Study the Physical Property Variations of Core Spun Cotton-Spandex Single Jersey Fabrics under Relaxation

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Abstract – *In this research, variations of structural spacing, stitch density, fabric thickness, areal density, fabric stiffness, flexural rigidity, air permeability, and bursting strength properties of cotton/spandex and cotton single jersey structures have investigated. These fabrics were knitted in high, medium and low stitch lengths and subjected to dry-, wet-, full- relaxation and washing treatments. Cotton/spandex structures have given higher stitch densities and lower structural spacing, higher areal densities and higher fabric thickness values than cotton structures. These physical properties increased with progression of treatments and structural spacing have decreased in further relaxation of stitches. They have shown good positive correlation with fabric tightness factor (stitch length^{-1}), but structural spacing had the negative correlation. Higher bending lengths and flexural rigidities have also given by cotton/spandex than cotton structures. Those properties are higher in course direction than in wale direction and positively correlate with stitch length^{-1}. Air permeability has given positive correlation with stitch length and also given lower air permeability with cotton/spandex structures. Bursting strength has shown positive correlation with stitch length^{-1} and higher values at higher treatment levels. Cotton/spandex structures have given higher bursting strengths compared to cotton. All the considered physical properties are significantly influenced by the machine set stitch lengths, the relaxation level and material type.*

Key words: *Cotton/spandex, single jersey fabrics, physical property, air permeability, bursting strength*

Nomenclature

CO-SP: Cotton/spandex	CO: 100% Cotton	TF: Tightness factor
H-TF: High tightness factor	M-TF: Medium tightness factor	L-TF: Low tightness actor
WPC^{-1}:Wales/cm	CPC^{-1}:Courses/cm	

1. INTRODUCTION

It is well known fact that structural changes take a place in knitted structures during relaxation treatments and laundering treatments (Sharma *et.al.* 1985), (Marmarali, 2003), (Herath and Kang, 2008). This may cause for the variations of physical properties of these fabric structures. It depends mainly on the fiber type, structure type, structural tightness factor, knitting conditions, relaxation and laundering treatments etc. This variations of physical properties effect on the performance, functional qualities, durability, aesthetic qualities etc. of these knitted fabrics (Hepworth 1982), (Herath and Kang, 2008).

Previous researches were carried out to investigate the physical property variations of several various knitted structures such as single jersey, rib, interlocks made from cotton, acrylic, polyester, polyamide and some of their combinations under the applications of various relaxation techniques (Sharma *et.al.* 1985), (Herath and Kang, 2008) (Mayruz and Ogulata, 2010). Results indicated that thickness, areal density, flexural rigidity, shear rigidity, stiffness, bursting strength of tested structures have significantly effected by stitch type, structural tightness factor, yarn composition, relaxation treatments etc.

(Sharma *et.al.* 1985), (Ertugrul and Ucar 2000), (Marmarali, 2003), (Herath and Kang, 2008). Thus, one research on the certain physical property variations such as thickness, areal density, air permeability of cotton-spandex made with full and half plated single jersey fabrics has reported that these properties significantly changed with the relaxation treatments (Marmarali, 2003).

In this experiment, variations of physical properties such as structural parameter variations, air permeability, fabric thickness, fabric stiffness and bursting strength of core spun cotton-spandex single jersey fabrics were investigated under various relaxation and laundering treatments. Thus, results are compared with those for similar fabrics knitted from 100% cotton yarns.

2. EXPERIMENTAL

Materials

Single jersey fabrics made from core spun (93 % of cotton and 7 % of spandex) cotton/spandex and cotton were knitted in a circular knitting machine in high, medium and low tightness factors. Ring spun unmerzerised cotton (30 Ne) and 40decitex "Creora" spandex filaments from Hyosung company, Korea, were used for spinning of cotton/spandex yarns. Table 1 gives yarn characteristics and knitting details are given with Table 2. In order to maintain sufficient tension, 6 cN was selected as an in-put tension for CO-SP yarns to knitting zone, based on the series of pre-experiments.

Selected machine set stitch length for CO-SP and CO single jersey fabrics are given in Table 3. These stitch lengths have been set in the machine using the setting of stitch cams, and stitch lengths were measured according to the standard procedure. Based on that TFs were classified as H-TF, M-TF and L-TF. In this table, machine off stitch lengths, which were calculated under 95% significant level, are given in parenthesis. It is clearly shown that, even though the machine set stitch lengths are same for both CO and CO-SP structures, the machine off stitch lengths are different, which is due to the "robin back effect" and the differences are given in square brackets in Table 3 as percentages. According to that, higher reductions show with CO-SP structures. Reason would be the higher resiliency property of CO-SP yarns. Thus, robin back effect decreased by increasing the tightness factor in CO-SP structures. But, CO fabrics show an opposite behavior.

