Properties of Cotton Yarns After Slack Swelling and Stretching in Presence or Absence of Alkali. II

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Received 5 May 2006; accepted 5 November 2006
DOI 10.1002/app.25738
Published online 14 August 2007 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: An investigation on the properties of solution-stretched ring spun and rotor spun cotton yarns at regular time intervals was made. Significant changes in the properties of these yarns are observed. The changes in fine structure are evaluated by means of infra red spectroscopy and X-ray diffraction methods. Ring spun cotton yarns exhibit better abrasion resistance than do rotor spun yarns. Abrasion resistance of NS-ring and rotor spun yarns is higher than their counter parts. WS-ring spun yarns are characterized by higher compression values, explaining the softness produced by the stretching treatment. The dyeability of the treated yarns is also studied with reactive dye, and the color values are found to be significantly greater for WS-ring and rotor spun yarns. J Appl Polym Sci 106: 3111–3118, 2007

Key words: abrasion; color; compression; crystallinity

INTRODUCTION

A great deal of work has been carried out on the swelling behavior of cellulosic fibers in various chemical reagents.[1–7] The properties of swollen and subsequent stretched cotton yarns in aqueous solution of sodium hydroxide have been reviewed by many authors.[8–12] Their studies reveal that the stretching treatments are carried out in the absence of solution, and only a few of them have dealt with solution stretching treatments. Hebeish et al discussed the mechanism of degradation of cotton yarns swollen and stretched to various levels in the mercerizing solution.[13]

However, properties of stretched yarns by keeping them immersed in the same swelling agent after slack swelling, by varying the stretching and swelling time, are not available in the literature. In continuation to our earlier reported article,[14] it is found that cotton yarns stretched in the presence of alkali solution show an increase in their tensile properties than the samples stretched in the absence of alkali solution. As abrasion, compression, and dyeing properties gain technological importance, it is essential to study these properties of solution-stretched ring spun and rotor spun cotton yarns. Hence, in this present study, the treated yarn samples are tested for abrasion resistance, compression, and dyeing properties. The salient observations are compared with the properties of slack-treated and conventionally stretched ring and rotor spun yarns.

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Journal of Applied Polymer Science, Vol. 106, 3111–3118 (2007)

EXPERIMENTAL

Materials and methods

Cotton yarn of 16s count (37 Tex) made on a ring and rotor spinning frame from a single fiber mixing was used for the present study. The chemicals used for all the treatments were of laboratory grade. Yarn samples consisting of 20 yarns in the lea form were prepared by wrap reel, scoured conventionally, and used for all the treatments.

Fabrication of stretching device

A rectangular stainless steel trough of dimension 75 $\times$ 1 $\times$ 1 cm^3 was designed (Fig. 1). The total capacity is 75 cm^3. A holder pin was located at one end of the trough and five other holders corresponding to the predetermined stretch levels (92, 94, 96, 98, and 100) were located at the other end. The minimum immersing height is fixed with 0.4 cm, and the capacity of the trough is about 30 mL. A provision is made to give continuous rotation inside the trough by manual operation at constant speed. Also, an outer jacket with an inlet and outlet was provided beneath the trough to carry out the treatments in hot and cold condition. Yarns treated in slack for a predetermined time will be stretched to the desired stretch level using this device.

Slack swelling and stretching treatment

The treatment was divided into three methods. In the first method, conventional slack treatment was followed with various time intervals. In the second one, followed by slack swelling, ring and rotor spun yarns

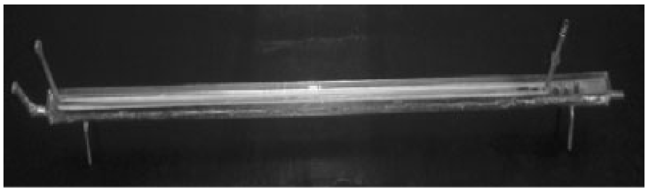

Figure 1 Device used for slack and stretching treatment.

were stretched in the presence of solution. In the final method, stretching was given to the yarns without solution followed by slack swelling. Aqueous sodium hydroxide (21% (w/w)) was used for all swelling and some stretching treatments.

Method I

The scoured ring and rotor spun cotton yarns were slack-swollen in sodium hydroxide solution for 5, 10, 15, 20, 25, 30 min in the trough itself, washed well[5] and air-dried.

Method II

The scoured yarns were treated with aqueous sodium hydroxide in slack condition in the trough for 5 min, and then stretched to 96% of their original length in the stretching device by means of fixing the yarns between the two endpins. While stretching, continuous rotations were given to the yarns at constant speed (1 rpm) for the remaining 25 min in the presence of swelling solution. The same method was repeated by varying the swelling time of 10, 15, 20, and 25 min and then stretched to 96% of their original length, and rotations were given with respective times of 20, 15, 10, and 5 min. The yarns were first washed with hot water and then cold water in the stretched state. They were then taken out, washed with hot water, cold water, neutralized with dilute acetic acid (0.1%), and finally air-dried, during which they remained at lengths already established. In each treatment, the trough was filled with the required level of solution with required concentration. These samples were designated as with solution ring spun (WS-ring) and with solution rotor spun (WS-rotor) yarns.

