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OPTICAL PROPERTIES OF POLYPROPYLENE FIBRES

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A method for measuring the optical properties of polypropylene fibres is presented. The diameter and the cross sectional shape of the fibre were determined from the forward scattering of a laser beam at 632.8 nm. The refractive indices of the outer layer (skin) of the fibre for light vibrating parallel and perpendicular to the fibre axis were measured using the Becke-line technique. Multiple beam Fizeau fringes in transmission and at reflection were applied to the measurement of the refractive indices of the inner layer of the fibre (core) for monochromatic light. The interferometric methods were also applied to study the variation of refractive indices of the fibre.

1. *Introduction*

The optical properties of a single fibre is characterized by its refractive indices of the skin and the core; and by the diameter. These are the basic parameters that specify the transmission characteristics of that fibre. Such optical properties cannot be determined by the Becke-line method because, it is only capable of determining the refractive index of the fibre's skin.

Both the double-beam and multiple-beam interference techniques have been used by Faust [1–3] in order to determine refractive index variation optically heterogeneous specimens. Barakat et al., [4–7] used multiple-beam Fizeau firinges in transmission and at reflection and the fringes of equal chromatic order for the determination of refractive indices and birefringence of fibres. Pluta [8, 9] developed and described the use of a double refracting interference microscope with variable amount and direction of wave front shear for the study of synthetic polymer fibres.

In our present work, the fibre diameter and the geometry of the cross section were determined from the light scattering profiles of single fibres. Also the refractive indices of the different layers of the fibre for light vibrating parallel and perpendicular to its axis were measured.

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2. *Results and discussion*

Measurement of the fibre diameter

The diameter of single polypropylene fibres and the degree of ellipticity were measured from the optical diffraction profile [10–12] produced on a screen. The measurements were taken on fifty fibres. Each fibre was scanned at ten orientations about the fibre axis separated by an angle ranging from 30° to 40° in each step.

Figs. 1a and b show two diffraction patterns for two samples of polypropylene fibres having diameters 51.2 and 48.6 microns respectively. The ellipticity of the cross-section of a fibre could be calculated by recording the pattern of the forward scattered laser light and calculating the coefficient of compression K from the well known relation

$$\alpha = 1 - K = 1 - \frac{b}{a}, \tag{1}$$

where, α is the compression of the ellipse, b/a is the ratio of the minor axis to the major axis in the ellipsoidal shape.

Fig. 2 gives the experimental results. It was found that the average value of the mean diameter is 47.78 ± 0.5 μm and that K is 0.91 ± 0.22. It is clear from Fig. 2a that some of the fibres have circular cross-sections and the others have ellipsoidal shapes.

Measurement of the refractive index of the fibre's skin

The Becke-line method was used to measure the refractive indices of the fibre's skin for light vibrating parallel ($n_s^{||}$) and perpendicular ($n_s^{\perp}$) to its axis and the birefringence (Δn_s). The immersion liquid was a mixture of α-bromonaphthalene ($n_D = 1.658$ at 20°C) and liquid paraffin ($n_D = 1.481$ at the same temperature). The results are given in Table I.

TABLE I

Principle refractive indices $n_s^{||}$ and $n_s^{\perp}$ and birefringence Δn_s of the skin of polypropylene fibres*

Temperature [°C]	$n_s^{\|\|}$	$n_s^{\perp}$	Δn_s
17.0	1.531	1.503	0.028
17.5	1.531	1.503	0.028
19.0	1.530	1.503	0.027
25.0	1.528	1.502	0.026

* The Becke-line method is repeated with known liquids until the nearest approximation to the refractive index is obtained. By this method, values can be measured with an accuracy of ± 0.0005 [12].

Interferometric determination of the mean refractive indices and birefringence for samples of polypropylene fibres

The interferometric methods have been utilized to measure the mean refractive indices $n_a^{||}$ and $n_a^{\perp}$ for light vibrating parallel and perpendicular to the fibre axis. The optical set-up for forming Fizeau fringes with an incident parallel beam, of monochromatic light