Table 1: Yarn characteristics used for knitting

Single jersey Material	Nominal count [Ne]	Measured count [tex]	Tensile strength [gf]	Extension at break [%]	Yarn twist [tpi]
CO-SP	30	20.40	305.0	8.94	24.41
CO	30	20.14	359.8	5.04	19.70

Table 2: Knitting details

Single jersey material	Machine diameter [inches]	Gauge	Machine RPM	No. of positive feeders	No. of needles
CO-SP and CO	30	28	22	72	2640

Table 3: Machine set stitch lengths in mm

Material	L-TF	M-TF	H-TF
CO-SP	2.90(2.68±0.020) [7.59%]	2.70(2.55±0.012) [5.55%]	2.50(2.40±0.010) [4%]
CO	2.90(2.84±0.021) [2.07%]	2.70(2.62±0.032) [2.96%]	2.50(2.42±0.041) [3.2%]

Method

Sample preparation: Sample size of 30x30 cm^2 were cut from cotton and cotton/spandex single jersey fabrics. Six samples were cut from knitted structures from each tightness factor. Samples were first subjected to dry- and wet- relaxation and then subjected to full relaxation followed by laundering treatments as given below. Relaxation treatments were done according to ASTM D 1284-76 and washing treatments were followed ISO 6330 standards.

Dry Relaxation: Samples were placed in a conditioning cabinet for 48 hours under standard temperature of 21 ± 1^0C and relative humidity (RH) of 65%±2)

Wet Relaxation: Dry relaxed samples were wetted in a water bath containing 0.05g/l of standard wetting agent, maintaining the temperature at about 38°C for 24 hours with minimum agitation. Samples were hydro-extracted and put in a conditioning cabinet for 48 hours under standard conditions (21°C±1 at RH of 65%±2).

Full Relaxation: Wet relaxed samples were washed thoroughly, briefly hydro extracted for 1 minute and tumbler dried for 60 min. around 70 °C. Samples were then laid on a flat surface in a conditioning cabinet for 48 hours under standard conditions.

Washing treatments: Fully relaxed samples were laundered 1st to the 5th cycle (W1 to W5)in a standard front loading machine under normal agitation. Washing temperature was set at 40^0C and rinsed with cold water and 0.1g/*l* standard wetting agent was used and mass of the total load was maintained as 3kg. After tumble drying for 60 minutes, samples were brought to the standard conditions.

According to the literature survey, structural changes occur during relaxation and washing treatments in the weft knitted fabric structures, which may cause for the variations of the physical properties of the fabrics affecting on the end uses. Therefore, structural spacing variations and stitch density variations of single jersey structures were measured according to the standard practice.

To measure the areal density (g/ m^2), sample size of 30×30cm^2 (from the middle area of the relaxed fabric type) were cut after each treatment stage. Then, 10 specimens per each tightness factor for each treatment stage were prepared and weight measurements were taken from standard electronic balance within 0.1% accuracy. This experiment was done according to the ASTMD 3776-96.

In measuring fabric thickness, standard digital thickness gauge meter with 40mm diameter of base plate, 14mm diameter of pressure foot and pressure of 3.42 k Pa (35g f/ cm^2) were used. Measurements were taken at 5 random places per specimen. That means, there were 30 data collected per tightness factor of each single jersey fabric type. This test was done according to the ASTMD 1776-96 (2002). Air permeability test was carried out using standard air permeability tester with test area of 38cm^2 and imposed air pressure of

125 Pa. There were five areas in a fabric specimen were subjected to this test and altogether 30 data were collected per tightness factor per single jersey structure. This experiment was carried out according to the ASTM D 737-96

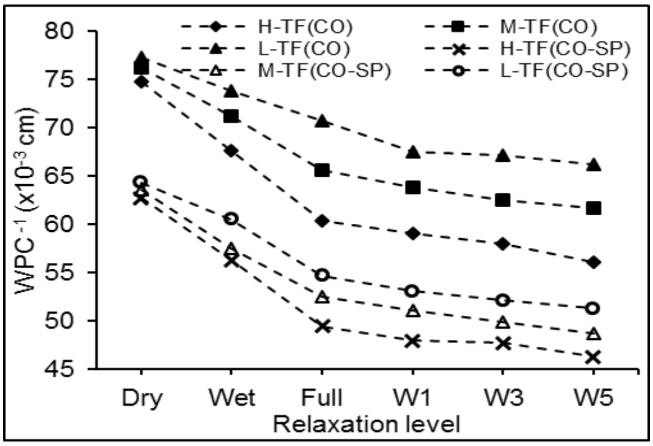
In order to measure the bursting strength of single jersey weft knitted structures, Mullen type hydraulic standard bursting strength tester was used according to the ASTM D 3786 standard. Applied hydraulic pressure was 20 kg/m^2 and diaphragm diameter was 50cm^2 with 2mm thickness.

In measuring the fabric stiffness, ASTM D 1388-96 standard was used. For CO single jersey fabric samples, only the heart loop method was suitable, due to its curling of cut edges of the specimens. However, cantilever method could be used for CO-SP single jersey fabrics due to its higher stitch densities and higher fabric tightness factors.

3. RESULTS AND DISCUSSION

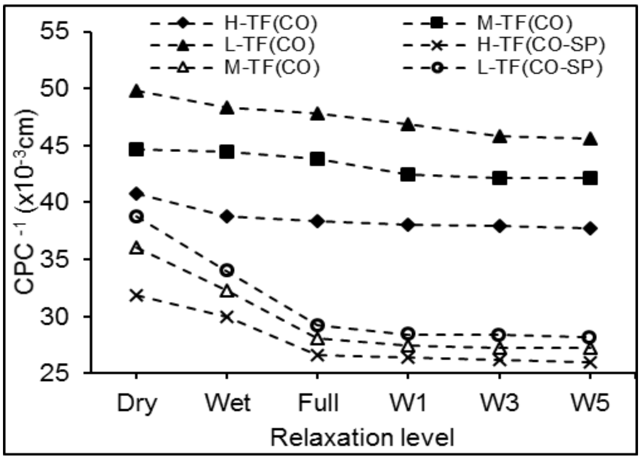
Structural spacing and stitch density variations

Figure 1 (a) and (b) shows the WPC^{-1} and CPC^{-1} variations of CO-SP and CO single jersey structures under relaxation and washing treatments.