Method III

In this method, slack swelling of yarns was followed as mentioned in Method II and stretching was given in the absence of solution, with same continuous rotations at constant speed in the stretching device. These samples were designated as no solution ring spun (NS-ring) and no solution rotor spun (NS-rotor) yarns. For comparison, conventionally stretched ring and rotor spun cotton yarns were also prepared by slack swelling the yarns for 30 min in sodium hydroxide and then restretching them to 96% stretch level.

X-ray crystallinity

To determine the crystallinity of the stretched yarns, the powder form of fibers was dispersed onto a stub and placed within the chamber of Bruker AXS D8 model X-ray diffractometer. The degree of crystallinity[15] (X_c) and crystalline index[16] was calculated from eqs. (1) and (2) as follows :

$$X_c\ (\%) = \frac{I_c}{I_c + I_a} \times 100 \qquad (1)$$

where X_c is the degree of crystallinity, and I_c and I_a represent the integrated intensities of crystalline and amorphous regions, respectively.

$$\text{Crystalline Index} = \frac{I_{002} - I_{\text{AM}}}{I_{002}} \times 100 \qquad (2)$$

where I_{002} and I_{AM} represent the integrated intensity of crystalline and amorphous regions, respectively.

FTIR studies

Infrared index values were also calculated from the ratio of the absorbances at 1372 and 2900 cm^{-1} bands[17] by base line technique. Earlier infra red spectra were recorded with Perkin-Elmer Spectrum RX 1 model, using KBr pellet technique.[18]

TABLE I
Crystallinity Values of Stretched Ring Spun Cotton Yarns

Swelling time (min)	Ring-WS			Ring-NS		
	Infrared index	Crystalline index	Crystallinity (%)	Infrared index	Crystalline index	Crystallinity (%)
Scoured	0.711	0.85	82	–	0.850	82
5	0.619	0.629	73	–	–	–
10	0.598	–	–	–	–	–
15	0.599	0.596	72	–	0.549	71
20	0.59	–	–	–	–	–
25	0.584	0.545	70	–	–	–
30	0.565	–	–	0.565	–	–

TABLE II
Crystallinity Values of Stretched Rotor Spun Cotton Yarns

Swelling time (min)	Rotor-WS		Rotor-NS	
	Crystalline index	Crystallinity (%)	Crystalline index	Crystallinity (%)
Scoured	0.85	82	0.85	82
5	0.52	70	–	–
10	–	–	–	–
15	0.482	67	0.467	67
20	–	–	–	–
25	0.447	67	–	–
30	–	–	–	–

Abrasion resistance

The yarn-to-yarn abrasion resistance of the treated yarns was measured by the instrument fabricated on the combined principle of Faasen and van Harten,[19] and Veer.[20] For each, sample 50 tests were carried out, and the number of cycles necessary to weaken the yarn so that it breaks under the influence of a 20 g weight was noted.

Compression property

For measuring the compression of stretched yarns, the yarn was compressed by placing it on a thickness gauge and measuring the thickness under suitable weights. Percent compression was calculated using the following formula.

$$\text{Compression (\%)} = \frac{T_o - T_m}{T_o} \times 100$$

where T_o is the thickness of the yarn at dead weight and T_m is the thickness of the yarn at maximum weight, 350 g. This is based on the method suggested by Kaswell et al.[21]

Dyeing

The stretched ring and rotor spun yarns were independently dyed with Drimarene Red HE3B according to the conventional exhaustion dyeing method, using sodium chloride and sodium carbonate. The dyeing was allowed to proceed at 80°C at a liquor ratio of 1 : 20. Dyeing was carried out for a specified time, and after dyeing the samples were taken out, thoroughly washed with cold water, soaped at boil, rinsed thoroughly in hot water, finally washed with cold water, and air-dried.

Color measurement

For color measurement, the dyed yarn samples were converted into 4-cm^2 area by folding the lea, and the color values were measured using spectrophotometer (Gretagmacbeth, 2180 UV) and Color iMatch software,

