Effect of UV radiation on the optical and some structural properties of irregular rayon acetate fibers

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A B S T R A C T

This recent study shed demonstration on how the structural parameters changes due exposure to UV radiation and different wavelengths. So this article throws light on the changes of the optical properties and some structural properties due exposure to UV radiation and different wavelengths on irregular rayon acetate fibers. Pluta polarizing interference microscope is used to study the changes for refractive indices and birefringence with different exposure times at three different intensities on irregular rayon acetate fibers. As the principal optical parameters determined, these give an indication of the isotropic refractive index, stress optical coefficient, stress due to UV radiation, optical configuration parameter, segment anisotropy, the number of molecules per unit volume and polarizability of a monomer unit can be obtained. Also by using different wavelengths are given the spectral dispersions, Cauchy's dispersion constants, the resonant wavelength, the oscillation energy, the dispersion energy, the dielectric constant and the dielectric susceptibility for rayon acetate fibers with different wavelengths at room temperatures. Illustrations are given using graphs and microinterferograms.

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1. Introduction

Rayon was one of the first man-made fibers; these fibers are a diverse group consisting of regenerated cellulose derived from wood pulp. Rayon acetate fibers consist of acetate which is chemically stable [1]. Natural, synthetic and man made fibers plays an important role in the electrical and textile industries where most fibers are now mixed.

Several authors have studied the effect of UV radiation on the physical and chemical properties of polymers in the form of fibers, films, and solutions [2–4]. They report that the mechanical properties of irradiated fibers deteriorate with increasing exposure times. The UV radiation from the sun is capable of exciting electrons to higher energy orbital levels.

Obviously, excitation will occur if the material concern is capable of absorbing radiant energy and this in turn depends on the nature of the bonds and groups within the polymer. Deteriorations in polymers are often caused by the joint effect of radiation from the sun together with oxygen [5].

Light and penetrating radiations are important physical influence on polymers, which are capable of inducing chemical reactions in them. At short wavelengths (230–410 nm), the light quanta may detach fragments from, molecules or break up the macromolecules. Such changes are usually produced by light radiation with these wavelengths. Thus, light can alter the physical and mechanical properties of the polymers. In the storage and service of polymeric articles, the action of light, heat, oxygen, and so may cause crosslinking of the macromolecules. This also detracts from the properties of a polymer by inducing brittleness, rigidity, and the ability to crystallize sharply [6].

Oriented polymers are produced industrially by extrusion of initially nonoriented fibers or films. The molecular mechanism responsible for the variation in the optical properties is clarified by observation of the birefringence. Birefringence depends on the molecular orientation in polymeric fibers because it contains a contribution from the polarizabilities of all molecular units in the samples [7]. It is a measure of the total molecular orientation of a system and is an excellent property to use for the study of polycrystalline polymers.

Varies techniques have been established to estimate the molecular orientations in polymer solids, including X-ray diffraction [8,9], sonic velocity measurements [10], NMR Raman spectroscopy [11], UV–visible [12], IR absorption dichroism [13] and birefringence [14]. The uses of interferometric methods are of considerable importance and they have been used in our laboratory several studies [15,16].

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The present article focuses attention on the effect of the exposure to UV radiation and different wavelengths for rayon acetate fibers, to calculate the optical parameters and density for determining essential industrial parameters. The stress optical coefficient, dielectric constant and susceptibility are calculated with other structural parameters. Measurements are carried out at three different intensities (15, 30 and 45 W/cm^2) for different periods ranged from 15 to 120 min. Also has been studied in the wavelength range 546–599 nm.

2. Theoretical considerations

The two beam interference technique by Pluta polarizing microscope [17,18] was used for determination the basic optical parameters of rayon acetate fibers. The experimental values of the refractive indices and birefringence were used to calculate the polarizability of monomer unit and other parameters by suitable equations given elsewhere [19–21].