Knitted structure	Fabric TF	Spacing reduction % from dry relax-W5
CO	H-TF	24.96
	M-TF	19.16
	L-TF	14.37
CO-SP	H-TF	26.16
	M-TF	23.54
	L-TF	20.30

(a)WPC^{-1} variations



Knitted structure	Fabric TF	Spacing reduction % from dry relax-W5
CO	H-TF	24.96
	M-TF	19.16
	L-TF	14.37
CO-SP	H-TF	26.16
	M-TF	23.54
	L-TF	20.30

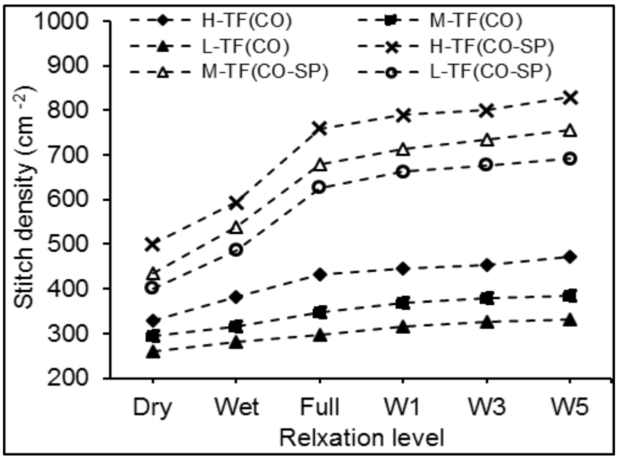
(b)CPC^{-1} variations

Figure 1: Structural spacing variations of CO and CO-SP single jersey fabrics

Figures show the higher wale spacing than course spacing in both the strictures and the structural spacing have significantly reduced with progressing the treatments as given in the tables with Figure1. Thus, steeper spacing reductions can be observed from dry relaxation to full relaxation in both CO-SP and CO structures compared to rest of the treatment. Thus, CO single jersey structures shows higher structural spacing than that of CO-SP single jersey structures. However, Figure 1 demonstrates very clearly that structural spacing positively correlates to the stitch length and reduction of spacing during treatments show a negative correlation to stitch length.

Figure 2 shows the stitch density variations of CO-SP and CO single jersey structures during the treatments. It shows that stitch densities increased with the progression of treatments as given in the table in Figure 2, because, plain stitches in the single jersey structures are more relaxed with the treatments specially contacting and agitation with water and also under tumbler drying, which results to change the stitch configuration during these relaxation treatments. Further, according to the table in Figure 2, stitch density increasing %s are positively correlates with the stitch density $^{-1}$ for CO structures and negatively correlates with the stitch density $^{-1}$for CO-SP single jersey structures.

Hence, CO-SP single jersey structures gave very high stitch densities than CO, even though both single jersey structures have knitted with same machine set stitch lengths. Reasons would be the lower machine off stitch lengths reported (as given in Table 3) with CO-SP due to their excellent stretch and recovering properties and robin back effect in knitting. Thus, Figure 2 shows that stich density variations negatively correlates to machine set stitch lengths. Steeper increases of stitch densities have given during dry relaxation to full relaxation of the samples. Stitch density variations shown in Figure 2 are caused by the structural spacing changes illustrated in Figure 1.

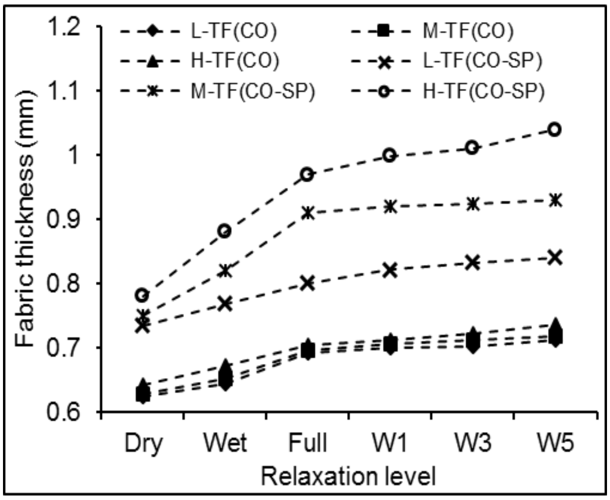


Knitted structure	Fabric TF	Stitch density increasing % from dry relax-W5
CO	H-TF	43.63
	M-TF	31.10
	L-TF	27.43
CO-SP	H-TF	65.70
	M-TF	73.33
	L-TF	72.49

Figure 2: Stitch density variations of CO and CO-SP single jersey fabrics

Fabric thickness variations

Figure 3 shows the fabric thickness variations of CO-SP and CO single jersey fabrics. It is very clear that CO-SP structures achieved significantly higher values than CO structures, even though both of these structures had the same machine set stitch lengths as given in the Table 3. Hence, according to the table given with Figure 3, it is very clearly showing that thickness of the single jersey fabrics increased with the progression of treatments and it positively correlates with stitchlength^{-1} or fabric TF in all the experimented cases of CO-SP and CO single jersey fabrics. However, CO-SP single jersey structures demonstrated very significant deviations of fabric thickness variations with their fabric TFs than CO single jersey fabrics. Reasons for these variations would be that they get the higher stitch densities due to higher resiliency property of CO-SP yarns and it results more bending the stitches into third dimension due to the more relaxation of stitches. Thus, due to higher stitch densities, structural jamming of single jersey structures may also give support to increase the fabric thickness values of CO-SP structures compared to CO structures.

