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Effect of enzyme softening of cotton hosiery yarns on knittability and dimensional properties of weft knitted fabrics

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Enzyme softening of cotton hosiery ring carded, ring combed and rotor yarns (19.68 tex) has been carried out using commercially available Bio-soft L+ acid type cellulase enzyme at optimized conditions. Knittability of enzyme-softened yarns has been studied and compared with their respective waxed yarns by measuring the actual loop length of knitted fabrics produced under different input tension and by maximum tight structure possible to knit in the given machine. It is observed that the enzyme softening improves the knittability of all three types of yarns to a significant level; the knittability of ring carded yarn improves to the level of ring combed yarn. Enzyme-softened rotor yarn shows the better knittability than enzyme-softened ring carded and combed yarns. The enzyme softening of yarn also increases the dimensional stability of single jersey fabric to a remarkable level. Among the enzyme-softened ring carded, ring combed and rotor yarns, the dimensional stability of ring combed yarn fabric is found to be very good. Changes in mass per unit area and thickness remain almost unaltered after wet relaxation treatments in case of enzyme-softened yarn fabrics.

Keywords: Cellulase enzyme, Dimensional properties, Dimensional constants, Enzyme softening, Knittability, Single jersey fabric, Tightness factor

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1 Introduction

Knittability is practically measured by machine efficiency rates and indicates low unscheduled machine downtime and defect levels. Low defects/100 yards indicate easy knitting conditions. The knittability of yarn depends on its strength (both tensile and bending) and frictional properties.[1] Variation in loop length of ±10% due to changes in yarn friction is experienced at a given cam setting and input tensions and this variation can be explained by the phenomenon of Robbing-Back.[2] The knitting performance of yarn, in terms of work required to knit the yarn into plain jersey, has been measured by the use of a sensitive torque transducer located on the driving shaft of an experimental knitting machine.[3]

In addition to normal yarn quality characteristics, the properties which influence the knitting performance are friction and lint shedding.[4] Friction affects the knitting of yarn by two ways: (i) it affects the tension of the yarn supplied to the knitting elements and (ii) a high friction increases the abrasion of yarn with knitting elements and guides. Tension in knitting is one of the factors controlling the amount of yarn placed round the needles and, therefore, affects the length of knitted goods.

The increase in yarn tension is totally dependent upon the coefficient of dynamic friction (μ) of yarn with metal surfaces.[5] The factor by which the tension is increasing after passing over four metallic guides is 2.6 times for μ=0.15 and 286 times for μ=0.90.

Shrinkage and dimensional instability are the most critical quality problems in weft knitted cotton fabrics. The factors causing shrinkage of cotton knits are known to be the swelling of fibres and the relaxation of internal stress, to which the yarns are subjected to during the knitting process. Many shrinkage control techniques have been developed over the years. ‘Compacting’ and replacing 100% cotton with cotton/synthetic fibres blends are some of them.

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A controlled treatment of cotton fabric with cellulase enzyme can considerably reduce fibre collapsing during drying and rewetting and improve the dimensional stability.[6] Cellulase enzyme treated cellulosic fabrics of various constructions and fibre compositions exhibit significant improvement in dimensional stability after subsequent washing and drying cycles.[7] The partial hydrolysis of fabrics with cellulase enzyme results in most effective stress relaxation with minimum weight loss.

The present paper reports the effect of enzymatic softening of yarn on knittability and dimensional stability of the weft knitted fabric after dry, wet and full relaxations.

2 Materials and Methods

Industrially scoured and bleached ring carded, ring combed and rotor yarns of 19.6 tex were treated with cellulase enzyme (Biosoft L+) at optimized conditions.[8] The optimized values for variables of softening process are given in Table 1

2.1 Study of Knittability

Enzyme-softened (optimized yarn), unsoftened and waxed ring carded, ring combed and rotor yarns were studied for knittability on a FAK test knitting machine (3.5 inch diameter and 24 gauge) by varying the input tension (2, 4, 6 and 8 gf) at a speed of 180 rpm. Nominal loop length set was 3.4 mm. The knittability was studied indirectly by measuring the actual loop length of fabrics produced under different input tension using ATIRA course length tester.[2] Another study was conducted to find out the possible tightest structure achievable for given yarn with an input yarn tension of 8 gf and machine speed of 180 rpm.

