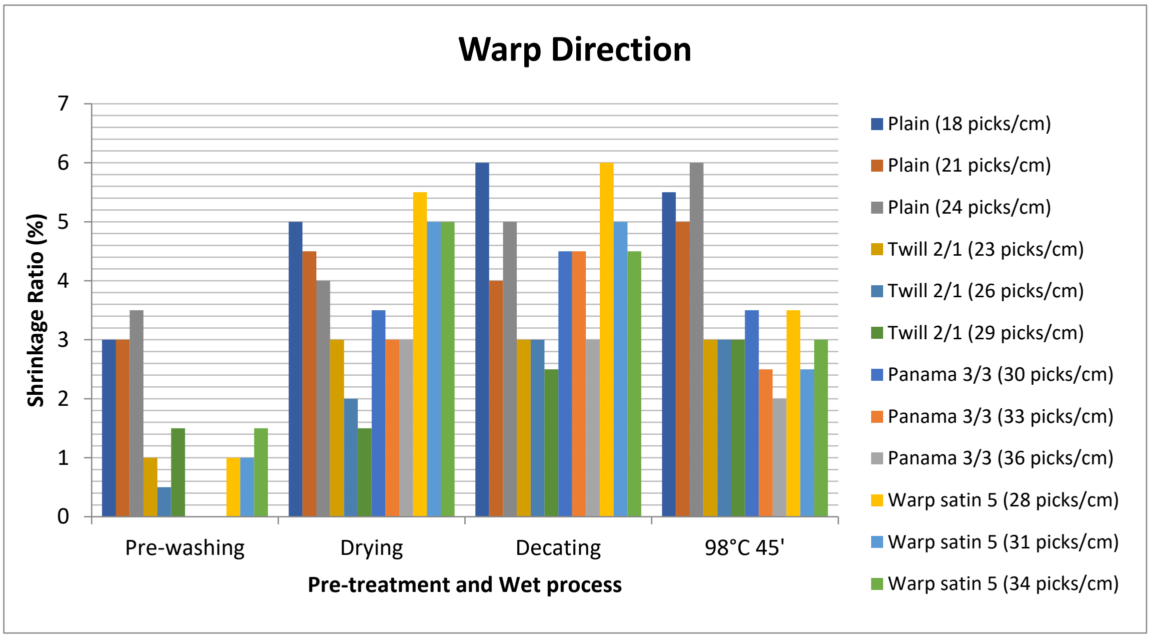

Figure 8. Results for Group C in warp direction

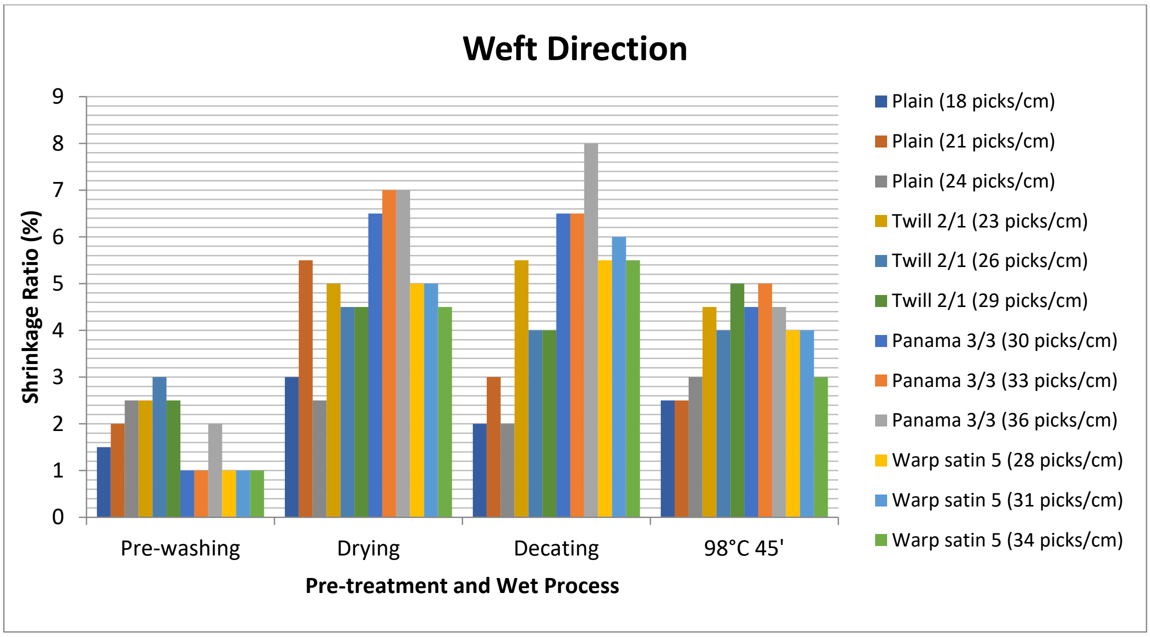

Figure 9. Results for Group C in weft direction**.**

Results for Group D: As expected, the shrinking values in the decating process couldn't be compensated in satin and panama weaves at the beginning of 110°C temperature, whereas these values are the same or more in plain and twill fabrics and it is seen that this result didn't change at the end of dyeing. Thus, it can be said that increasing the dyeing temperature does not stimulate the effect of hygral expansion more in tightly structure weaves. When the dyeing temperature was raised, the shrinking values in the warp direction increased a little more than that at the boiling temperature. While the plain fabric shows the highest