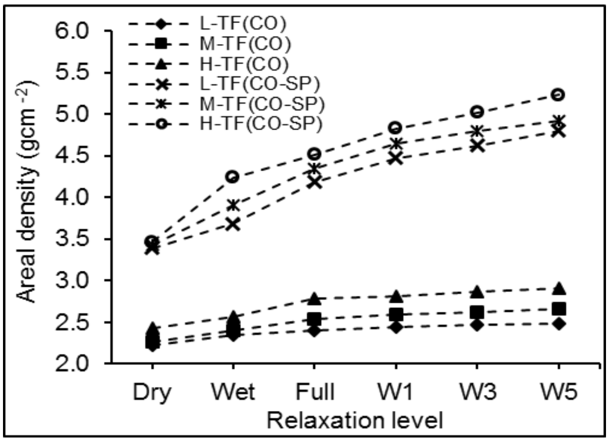


Knitted structure	Fabric TF	Fabric thickness increasing % from dry relax-W5
CO	H-TF	14.66
	M-TF	14.33
	L-TF	14.13
CO-SP	H-TF	33.21
	M-TF	24.00
	L-TF	14.44

Figure 3: Fabric thickness variations of CO and CO-SP single jersey fabrics

Fabric areal density variations

Fabric areal density is expressed as the weight in grams per unit area of a fabric. In industry, this is very frequently used to determine the quality of a fabric. Figure 4 shows the areal density variations of CO-SP and CO single jersey fabrics.



Knitted structure	Fabric TF	Area density increasing % from dry relax-W5
CO	H-TF	19.88
	M-TF	17.33
	L-TF	11.56
CO-SP	H-TF	51.17
	M-TF	43.51
	L-TF	41.53

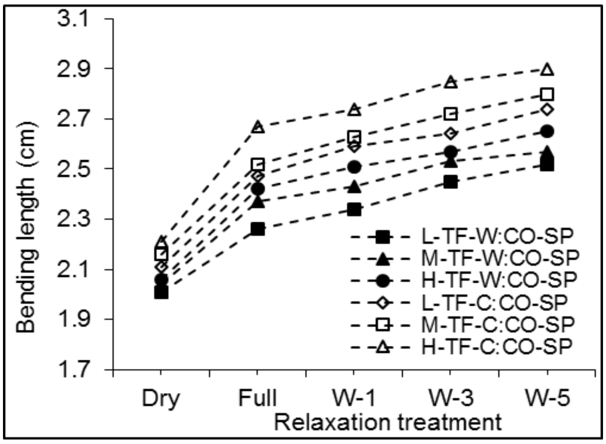
Figure 4: Areal density (gm^{-2}) variations of CO and CO-SP single jersey fabrics

According to the Figure 4, areal density positively correlates with the fabric TF or stitch length^{-1}. Therefore, H-TF structures of CO-SP and CO single jersey fabrics gave significantly higher areal density values. However, CO-SP structures have given significantly higher areal densities than CO structures, even though both of these structures consisted of the same machine set stitch lengths in manufacturing. Thus, according to the table given with Figure 4, progression of treatments gives areal density increases in both CO-SP and CO single jersey structures. Main reason for the increasing areal densities of CO and CO-SP single jersey fabrics is due to the changing of stitch densities with respect to the CO and CO-SP fabrics subjected to the treatments, as shown in Figure 2.

Stiffness property variations

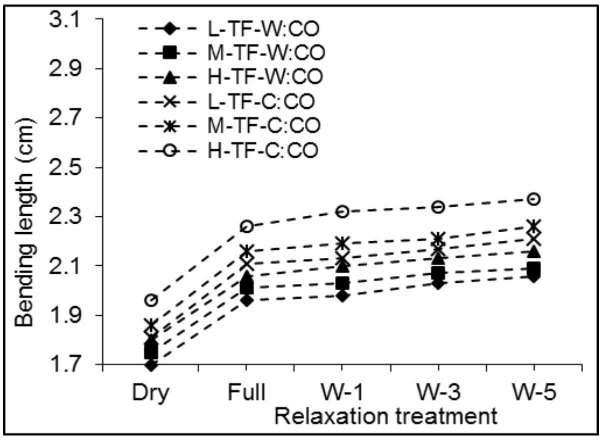
Stiffness is one of the main properties of textile fabrics in relation to the drapability and several other functional properties such as handle, comfort properties etc. In this research, stiffness has been expressed in terms of bending length and flexural rigidity.

