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# Dimensional stability of cotton, tencel and tencel/cotton blend plain weft knitted fabrics

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Pure cotton, 33/67 tencel/cotton, 67/33 tencel/cotton, and pure tencel yarns of 30 Ne count have been produced in the cotton spinning system and then used for knitting plain weft structure with three ranges of tightness factor to study their dimensional stability. Then knitted fabrics are subjected to dry, wet and tumble dry relaxations. Courses per inch(cpi), wales per inch(wpi), fabric thickness and areal density are measured at the end of each relaxation. Constants $k_1$, $k_2$, $k_3$, $k_4$ values for stitch density, cpi, wpi and loop shape factors are calculated using measured stitch length. Test results are subject to multilevel factorial analysis to determine factor contribution to the dimensional changes. It is found that the fibre contribution to the shrinkage is very less as compared to the contribution made by stitch length and relaxation treatments. Similarly, the quantum of length and width shrinkage is determined primarily by the stitch length (tightness factor). This is also confirmed by the calculation and comparison of loop shape factor. Thickness of the fabric is influenced significantly by relaxation treatment and fibre composition. Areal density is primarily determined by relaxation treatment and stitch length rather than by fibre composition. Hence, it is concluded that tencel and cotton are similar in dimensional characteristics.

**Keywords**: Areal density, Cotton, Cotton/tencel blend, Stitch length, Tencel, Weft knitted fabric

## 1 Introduction

Nowadays knitted fabric is widely used worldwide as outer wear also. Particularly plain weft knitted and double knitted structures are popular among consumers. However, the shrinkage of knitted cloth is still unavoidable but controllable. This is possible by applying a scientific approach in selecting the relevant parameters during knitting. Shrinkage of knitted structure has been critically analysed by technocrats. Doyle[1] explained the fundamental aspects of the design of knitted fabrics early in 1953. According to him, the relaxation allows the loop structure to conform itself to minimum energy state. Knitted structure has been studied closely and several phenomena of dimensional stability have been explained by many workers[2-4].Munden[5]analysed the geometry of single knitted loop and developed equations describing the relationship between dimensional properties and stitch length. During the course, he introduced a series of k values as dimensionless constants. Munden[6] in his paper discussed about the slack and tight knit structure and stated that they differ during relaxation.

Postle[7] studied the dimensional stability of a wide range of natural and synthetic fibre knitted fabrics at different relaxation stages. Hurley[8] reported that the wet relaxation increases with increase in temperature. Knapton[9] examined the dimensional properties of knit structure and stated that the structure is determinate only on complete relaxation. According to them longer tumble drying duration is needed to relax the fabric completely. Burnip and Abbas[10] measured loop length, courses per inch (cpi), wales per inch (wpi), stitch density, and weight per square unit at each state of relaxation. They concluded that washing and tumbling are effective under relaxation stage of the knitted structure. Blank[11] studied the effect of fabric distortion and knitting machine setting on shrinkage of cotton and polyester/cotton blend. Knapton *et al*[12]. reported that the dimensional stability could be attained either by mechanical finishing or by chemical treatment. Gower and Hurt[13] investigated dry relaxed fabric dimensions of plain structure for stitch length and observed that the tumbling introduces energy needed for relaxation. Heap *et al*[14]. detailed about the

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Starfish project and suggested to conduct 5 cycles of relaxation to bring fabrics to reference state (strain free, fully relaxed state). Puckan and Subramaniam[15] studied the stability of cotton, polyester and cotton/polyester knitted fabric of ring and rotor yarn. They observed identical shrinkage character between ring and rotor yarn fabrics.

Mackay *et al.*[16] carried out 50 cycles of relaxation on cotton, wool and acrylic to relax the fabric and discussed about them. Quaynor *et al.*[17] examined the deformation of single jersey and 1x1 rib structures during laundering with variation in the count, tightness and stitch length. They concluded that the knitting conditions and relaxation are the prime cause of shrinkage. Coertz *et al.*[18] applied cellulose to impart dimensional stability but they observed improvement with significant strength loss. Anand *et al.*[19] examined the effect of laundering with detergent and line drying. They stated that tumble drying induces more shrinkage. Mahamadi and Jedd[20] used ultrasonic waves to relax knitted fabric and found it suitable for quality control purpose in the laboratory. The knitted structure of polyester micro denier fibre yarn was dealt by Srinivasan *et al.*[21] and it was stated that this fabric is better in terms of stability. Karne *et al.*[22] studied the shrinkage of single jersey fabric of ring and compact yarn. Moghassem and Tayebi[23] investigated the effect of mercerization treatment on stability of cotton plain knits and observed improvements, close to the theoretical value. Onal and Candan[24]stated that polyester/cotton blend knitted fabric has minimum shrinkage. According to them the fabric structure is mainly influenced by knit type and tightness factor.

