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Study on cotton ring- and OE rotor yarns characteristics: Part III – Effect of enzymatic wet processing on various characteristics

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The changes in cotton yarn characteristics as a result of chemical treatments have been studied. It is observed that the yarn characteristics depend on yarn structural features, twist factor and chemical treatment. Analysis of the mechanical and surface characteristics shows that the caustic scouring remarkably improves the tenacity, abrasion resistance, dye uptake and residual shrinkage of both ring- and OE rotor-spun yarns. The increase in each of these characteristics decreases with the increasing twist factor. Treatment of enzyme scoured-hydrogen peroxide bleached cotton yarns with G-Zyme VGB enzyme, on the other hand, results in a significant decrease in their tenacity, abrasion resistance and hairiness. Additionally, enzyme-softened yarns have similar breaking extension, less surface roughness and higher absorbency values. The yarns spun with notched nozzle are relatively stronger, less hairy and less rough, have lower abrasion resistance and pick up more dye as compared to the yarns made with the plain nozzle regardless of the experimental conditions.

Keywords: Cellulase enzyme, Cotton, Ring-spun yarn, Rotor-spun yarn, Yarn-to-metal friction

1 Introduction

Cotton fibres contain approximately 90% cellulose and various non-cellulosics such as waxes, fats, pectins, proteins and colouring matter. Surface waxes are natural lubricating agents in yarn spinning and fabric weaving, but their hydrophobic nature is responsible for non-wetting behaviour of cottons by water and impedes efficient and uniform dyeing and finishing. These non-cellulosic substances have been traditionally removed by alkaline scouring. The industrial scouring process consists of alkaline treatment in the presence of wetting and sequestering agents. Alkaline scouring also imparts the hydrophilic character and permeability necessary for subsequent processing, improves fabric wettability and, at the same time, causes fabric shrinkage and increase in fabric thickness.[1] Treating cotton substrates with hydrogen peroxide under boiling conditions in an alkaline medium is another step to dyeing textiles. There are, however, several environmental issues associated with conventional alkaline scouring which requires large quantities of water and energy and generates a huge amount of highly alkaline water effluent.[2] Enzyme treatment of textiles, typically in the form of cotton fabric, has been introduced in textile wet processes as a new means of enhancing cotton wettability under mild reaction conditions. While there is a great interest in enzymatic pretreatments such as desizing and scouring[3-14], biopolishing is currently the major textile application. The effects of enzyme treatment on fibre dyeing properties are also being extensively studied.[15-17] There are occasional references to the enzymatic scouring of rotor yarns in the literature[18], but none so far addressed the question of the extent to which the enzymatic treatments affect the properties of OE rotor yarns produced with varying twist factors and draw-off nozzles .The findings of several trials conducted at Technological Institute of Textile & Sciences with the aim of determining the effect of caustic and enzymatic scouring treatments on tensile and recovery characteristics of cotton ring and OE rotor-spun yarns have already been published.[19-20] This paper aims at investigating the variations in mechanical and surface characteristics of cotton ring- and rotor-spun yarns as a consequence of enzymatic wet processing.

2 Materials and Methods

2.1 Preparation of Yarn Samples

Two sets of yarns of 29.5 tex were spun from J-34

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cotton (2.5% span length, 24.3 mm ; fineness, 1.8 dtex ; tenacity, 21.0 g/tex ; and breaking extension, 6.5 %) on ring and rotor spinning machines. Laps were made on Lakshmi Rieters' blowroom line and carded on MMC card. The conversion to drawn sliver was carried out by using Lakshmi Rieters' draw frame DO/2S. Two drawing passages were given to carded slivers to produce a finisher sliver of 0.13 Ne. The drawn sliver was spun into yarns on Ingolstadt rotor spinner RU11/80(4602). The machine parameters used for spinning rotor yarns included a 48mm rotor running at 833.33rps, a saw -tooth opening roller type of clothing (OS/21; teeth/cm^2, 24 ; and face angle, 100^0), an opening roller speed of 100 rps ; two draw-off nozzles— notched (exterior diam.,15.5 mm and interior diam., 3mm) and plain (exterior diam., 15.5 mm and interior diam., 3mm), and twist factors of 43.07, 47.85 and 52.64. For ring spinning, the drawn sliver was converted into a suitable roving and then spun on a Lakshmi Rieters' ring frame G5/1.