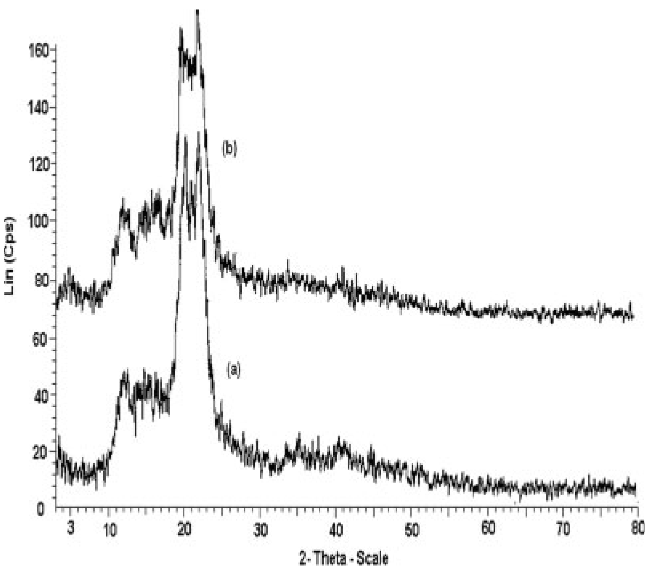

Figure 2 X-ray diffraction relative intensity curve of stretched ring spun cotton yarns (15-min swelling/15-min stretching). (a) WS-ring. (b) NS-ring.

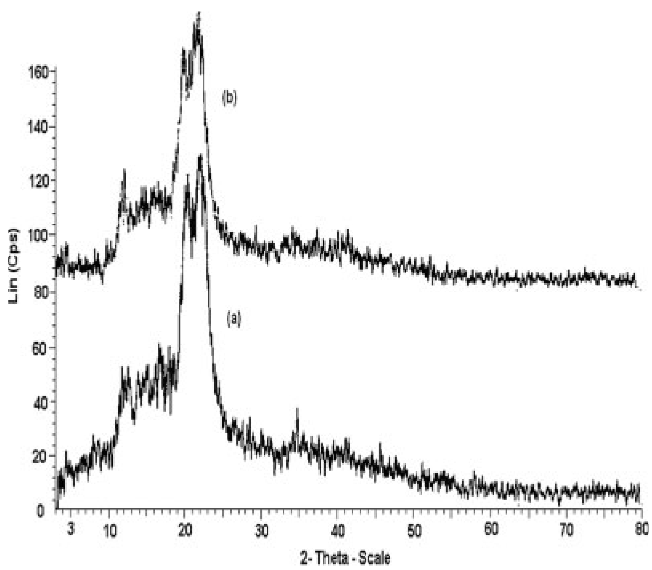

Figure 3 X-ray diffraction relative intensity curve of stretched rotor spun yarns (15-min swelling/15-min stretching). (a) WS-rotor. (b) NS-rotor.

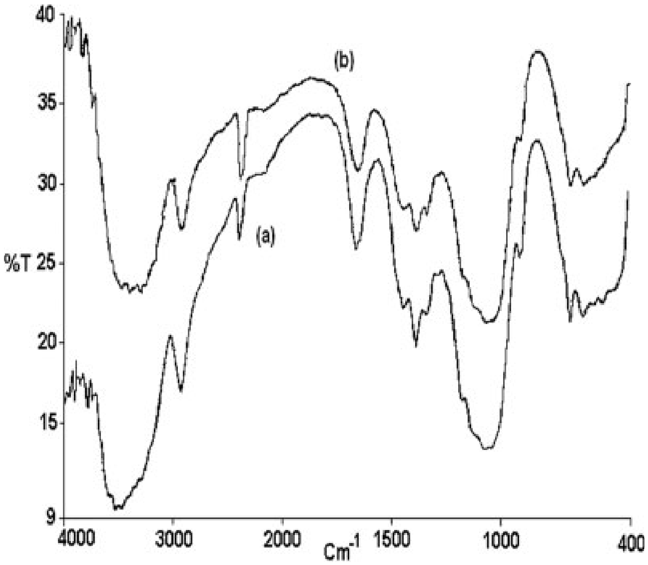

Figure 4 FTIR spectra of ring spun cotton yarns stretched with solution. (a) 5-min swelling/25-min stretching. (b) 10-min swelling/20-min stretching.

according to the CIELAB color difference concept at standard illuminant D65/10° observer, in the wavelength range of 360–750 nm at 10-nm intervals.

RESULTS AND DISCUSSION

Crystallinity

Data on crystallinity of stretched ring and rotor spun yarns from XRD and FTIR techniques are presented in Tables I and II. The crystallinity values of both WS-ring and rotor spun yarns show a decrease with increase in swelling time. A good correlation between the values calculated from both the techniques is obtained. In case of solution-stretched yarns, the effect of stretch is more pronounced than NS-ring and rotor spun yarns, which explain the decrease in crystallinity values of WS-ring and rotor spun yarns swollen and stretched to 15 min. Ring spun yarns are characterized by greater extent of reduction in crystallinity by these stretching treatments. The spectral illustration of the treated yarns is presented in Figures 2–6.