Many workers have tried to address the most common subject of knitted fabric shrinkage. Even today studies are being carried out in this area. Lo[25] in his study on relaxation of knitted fabric stated that the most relevant yarn properties are friction and flexural rigidity. Mak *et al.*[26] observed that tencel exhibits small bending rigidity and bending moment. At the same time the work on the dimensional stability of tencel and tencel/cotton blend knitted structure is limited and not reported much in detail. Hence, it was decided to investigate dimensional stability of cotton, tencel/cotton blend and tencel plain weft knitted fabrics. This study would certainly help to understand this emerging fibre in terms of shrinkage.

## 2 Materials and Methods

A designed experiment was conducted using full factorial design. Fibre composition, stitch length and relaxation treatments were the three factors considered. Four levels (pure cotton, 67/33cotton/ tencel, 33/67 cotton/tencel and pure tencel) were chosen in fibre composition. Three levels (2.7, 2.9 and 3.1mm) were considered each in stitch length. Dry, wet and tumble drying tried in relaxation treatments. Pure cotton, 33/67 tencel/cotton, 67/33 tencel/cotton, pure tencel yarns were developed. 30 Ne yarn was produced in the cotton spinning system[27]. Yarn properties are given in Table 1. Yarn samples were used to knit single jersey knitted fabric. With regard to knitting stiffness, tight, medium and slack structures were selected with stitch length of 2.7, 2.9 and 3.1mm (ref. 28). The relevant tightness factor were 16.3, 15.2 and 14.2. Commercial knitting machine (Make: Shinta-2005, Taiwan) was used to knit all the

Table 1— Properties of yarn

| Characteristics | Pure cotton | 33/67 tencel/cotton | 67/33 tencel/cotton | Pure tencel |
|---|---|---|---|---|
| Count | 29.2 | 29.3 | 29.5 | 29.7 |
| Count CV, % | 1.2 | 0.69 | 0.72 | 0.74 |
| Single yarn strength, g/tex | 19.12 | 19.32 | 20.74 | 28.49 |
| CSP | 3086 | 3617 | 4648 | 5054 |
| Elongation, % | 6.18 | 6.21 | 6.83 | 10.06 |
| U % | 10 | 9.67 | 9.41 | 9.58 |
| Yarn diameter, mm | 0.177 | 0.161 | 0.163 | 0.165 |
| Yarn diameter (swelling), mm | 0.225 | 0.224 | 0.221 | 0.222 |
| Packing fraction | 0.543 | 0.713 | 0.633 | 0.614 |
| Hairiness, H | 5.7 | 5.43 | 5.32 | 5.22 |
| Bending rigidity, $mg.mm^2$ | 72.13 | 42.3 | 31.55 | 15.73 |
| Coefficient of friction (yarn to metal) | 0.15 | 0.07 | 0.06 | 0.06 |

samples. The machine has the specifications: 20 inch cylinder diameter and 24 needles per inch. During knitting, the machine was set to maintain uniform tension of 10 cN using positive feeder (number of feeder 60). Knitting parameters like stretcher board setting and take down tension were maintained constant throughout the knitting processes.

#### 2.1 Relaxation Treatment

All the knitted samples were subject to following relaxation treatments:

(i) Dry Relaxation—During dry relaxation, samples were allowed to relax in a dry state for 48 h (ref. 29). Samples from the machine were unfolded and left flat under standard atmosphere. This relaxation is considered as dry relaxation.

(ii) Wet Relaxation— As suggested in literature, perforated tray was used to place the samples during wet relaxation. The tray was immersed in the water at room temperature for 24 h with occasional soaking[30]. Samples were removed and allowed to dry under shadow. This treatment is considered as wet relaxed treatment.

(iii) Tumble Dry Relaxation— Samples were washed at 60 °C in a standard domestic washing machine for 30 min with a standard wetting agent (SDC reference detergent Type I). The samples were then tumble dried in a standard tangle free tumble drier at 60 °C for 60 min (ref. 30). Samples were taken out and left flat before measurements were taken. During washing and tumble during AATCC-135 test method was followed.

