A New Method of Determining the Optical Properties of Cotton Fibers Using Polarizing Interference Microscopy

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Synopsis

The refractive indices, birefringence, and cross-sectional area of cotton fibers was measured using interference polarizing microscope constructed by M. Pluta. A new technique was suggested by realizing the measurements at the perpendicular position of the duplicated image of fiber to the interference fringe. The proposed procedure is a combination of modification of Hamza method and Pluta dual wavelength method, and it was possible to measure at once the three mentioned features of single fiber at one time.

INTRODUCTION

The optical properties of fibers are a manifestation of many of their structural characteristics, and, therefore, measuring the refractive indices and birefringence of a fiber has been recognized as providing useful information about the processability of the fiber.

For chemical fibers, a number of methods have been developed that enable measurement of the refractive index and the birefringence. Because of objective difficulties, only some of the methods have been adapted for cotton, although the importance of understanding the optical properties of cotton is commonly recognized.

One of the methods that have been adapted for cotton is the universally used Becke line method,[1–3] which is useful for fibers with variable shapes of cross section.

Recently, attempts have been reported to use interference microscopy for fibers with irregular cross sections[4] and fibers having a core and a skin.[5]

The first to attempt determination of the refractive indices for cotton using the Pluta polarizing interference microscope was Hamza,[6] who, making use of the Simmens technique,[7,8] measured the values of mean refractive indices and birefringence for two varieties of Egyption cotton. He determined the integral fringe shift area enclosed under the fringe, and the cross-sectional areas were measured from electron microscopy images of the fiber cross sections. The values of the refractive indices for light vibrating parallel and perpendicular to the fiber axis were determined in relation to the refractive index of the immersion liquid.

We are presenting now the results obtained using a modification of Hamza's procedure. The modified procedure also includes the use of Pluta's microscope, and the calculation is in agreement with Simmens. It differs from Hamza's procedure in that the fiber is placed in a immersion liquid of high dispersion of

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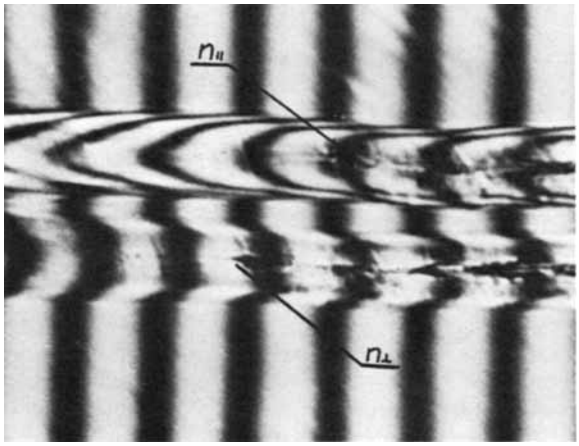

Fig. 1. Duplicated image of a cotton fiber (interference microscope MPI-3).

refractive index and measurement is carried out for two wavelengths of light, the fiber being oriented perpendicular to the interference fringes (Fig. 1), and the double-refracting lens prism is positioned crosswise to barrel prism No. 2 of microscope MPI-3 (in accordance with Ref. 9). Observed are two images of the fiber: One with a refractive index $n_{\|}$ and the other with a refractive index $n_{\perp}$. Thus, the proposed method is a combination of the Simmens method and the dual wavelength method.[10]

The values of the refractive indices and birefringence were calculated from two measurements performed precisely at the same point of the same fiber. As mentioned for each measurement, a different wavelength of light was used. The used immersion liquid had a relatively high dispersion of refractive index. As the preliminary results show, the cotton fiber is characterized by a relatively low dispersion of the refractive index values. In the light of the presented facts, the refractive indices could be measured with the interference fringe shift varying with changes of the wavelength of light.

Using the results of the discussed measurements, the following four equations were calculated:

$$n_{\|} - n_1 = \frac{F_{\|1} \cdot \lambda_1}{h_1 \cdot M \cdot A}$$

$$n_{\|} - n_2 - \frac{F_{\|2} \cdot \lambda_2}{h_2 \cdot M \cdot A}$$

$$n_{\perp} - n_1 = \frac{F_{\perp 1} \cdot \lambda_1}{h_1 \cdot M \cdot A}$$

$$n_{\perp} - n_2 = \frac{F_{\perp 2} \cdot \lambda_2}{h_2 \cdot M \cdot A}$$

where: $n_{\|}$, $n_{\perp}$ = refractive indices of the fiber for light vibrating parallel and perpendicular to the fiber axis; n_1, n_2 = refractive indices of the immersion liquid for light wavelengths λ_1 and λ_2, respectively; h_1, h_2 = interfringe spacings for light wavelengths λ_1 and λ_2, respectively; $F_{\perp 1}$, $F_{\perp 2}$ = areas enclosed by interference fringe shift for light vibrating perpendicular to the fiber optical axis, respectively, for wavelengths λ_1 and λ_2; $F_{\parallel 1}$, $F_{\parallel 2}$ = areas enclosed by the interference fringe shift for light vibrating parallel to the fiber optical axis, respectively, for wavelengths λ_1 and λ_2; λ_1, λ_2 = wavelengths of light used in the measurements; A = fiber cross-sectional area; M = magnification.