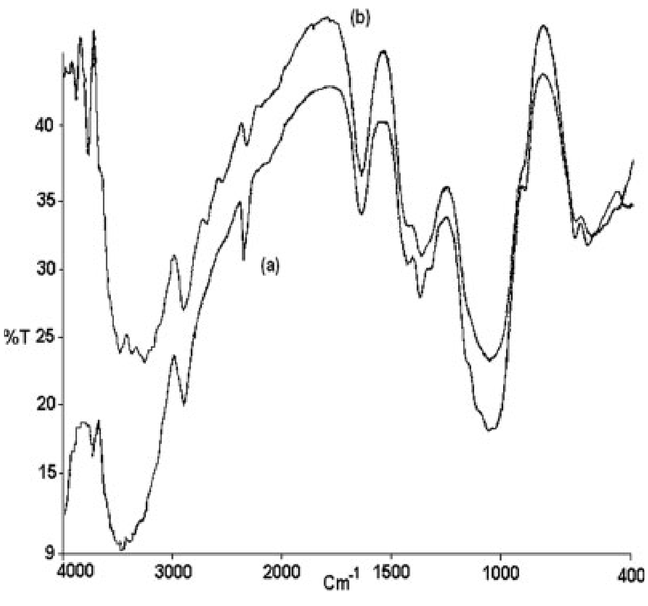

Figure 5 FTIR spectra of ring spun cotton yarns stretched with solution. (a) 15-min swelling/15-min stretching. (b) 20-min swelling/10-min stretching.

Abrasion resistance

Slack-treated ring and rotor spun cotton yarns are tested for their yarn-to-yarn abrasion resistance, and the values are plotted in Figure 7. Ring spun yarns

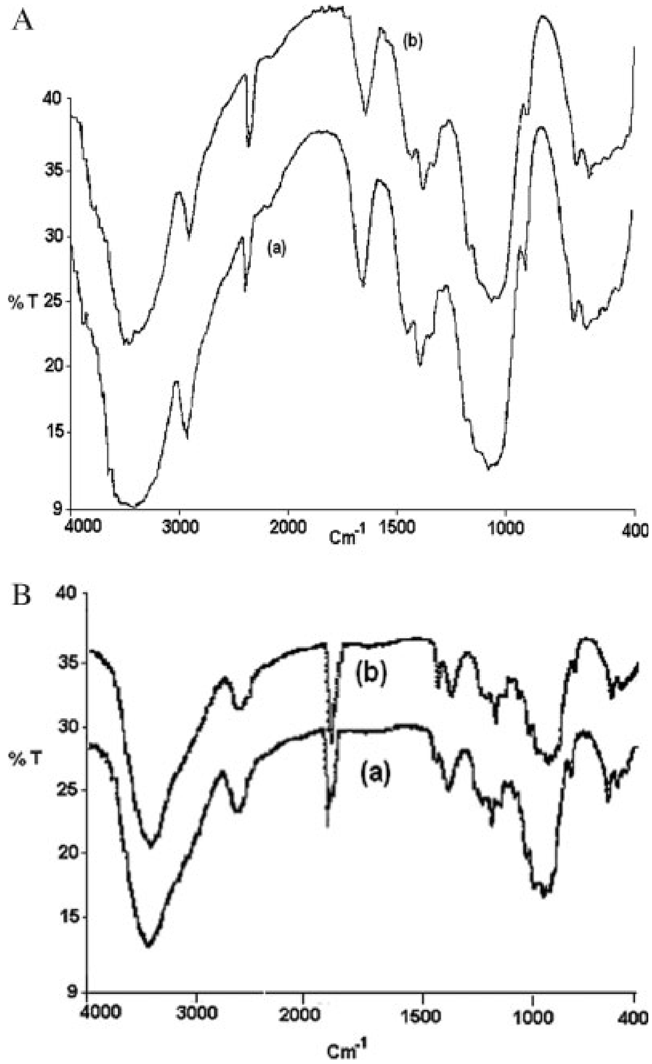

Figure 6 (A) FTIR spectra of ring spun cotton yarns stretched with solution: (a) 25-min swelling/5-min stretching, (b) conventional stretching. (B) FTIR spectra of stretched ring spun cotton yarns (15-min swelling/15-min stretching): (a) with solution, (b) without solution.

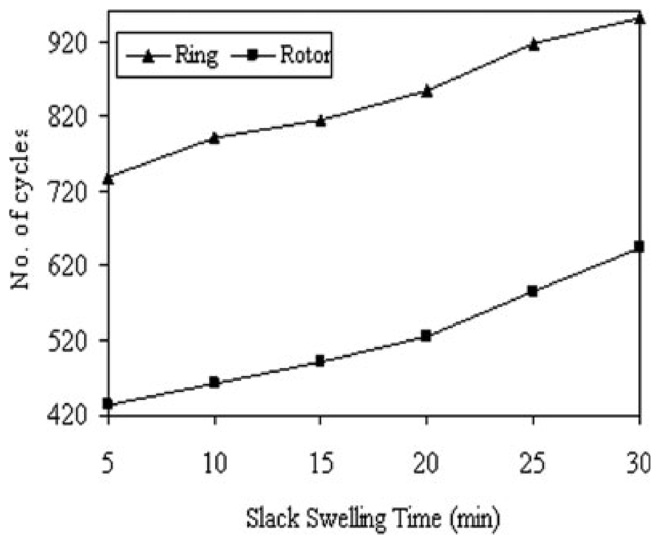

Figure 7 Abrasion property of slack-swollen ring spun and rotor spun cotton yarns at various time intervals.