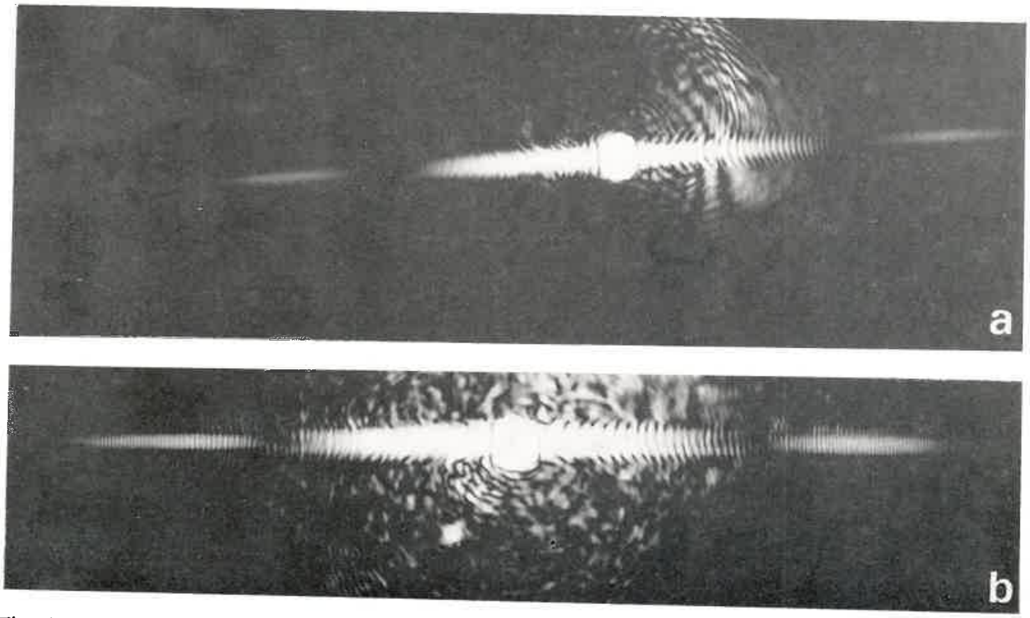

Fig. 1a, b. Two diffraction patterns for two samples of polypropylene fibres having different diameter

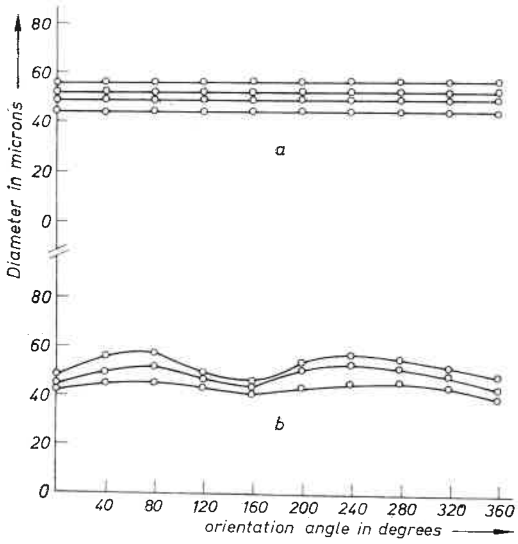

Fig. 2. Polypropylene fibre diameter at different angular orientation a) circular shapes, b) ellipsoidal shapes

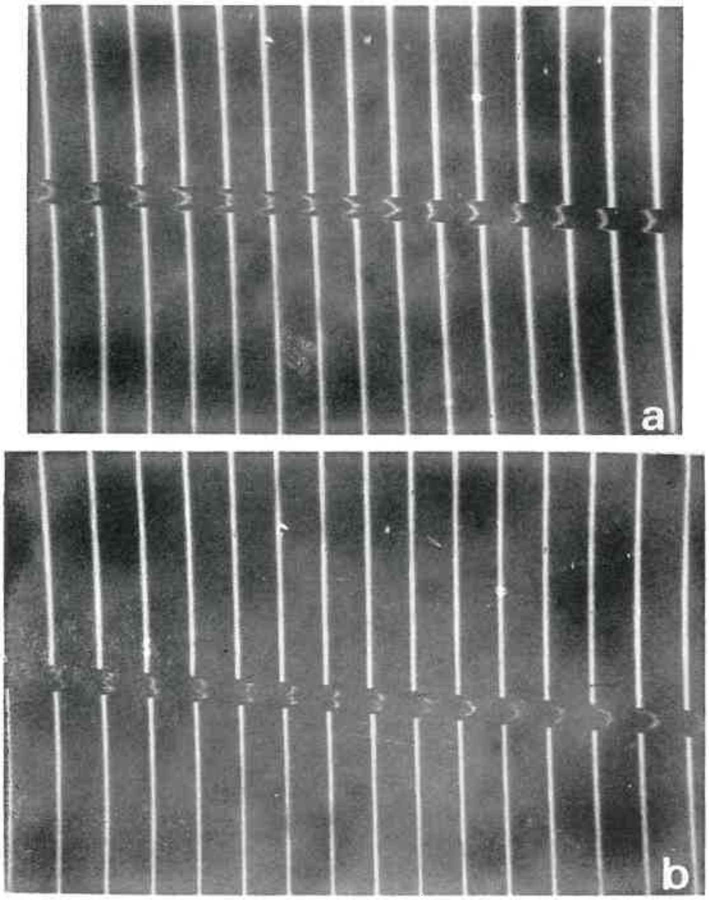

Fig. 3a, b. Transmission multiple beam Fizeau fringes for light vibrating parallel and perpendicular to the fibre axis, respectively