shortening, still the shrinking values of the other weaves are close to each other. In the dyeing of fabrics with the same warp density under high temperature and pressure, no significant relation could be found between the shrinkage values in the warp direction and the weft density. The shrinking ratios in the weft direction in panama and twill weaves are slightly higher when compared to the others. As the temperature is increased, there is a further increase in these values. Also, in this process, in satin and panama fabrics, the weft-directional shrinkage ratios are lower at the end of dyeing than those obtained with decatised process and higher in plain and twill fabrics. Results are depicted in Figures 10 and 11 [8].

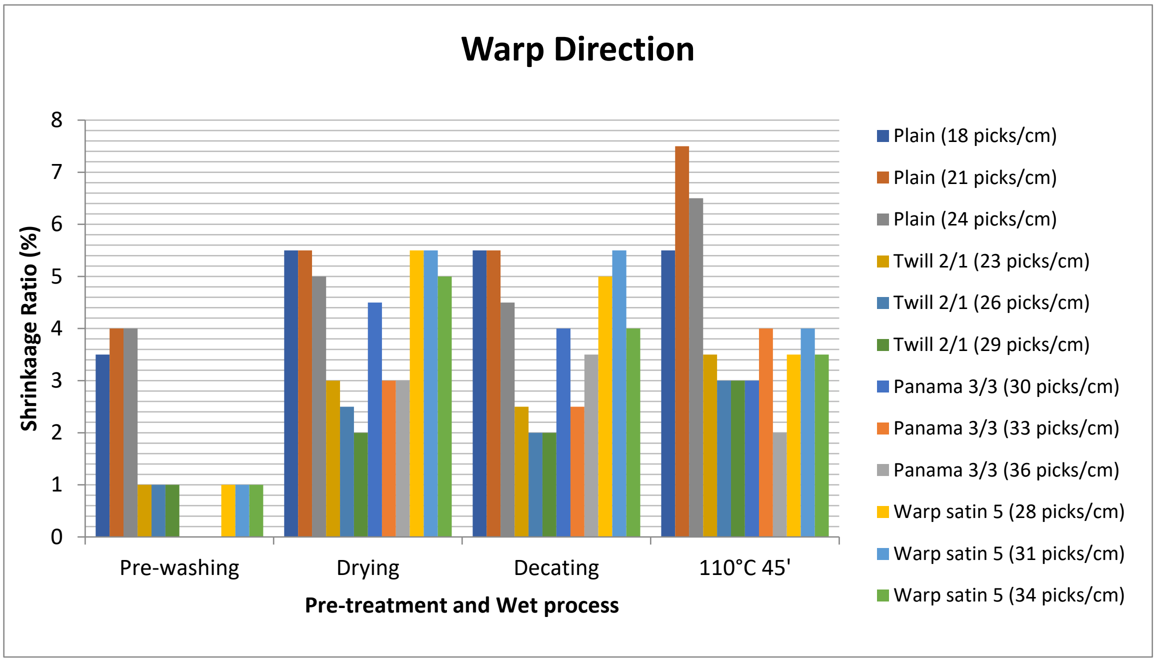

Figure 10. Results for Group D in warp direction.