Figure 5 and 6 shows the variations of bending length of CO-SP and CO single jersey fabrics in wale (indicated in figure by *W)* and course (indicated in figure by *C*) directions. It is shown that CO-SP single jersey structures have given higher bending lengths than CO structures in both wale and course directions. Thus, in both fabric types, higher stiffness (due to higher bending lengths) are given in course direction than that of wale direction. Reason could be the higher course cm^{-1} (measured as 20.07 -24.55 and 25.8-31.4 courses/cm in CO & CO-SP respectively at dry relax and 21.9 -26.49 and 35.47-38.42 courses/cm in CO and CO-SP respectively after W-5) than wale cm^{-1} (measured as 12.73 - 13.38 and 15.55-15.95 wales/cm in CO & CO-SP respectively at dry relax and 15.1 -17.83 and 19.51-21.6 wales/cm in CO and CO-SP respectively after W-5).



Knitted structure	Fabric TF	Bending length increasing % from dry relax-W5
CO	H-TF	20.00
	M-TF	19.43
	L-TF	21.18
CO-SP	H-TF	20.92
	M-TF	21.51
	L-TF	22.09

Figure 5: Bending lengths of CO-SP fabrics in wale and course directions



Knitted structure	Fabric TF	Bending length increasing % from dry relax-W5
CO	H-TF	28.64
	M-TF	25.98
	L-TF	25.37
CO-SP	H-TF	31.22
	M-TF	29.63
	L-TF	29.86

Figure 6: Bending lengths of CO fabrics in wale and course directions

Thus, according to the tables given with Figures 5 and 6, bending lengths have increased i.e: increasing the fabric stiffness) with the progressing of treatments. Possible reasons would be that progression of treatments also increases the stitch densities, which results higher bending lengths (stiffness) in both types of knitted structures. Other possible reason is that increasing the restrictions to yarn movements and the yarn compressional forces due to increasing of course and wale densities can restrict the bending of fabric samples. Thus, it can be assumed that as the rigidity and straightness of spandex filaments in the CO-SP yarn structure, the core spun yarns may have higher flexural rigidity values than 100% CO yarns, which can also increase the stiffness properties. Hence, higher thickness of CO-SP single jersey structures may have additional influence on the higher bending lengths and flexural rigidity. Thus, bending length of fabric samples positively correlates to the stitch length $^{-1}$, which is clearly demonstrated by Figures 5 and 6.

Thus, flexural rigidity, which is a mechanical value of the fabric stiffness, has been calculated using the following equation given in ASTMD 1386-96.

$$Flexural\ rigidity\ (mg.cm) = W \times C^3 \quad (1)$$

where W-areal density (mg/cm^2); C-bending length (cm)

Then, flexural rigidity values were determined using equation (1). The results are shown in Figures 7 and 8 in course and wale directions respectively.

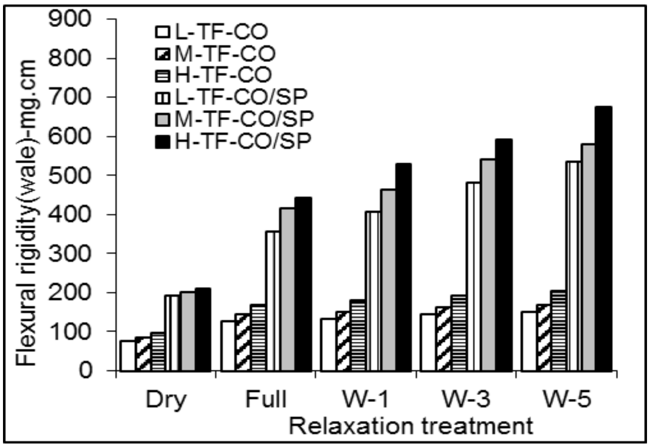


Figure 7: Flexural rigidity variations of single jersey fabrics in wale direction

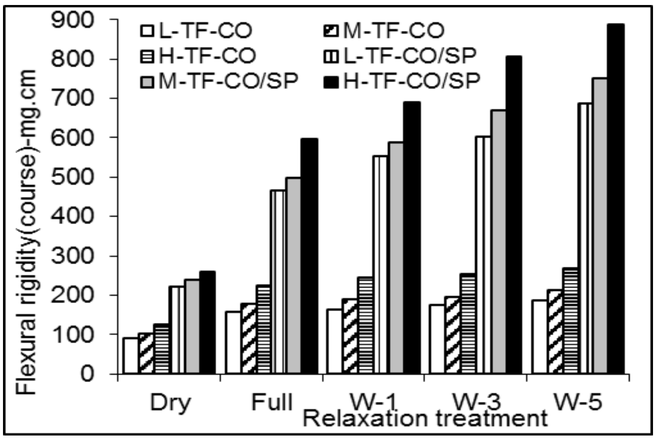
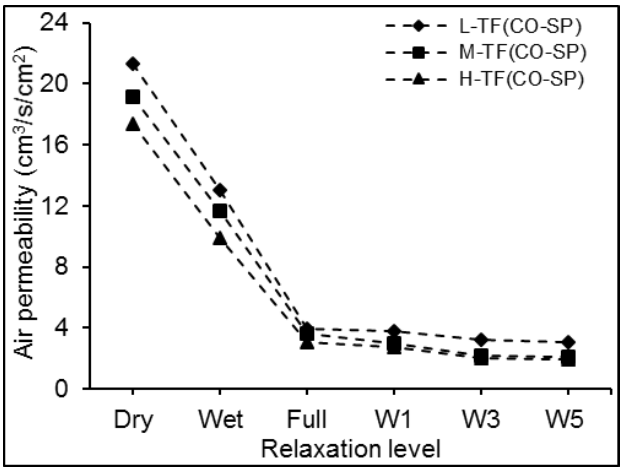


Figure 8: Flexural rigidity variations of single jersey fabrics in course direction

CO-SP single jersey fabrics have given significantly higher flexural rigidity values than CO structures and thus, flexural rigidity of tested samples positively correlate to fabric rightness factor and stitch length^{-1}. Reason could be the higher areal density and bending lengths achieved by CO-SP samples compared to CO structures, as described earlier. Meanwhile, flexural rigidity has increased with progression of treatments. This is especially observed in the case of CO-SP single jersey structures, both in course and wale directions. However, in CO structures, there is no significant increase in flexural rigidity observed after full relaxation.

