NOTE

The Rigidity Modulus of Modified Cotton Fibers

INTRODUCTION

The modulus of rigidity that is a measure of the resistance of a material to a change of shape is an important property especially for fibers with a helical array, as it becomes effective even on the application of a normal tensile load. But there is little information in the literature on this property or the effect of other properties such as maturity and chemical treatments on it.

The shape of fibers play a very important role in determining their torsional properties. The term "shape factor" is used as a quantitative measure that is defined as ratio of the torsional rigidity of a fiber of a given cross-sectional shape to that of a similar fiber of circular cross section. Meredith[1] used this ratio to determine the shape factors for various fibers. This method may not be strictly valid for native cotton fibers because they collapse to different degrees between and within the same variety as a result of differences in their cell wall thickness and, therefore, twist (convolute) to different degrees.

The helical arrangement of microfibrils in the cell wall of cotton fiber is known to be a major contributor to the mechanical properties.[2] If convolutions can be safely removed by liquid ammonia treatment, its effect on the rigidity modulus can be elucidated.

EXPERIMENTAL

Two varieties of *G. hirsutum* cotton plant were grown: an unspecified American Upland and Nigeria samaru 26J. They were both grown in Glasgow in a greenhouse. Nigeria samaru 26J was also field grown in Nigeria. Cotton bolls were harvested at different stages of maturity, i.e., a 10 day interval from 20 days after flowering until boll opening.

An open boll of a *G. barbadense* variety (ashmouni) was also used in this investigation for comparison, and ramie fibers were also investigated, being the most oriented cellulosic fiber.

Measurement of Rigidity Modulus

Fibers were selected for this test on the basis that their wall thickness fell within the average value of the sample. With matured fibers, only those that were reasonably free of convolutions were selected.

Ten of these fibers were selected from each sample and made into 2 cm lengths by cutting from the middle. These fibers were then weighed on a micro-balance and left in a conditioned environment for 24 h.

A torsion pendulum of the single pendulum type was used. A typical arrangement of the pendulum is shown in Figure 1. (Appendix). Measurement procedure is described elsewhere (1).

The modulus of rigidity, η was calculated using the following relationships:

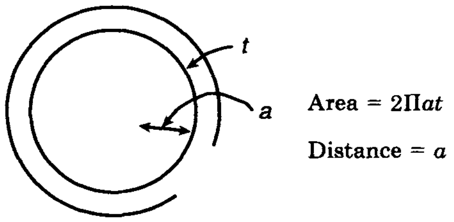
$$\eta = \frac{8\Pi^3 IL}{S^2T^2} = \frac{8\Pi^3 IL\rho^2}{T^2m^2}\, Pa$$

where η = Rigidity Modulus
I = Moment of Inertia of the Inertia bar
L = Length of the specimen
T = Period of Oscillation
$\mathcal{E}$ = Shape factor (value of 1 for treated but mature fibers) The shape factor of immature fibers was estimated from the following relationship

$$\mathcal{E} = \frac{S^2}{2\Pi Im}$$

where S = Cross-sectional area of the fiber estimated from the wall thickness.
Im = A real moment of Inertia for annulus (thin).
$= 2\Pi a^3 t$

thus



Fiber section

where a = Radius of the hole
t = mean wall thickness
$S = m/\rho$

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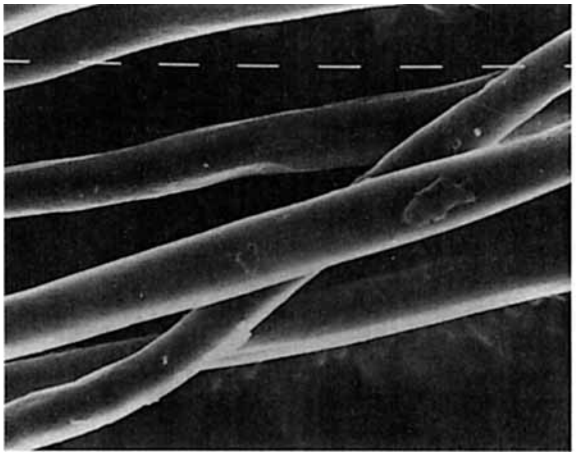

Plate 1

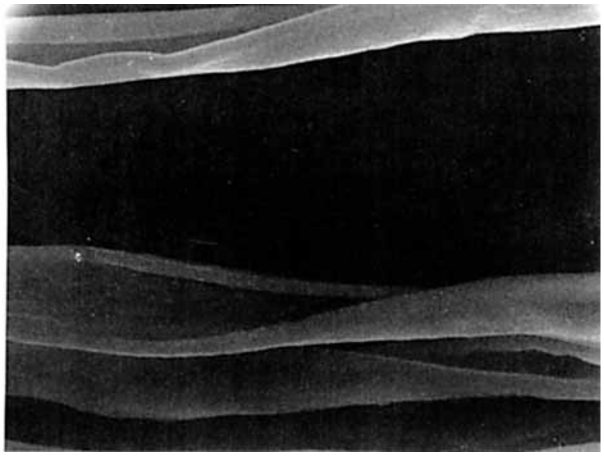

Plate 3

m = Mass per unit length
ρ = Fiber density.

