Effect of Aqueous Swelling and Stretching on the Structure and Properties of Cotton

S. S. DOKE, *Victoria Jubilee Technical Institute, Bombay, India* and K. R. KRISHNA IYER, *Cotton Technological Research Laboratory, Bombay, India*

Synopsis

Spectacular changes in structure and properties of cotton have been found to result from swelling and stretching treatments in water. Fibers from one variety of cotton (Sudan) were swollen in water and stretched to their limit. While one lot was dried in the stretched state, another was allowed to dry in the slack condition after being subjected to stretch. The two types of treatments produced considerable changes in structural and physical properties, the stretch drying being more drastic. Enhancement of breaking load and tenacity without much loss in extensibility improved fibrillar orientation without change in crystallinity; reduction in ribbon width wall thickness and number of convolutions, etc. are some of the changes resulting from the treatment.

INTRODUCTION

Extensive studies have been reported from time to time on the changes in morphology, fine structure, and mechanical properties brought about in cotton fibers by the swelling action of many chemical reagents.[1] Water, the commonest of swelling agents, is known to cause only intercrystalline swelling and it is believed that permanent structural changes cannot result from the action of water. Recent experiments at CTRL have, however, shown that if swelling is accompanied by stretch, irreversible changes in morphology and structure can result. This communication discusses some results.

EXPERIMENTAL

Unkiered fibers from a Sudan variety were swollen and stretched by a standard procedure.[2] A parallel fiber bundle held in jaws was swollen in water for about 5 min and then stretched to a nominal level of 10% above the initial length. The intention was to stretch the fibers to their limit. Taking advantage of the fact that the bundle is far from a perfect array of parallel and straightened fibers, the stretch was slowly increased to a nominal value of 10% at which many fibers were found to have broken. The surviving fibers were presumed to be those stretched to their limit. The stretched bundle, still between jaws, was dried in an oven at 80°C for 3 h. The fibers were then released from the jaws and the broken fibers were carefully removed by combing alternately from the two ends of the bundle. The fibers thus prepared are referred to as "stretch-dried." Another set of "slack-dried" sample was prepared by allowing the sample to dry without tension. For this, the swollen fiber bundle was held at 10% stretch for 1 min and then released and dried at 80°C for 3 h.

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Standard methods[3] were used for obtaining linear density (cut-and-weigh method), convolution frequency, fiber width, and cross-sectional profile. Fibrillar orientation expressed in terms of 50% X-ray angle was calculated from the 002 diffraction profile of a fiber bundle obtained by using a Philips X-ray generator fitted with diffractometer.[4] Crystallinity was determined by infrared spectroscopy employing the 342 cm^{-1} absorption band according to the practice at CTRL.[5]

The Instron tensile tester was used to determine single fiber tenacity. Fibers mounted on plastic strips with a gauge length of 1 cm were tested on the machine with a breaking time of 20 ± 3 s. Tests were carried out on untreated, stretch-dried, and slack-dried fibers, both at 65% RH and in the wet state. For each test 100 fibers were broken. Tenacity was calculated from the mean breaking load of 100 fibers using the tex value obtained by cut-and-weigh method. Tenacity of wet samples is the ratio of mean breaking load of wet fibers and the tex value of dry (65% RH) fibers.

RESULTS AND DISCUSSION

Light microscopy data presented in Table I show that the fiber becomes deconvoluted and reduced in ribbon width and wall thickness as a result of swelling and stretching in water. In all these properties, the changes are more drastic in stretch-dried sample. While the stretch undergone by the fiber can be expected to cause a reduction in linear density and in the overall lateral size, the decrease in ribbon width must be attributed to the swelling of the fiber and to the permanent rounding of the cross-sectional profile. From the tracings shown in Figure 1 it is clear that the cross section has become more circular, the change being predictably more in the stretch-dried fiber than in the slack-dried one. The cross-sectional tracings also reveal that the wall thickness has become recognisably lower. This is also evident from the microscopy data in Table I. The decrease in wall thickness suggests that the fiber wall has become compact as a result of the treatment. Convolutions suffer a sizeable reduction in both the treated samples.