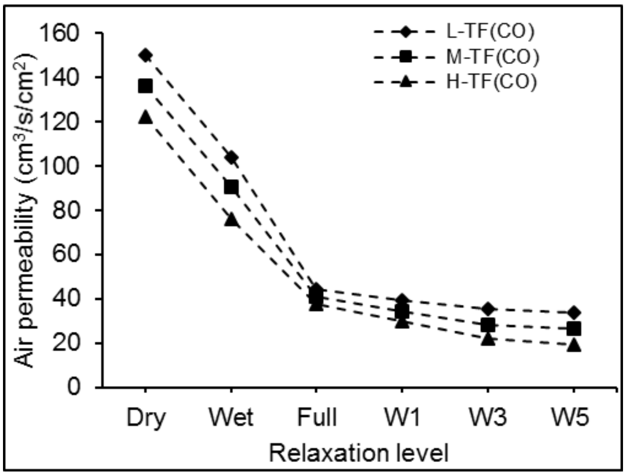
Air permeability variations

Air permeability of a fabric is defined as the volume of air in cm^3, which is passed in one second through $1cm^2$ of the fabric at a pressure difference of 10 mm head of water. This physical property is very important in concern of comfort in clothing.
Figure 9 shows the variations of air permeability of CO and CO-SP single jersey fabrics subjected to relaxation treatments.



Knitted structure	Fabric TF	Air permeability reducing % from dry relax-W5
CO	H-TF	28.64
	M-TF	25.98
	L-TF	25.37
CO-SP	H-TF	31.22
	M-TF	29.63
	L-TF	29.86

(a) For CO-SP single jersey structures



Knitted structure	Fabric TF	Air permeability reducing % from dry relax-W5
CO	H-TF	85.63
	M-TF	80.62
	L-TF	84.28
CO-SP	H-TF	88.74
	M-TF	88.98
	L-TF	88.74

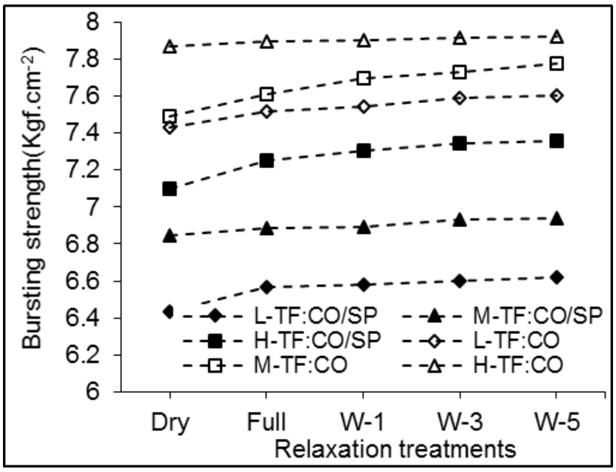
(b) For CO single jersey structures

Figure 9: Air permeability variations of CO and CO-SP single jersey fabrics

The table given with the Figure 2 shows that air permeability reduced with the relaxation treatments. Further, it is very clearly shown that air permeability has drastically decreased from dry relaxation to full relaxation in both knitted structures (as for CO about 70% and for CO-SP about 82%), due to increasing of stitch densities as illustrated in Figure 2, which is resulted of increasing areal density as described previously. Further, air permeability has reduced with progression of laundering treatments due to the same reason, but the rate is significantly lower than dry- to full-relaxation period. Thus, CO single jersey fabrics have shown higher air permeability values than CO-SP single jersey fabrics under the each treatment level because of their lower stitch density variations, which makes higher porosity in the knitted structure, compared to CO-SP single jersey fabrics. Hence, air permeability of single jersey CO and CO-SP knitted structures show a positive correlation to the machine set stitch length (or proportionate to the fabric tightness factor^{-1}). This could be happened due to making more structural spacing in the fabric with lower stitch lengths, which enables for higher air permeability in the fabrics.

Bursting strength variations

Bursting strength variations of CO and CO-SP single jersey knitted fabrics under relaxation treatments are shown in figure 10.



Knitted structure	Fabric TF	Bursting strength increasing % from dry relax-W5
CO	H-TF	0.64
	M-TF	3.79
	L-TF	2.34
CO-SP	H-TF	3.66
	M-TF	1.39
	L-TF	2.89

Figure 10: Bursting strength variations of CO and CO-SP single jersey fabrics

It shows that bursting strength of CO and CO-SP single jersey fabrics positively correlate to stitch length^{-1} of fabric. Because, lower stitch lengths results higher stitch densities as shown in Figure 2, which can bear the three dimensional bursting forces than lower stitch length knitted fabrics. Thus, bursting strength increased with the relaxation of knitted structures during progressing of treatments as the table given with Figure 10, because, stitch configuration changes during relaxation results higher stitch densities, which can bear bursting forces.