The average mass of the Inertia bar for mature fibers = 30.6 mg ± 0.207.

The average value of I for mature fibers = 4.41 mg cm^2 (c.v. = 0.68%).

The average mass of the Inertia bar for immature fibers = 18.69 mg ± 0.400.

The average value of I for immature fibers = 1.92 mg cm (c.v. = 0.93%).

RESULTS AND DISCUSSION

The scanning electron micrographs revealed the absence of convolutions in mature fibers after the liquid ammonia treatment to cellulose III lattice structure and subsequent regeneration to cellulose I lattice structure (Plates 1 and 2). The immature fibers remained almost unchanged despite the lattice conversion to cellulose III (Plate 3)—hence, the need to calculate the shape factor from the cell wall thickness.

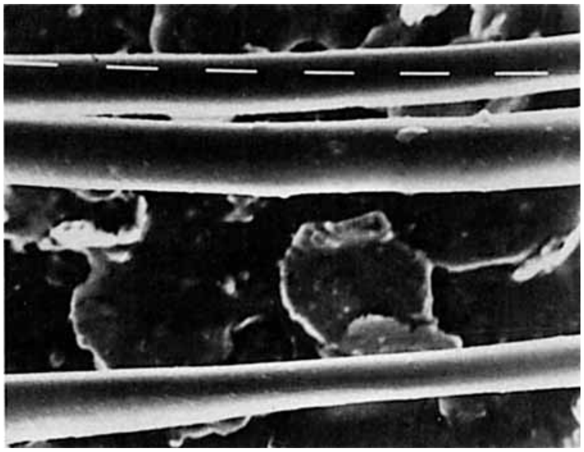

Plate 2

The mean modulus of rigidity values calculated are shown in the last column in Table I. The mean values of fiber weight per centimeter and the mean time of oscillation (second) are also given in the second and fourth columns, respectively.

Table I(A–C) includes results from the untreated, treated, and regenerated fibers of samaru, Nigeria, and Glasgow, respectively, at various stages of maturity. There is a slight increase in the modulus with increase in maturity. Orientation and tensile modulus have been found to increase with increase with maturity.[5] This investigation shows that the molecular orientation has little effect on the rigidity modulus.

Meredith made similar observation with rayons over 30 years ago (namely, viscose rayon, fibro, tenasco, and fortisan) and found an almost constant value of rigidity of about 1 GPa.[1] The results from this investigation were also found to be constant at about 1.9 GPa for cellulose III and at 2.0 GPa for regenerated fibers. This observation probably indicates that the general lateral cohesion of chain molecules in fibers is independent of the variation in the longitudinal alignment of these chains. But the fact that the results obtained here is about twice those of rayons shows the importance of helical structure in influencing the rigidity modulus. The average low value of 1.5 GPa recorded for ramie fibers seem to confirm this effect, taking ramie as ideal with a helical angle of about 6°.

The average rigidity moduli of the untreated and regenerated fibres were found to be 2.34 and 2.05 GPa, respectively. The decrease of about 10% in the rigidity modulus can be attributed to the effect of convolutions.

Table I Mean Weight per Centimeter, Fiber Length, Time of Oscillation, and Modulus of Rigidity of Cotton Fibers at Various Stages of Maturity and Ramie Fibers