Fig. 4. Reflection for light vibrating perpendicular to the fibre axis

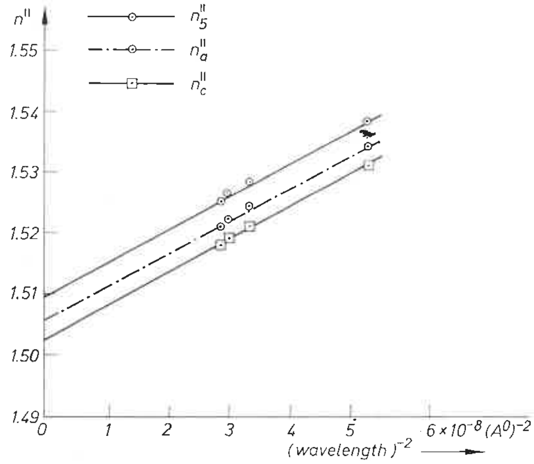

Fig. 5. The variation of refractive indices ($n_s^{||}$, $n_a^{||}$ and $n_c^{||}$) with $1/\lambda^2$

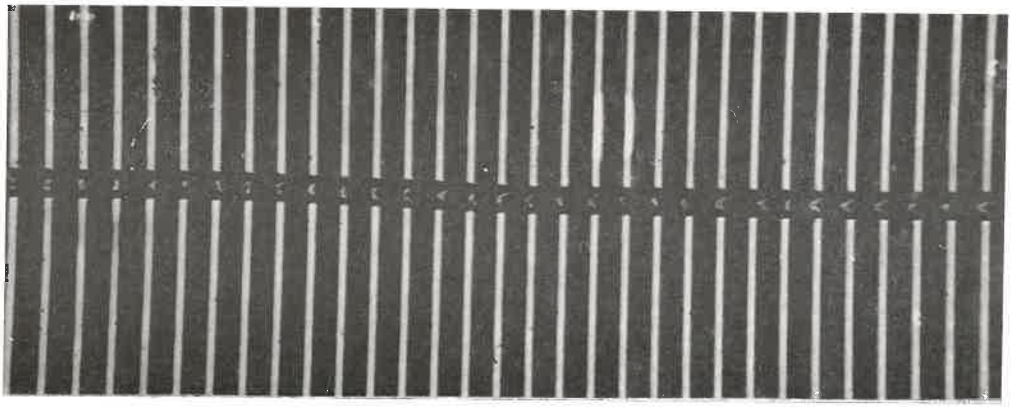

Fig. 6. Transmission multiple beam Fizeau fringes for light of wavelength 546.1 nm. vibrating parallel to the fibre axis

of wavelength 546.1 nm, normal to the interferometer was used [6]. The value of the mean refractive index (n_a) of the fibre can be determined, by obtaining the value of the fringe shift dz as a fraction of an order separation Δz between two consecutive straightline fringes from the relation:

$$\left(\frac{dz}{\Delta z}\right)\lambda/2 = (n_a - n_L)t_f, \tag{2}$$

where t_f is the fibre thickness traversed by the beam.

If we consider that the core is immersed in the skin, equation (2) becomes:

$$\left(\frac{dz_c}{\Delta z}\right)\lambda/2 = (n_c - n_s)t_c, \tag{3}$$

where, dz_c is the fringe shift in the core, n_c is the refractive index of the core material, n_s is the refractive index of the skin, and t_c is the core thickness.

The mean refractive index of the fibre can be calculated from the relation

$$n_a = n_s(t_s/t_f) + n_c(t_c/t_f). \tag{4}$$

Fig. 3a shows transmission multiple-beam Fizeau for light vibrating parallel to the fibre axis using monochromatic light of wavelength $\lambda = 546.1$ nm. The refractive index of the immersion liquid was $n_L = 1.5220$. The temperature of the experiment was 19.5°C. It is to be noted that the shift for the light passing through the skin of the fibre is towards smaller interferometric gap (t_g); while for light passing through the core of the fibre, the shift is towards the greater (t_g). This means that, $n_s^{||} > n_L$, $n_c^{||} < n_s^{||}$. The displacement in the core of the fibre $\frac{dz_c}{\Delta z} = 0.626$ and the thickness of the core t_c (measured from the interferogram) = 62.2 microns, $n_s^{||} = 1.530$, therefore, $n_c^{||} = 1.527$.