Hence, CO single jersey fabrics have shown higher bursting strength values than that of CO-SP single jersey fabrics, even though they have knitted with same machine set stitch lengths and CO-SP showed higher stitch densities as given in Figure 2. Reason could be hypothesized as the modulus and strength of CO-SP yarns can be reduced with repeated tumble drying done at each relaxation stage from full relaxation to W-5. Then, soft segments in polyurethane molecules (from polyols) in spandex filaments may affect by this, because they have lower melting point and very low glass transition temperature (Tg : 190 - 200K) compared to the hard segments of polyurethane molecules (from diisocynate). But, this change may not happen with CO fabrics as they have good resistant to heat. Thus, it can be observed a significant increasing of bursting strengths from dry relaxation to full relaxation than during progression of washing treatments (W-1 to W-5). Because, structural parameters increase rapidly in this period and results higher stitch densities for both knitted structures as shown in figure 2 [Herath and Kang, 2008)]. Therefore, the increasing stitch densities would have not much significantly affected on the variations of bursting strength of CO-SP single jersey fabrics, but the effect of repeated washing and tumbler drying have given very significant influence on it.

Multiple regression models and ANOVA analysis

Based on the multiple regression technique and ANOVA analysis, mathematical models for flexural rigidity, air permeability and bursting strength variations of CO and CO-SP single jersey fabrics were established under 95% significant level. In establishing these models, data obtained in full relaxation, after 1st(W1), 3rd (W3) and 5th (W5) machine wash cycles were used. Table 4 and 5 show the multiple regression model and ANOVA analysis for flexural rigidity variations of CO and CO-SP single jersey fabrics.

Table 4: Multiple linear regression model for flexural rigidity of CO-SP plain fabrics

Regression model for full relaxation to 5th washing cycle

Direction	variables entered	Correlation model	Pr>F	R^2
Wale	M, t	Y = -779.683+2.355M+547.901t	<0.0001	0.9740
Course	M, t	Y = -1051.037+3.52M+574.062t	<0.0001	0.9630

Note: Y- Flexural rigidity (mg.cm); M-weight/area (g/m^2); t-thickness (mm)

ANOVA summary for regression model

Direction	Variable	Standard error	Standardized estimate	t value	Pr> $\lvert t \rvert$	F value
Wale	Intercep	60.931	0	-12.79	<0.0001	228.5
	M	0.279	0.664	8.453	<0.0001	
	t	116.419	0.370	4.706	0.001	
Course	Intercep	217.67	0	-8.067	0.004	154.3
	M	0.828	0.819	7.284	0.005	
	t	205.49	0.246	2.188	0.116	

Note: df: regression=2; residual=12: $F_{0.05}$=3.89

Table 5: Multiple linear regression model for flexural rigidity of CO plain fabrics

Regression model for full relaxation to 5th washing cycle

Direction	variables entered	Correlation model	Pr>F	R^2
Wale	M, t	Y = -393.853+1.48M+398.64t	<0.0001	0.9890
Course	M, t	Y = -635.132+2.4M+565.776t	<0.0001	0.9940

Note: Y- Flexural rigidity (mg.cm); M-weight/area (g/m^2); t-thickness (mm)

ANOVA summary for regression model

Direction	Variable	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Wale	Intercept	21.292	0	-18.49	<0.0001	564.2
	M	0.116	0.638	12.72	<0.0001	
	t	49.236	0.406	8.097	<0.0001	
Course	Intercept	25.537	0	-24.87	<0.0001	936.9
	M	0.140	0.671	-17.19	<0.0001	
	t	59.052	0.374	9.581	<0.0001	

Note: df: regression=2; residual=12: $F_{0.05}$*=3.89*

Table 4 shows very strong correlations (R^2>0.96) of flexural rigidity to weight density and thickness values in both wale and course directions of CO-SP plain fabrics. Predicted models are highly significant (p<0.0001) at 95% significant level. According to "standardized estimate" data, both weight density and thickness give positive effect on flexural rigidity of both directions, but weight density effect is at least two times higher than that of thickness.

According to the values given in Table 5, CO plain fabrics also show very strong correlation in both wale and course directions (R^2>0.98). Predicted models are highly significant (p<0.0001) at 95% significant level, as indicated by their F values. Thus, according to "standardized estimate" data, weight density effect is higher than that of thickness on flexural rigidity of CO plain fabrics in concern of both wale and course directions. Hence, weight density and thickness give positive effect in all cases.

Tables 6 and 7 show the multiple regression model and ANOVA analyses for air permeability variations of CO and CO-SP single jersey fabrics.