#### 2.2 Testing

All the samples were conditioned under standard atmosphere before the measurement was made for dimensional properties. Cpi, wpi, thickness and areal density were determined to study the dimensional stability of the fabrics[10]. Course and wale densities were determined using one inch pick glass. Ten measurements were made on each sample and average was taken. IS: 7702-1975 test method was used to determine fabric thickness (mm) on Shirley tester. During measurement proper care was taken to maintain smooth and flat surface without crease and fold. Ten observations were made for each sample and average was taken. Fabric areal density is the weight of fabric in gram per square meter. Fabric samples were cut using GSM cutter. Cut samples were then weighed using standard electronic balance to determine weight. IS: 1964-1970 standards were followed. Five specimens were cut and weighed for each sample.

## 3 Results and Discussion

The stitch length, measured in all the samples, is found less than that of the set value but only to a very small extent. Courses per inch is inversely propositional to stitch length. Lower stitch length results in shorter and wider loops. The change in the cpi and wpi (length and width shrinkage) is influenced mainly by stitch length. Munden[6] also stated that the shrinkage of slack and tight structure is different. This is also confirmed for tencel and tencel/cotton blend fabrics, as the tight structure shows lower length and higher width shrinkage. This appears good both for dry to wet and wet to tumble dry relaxation. Tumble drying brings about considerable change in the length and width shrinkage. This is due to the energy supplied by high temperature coupled with tumble action to loop to attain minimum energy configuration. This tumble action helps to overcome frictional restrain[8]. Hence, potential shrinkage due to knitting stress and fabric distortion during processing is made to reduce during wet and tumble relaxation. Yarn length shrinkage is found negligible due to the relaxation treatment[2,19].

The values of $k_1$, $k_2$, $k_3$, $k_4$ are calculated from cpi, wpi and measured stitch length Table 2. The equations derived by Munden[5] to calculate k values are used for this study. In dry state, $k_2$ value is different among fabrics with different tightness factor. But $k_1$ value is also similar to $k_2$in all the stiffness. Wet relaxation makes changes in the $k_1$, $k_2$, $k_3$values, depending upon tightness factor as explained by Munden[5]. This trend continues in tumble drying also. As far as loop shape factor is considered, tight structure exhibits highest value (1.49) in dry state. For medium and slack structures, the value of loop shape factor is 1.19 and 1.08 respectively. Loop shape factor changes during wet and tumble treatment. For tight structure this value has come down to 1.31.at the end of tumble drying, whereas for medium and slack structures this value increases to the final value 1.3 and 1.29 respectively. This indicates that the explanation given by Munden[6] on shrinkage holds good for tencel yarn also. He stated that the shrinkage of fabric is only due to the relaxation of knitted loop returning to strain free natural configurations (cpi/wpi=1.3). According to him, this is governed only by the length of the yarn knitted into one loop. All other yarn and knitting parameters alter this length