The above results show that the treatment tends to bring the fiber morphologically closer to its own state before boll opening. The initial desiccation of the fiber during the boll opening is a significant event because drastic changes

TABLE I
Morphological and Fine Structural Data on Untreated and Swollen and Stretched Fibers from Sudan Variety

Property \ Sample	Raw fiber	Slack-dried	Stretched-dried
Convolutions per cm	59	36	20
Ribbon width (μm)	17.8	16.6	16.6
Wall thickness (μm)	5.4	4.8	3.8
Infrared crystallinity index	0.63	—	0.62
50% X-ray angle	29.7	21.6	13.1
50% X-ray angle after rewetting and drying	29.7	21.9	15.8

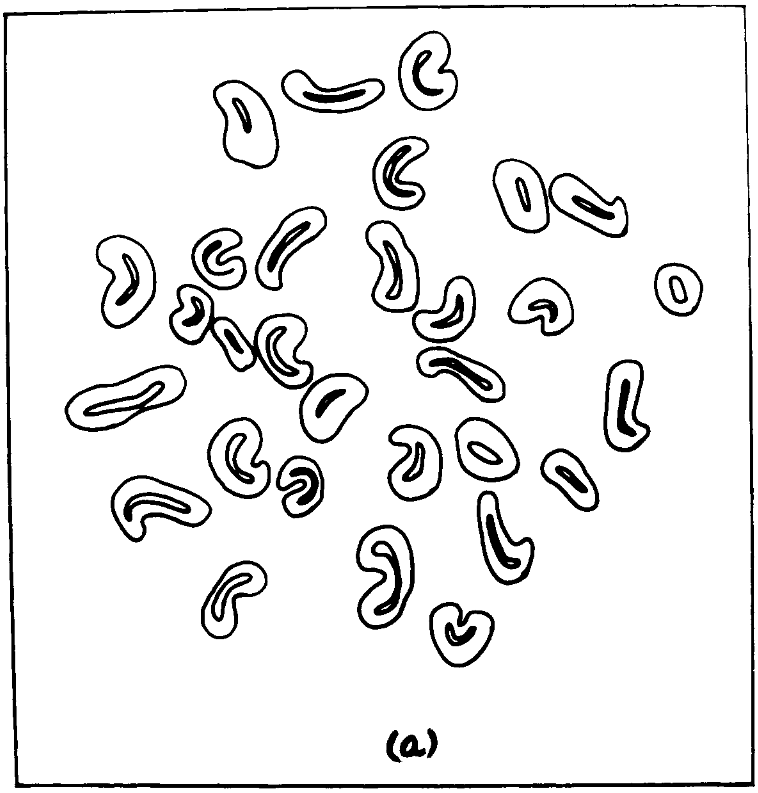

Fig. 1. Tracings of cross-sectional profiles of fibers from Sudan cotton: (a) raw fibers and (b) stretch-dried fibers.

occur in the fiber morphology. Once the fiber has collapsed, subsequent swelling in water cannot restore its original morphology except perhaps when the fiber is kept immersed in water. On drying the fiber, the collapsed structure returns. The present results, however, show that irreversible morphological changes can occur if the aqueous swelling is accompanied by stretch. The fiber thus tends to come close to the form it had in the boll.

The 50% X-ray angle of the different fiber samples are also included in Table I. The stretch-dried sample has considerably lower value of X-ray angle while the slack-dried one assumes a value almost midway. On rewetting and drying, the samples gave nearly the same X-ray angle, suggesting that the structural change brought about by the treatment is quite stable.

Crystallinity does not seem to change as a result of this treatment. The IR crystallinity index is found to be nearly equal for the raw and stretch-dried fibers. This is not surprising in view of the purely intercrystalline nature of the swelling by water. It may be noted that other swelling agents like NaOH and $ZnCl_2$ penetrate the crystalline regions of the fiber and produce considerable decrystallization.

The most impressive changes are found in breaking strength and tenacity (Table II). The stretch-dried sample has recorded 45% higher strength and 60% higher tenacity than the untreated fiber. The corresponding figures for slack-dried sample are 35 and 40%, respectively. The higher strength must be