2.2 Study of Dimensional Properties

For studying the dimensional, comfort and low-stress mechanical properties, the single jersey fabrics with a tightness factor of 1.5 $tex^{1/2}$ mm^{-1} were produced from enzyme-softened and unsoftened yarns of ring carded, combed, and rotor yarns (19.68 tex) in the FAK test knitting machine. One part of fabrics produced from unsoftened yarns was treated with cellulase enzyme Biosoft L+ at optimized conditions for the comparison purpose. All the groups of sample were subjected to dry, wet and full relaxation treatments.

Table 1 — Optimized values of enzyme softening process

Parameter	Ring carded yarn	Ring combed yarn	Rotor yarn
Concentration, % owm	3	2.4	2.25
Temperature, °C	50	50	50
Time, min	60	50	50

Dry Relaxation

Fabric samples were kept on a flat surface for two weeks under standard atmospheric condition of 27 °C and 65% RH and then dry relaxed dimensions (loop length in cm, courses/cm, wales/cm, mass/unit area in g/m^2 and thickness in mm) were measured.[9]

Wet Relaxation

Dry relaxed fabrics were wet relaxed by keeping the fabrics samples flat in a tray containing water plus wetting agent at 30°C for 15 h after which it was removed. The excess water was hydroexracted and then allowed to dry flat in an oven maintained at 60°C and dimensional parameters of knitted fabrics were measured.[10]

Washing (Dynamic Wet Relaxation)

Wet relaxed samples were subjected to full relaxation treatment by washing with a wetting agent and a washing powder (0.5% owm) which does not contain softener or fabric conditioner in a standard washing machine at 60 °C followed by rinsing three times in water and then tumble dried at 70 °C.

After each relaxation process, wale and course densities were measured using a magnifying glass; ten measurements for each dimension were made at different places on the tubular fabrics. Mean values of courses/cm and wales/cm were then calculated, and the product of these means was used to calculate stitch density. The loop length was measured on an ATIRA course length tester. Thickness of the fabric was measured on a thickness meter based on BS 2544. Weights were obtained from average measurements of 10 samples of 5cm × 5 cm fabric using electronic balance and they are converted into mass per unit area.[10] Linear shrinkage (s) for each fully relaxed sample was calculated using the following relationship:

$$\text{Shrinkage (s), \%} = 100(L_o - L_1)/L_o$$

where L_o is the distance between the data lines before washing; and L_1, the distance between the data lines after washing.

Table 2 — Effect of enzymatic softening of yarns on knittability at various tension levels
[Nominal loop length = 3.4 mm]

Yarn	Condition	Loop length, mm				% change in loop length			
		2 gf	4 gf	6 gf	8 gf	2 gf	4 gf	6 gf	8 gf
Ring carded	Unsoftened	3.25	3.18	3.05	3.00	4.4	6.5	10.29	11.8
	Softened	3.34	3.30	3.11	3.08	1.8	2.9	8.5	9.4
	Waxed	3.17	3.24	3.12	3.03	6.8	4.7	8.2	10.9
Ring combed	Unsoftened	3.26	3.16	3.14	3.03	4.1	7.1	7.6	10.9
	Softened	3.38	3.25	3.22	3.11	0.59	4.4	5.3	8.5
	Waxed	3.34	3.23	3.18	3.08	1.8	5.0	6.5	9.4
Rotor	Unsoftened	3.30	3.24	3.19	3.10	2.9	4.7	6.2	8.8
	Softened	3.34	3.29	3.27	3.11	1.8	3.2	3.8	8.5
	Waxed	3.33	3.28	3.24	3.13	2.0	3.5	4.7	7.9

The values 2,4,6 and 8gf are input tension.