Fig. 3b is for this fibre but for the other direction of light vibration. For light passing through the skin of the fibre; the shift is towards greater t_g, while for light passing through the core of the fibre, the shift is towards smaller t_g. This means that, $n_s^{\perp} < n_L$ and n_c, and $n_c^{\perp} > n_s^{\perp}$.

In the core of the fibre the displacement $\frac{dz_c}{\Delta z} = 0.547$; and from the Becke-line results $n_s^{\perp} = 1.503$, therefore, $n_c^{\perp} = 1.505$ and thus $\Delta n_c = 0.023$.

For this fibre we have $t_s = 15.8$ microns, $t_s/t_f = 0.203$ and $t_c/t_f = 0.797$. Substituting in equation (4), we get $n_a^{||} = 1.528$ and $n_a^{\perp} = 1.504$, therefore, the mean birefringence $\Delta n_a = 0.024$.

Fig. 4 shows reflection multiple-beam Fizeau fringes for light vibrating perpendicular to the fibre axis using monochromatic light of wavelength $\lambda = 546.1$ nm, n_L being 1.5141. The temperature of the experiment was 31°C. The fringe shift was towards greater t_g, i.e. $n_L > n_a^{\perp} \cdot \frac{dz_a}{\Delta z} = 0.324$; $t_f = 57.0$ microns, therefore, $n_a^{\perp} = 1.512$.

Application of multiple-beam Fizeau fringes to determine the constants of Cauchy's dispersion formula for polypropylene fibres

Table II gives the results of experimental determination of the refractive indices $n_s^{||}$, $n_a^{||}$ and $n_c^{||}$ for different wavelengths of light. A relation shown in Fig. 5 between the refractive indices ($n_s^{||}$, $n_a^{||}$ and $n_c^{||}$) and $1/\lambda^2$ was constructed to evaluate the constants A and B of Cauchy's formula

$$n_\lambda = A + B/\lambda^2. \qquad (5)$$

TABLE II

Variation of the refractive indices $n_s^{||}$, $n_a^{||}$ and $n_c^{||}$ with the wavelength λ for polypropylene fibres

Wavelength nm	n_L	$\frac{dz^{||}}{\Delta z}$	$n_a^{||}$	$n_s^{||}$	$n_c^{||}$
589.3	1.5158	1.019	1.521	1.525	1.518
578.0	1.5167	1.090	1.522	1.526	1.519
546.1	1.5188	1.137	1.524	1.528	1.521
436.0	1.5301	1.181	1.534	1.538	1.531

The values of A and B are shown in Table III.

TABLE III

Values of the Cauchy's formula constants

Layer	Skin	Mean	Core
A	1.510	1.506	1.503
B	5.5×10^5	5.5×10^5	5.5×10^5

Variation of the mean refractive index along the axis of polypropylene fibres

Fig. 6 is an interferogram which shows transmission multiple-beam Fizeau fringes for light vibrating parallel to the fibre axis for a polypropylene sample. $n_L = 1.5240$ at 17.5°C and $\lambda = 546.1$ nm. The shift was found to be towards the apex of the wedge, i.e. $n_L < n_a^{||}$. It is to be noted that variation in the shape of the shift exists along the fibre; i.e., $n_a^{||}$ varies along the fibre axis. Table IV gives the measured values of $n_a^{||}$ over 1.2 mm length of the fibre.

TABLE IV

The mean refractive index of a polypropylene fibre along its axis

Distance in microns	$n_a^{\|\|}$	Distance in microns	$n_a^{\|\|}$	Distance in microns	$n_a^{\|\|}$
0	1.531	476	1.530	869	1.529
67	1.530	542	1.530	938	1.530
132	1.528	605	1.530	1003	1.529
201	1.528	671	1.530	1072	1.529
276	1.530	734	1.529	1139	1.529
343	1.530	803	1.529	1207	1.529
410	1.530				

The accuracy and limitations of the interferometric method

There are several factors that can influence the effectiveness of the interferometric method. These are:

a) The thickness of the tested fibre should be less than 0.1 mm.

b) The refractive index measurements under favourable conditions being accurate to within ± 0.0001.

c) The use of a small interferometric gap is recommended in order to assure that the image faithfully portrays the structure of the fibre.

d) Irregularities in the surfaces of the interferometer plates will lead to their own fringe displacements, and therefore, they should be avoided.

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