2.2 Treatments

All the yarns were scoured in skein form in a laboratory winch machine. The yarns were divided into two lots. One was scoured with sodium hydroxide and the other was subjected to simulated enzymatic scouring with Bactosol.co.ip (acid cellulase), bleaching and biopolishing. Scouring with Bactosol.co.ip enzyme (2mL/L) occurred at 90^{0}C for 1h at *p*H 8.0 and a liquor ratio 30:1, followed by deactivation in cold water for 5 min. Resiwet EECW (0.5g/L) was added to the scouring bath to improve the absorbency of the samples. The yarns were thoroughly washed in cold water and air dried. For alkaline scouring, 4% aqueous sodium hydroxide was prepared and the yarns were treated at a liquor ratio of 30:1 for 2.5h at 95^{0}C. After scouring, the yarns were thoroughly washed with hot water, twice with cold water, and then dried under atmospheric conditions. Hydrogen peroxide bleaching involved the following procedure: the bleaching bath was made of 1.5%(owf) commercial H_2O_2, the liquor ratio was 30:1, and the bleaching lasted for 1h at 85^{0}C. The bleached sample was then neutralized in 10% acetic acid followed by rinsing with distilled water. Biopolishing of alkaline scoured- bleached sample with G-Zyme VGB (1.5%) was carried out at 55^{0}C for 1h at *p*H 4.5 in the presence of 0.5% Kleenox PSF. The yarn samples were later thoroughly washed, air dried and conditioned.

2.3 Test Methods

All the yarns were tested according to standard ASTM procedures. Tensile properties of all the yarns were measured on an Instron using 500mm test specimen and 200mm/min cross-head speed. The mean yarn tenacity and breaking extension were averaged from 50 observations for each yarn sample. Zweigles hairiness meter (Model G 565) was used to record yarn hairiness and a spectrophotometer to assess dye absorbency of the yarns. Yarn-to-metal friction was measured on the Shirley yarn friction recorder winder according to ASTM D 3108 procedure and yarn flexural rigidity on weighted ring yarn stiffness tester using the ring loop method. CSI abrasion tester was used to measure flat abrasion resistance of yarn samples. Residual shrinkage of yarns was estimated by the method mentioned in BSI handbook.

3 Results and Discussion

The influence of six experimental variables, viz. yarn structure, draw-off nozzle profile and chemical treatments, on the yarn properties was assessed for significance using analysis of variance; the confidential level used was 99%. Only first order interactions were considered.

3.1 Tensile Properties

Table 1 shows that the tenacity indices of caustic scoured yarns are appreciably higher than that of the untreated yarns. The yarns spun with higher twist factor exhibit lesser increase in tenacity. However, a substantial but consistent decrease in tenacity occurs for all yarns after enzymatic scouring and it further drops slightly when these yarns are bleached with hydrogen peroxide. The decreased yarn tenacity is explained by the decreased degree of polymerization due to hydrogen peroxide bleaching. Exposing yarns to Bactosol.co.ip enzyme causes marked decrease in tenacity due to cellulose degradation of cotton material. However, the extent of tenacity decrease appears to be dependent on the yarn structure. Larger reduction in tenacity of biopolished rotor yarns, in particular, results from more open structure and easier penetration of enzyme liquid. Besides, some fibres within the rotor yarn suffer crack, which affect the tensile strength.[21] Moreover, the yarns spun with notched nozzle show significantly higher tenacity than those made with a plain nozzle, irrespective of the pre-treatments used.

Table 1—Tenacity, breaking extension and abrasion resistance of cotton ring- and OE rotor –spun yarns

Treatment with	Twist factor	Tenacity, g/tex			Breaking extension, %			Abrasion resistance, cycles		
		Ring yarn	Rotor yarn		Ring yarn	Rotor yarn		Ring yarn	Rotor yarn	
			Plain nozzle	Notched nozzle		Plain nozzle	Notched nozzle		Plain nozzle	Notched nozzle
Untreated	43.07	13.0	9.7	10.3	4.4	5.7	5.6	310	186	168
	47.85	13.9	10.5	10.8	4.8	6.1	5.8	472	258	201
	52.64	13.5	10.1	10.4	4.6	5.9	5.7	529	273	213
NaOH	43.07	13.8	10.0	10.8	4.2	4.9	4.4	323	202	198
	47.85	14.2	10.6	11.0	4.3	5.7	5.4	495	305	253
	52.64	14.1	10.4	10.8	4.2	5.0	4.5	543	313	274
Bactosol.co.ip	43.07	13.0	9.1	9.8	4.1	4.5	4.2	357	172	151
	47.85	13.7	9.9	10.4	4.2	4.9	4.6	513	240	184
	52.64	13.4	9.2	10.2	4.1	4.7	4.5	560	246	195
Bactosol.co.ip	43.07	11.8	8.8	9.0	4.0	4,2	4.1	290	154	135
+H_2O_2	47.85	12.9	9.3	10.2	4.2	4.4	4.3	439	225	149
	52.64	12.8	8.9	9.8	4.1	4.3	4.2	496	232	178
Bactosol.co.ip +	43.07	11.7	8.2	8.9	4.0	4.1	4.1	280	135	116
H_2O_2 + G-Zyme	47.85	12.3	9.1	10.1	4.1	4.3	4.2	420	152	126
	52.64	12.0	8.7	9.5	4.0	4.2	4.1	450	179	158