Table 2—k constant values for dry, wet and tumble relaxed single jersey fabrics

| Parameter | Tight structures | | | | Medium structures | | | | Slack structures | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | k1 | k2 | k3 | k4 | k1 | k2 | k3 | k4 | k1 | k2 | k3 | k4 |
| **Cotton** | | | | | | | | | | | | |
| Dry relaxation | 19.32 | 5.37 | 3.60 | 1.49 | 17.54 | 4.59 | 3.90 | 1.38 | 17.02 | 4.43 | 4.05 | 1.09 |
| Wet relaxation | 21.41 | 5.48 | 4.00 | 1.37 | 21.7 | 5.23 | 4.15 | 1.26 | 21.97 | 5.2 | 4.22 | 1.23 |
| Tumble dry relaxation | 24.24 | 5.64 | 4.29 | 1.31 | 23.67 | 5.52 | 4.29 | 1.29 | 24.13 | 5.6 | 4.31 | 1.3 |
| **33/67 tencel/cotton** | | | | | | | | | | | | |
| Dry relaxation | 18.51 | 5.25 | 3.52 | 1.49 | 17.54 | 4.57 | 3.82 | 1.20 | 17.02 | 4.34 | 3.99 | 1.09 |
| Wet relaxation | 21.41 | 5.36 | 3.91 | 1.37 | 21.14 | 5.19 | 4.07 | 1.28 | 21.3 | 5.12 | 4.16 | 1.23 |
| Tumble dry relaxation | 23.27 | 5.53 | 4.21 | 1.31 | 23.00 | 5.47 | 4.21 | 1.30 | 23.33 | 5.49 | 4.25 | 1.29 |
| **67/3 tencel/cot**ton | | | | | | | | | | | | |
| Dry relaxation | 18.57 | 5.25 | 3.53 | 1.49 | 17.54 | 4.56 | 3.83 | 1.19 | 17.02 | 4.33 | 4.00 | 1.08 |
| Wet relaxation | 21.41 | 5.33 | 3.92 | 1.36 | 21.02 | 5.15 | 4.08 | 1.26 | 21.26 | 5.09 | 4.17 | 1.22 |
| Tumble dry relaxation | 23.15 | 5.49 | 4.22 | 1.30 | 22.70 | 5.41 | 4.20 | 1.29 | 23.34 | 5.48 | 4.26 | 1.29 |
| **Tencel** | | | | | | | | | | | | |
| Dry relaxation | 18.64 | 5.28 | 3.53 | 1.49 | 17.54 | 4.57 | 3.83 | 1.19 | 17.02 | 4.34 | 4.02 | 1.08 |
| Wet relaxation | 21.41 | 5.39 | 3.92 | 1.37 | 21.26 | 5.19 | 4.09 | 1.27 | 21.31 | 5.11 | 4.17 | 1.22 |
| Tumble dry relaxation | 23.47 | 5.55 | 4.23 | 1.31 | 23.00 | 5.47 | 4.21 | 1.30 | 23.39 | 5.49 | 4.26 | 1.29 |

k1,k2,k3,k4 – Constant values for stitch density, cpi, wpi,and loop shape factors respectively.

only. Hence, it is also concluded that the quantum of length and width shrinkage is the result of loop returning to this natural configuration. Tumble drying promotes this as compared to washing treatment[31]. The shrinkage can be controlled if appropriate stitch length is selected. Even though tencel yarn is different in characteristics from cotton, these characteristics are not reflected in the final fabric. This argument contradicts the view expressed by Ucar and Karakas[28]. They observed the increase in length- wise shrinkage for lyocell pile loop structure.

Relaxation treatment and yarn diameter have an influence on fabric thickness. Fabric thickness increases with wet and tumble relaxation. This is due to the movement of course and wale close to each other during relaxation. This makes three dimensional change in the fabric. It is interesting to note that tencel and tencel/cotton blend fabric show lower thickness value. It may be due to better packing ability of tencel fibre into yarn. Tightness factor is also affected, but its contribution is only limited[10]. This is apparent from the factor analysis.

Test data are subject to general factorial regression analysis using Minitab 17 software in order to determine the contribution of each factor to the change in dimensional parameters of single jersey knitted fabric statistically. From Table 3, it is clear that the effect of fibre composition, though significant, is only marginal. It is found that the stitch length has the highest influence on length shrinkage (65%). The contribution of relaxation treatment to this shrinkage is 28%. Two-way interaction between relaxation treatment and stitch length is also observed. This value is more than the contribution value of fibre type, whereas the contribution value for stitch length and treatments for width shrinkage are 28% and 58% respectively. This may be due to the difference in length and width shrinkage values of tight and other two structures. The regression coefficients for cpi and wpi effects are 99.99 and 99.98 respectively.

Table 4 shows the factor analysis for thickness and areal density data. Fibre composition has its influence. This is due to the dimensional effect of tencel and tencel/cotton blend yarn. The contribution of treatment and fibre type is 61% and 28% respectively. Stitch length has only 6 % contribution. Graph for thickness descends towards tencel. This is for both relaxation treatment and stitch length.

Relaxation treatment has influence on the areal density of single jersey fabric. It may be due to the three dimensional consolidation of the structure. The contribution of stitch length to areal density is more than that of relaxation treatment. Even though significant (p=0.000, Table 4), fibre composition has very little influence.