3 Results and Discussion

3.1 Effect of Enzyme Softening on Knittability

3.1.1 Difference between Actual Loop Length and Nominal Loop Length under Different Input Tension

It can be observed from Table 2 that there is a significant difference between the loop length of unsoftened, softened and waxed yarns (95% confidence interval) and there is a gradual decrease in loop length as tension increases for the three types of yarn studied. Percentage change in loop length over nominal loop length is markedly lower for enzyme-softened yarn than their corresponding unsoftened yarn. This can be attributed to the fact that the enzyme-softened yarn not only has lower kinetic frictional value but also better compressional softness than their corresponding waxed and unsoftened yarn.[8] It has been observed that the improvement in knittability of carded ring yarn after enzyme softening is equal to combed waxed ring yarn as given in Table 2.

Enzyme treatment, in general, improves the knittability of all the yarns than their respective waxed counterparts. It is noted that as tension increases, the reduction in loop length is higher in case of unsoftened ring carded yarn. At each tension level the unsoftened yarn has low loop length than its waxed and enzyme-softened counterparts. This may be due to the fact that unsoftened ring-spun carded yarn exerts high frictional resistance in knitting zone due to its high kinetic frictional value (μ = 0.32), which has resulted from its high hairiness. Enzyme-softened ring carded yarn shows lower reduction in loop length along with high loop length at all tension levels than the waxed and unsoftened yarns. The same trend has been observed for ring combed and rotor yarns also.

The result also indicates that the enzyme-softened rotor yarn has the least decrease in loop length as tension increases. Ring combed yarn has moderate reduction in loop length as tension increases. At all tension levels, softened rotor yarn yields higher loop length and hence the best knittability. This may be due to the fact that softened rotor yarn has highly improved compressional properties with μ = 0.21, which is within tolerable limit as suggested by Moss[11] in order to overcome press-offs under commercial input tensions applied. Regression equations for loop length in terms of input tension are given in Table 3. Enzyme-softened yarn fabrics show higher slope than those of the unsoftened and waxed yarns for all the yarns studied.

3.1.2 Maximum Achievable Tightness Factor

Studies on knittability in terms of maximum achievable tightness factor show that the ring carded yarn enables a tightness factor of 2.0 $tex^{1/2}mm^{-1}$ compared to 1.9 $tex^{1/2}mm^{-1}$ for combed yarn and 1.93 $tex^{1/2}mm^{-1}$ for rotor yarn in unsoftened conditions (Table 4). Enzyme softening improves the tightness

Table 3 — Linear regression equations of loop lengths at various tension levels in ring and rotor yarns

Yarn	Condition	Regression equation	Multiple *R*	R^2	Standard error
Ring carded	Unsoftened	$Y = -0.0041x+0.3334$	0.98166	0.96366	0.00251
	Softened	$Y = -0.0049x+0.3455$	0.95299	0.9082	0.00493
	Waxed	$Y = -0.0035x+0.3331$	0.98267	0.96563	0.00254
Ring combed	Unsoftened	$Y = -0.0035x+0.3325$	0.98127	0.96289	0.00215
	Softened	$Y = -0.0042x+0.3454$	0.9718	0.94439	0.00323
	Waxed	$Y = -0.0041x+0.3419$	0.98785	0.97585	0.00205
Rotor	Unsoftened	$Y = -0.0032x+0.3372$	0.99599	0.99200	0.00091
	Softened	$Y = -0.0036x+0.3435$	0.93074	0.86628	0.00446
	Waxed	$Y = -0.0031x+0.3407$	0.97045	0.94178	0.00246

Table 4 — Maximum achievable tightness factors of fabrics

Yarn	Maximum tightness factor $tex^{1/2}mm^1$		Per cent improvement
	Unsoftened yarn fabric	Enzyme-softened yarn fabric	
Ring carded	2.00	2.07	3.5
Ring combed	1.94	2.10	8.2
Rotor	1.93	2.12	10

factor by 3.5%, 8.2% and 10% in ring carded, ring combed and rotor yarns respectively. It is possible to knit the tightest structure with a tightness factor of 2.12 $tex^{1/2}mm^{-1}$ with enzyme-softened rotor yarn.

3.2 Effect of Softening on Dimensional Properties of Weft Knitted Fabrics

The dimensional properties of weft knitted fabrics made from ring carded, ring combed and rotor yarns under 3 different conditions (unsoftened fabrics, fabric softened in fabric stage and fabric softened in yarn stage) and the corresponding dimensional properties after relaxation are given in Table 5. Dimensional constants are given in Table 6. Shrinkage % values are given in Table 7. Dimensions of these fabrics vary considerably more in their washed state than in dry relaxed state. For each fabric type, as the relaxation process progresses, the course and wales densities increase significantly.