Table 6: Multiple linear regression model for air permeability for CO-SP single jersey fabrics

Regression model for full relaxation to 5^{th} washing cycle

Number of variables	variables entered	Regression model	Pr>F	R^2
2	M, t	Y = 54.283-0.175M+7.172t	<0.0001	0.9190

Note: Y-air permeability ($cm^3/cm^2/s$); M-weight/area (g/m^2); t-thickness (mm)

ANOVA summary of regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F
Intercept	54.283	5.141	0	10.56	<0.0001	68.1
M	-0.175	0.024	-1.039	-7.44	<0.0001	
t	7.172	0.982	0.102	7.30	0.479	

Note: df: regression=2; residual=12 : F0.05=3.89

Table 7: Multiple linear regression model for air permeability of CO single jersey fabrics

Regression model for full relaxation to 5th washing cycle

Number of variables	variables entered	Regression model	Pr>F	R^2
2	M, t	Y = 949.78+0.423M-1402.15t	<0.0001	0.9780

Note: Y- air permeability ($cm^3/cm^2/s$); M-weight/area (g/m^2); t-thickness (mm)

ANOVA summary of regression model

Variable	Estimated coefficients	Standar d error	Standardized estimate	t value	Pr> $\lvert t \rvert$	F
Intercept	949.78	40.434	0	23.49	<0.0001	68.2
M	0.423	0.221	0.140	1.913	0.08	
t	1402.15	0.930	-1.098	-14.99	<0.0001	

Note: df: regression=2; residual=12: F0.05=3.89

According to the Table 6, air permeability of CO-SP single jersey structures have shown higher and very stronger correlation to weight density and thickness values (R^2>0.91). But, according to "standardized estimate" data, weight density gives higher and negative effect on air permeability, but the effect given by fabric thickness is lower and positive

Table 7 shows a very strong multiple regression model on air permeability (R^2>0.97) with the variables such as areal density and fabric thickness. According to "standardized estimate" data, fabric thickness gives very strong positive effect, but areal density shows comparatively very much lower positive effect on air permeability of CO single jersey fabrics.

Tables 8 and 9 show the multiple regression model and ANOVA analysis for bursting strength variations of CO and CO-SP single jersey fabrics.

Table 8: Multiple linear regression model for bursting strength of CO-SP single jersey fabrics

Regression model for full relaxation to 5th washing cycle

Number of variables	variables entered	Regression model	Pr>F	R^2
2	M, t	Y = 4.737+0.006M+4.619t	<0.0001	0.8690

Note: Y-bursting strength (Kgf /cm^2); M-weight/area (g/m^2); t-thickness (mm)

ANOVA summary of regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\lvert t \rvert$	F
Intercep	4.737	0.295	0	16.038	<0.0001	39.7
M	0.006	0.0013	0.807	4.539	0.001	
t	4.619	0.564	1.455	8.185	<0.0001	

Note: df: regression=2; residual=12: F0.05=3.89

Table 9: Multiple linear regression model for bursting strength of CO single jersey fabrics

Regression model for full relaxation to 5th washing cycle

Number of variables	variables entered	Regression model	Pr>F	R^2
2	M, t	Y = 6.78+0.015M-2.649t	<0.0001	0.8630

Note: Y-bursting strength (Kgf/cm²); M-weight/area (g/m²); t-thickness (mm)

ANOVA summary of regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\lvert t \rvert$	F
Intercept	6.78	0.394	0	17.212	<0.0001	37.7
M	0.015	0.002	1.300	7.178	<0.0001	
t	-2.649	0.911	-0.527	-2.908	0.013	

Note: df: regression=2; residual=12: F0.05=3.89

According to the Table 8, bursting strength of CO-SP single jersey fabrics have very strong correlation (R^2>0.86) with areal density and thickness, which gives negative and positive effects on bursting strength respectively. According to "standardized estimate" data, thickness can give higher effect than areal density on bursting strength of CO-SP single jersey fabrics.

In the case of bursting strength of CO single jersey fabrics, areal density and thickness are also given strong correlation on it as given in Table 9 (R^2>0.86). But, according to the 'standard estimate data", the effect of weight density and thickness are positively and negatively affecting on bursting strength respectively. Thus, this predicted models given in Tables 4, 5, 6, 7, 8 and 9 are highly significant at 95% significant level.

CONCLUSIONS

Significant structural changes occur during relaxation of knitted stitches in the single jersey fabrics due to the treatments done and it rapidly increases with progression of treatment. Due to this, structural spacing, which correlates to the machine set stitch lengths, significantly reduced with during treatments. CO-SP single jersey fabrics gave lower structural spacing than that of CO fabric, even though both have knitted with same machine set stitch lengths. Thus, steeper structural spacing reductions reported from dry relaxation to full relation compared to further treatment levels. Stitch density variations showed the same tendencies in all relaxation levels with both CO-SP and CO single jersey structures.

Fabric thickness has increased during relaxing the knitted stitches and it has showed the progressive results with the high level of treatments. CO-SP single jersey fabrics showed significantly higher fabric thicknesses than CO fabrics under same machine set stitch lengths. Fabric thickness has given negative correlation to the stitch lengths. Similar types of tendencies can be given by the variations of areal densities, fabric stiffnesses and flexural rigidity of both CO-SP and CO single jersey structures during treatments. Thus, fabric stiffness is higher in course direction than in wale direction in both fabric types under the treatments. Thus, bursting strengths of single jersey fabrics, which is progressively increased with higher level of treatments, reported the higher values in CO-SP fabrics compared to CO fabrics under the treatments and it is negatively correlates to stitch length.

Fabric stiffness, flexural rigidity, air permeability and bursting strength of CO-SP and CO single jersey fabrics showed the strong correlations with areal density and fabric thickness of the fabric and all the considered physical properties are significantly influenced by the machine set stitch lengths, the relaxation level and material type.

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