From the above equations the values of cross-sectional area of the fibers (A), the two refractive indices ($n_\parallel$, $n_\perp$) and then the birefringence (Δn) for each of the tested fibers were calculated. For this purpose only any three out of the equations given were required. This procedure of solving only any three of the four equations is possible in this case because the following relationship is true:

$$\frac{\lambda_2(F_{\parallel 2} - F_{\perp 2})}{h_2} = \frac{\lambda_1(F_{\parallel 1} - F_{\perp 1})}{h_1}$$

This method also could make possible the analysis of changes of fiber cross-section area and birefringence along its length from base to the top.

The procedure as described above has not been so far used for measuring the optical properties of cotton fibers.

EXPERIMENTAL RESULTS AND DISCUSSION

The following three varieties of cotton were studied: Sudan-Barac 69, Guatemala Stoneville, and California-Arizona (Acala).

A polarizing interference microscope, MPI-3, was used to obtain photographic images of the fibers in accordance with the described procedure. Narrow-band interference filters were used to obtain monochromatic light of wavelengths λ_1 = 546 nm and λ_2 = 590 nm. Methyl salicylate was used as the immersion liquid. The spectral dispersion of the refractive index of the immersion liquid was determined by means of the Pulfrich refractometer, as shown in Figure 2.

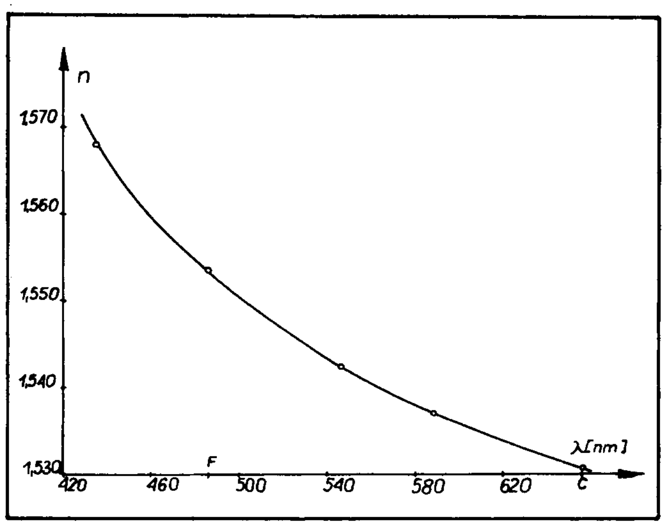

Fig. 2. Spectral dispersion diagram of the refractive index of methyl salicylate: $n^F - n^c$ = 0.023.

TABLE I
The Characteristics of Cotton Fiber

Item	Cotton	$n_{\parallel}$	$n_{\perp}$	n_{iso}	Δn	A (μm^2)	Tenacity (kNm/kg)	Linear density (μg/m)
1	Sudan-Barac 69	1.589	1.534	1.552	0.055	102	212	0.170
2	Guatemala Stoneville	1.587	1.540	1.556	0.047	161	118	0.242
3	California-Arizona (Acala)	1.576	1.539	1.552	0.036	136	141	0.208

The values of mean refractive indices, the birefringence, and the cross-sectional areas of the fibers, calculated from the above equations, are listed in Table I. The table includes also the values of linear density, determined gravimetrically and values of tenacity (kNm/kg) determined by means of a steelometer.

The obtained results do not substantially differ from the published data (with the exception of the birefringence reported by Hamza[6] which is little more than half the value found in the present study). The polarizing interference microscopy method used should enable calculation of the mean optical birefringence for the fibers.

Since it has been suggested[11] that the outer layers of cotton fiber have a higher value of refractive index than the inner layers, the mean refractive index ought to be lower than of the outer layers. If the Becke line technique enables calculation of refractive index for the outer layers,[3] the results obtained by this technique would be higher. However, the two methods would have to be compared in relation to fibers sampled from the same population. Note that the values n_{iso} of Table I are in good agreement with the literature data.[3]

The calculated values of cross-sectional area of the fibers are correlated to the independently determined values of linear density (μg/m). This is evidence that the obtained results are correct.

The finest of the studied cottons, the Sudan-Barac 69, has a much higher birefringence than the other cottons. It has also the highest tenacity. The cotton Sudan-Barac 69 belongs to the variety Gossypium Barbadense, whereas the remaining two cottons are Gossypium Hirsutum. The Gossypium Barbadense fibers are relatively long; they are also fine and strong.

Therefore, the higher values of Δn an $n_{\parallel}$ obtained for Sudan-Barac 69 are in favor of the argument[3] that the long staple cottons have higher values of the indices.

CONCLUSIONS

The presented results prove the suitability of the Pluta microscope for measuring the refractive indices for light vibrating parallel and perpendicular to the fiber axis and the birefringence of fibers with irregular cross sections, such as cotton fibers.

The proposed modification of the Hamza method enables at once measurement of the optical properties and of the cross-sectional areas of individual fibers.

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