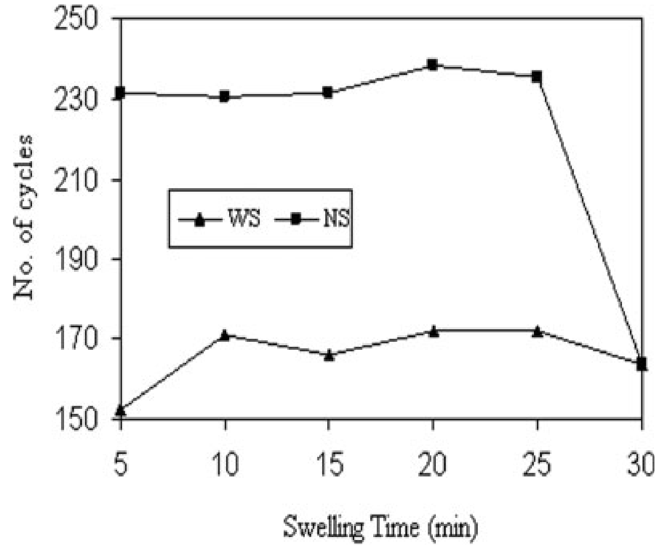

Figure 9 Abrasion property of rotor spun cotton yarns stretched with and without solution.

exhibit higher abrasion resistance than rotor spun yarns because of the presence of poor wrapping fibers in the outer layer of the rotor spun yarns.[22] Number of cycles taken to abrade the yarns increases with increase in swelling time in both ring and rotor spun yarns.

Abrasion resistance of WS-ring and NS-ring spun yarns are plotted in Figure 8. Initially, both WS-ring and NS-ring spun yarns show a steady increase up to 15-min swelling time and then a fall is noted in the plot. The values seem to be higher for NS-ring spun yarns. Stretching treatment generally lowers the abrasion resistance of yarns, while in solution stretching treatment much more reduction is observed due to the fact that the effect of stretch is more detrimental in this case.

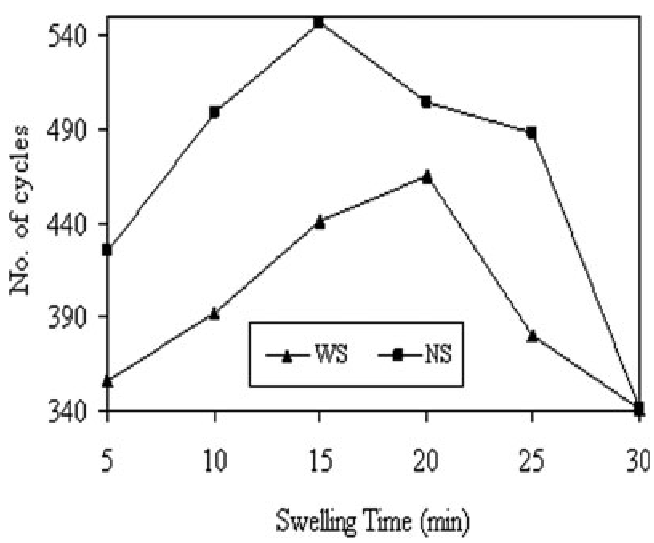

Figure 8 Abrasion property of ring spun cotton yarns stretched with and without solution.

Figure 9 shows the response of WS-rotor and NS-rotor spun yarns to abrasion resistance. No spectacular increase with swelling time is observed in both the cases. Rotor spun yarns also show better abrasion resistance in case of NS-rotor spun yarns. The poor abrasion resistance exhibited by these yarns may be due to a slight damage which occurs on the fiber surface during solution stretching treatment.[14]

Compression characteristics

Slack-treated ring and rotor spun yarns are measured for their percent compression and are plotted in Figure 10. With increase in swelling time, a steady increase followed by a gradual increase at higher swelling time is observed. Higher percent compression is noticed in

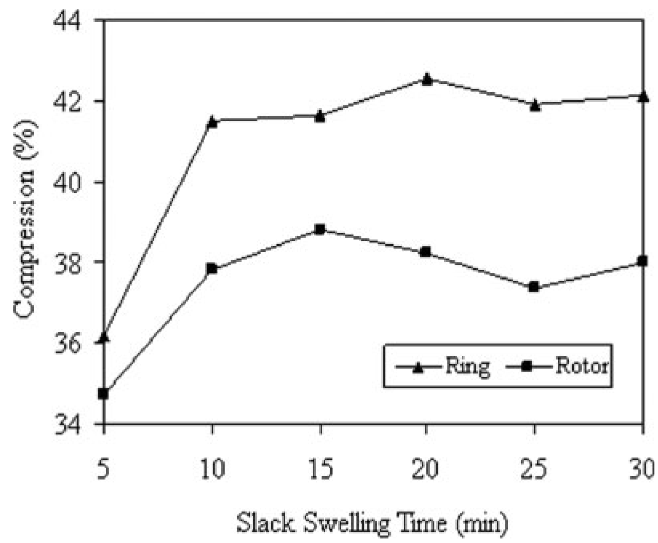

Figure 10 Compression behavior of slack swollen ring and rotor spun cotton yarns at various time intervals.