Table 3—ANOVA for cpi and wpi *vs*. fibre composition, stitch length and relaxation treatment

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| **Courses per inch** | | | | | |
| Fibre composition | 3 | 4.648 | 1.549 | 293.53 | 0.000 |
| Stitch length, mm | 2 | 620.904 | 310.452 | 58822.47 | 0.000 |
| Relaxation treatment | 2 | 271.577 | 135.789 | 25728.37 | 0.000 |
| 2-way interactions | 16 | 61.091 | 3.818 | 723.45 | 0.000 |
| Fibre composition*stitch length mm | 6 | 0.618 | 0.103 | 19.53 | 0.000 |
| Fibre composition*relaxation treatment | 6 | 0.158 | 0.026 | 5.00 | 0.009 |
| Stitch length mm*relaxation treatment | 4 | 60.314 | 15.079 | 2857.00 | 0.000 |
| Error | 12 | 0.063 | 0.005 | | |
| Total | 35 | 958.283 | | | |
| $R^2$ = 99.99% | | | | | |
| **Wales per inch** | | | | | |
| Fibre composition | 3 | 2.410 | 0.8032 | 333.65 | 0.000 |
| Stitch length, mm | 2 | 47.165 | 23.5825 | 9795.81 | 0.000 |
| Relaxation treatment | 2 | 96.822 | 48.4108 | 20109.12 | 00000 |
| 2-way interactions | 16 | 21.502 | 1.3439 | 558.23 | 0.000 |
| Fibre composition*stitch length, mm | 6 | 0.099 | 0.0166 | 6.88 | 0.002 |
| Fibre composition*relaxation treatment | 6 | 0.009 | 0.0016 | 0.65 | 0.688 |
| Stitch length, mm *relaxation treatment | 4 | 21.393 | 5.3483 | 2221.62 | 0.000 |
| Error | 12 | 0.029 | 0.0024 | | |
| Total | 35 | 167.928 | | | |
| $R^2$ = 99.98% | | | | | |

Table 4—ANOVA for thickness and areal density *vs*. fibre composition, stitch length and relaxation treatment

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| **Thickness** | | | | | |
| Fibre composition | 3 | 0.004867 | 0.001622 | 38.88 | 0.000 |
| Stitch length, mm | 2 | 0.000976 | 0.000488 | 11.69 | 0.002 |
| Relaxation treatment | 2 | 0.010472 | 0.005236 | 125.49 | 0.000 |
| 2-way interactions | 16 | 0.000304 | 0.000019 | 0.46 | 0.928 |
| Fibre composition*stitch length, mm | 6 | 0.000152 | 0.000025 | 0.61 | 0.721 |
| Fibre composition*relaxation treatment | 6 | 0.000085 | 0.000014 | 0.34 | 0.904 |
| Stitch length, mm*relaxation treatment | 4 | 0.000068 | 0.000017 | 0.41 | 0.801 |
| Error | 12 | 0.000501 | 0.000042 | | |
| Total | 35 | 0.017119 | | | |
| $R^2$ = 97.08% | | | | | |
| **Areal density** | | | | | |
| Fibre composition | 3 | 189.9 | 63.30 | 10.50 | 0.001 |
| Stitch length, mm | 2 | 3701.0 | 1850.48 | 307.10 | 0.000 |
| Relaxation treatment | 2 | 9593.4 | 4796.69 | 796.05 | 0.000 |
| 2-way interactions | 16 | 167.3 | 10.46 | 1.74 | 0.169 |
| Fibre composition*stitch length, mm | 6 | 14.2 | 2.36 | 0.39 | 0.871 |
| Fibre composition*relaxation treatment | 6 | 27.9 | 4.65 | 0.77 | 0.607 |
| Stitch length, mm*relaxation treatment | 4 | 125.2 | 31.31 | 5.20 | 0.012 |
| Error | 12 | 72.3 | 6.03 | | |
| Total | 35 | 13723.8 | | | |
| $R^2$ = 99.47% | | | | | |

## 4 Conclusion

The characteristics of friction, swelling, and flexural rigidity are different for tencel yarn, but they are not influencing dimensional characteristics of tencel and tencel/cotton blend plain knitted fabrics. From the multi-level regression analysis of the means of data, it is evident that relaxation treatment and tightness factor influence the length and width shrinkage. Loop shape introduced by Munden is reevaluated and found fit for this study. Again, this has confirmed that the contribution of relaxation treatment to the shrinkage can be minimized if proper stitch length is selected. Hence, cotton and tencel are similar to the plain weft knitted shrinkage behavior. The dimensional stability of these fabrics is determined by stitch length and relaxation treatment. Change in thickness is due to relaxation treatment and fibre type. Fibre type has its influence on thickness through difference in yarn diameter. Areal density is primarily influenced by relaxation treatment. This is due to the three dimensional consolidation brought about by relaxation treatments.

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