ANOVA test (2-way) has been performed in order to find out whether the relaxation treatment and enzyme softening conditions [unsoftened fabric (USF), enzyme-softened fabric (ESF) and enzyme-softened yarn fabric (ESY)] significantly affect the dimensional parameters (loop length, courses/cm, wales/cm, stitch density, weight/m^2 and thickness). The test was carried out separately for ring carded, ring combed and rotor yarn knitted fabrics. 95% confidence interval was used to find out the significance.

3.2.1 Loop Length of Fabrics

Table 5 shows that the loop length decreases as the relaxation process progresses in all the cases. Fabrics made from enzyme-softened yarns (ESY) have higher loop length than that of unsoftened (USF) and enzyme-softened (ESF) fabrics in all stages of relaxation. This confirms that the effect of enzyme softening of yarn is retained even after relaxation. After full relaxation, the order of loop length of ESY fabrics for given machine setting and knitting conditions is as follows:

Ring combed yarn > rotor yarn > ring carded yarn

2-way ANOVA test results show that the relaxation treatment and enzyme softening affect loop length in ring carded yarn fabrics; however, the effect is significant in ring combed and rotor yarns fabrics.

3.2.2 Courses and Wales per Centimeter of Fabrics

From Table 5 it is observed that as the relaxation treatments progress, there is an increase in courses/cm and wales/cm. This increase is of lower magnitude for ESY fabrics compared to ESF and USF fabrics. Dynamic wet relaxed (washed) ESY fabric of ring

Table 5 — Effect of relaxation treatment on dimensional properties of ring carded, ring combed and rotor yarn fabrics

Property	Grey			Static dry relaxation			Static wet relaxation			Dynamic wet relaxation		
	USF	ESF	ESY	USF	ESF	ESY	USF	ESF	ESY	USF	ESF	ESY
Ring carded yarn fabric												
Loop length, cm	0.26	0.257	0.275	0.24	0.25	0.27	0.23	0.24	0.26	0.21	0.23	0.255
Courses/cm	16.75	18.00	17.50	18.55	18.45	18.25	19.7	19.80	19.10	21.59	20.55	19.35
Wales/cm	13.50	13.80	13.00	14.00	14.25	13.56	15.70	14.75	14.10	17.00	15.25	14.99
Mass per unit area, g/m^2	138.5	140.8	128.0	139.0	141.50	130.8	142.0	144.0	138.5	149.3	146.0	140.0
Thickness, mm	0.58	0.54	0.50	0.58	0.54	0.51	0.58	0.55	0.51	0.59	0.56	0.52
Ring combed yarn fabric												
Loop length, cm	0.27	0.26	0.275	0.25	0.26	0.27	0.24	0.25	0.26	0.23	0.24	0.265
Courses/cm	17.00	17.10	17.20	18.00	18.00	17.85	19.94	19.00	19.00	20.99	19.98	19.35
Wales/cm	13.40	14.00	13.50	14.00	14.62	13.98	14.88	14.65	14.85	15.70	15.45	15.30
Mass per unit area, g/m^2	135.0	138.4	134.0	137.0	139.0	135.5	138.8	140.5	135.80	142.0	141.0	138.0
Thickness, mm	0.55	0.53	0.51	0.56	0.54	0.51	0.57	0.55	0.52	0.59	0.55	0.52
Rotor yarn fabric												
Loop length, cm	0.255	0.25	0.28	0.25	0.245	0.27	0.24	0.24	0.26	0.22	0.23	0.26
Courses/cm	17.4	17.85	17.00	17.90	18.35	18.00	19.00	19.35	18.5	20.98	20.35	19.2
Wales/cm	13.52	13.68	13.22	14.60	14.45	14.1	15.50	15.00	14.9	16.10	16.30	15.25
Mass per unit area, g/m^2	137.0	141.0	127.0	139.0	142.0	135.0	145.0	143.5	140.0	150.3	147.0	141.0
Thickness, mm	0.54	0.53	0.52	0.54	0.53	0.53	0.56	0.53	0.53	0.58	0.54	0.53