Table 1 also shows that breaking extension of either yarn does not change appreciably with chemical treatments. In any event, it is evident that the breaking extensions of the scoured and bleached yarns are not inferior to the untreated yarns. In the case of biopolished yarns, the dependence of breaking extension on enzyme softening is not remarkably recognized in this experiment, although yarns show slightly higher extension than enzyme scoured-bleached ones. The greater decrease in breaking extension exhibited by the rotor – spun yarns compared to those of ring- spun yarns confirms the greater sensitivity of the rotor-spun yarns. The influence of twist factor on breaking extension of the treated yarns is similar to that on yarn tenacity. The effect of draw-off nozzle profile is also along the expected lines; a notched nozzle slightly lowers the breaking extension of both untreated and treated yarns due to the increase in false twist, which ultimately makes the yarns more compact. This compactness results in loss in breaking extension.

3.2 Abrasion Resistance

The abrasion resistance data in Table 1, although obviously affected by all treatments, confirms the expected effectiveness of the scouring agents. The increased abrasion resistance of cotton ring and rotor yarns is generally larger for the yarns scoured with sodium hydroxide. This is believed to be the outcome of fibre-to-fibre friction.[22] The fibre-to-fibre friction, which effectively reduces the slippage of core fibres, increases during caustic scouring, resulting in higher abrasion resistance. While the abrasion resistance of rotor yarns reduces after enzymatic scouring, it further reduces marginally following the hydrogen peroxide bleaching. Significantly, however, enzymatic softening of both enzymatic scoured-bleached ring- and rotor- spun yarns causes remarkable reduction in abrasion resistance, presumably due to the mechanical action as well as removal of wax and fats during enzyme application. Nevertheless, the yarns produced with a notched nozzle show poor abrasion resistance as compared to the yarns made with a plain nozzle. The lower abrasion resistance results due to increased false twist, which, in turn, causes parts of the coiled fibres to become untwisted.[23] Thus, the slack coils shift easily under the abrasive action of the flat bar, causing a rapid breakdown of the yarn core towards the end.[24] Also, the increased abrasion of high twisted yarns indicates an increase in incidence of sheath fibres.

3.3 Flexural Rigidity

Table 2 shows that all chemical treatments, except biopolishing, cause an increase in flexural rigidity regardless of the yarn structure. The swelling of fibres during enzymatic scouring and bleaching might increase the compactness of the structures, resulting in lesser freedom of fibre movement during bending. However, increase in flexural rigidity is more marked in rotor yarns than in ring-spun yarns. One possible explanation for the greater increase in flexural rigidity is that rotor yarns absorb more chemical liquor and therefore are more sensitive to pre-treatment processes. Consequently, the process causes more severe increase in flexural rigidity of rotor yarns as compared to ring yarns. Moreover, increased twist factor normally increases flexural rigidity. On the other hand, exposure of treated yarns with Bactosol.co.ip enzyme and hydrogen peroxide to biopolishing results in improved flexural rigidity. This is accomplished through enzymatic hydrolysis of cellulose of cotton fibre in combination with mechanical action, resulting especially in surface etching.[25] Note that the values of flexural rigidity for yarns made with a plain nozzle are much lower compared to the values for the equivalent yarns produced with notched nozzle.