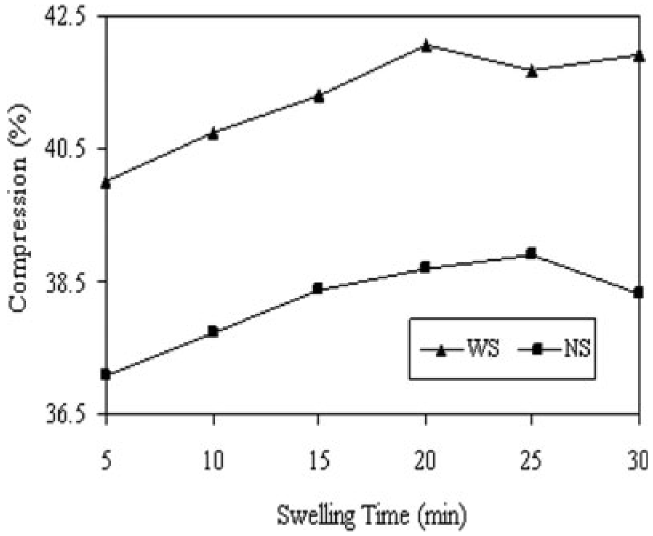

Figure 11 Compression behavior of ring spun cotton yarns stretched with and without solution.

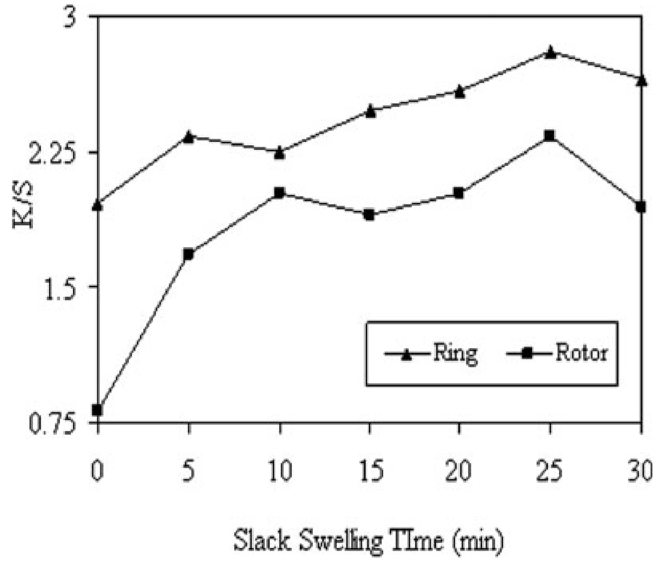

Figure 13 Color values of slack-swollen ring spun and rotor cotton spun yarns at various time intervals.

ring spun yarns than rotor spun yarns. This could be explained by the phenomenon that the wrapper fibers present in the rotor spun yarns prevent the spreading of fibers during compression. In ring spun yarns it is facilitated because of the absence of wrapper fibers.

The percent compression of WS and NS ring spun yarns are depicted in Figure 11. In both the cases, with increase in swelling time a gradual increase in their compressibility is observed. WS-ring spun yarns are characterized by higher values of compression than NS-ring spun yarns, explaining the softness produced by the solution stretching treatment.

The compressibility of WS and NS-rotor spun yarns is illustrated in Figure 12. Both WS and NS-rotor spun yarns show a steady increase initially, and further a gradual increase is noticed. NS-rotor spun yarns exhibit increased compressibility than WS-rotor spun yarns, which is contradictory to that of ring spun yarns. However, on comparison slack-treated yarns exhibit higher degree of compression than stretched yarns, which could be explained by the hardness produced by the application of stretch.

Color values

Slack-swollen ring and rotor spun yarns are measured for the K/S values and are shown in Figure 13. Ring spun yarns show better color yield than rotor spun yarns, which may be explained by the yarn

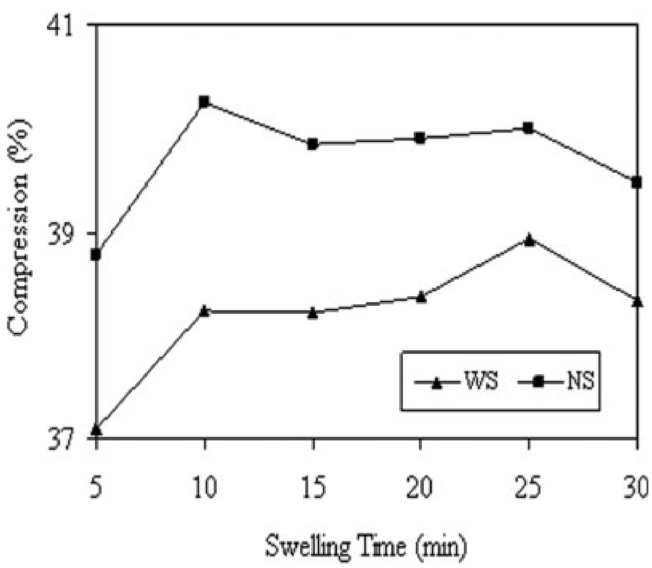

Figure 12 Compression behavior of rotor spun yarns stretched with and without solution.