Table 6 — Dimensional constants of weft knitted fabrics

Parameter	Grey			Dry relaxation			Static wet relaxation			Dynamic wet relaxation		
	USF	ESF	ESY	USF	ESF	ESY	USF	ESF	ESY	USF	ESF	ESY
Ring carded yarn												
k_c	4.35	4.63	4.81	4.45	4.61	4.92	4.53	4.75	4.97	4.53	4.73	4.90
k_w	3.51	3.55	3.64	3.36	3.56	3.66	3.61	3.54	3.67	3.57	3.51	3.82
k_s	15.26	16.44	17.51	14.95	16.41	18.01	16.35	16.82	18.24	16.17	16.60	18.70
Stitch density, loops/cm^2	226.13	248.40	227.50	259.70	262.90	247.47	309.29	292.05	269.31	367.03	313.39	290.06
Ring combed yarn												
k_c	4.59	4.45	4.73	4.50	4.7	4.82	4.79	4.75	4.94	4.83	4.81	5.13
k_w	3.62	3.64	3.71	3.50	3.80	3.77	3.57	3.66	3.861	3.61	3.71	4.05
k_s	16.61	16.21	17.55	15.75	17.86	18.17	17.10	17.41	19.07	17.44	17.84	20.80
Stitch density, loops/cm^2	227.80	239.40	232.20	252.00	263.16	249.54	296.71	278.35	282.15	329.54	308.69	282.15
Rotor yarn												
k_c	4.437	4.46	4.76	4.475	4.51	4.86	4.56	4.64	4.81	4.61	4.70	5.00
k_w	3.45	3.42	3.70	3.65	3.54	3.81	3.72	3.6	3.9	3.54	3.8	4.00
k_s	15.31	15.25	17.6	16.3	15.96	18.5	16.96	16.7	18.76	16.32	17.86	20.00
Stitch density, loops/cm^2	235.25	244.20	224.40	261.34	265.16	253.80	294.50	290.25	275.65	337.78	331.71	292.80

Table 7 — Shrinkage of weft knitted fabrics

Fabric	Length-wise shrinkage, %			Width-wise shrinkage, %		
	USF	ESF	ESY	USF	ESF	ESY
Ring carded yarn	7.0	2.5	1.8	8.0	3.5	2.3
Ring combed yarn	6.5	2.5	1.5	7.5	3.0	1.0
Rotor yarn	9.0	3.0	2.0	10.0	4.0	2.5

combed yarn has shown less change in courses and wales per centimeter than ring carded and rotor yarn ESY fabrics.

2-way ANOVA test shows that the relaxation treatment and enzyme softening conditions affect the courses/cm of ring carded yarn fabric significantly. Similar trend is also observed in ring combed and rotor yarn fabrics. However, the relaxation treatments affect the wales/cm of ring carded yarn fabric significantly. Enzyme softening conditions do not significantly affect the wales/cm of ring carded and combed yarn fabrics. Relaxation treatment and enzyme softening conditions affect the wales/cm of rotor yarn fabrics significantly.

3.2.3 Stitch Density of Fabrics

It is observed from Table 6 that the change in stitch density of all washed enzyme-softened yarn fabrics (ESY) is remarkably lower than that of their respective washed unsoftened fabric (USF). Among all the three softened yarn fabrics, ring combed yarn fabric has the lowest change in stitch density at all the stages of relaxations. Change in stitch density of all ESY fabric becomes almost unchanged after the static wet relaxation treatment. This may be due to the fact that the strain and stress imparted to the yarn in yarn manufacturing are released by enzymatic hydrolysis of yarn and the strain introduced by knitting action is released at the time of static wet relaxation of fabric.

2-way ANOVA results show that the relaxation treatment significantly affects the stitch density of ring carded yarn fabrics. However, the stitch densities of ring combed and rotor yarn fabrics are affected by both relaxation treatment and enzyme softening conditions significantly.