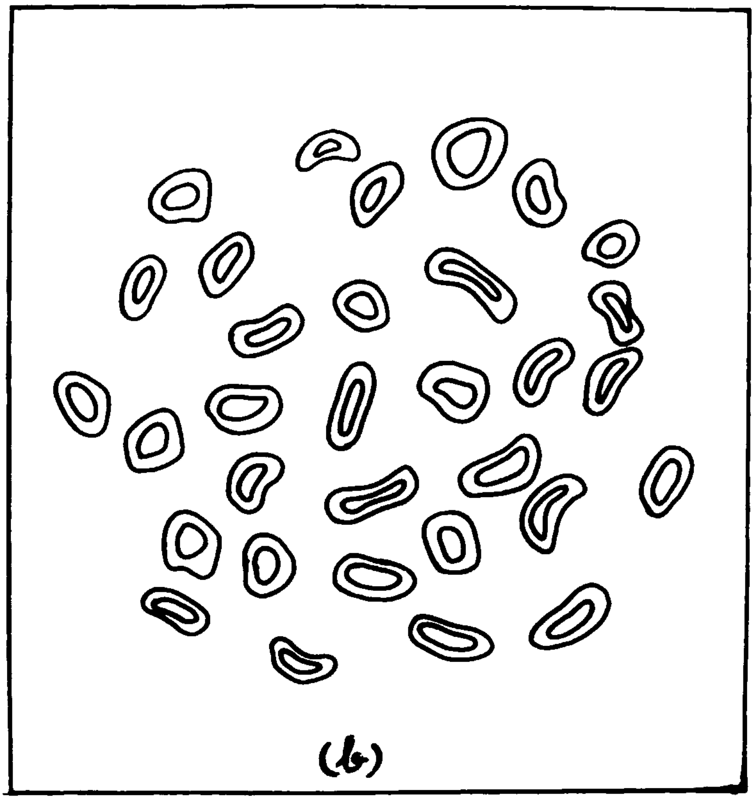

Fig. 1. (*Continued from the previous page.*)

attributed to the improvement in the fibrillar orientation as well as to the removal of built-in strains. In case of stretch-dried sample, while the tenacity has increased from 33.9 to 54.5 g/t, the X-ray angle has decreased from 30° to 13°. On the other hand, in the slack-dried sample, the strength increase (from 33.9 to 47.7 g/t) is somewhat close to that found in stretch-dried fiber (from 33.9 to 54.5 g/t); but the decrease in X-ray angle (from 30° to 22°) in slack-dried fiber is only half of that found in stretch-dried fiber (from 30° to 13°). These results tend to suggest that the fiber derives its enhanced strength

TABLE II
Load–Elongation Data on Untreated and Swollen and Stretched Fibers from Sudan Variety

Sample	Breaking load (g)	Linear density (m tex)	Tenacity (g/t)	Breaking elongation (%)
Raw fiber at 65% rh	5.5	162	33.9	8.7
Raw fiber in wet state	6.3	—	38.9	10.3
Slack-dried fiber	7.4	155	47.7	9.8
Slack-dried in wet state	7.2	—	46.6	11.0
Stretch-dried fiber	8.0	147	54.5	6.7
Stretch-dried fiber in wet state	7.6	—	52.0	8.6

more from the elimination of built-in strains than from the improved fibrillar alignment.

The above inference is strengthened by the fact that the increase in tenacity on wetting (15% from 33.9 to 38.9 g/t), which is a characteristic typical of cotton, is nullified and in fact rendered marginally negative by the swelling-stretching treatment (54.5–52.0 g/t). It would appear that when raw fibers are swollen, the strains are removed temporarily and a gain in strength is noticed. As the fiber dries up, the strength falls to the initial value. On the other hand, if the swelling is accompanied by stretch, as in the present experiments, the strains seem to be permanently removed, and, on such strain-free fibers, water has little effect.

It is also significant to note that, in both the treated samples, the increase in strength is achieved without much reduction in elongation. The reciprocal relation between orientation and breaking extension characteristic of alkali treated fibers does not seem to operate in fibers subjected to aqueous swelling.

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References

1. J. O. Warwicker, R. Jeffries, R. L. Colbran, and R. N. Robinson, *Review of the Literature on the Effect of Caustic Soda and Other Swelling Agents on the Fine Structure of Cotton*, Shirley Institute, Manchester, 1966.

2. T. Radhakrishnan, B. V. Iyer, G. Viswanathan, and H. Wakeham, *Text. Res. J.*, **29**, 322 (1959).

3. V. Sundaram, *Handbook of Methods of Tests for Cotton Fibres, Yarns and Fabrics*, Cotton Technological Research Laboratory, Bombay, 1979.

4. P. K. Chidambareswaran, S. Sreenivasan, N. B. Patil, V. Sundaram, and B. Srinathan, *J. Appl. Polym. Sci.*, **20**, 3443 (1976).

5. P. Bhama Iyer, K. R. K. Iyer, and N. B. Patil, *Proceedings of the 17th Technological Conference of ATIRA, BTRA and SITRA*, Coimbatore, India, 1976, . 109.

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