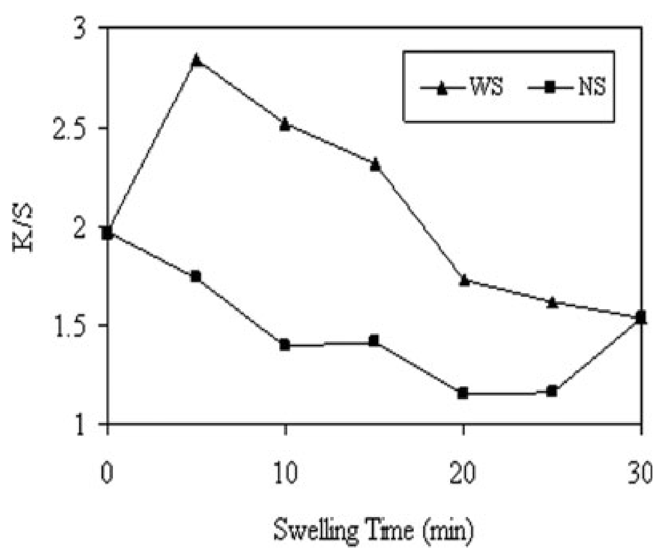

Figure 14 Color values of ring spun cotton yarns stretched with and without solution.

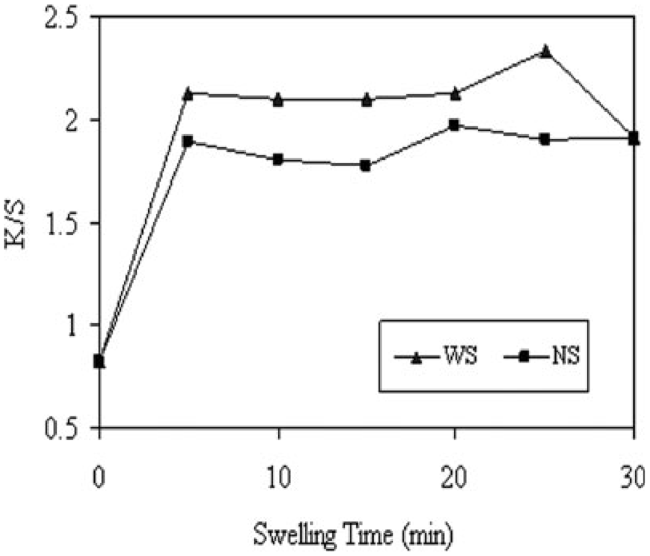

Figure 15 Color values of rotor spun cotton yarns stretched with and without solution.

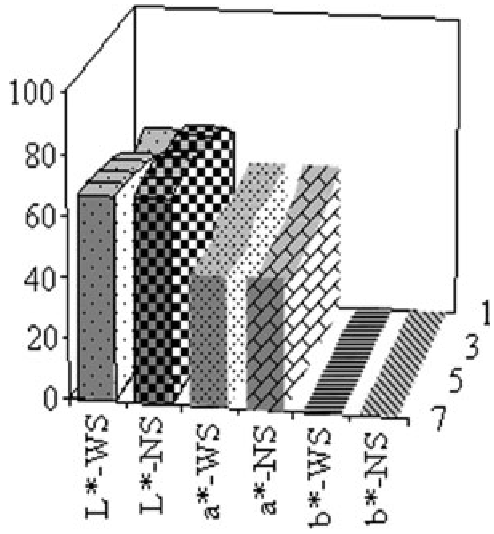

Figure 16 *L**, *a**, and *b** values of ring spun cotton yarns stretched with and without solution.

structure. It is also evident that with increase in swelling time an increase in K/S value is noted in both ring and rotor spun yarns. This may be due to the considerable enlargement in pore volume during swelling in sodium hydroxide, which increases with increase in swelling time.

The K/S values of WS-ring and NS-ring spun yarns are shown in Figure 14. It is obvious that NS-ring spun yarns show poor color values than scoured yarns. But it is interesting to observe that WS-ring spun yarns show higher color values than NS-ring spun yarns. Also, WS-ring spun yarns exhibit better color values than conventionally stretched ring spun yarns. It is well known[23] that a considerable enlargement in pore volume occurs during swelling, while the application of stretch limited this expansion. But when the yarns are stretched in the solution, the limitation of pores while stretching is accompanied by enlargement in pore volume by swelling, that is, both swelling and stretching takes place simultaneously, which results in higher accessibility to dye molecules in the dye bath, yielding better color yield than their counterparts.