3.4 Hairiness

Hairiness comparisons of replicate sample of original untreated cotton yarns with hairiness of treated yarns show that neither enzyme scouring nor hydrogen peroxide bleaching causes an appreciable change in hairiness of ring- spun yarns (Table 2). On the other hand, the hairiness of rotor- spun yarns markedly increases after enzymatic scouring. In all trials, however, biopolishing significantly reduces hairiness in both yarn structures. Cellulase enzyme hydrolyzes cellulose by reacting to the beta – 1, 4 - glycoside linkage of the cellulose molecule. As a result, the yarn surface becomes smooth with the loss of surface fibres.[26] Also, the change of hairiness related to yarn twist is evident in both the yarn structures. The higher the twist factor, the lesser is the hairiness. Change in draw-off nozzle also reduces hairiness. The notched nozzle produces fewer hairs at a constant machine twist.

3.5 Yarn Friction

Invariably, the yarn-to-metal friction in ring yarns is very high ; treatment with chemicals, expect enzyme softening, causes a sharp increase in yarn-to-metal friction regardless of the spinning mode used (Table 2). Significantly, however, the increase in

Table 2 —Flexural rigidity, hairiness and yarn-to-metal friction of cotton ring- and OE rotor –spun yarns

Treatment with	Twist factor	Flexural rigidity $\times 10^{-3}$, g .cm^2			Hairs / 10 m			Yarn-to-metal friction, μ_{fm}		
		Ring yarn	Rotor yarn		Ring yarn	Rotor yarn		Ring yarn	Rotor yarn	
			Plain nozzle	Notched nozzle		Plain nozzle	Notched nozzle		Plain nozzle	Notched nozzle
Untreated	43.07	1.88	2.27	2.38	84	5	3	0.265	0.253	0.246
	47.85	2.02	2.35	2.47	71	3	2	0.263	0.243	0.239
	52.64	2.15	2.43	2.51	58	2	2	0.255	0.238	0.234
NaOH	43.07	2.13	2.47	2.54	86	35	21	0.276	0.264	0.258
	47.85	2.20	2.49	2.57	74	22	18	0.270	0.255	0.248
	52.64	2.29	2.51	2.62	63	21	16	0.264	0.245	0.241
Bactosol.co.ip	43.07	2.01	2.37	2.48	88	36	29	0.281	0.269	0.262
	47.85	2.12	2.42	2.52	75	29	26	0.275	0.259	0.253
	52.64	2.21	2.46	2.54	66	27	22	0.270	0.252	0.248
Bactosol.co.ip +H_2O_2	43.07	2.22	2.50	2.55	89	39	31	0.282	0.273	0.265
	47.85	2.28	2.56	2.63	76	28	28	0.280	0.264	0.259
	52.64	2.35	2.61	2.67	68	29	26	0.279	0.255	0.250
Bactosol.co.ip + H_2O_2 + G-Zyme	43.07	1.90	2.33	2.37	70	21	16	0.261	0.246	0.237
	47.85	2.15	2.35	2.42	60	18	17	0.258	0.241	0.235
	52.64	2.20	2.41	2.48	47	12	9	0.253	0.233	0.228

yarn-to-metal friction is substantially more in yarns subjected to enzyme scouring followed by bleaching with hydrogen peroxide. The biopolished yarns seem to have the least yarn-to-metal friction and it further reduces with the increase in twist factor because a high twist factor reduces yarn contact with metal surface. For rotor yarns, yarn-to-metal friction seems to be the highest for the plain nozzle, irrespective of the yarn twist.

3.6 Residual Shrinkage

Table 3 shows that, on average, rotor yarns exhibit higher residual shrinkage as compared to ring- spun yarns. Comparative data on the residual shrinkage of treated yarns show that the scouring with sodium hydroxide results in higher residual shrinkage than enzyme scouring. This is partly due to the release of stress and chemical reaction of sodium hydroxide with cellulose, which tend to swell the fibres, thereby reducing their length. Further treatment of enzyme scoured yarns with hydrogen peroxide, i. e. bleaching, continues to significantly increase the residual shrinkage because additional pores are created when the yarns undergo sequentional bleaching. Consequently, fibres swell more. The comparison of residual shrinkage of yarns after biopolishing treatment with yarns subjected to enzymatic scouring followed by hydrogen peroxide bleaching shows no marked difference. Twist plays a key role in influencing residual shrinkage, the latter increases with increasing twist factor for both types of yarns. For rotor yarns, shrinkage is generally higher for notched nozzle .