3.2.4 Dimensional Constants of Fabrics

Table 6 shows that there is a gradual increase in the value of k_c from dry relaxed state to fully relaxed state. Values of k_c in the range of 4.9-5.13 and k_w in the range of 3.82-4.05 are obtained after dynamic wet relaxation (washing) for ESY fabrics, comparable well with the values of 5.3 and 4.1 given by Munden *et al*.[9] After the dynamic wet relaxation treatment, ESY fabrics show k_s values in the range of 19.15-20.8 against a value of 21 obtained by Munden *et al*.[9]

In each stage of relaxation process, the dimensional constants (k_c, k_w and k_s) are found high in case of enzyme-softened yarn fabric. Therefore, it is confirmed that the loop configuration of the fabrics gets stabilized only in the case of enzyme- softened yarn fabric and not in unsoftened yarn fabric or enzyme-softened fabric.

3.2.5 Shrinkage of Fabrics

All USF fabrics have very high length-wise and width-wise shrinkage (Table 7), whereas all ESY fabrics have very low shrinkage in length-wise and width-wise directions. Between ESY and ESF fabrics also, there is small but significant difference in both length-wise and width-wise shrinkage. Ring combed yarn results in fabric with lowest shrinkage of 1.5% in length-wise direction and 1.0% in width-wise direction. Therefore, enzyme softening in yarn stage may be adopted as a method to control knitted fabric shrinkage.

3.2.6 Mass per Unit Area and Thickness of Fabrics

Table 5 shows that as the relaxation treatments progress there is an increase in mass per unit area (g/m^2) with slight increase in thickness for all ring carded, ring combed and rotor yarn fabrics and this increase is very low for ESY fabrics of ring and rotor yarns. Mass per unit area and thickness (mm) remain almost unaltered after wet relaxation treatments of ring and rotor yarn ESY fabrics.

2-way ANOVA test results show that the relaxation treatment significantly affects weight per square meter and thickness of ring carded yarn fabrics; the effect is however not significant by enzyme softening. Similar trend is also observed in case of ring combed and rotor yarn fabrics.

4 Conclusions

Enzyme softening improves the knittability of all the three types of yarn studied. This improvement in knittability may be attributed to the better compressional and frictional properties.

4.1 The knittability of ring carded yarn improves to the level of ring combed waxed yarn by enzyme softening. The best knittability is found in enzyme-softened rotor yarn.

4.2 Reduction in loop length (w.r.t. nominal loop length) with the increase in input tension is minimum with enzyme softening for all the yarns.

4.3 It is possible to produce tight structures with enzyme-softened yarns, and in terms of maximum achievable tightness factor, softened rotor yarn shows better knittability than ring carded and combed yarns.

Enzyme softening of yarn increases the dimensional stability of the knitted fabric produced from that yarn to a remarkable level.

4.4 Among the enzyme- softened ring carded, ring combed and rotor yarns, the dimensional stability is found to be very good in enzyme- softened ring combed yarn fabrics.

A minimum length-wise fabric shrinkage of 1.5% and width-wise shrinkage of 1 % after full relaxation is achieved with enzyme softening in yarn stage

4.5 Changes in mass per unit area and thickness remain almost unaltered after wet relaxation treatments in case of enzyme -softened yarn fabric.

References

1 Dias, *J Text Inst*, 85 (1994) 173.

2 James J F Knapton & Dennis L Munden, *Text Res J*, 36 (1966) 1081.

3 James J F Knapton, *Text Res J*, 37 (1967) 539.

4 Howell H G, *Monograph Friction in Textiles*, Vol. 38 (The Textile Institute, UK), 1959, 149.

5 Moss E, *British J Appl Phys*, 2 (1952) 19.

6 Attur Cavaco-Paulo, *Text Res J*, 71 (2001) 842.

7 Joao M. Cortez, John Ellis & David P Bishop, *Text Res J*, 72 (2002) 673.

8 Bhaarathi Dhurai & Natarajan V, *Indian J Fibre Text Res*, 31 (2006) 565.

9 Munden D, *J Text Inst*, 50 (1959) T448.

10 Leticia Quaynor, Masaru Nakajima & Masaoki Takahashi, *Text Res J*, 69 (1999) 285.

11 Moss E, *British J Appl Phys*, 19 (1951) 49.