The color values of WS-rotor and NS-rotor spun yarns are illustrated in Figure 15. WS-rotor yarns are also characterized by higher color values than the other case. But the increment is to a smaller extent when compared with that of ring spun yarns. Also, WS-rotor spun yarns exhibit higher K/S values than conventionally stretched yarns. There is no considerable change in K/S values with increase in swelling time.

The L^*, a^*, b^* values of WS and NS-ring spun yarns are noted in Table III. Both WS and NS-ring spun yarns show higher values of lightness than the scoured sample. An increment in the lightness value with increase in swelling time is noted. The decrease in the lightness values of WS-ring spun yarns justifies the enhanced color values of these yarns (Fig. 14). A decrease in a^* and b^* values with increase in swelling time is also noted. The graphical representation of L^*, a^*, and b^* values of WS and NS-ring spun yarns is given in Figure 16.

Table IV presents the L^*, a^*, and b^* values of WS and NS-rotor spun yarns. A gradual increase in their

TABLE III
L^*, a^*, b^* Values of Stretched Ring Spun Cotton Yarns

Swelling time (min)	Ring-WS			Ring-NS		
	L^*	a^*	b^*	L^*	a^*	b^*
Scoured	58.55	48.07	0.04	58.55	48.07	0.04
5	54.50	47.19	0.07	65.1	43.13	−1.12
10	60.34	45.29	1.11	67.24	39.95	−0.58
15	62.83	47.86	−0.53	66.87	39.40	−1.41
20	64.54	41.31	−0.83	69.72	39.09	−0.72
25	65.90	42.35	−0.39	68.73	36.56	−0.34
30	66.67	42.62	−0.77	66.67	42.62	−0.77

TABLE IV
L^*, a^*, b^* Values of Stretched Rotor Spun Cotton Yarns

Swelling time (min)	Rotor-WS			Rotor-NS		
	L^*	a^*	b^*	L^*	a^*	b^*
Scoured	71.47	31.03	−0.85	71.47	31.03	−0.85
5	61.56	41.24	0.64	63.56	42.05	0.44
10	62.14	42.50	0.75	64.81	43.46	−0.19
15	61.26	42.60	0.73	63.32	45.00	1.11
20	62.47	43.90	0.61	62.70	45.40	1.05
25	62.34	39.01	0.61	62.55	47.20	1.25
30	63.95	43.39	0.56	63.95	43.39	0.56

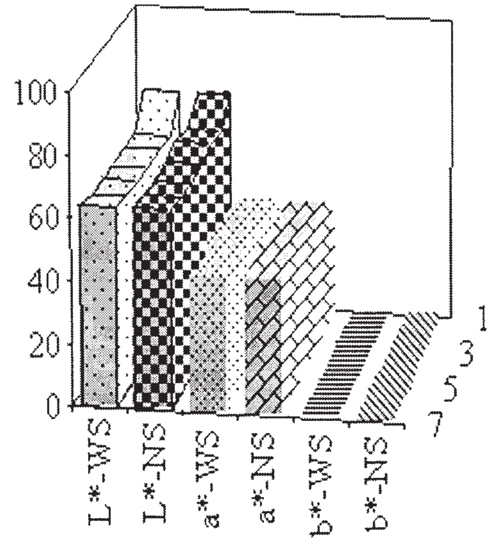

Figure 17 *L**, *a**, and *b** values of rotor spun cotton yarns stretched with and without solution.

lightness values with increase in swelling time is observed. The lightness values of NS-rotor spun yarns are greater than WS-rotor spun yarns, explaining the increment in the color values exhibited by these yarns (Fig. 15). However, stretched yarns show lower values of lightness than scoured yarns. The values of *a** and *b** are greater for NS-rotor spun yarns than their counterparts (Fig. 17).

CONCLUSIONS

Crystallinity of WS-ring and rotor spun yarns decreases with increase in swelling time. The crystallinity values of WS-ring and rotor yarns are higher than NS-ring and rotor yarns. Slack-treated ring and rotor spun yarns show an increase in their abrasion resistance with increase in swelling time. NS-ring and rotor spun yarns exhibit better abrasion resistance than WS-ring and rotor spun yarns. The compression values of WS-ring spun yarns are higher indicating the softness of the yarns. Slack-treated ring spun yarns show higher compression values due to the prevention of spreading of fibers by wrapper fibers in rotor spun yarns. Ring and rotor spun yarns stretched in presence of solution show better color yield than their counter parts.

The authors are grateful to Dr.T. Vasudevan, Professor and Head, Department of Industrial Chemistry for aiding fruitful suggestions and constant inspiration to finish the work.

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