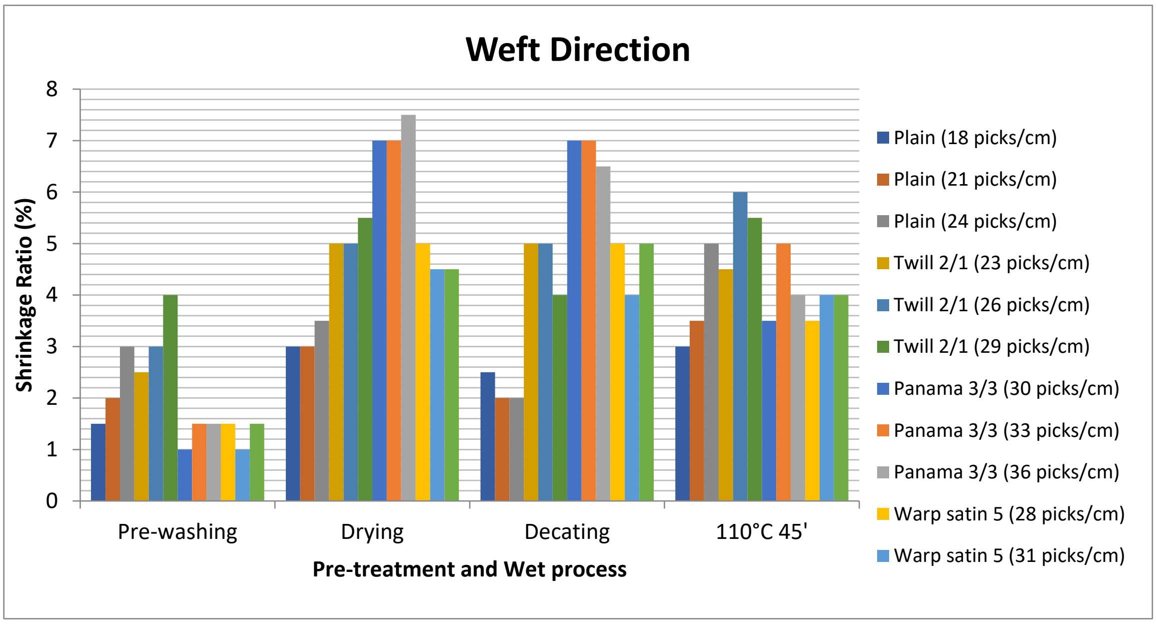

Figure 11. Results for Group D in weft direction.

4. Conclusions

The shrinkage rates due to the hygral expansion, measured after prewashing and decating treatments tend to decrease in subsequent operations. The amount of decrease is lower in case of plain and twill weave samples as it disappears at the end of the process. Whereas, the effect of hygral expansion continues for satin and panama weave samples. The yarns can continue to expand because of the assist of longer floating yarn in these particular samples. In the plain weave samples, the contraction in warp direction has always been higher than that in the weft direction for all processes. The sample with the lowest pick density, exhibited the lowest contraction value in comparison with other pick densities. For wet treatments at the boiling temperature, the change of pick density appears to have no significant effect on the contraction in warp direction. The measured contraction rates of the samples vary in a similar range except for the plain weave.

The contraction rates for the dyeing process and neutral wet treatment at 98°C look like very close for the plain and twill samples. With an increase in temperature, the contraction rate also increases. However, the hygral expansion drops down despite of higher fixation performance. In case prewashing and decating process, the plain and twill samples generate lower contraction in weft direction. With the lowering pick density, the contraction in weft direction shows a tendency to decrease for all samples. The contraction rate in the weft direction is the highest for the twill samples and the lowest for the plain samples. The weftwise contraction rate for the dyeing process at 98°C has produced higher rate than that of the neutral wet treatment at 98°C for the satin and panama samples. With an increase in temperature, the contraction rate, in general, also tends to increase.

In overall, the contraction ratios during wet treatments were recorded as 3-6% in the warp direction and as 4-8% in the weft direction. It is observed that approximately 35-40% of the overall contraction of raw fabric is due to the wet treatments of which 65% of the contraction occurs in the dyeing process. In conclusion, the temperature and period of process together with the pick density appear to have strong influence on the contraction rates [8].

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