Specimen (Fiber)	Age (days)	Wt/cm g/cm (10^{-6})	Fiber Length (cm)	Oscillation (s)	Modulus of Rigidity (GPa)
(A) Samaru 26J, Nigeria, untreated cotton					
Samaru 26J	30	1.40	1.021	7.20	1.80 ± 0.09
Nigeria	45	1.73	1.032	5.60	1.91 ± 0.07
	Open	2.09	1.022	6.00	2.31 ± 0.06
Ashmouni	Open	2.10	1.020	5.60	2.62 ± 0.05
Glasgow	Open	2.20	1.202	5.80	2.23 ± 0.06
Upland	Open	2.14	1.202	6.30	2.24 ± 0.06
Ramie	Mature	8.05	1.021	4.10	1.46 ± 0.04
(B) Cellulose III fibers Samaru 26J, Nigeria					
Samaru 26J	30	1.65	1.022	6.90	1.34 ± 0.04
Nigeria	45	1.83	1.031	5.70	1.70 ± 0.04
	Open	2.02	1.020	5.92	1.80 ± 0.03
Ashmouni	Open	2.06	1.020	5.75	1.84 ± 0.03
Ashmouni	C III II	2.30	1.020	5.56	1.61 ± 0.03
Ramie	Mature	8.12	1.021	4.00	1.50 ± 0.03
Samaru 26J, Glasgow					
	30	1.24	1.030	8.40	1.70 ± 0.04
	40	1.42	1.023	6.94	1.84 ± 0.04
	60	1.98	1.020	5.65	2.05 ± 0.04
	Open	1.96	1.022	5.54	2.11 ± 0.03
Mean					1.90 ± 0.04
(C) Regenerated fibers Samaru 26J, Nigeria					
Samaru 26J	30	1.42	1.023	7.10	1.80 ± 0.05
Nigeria	45	1.80	1.034	5.54	1.90 ± 0.05
	Open	1.98	1.023	5.67	2.05 ± 0.04
Ashmouni	Open	1.96	1.021	5.63	2.12 ± 0.03
Ramie	Mature	8.00	1.020	4.10	1.47 ± 0.03
Samaru 26J, Glasgow					
	30	1.21	1.020	8.70	1.61 ± 0.05
	40	1.40	1.020	6.65	2.05 ± 0.05
	60	1.96	1.022	5.60	2.14 ± 0.06
	Open	1.96	1.021	5.48	2.24 ± 0.03
Mean					2.00 ± 0.05

CONCLUSION

1. The modulus of rigidity of liquid ammonia treated and regenerated fibers are constant at around 1.8 and 2.1 GPa, respectively, and varies about 10% depending on maturity.
2. Convolutions may contribute as much as 10% to the rigidity modulus of cotton fibers.

APPENDIX: CALCULATION OF THE MOMENT OF INERTIA OF THE INERTIA BAR

The Inertia bar was made up of stirrup and wire. Care was taken to ensure that the fiber coincided with a line passing through their centers of gravity. The moments of inertia (I) of the bars were derived by calculation from

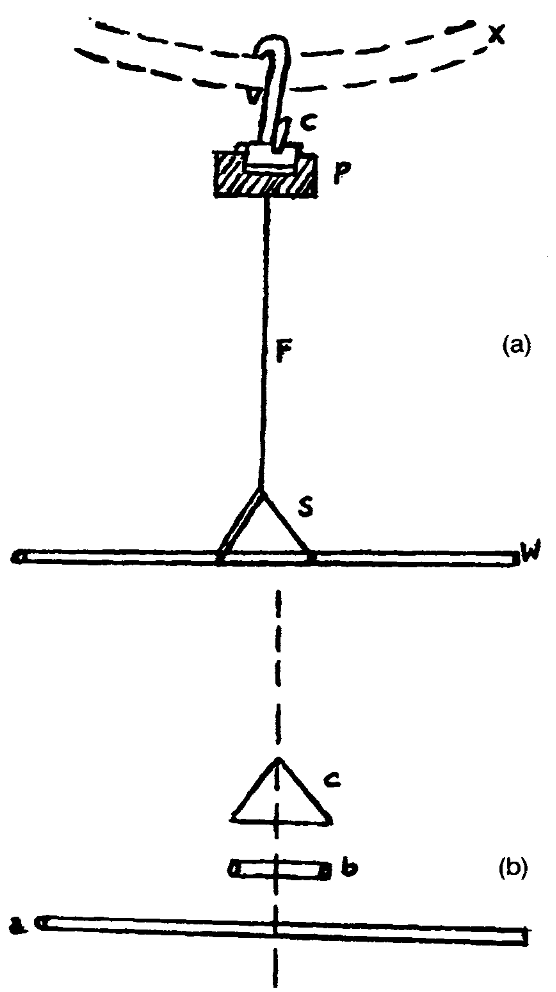

Figure 1 (a) Typical arrangement of a torsion pendulum. F = fiber specimen, S = stirrup, W = wire, P = emery paper stub, C = clip, X = circular frame. (b) Diagram illustrating the elements of the inertia bar: a = solid wire, b = hollow sleeve, c = triangular lamina.

the known masses m_1 and m_2 of the wire and stirrups; thus,

$$I = I_1\ (\text{wire}) + I_2\ (\text{stirrups})$$

The stirrup is actually a combination of a triangular lamina and a cylindrical sleeve (see Fig. 1 below), i.e.:

$$I_2 = I_3 + I_4$$

$$I = I_1 + I_3 + I_4$$

where I_3 and I_4 refer to the I of the sleeve (mass m_3) and the lamina (mass m_4), respectively. Therefore,

$$I = \frac{m_1 L^2}{12} + \frac{m_3 a^2}{12} + \frac{m_4 a^2}{6}$$

where L is the wire length; a, the sleeve length (base of lamina).

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