3.7 Dye Uptake

Table 3 shows the mean values of dye uptake for various yarns. Expectedly, all rotor yarns pick up relatively more dye after appropriate chemical treatments. There is less increase in mean values for the ring-spun yarns. The results of the variance analysis indicate that the type of scouring treatment has significant influence on the dye uptake of yarns. In effect, the dye uptake of alkaline scoured yarns is much higher than those of enzymatic scoured ones. This is the result of increased absorption of yarns towards the dye liquor brought out by the removal of non-cellulosic substances during scouring treatment. Further, enzymatic scouring followed by hydrogen peroxide bleaching also leads to a significant increase in dye uptake obviously due to increased absorbency of the yarn structures. Note again that the yarns that are biopolished in addition to enzymatic scouring-bleaching show substantially increased dye uptake compared to both untreated and treated yarns. This is

Table 3—Residual shrinkage and dye uptake of cotton ring- and OE rotor –spun yarns

Treatment with	Twist factor	Residual shrinkage, %			Dye uptake, *K/S*		
		Ring yarn	Rotor yarn		Ring yarn	Rotor yarn	
			Plain nozzle	Notched nozzle		Plain nozzle	Notched Nozzle
Untreated	43.07	-	-	-	10.34	1.45	1.37
	47.85	-	-	-	1.29	1.42	1.35
	52.64	-	-	-	1.21	1.40	1.33
NaOH	43.07	3.71	4.07	4.28	1.42	1.55	1.48
	47.85	3.78	4.66	5.35	1.35	1.53	1.47
	52.64	3.93	4.95	5.46	1.28	1.51	1.43
Bactosol.co.ip	43.07	3.56	3.84	3.90	1.38	1.51	1.46
	47.85	3.68	4.02	4.20	1.31	1.49	1.44
	52.64	3.83	4.32	4.48	1.24	1.47	1.41
Bactosol.co.ip +H_2O_2	43.07	4.04	4.34	4.88	1.48	1.63	1.56
	47.85	4.27	4.96	5.52	1.47	1.62	1.54
	52.64	4.58	5.41	5.70	1.42	1.59	1.52
Bactosol.co.ip + H_2O_2 + G-Zyme	43.07	3.82	4.27	4.79	1.52	1.65	1.58
	47.85	4.15	4.65	5.22	1.51	1.64	1.56
	52.64	4.52	5.18	5.14	1.48	1.62	1.55

quite understandable because cellulase enzyme removes protruding fibres, which, in turn, decreases the scattering coefficient, thus increasing *K/S* values of cellulose treated materials. The use of high twist factor or a notched nozzle results in a considerable reduction in dye uptake, as expected.

4 Conclusions

4.1 Enzymatic scouring changes the tensile characteristics of the cotton yarns. Tenacity is reduced along with the breaking extension and abrasion resistance. Caustic scouring, on the other hand, has more marked effect on the properties of rotor yarns than on ring-spun yarns. There is an increase in tenacity, abrasion resistance, residual shrinkage and dye uptake with caustic scouring. The increase in each of these characteristics decreases with increasing twist factor. The yarns spun with notched nozzle are relatively stronger, less hairy and less rough. They have lower abrasion resistance and pick up less dye as compared to their plain nozzle counterparts.

4.2 Hydrogen peroxide bleaching increases the dye uptake and residual shrinkage but reduces abrasion resistance of enzyme scoured cotton ring- and rotor-spun yarns .While the tenacity change due to hydrogen peroxide bleaching is small, the surface roughness increase is relatively large. There is essentially no difference in the breaking extension and hairiness of enzyme scoured and enzyme scoured- bleached yarns. The mechanical properties of the enzyme- softened yarns are similar to those of hydrogen peroxide bleached yarns. Enzyme softening reduces yarn tenacity, abrasion resistance and hairiness. The advantage of enzyme softening includes no change in breaking extension, less surface roughness and higher absorbency. Additional research is necessary to further examine and characterize the effect of other enzymes, and to meaningfully discuss their contribution to yarn quality.

Industrial Importance: Enzymatic treatment is of interest and has several advantages from the aspects of energy saving, pollution control, and safety. Besides, it also modifies the tensile and surface characteristics of cotton textiles and their behaviour during weaving. The study suggests that yarn formation mode also plays a dominant role in the ease of penetration of the chemicals, especially in the case of the enzymatic scouring process. Due to their high absorbency and more openness, rotor-spun yarns offer easier access to the enzyme systems than ring-spun yarns. Such a study would be useful for establishing the optimal experimental conditions of an enzyme necessary for improving mechanical and surface characteristics of cotton substrates, for better results.

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