2.1. Mean polarizability of monomer unit

As the refractive index of a polymer depends on the total polarizability of the molecules, the polarizability of the dielectric $\alpha^{\|}$ is given by [22]:

$$\frac{n_{\|}^2 - 1}{n_{\|}^2 + 2} = \frac{v\alpha^{\|}}{3\psi} \tag{1}$$

with analogous formula used for $n^{\perp}$. Where $n^{\|}$, $n^{\perp}$ are the mean refractive indices for light vibrating along and across the axis's of the fiber, v is the number of chains per unit volume ($v = N_A\rho/M$), N_A is Avogadro's number, ρ is the polymer density, M is the monomer molecular units (molecular weight = 288) for rayon acetate fibers [1], and Ψ is the permittivity of free space (8.85×10^{-12} Fm^{-1}).

2.2. Stress optical coefficient

The value of the stress optical coefficient C_s is depends on the chemical structure of the polymer. Also, the value of this coefficient depends solely on the mean refractive index and the optical anisotropy of the random link, as seen in the following equation [22]:

$$C_s = \frac{2\pi}{45KT} \left[\frac{(\bar{n}^2 + 2)^2}{\bar{n}} \right] [\alpha^{\|} - \alpha^{\perp}] \tag{2}$$

where $\bar{n}$ is the mean refractive index, k is the Boltzmann constant and T is the absolute temperature.

2.3. The segment anisotropy

The segment anisotropy γ_s is related to the stress optical coefficient and given by the following equation [22]:

$$C_s = \frac{\gamma_s}{90\psi KT} \frac{[\bar{n}^2 + 2]^2}{\bar{n}} \tag{3}$$

So, we can determine γ_s.

2.4. Determination due to UV stress

A transformation of initially crystalline and amorphous fibers by UV radiation treatment to introduce structural changes is also known, as polymer chains align in the direction of an applied UV stress due to the mobility of the molecules. The average chain orientation of both the amorphous and crystalline regions in the network was measured by birefringence (Δn) in the present work, so we

can obtain the deformation due to UV stress σ from the following equation

$$C_s = \frac{\Delta n}{\sigma} \tag{4}$$

2.5. Optical configuration parameter

The optical configuration parameter ($\Delta\alpha$) is related to the C_s by the following equation [23]:

$$\Delta\alpha = \left(\frac{45KTC_s/2\pi}{(n^2 + 2)^2} \right) \bar{n} \tag{5}$$

where $\Delta\alpha = \alpha^{\|} - \alpha^{\perp}$.

The total number of molecules per unit volume J is determined from the birefringence Δn and the difference in the polarizabilities of the macromolecules as follows [4]:

$$J = \frac{\bar{n}\Delta n}{2\pi} \left[\frac{(\bar{n})^2 + 2}{3} \right]^{-2} (p^{11} - p^{\perp})^{-1} \tag{6}$$

where $p^{\|}$ and $p^{\perp}$ are the polarizabilities per unit volume.

2.6. Density and degree of crystallinity

The isotropic refractive index n_{iso} given by [24]:

$$n_{\text{iso}} = (n^{\perp 2} n^{\|})^{1/3} \tag{7}$$

The density ρ is expressed in terms of n_{iso} as obtained De Vries from the following equation [19]:

$$\frac{n_{\text{iso}}^2 - 1}{n_{\text{iso}}^2 + 2} = \varepsilon\rho \tag{8}$$

where ε is a constant found to be 0.218 cm^3/gm for rayon acetate fibers and the degree of crystallinity χ was determined by following the relation [25]:

$$\chi = \frac{(\rho - \rho_a)}{(\rho_c - \rho_a)} \tag{9}$$

where ρ_c and ρ_a are the densities of the crystalline and non-crystalline regions ($\rho_c = 1.35$ gm/cm^3 and $\rho_a = 1.25$ gm/cm^3 for rayon acetate fiber), ρ is the experimental measured value of density.

2.7. The mean square density fluctuation

For two phase structure consisting of amorphous and crystalline regions with densities ρ_a and ρ_c. The mean square density fluctuation $\langle\eta^2\rangle$ can be calculated from the following equation [26]:

$$\langle\eta^2\rangle = [\rho_c - \rho_a]^2 \chi[1 - \chi] \tag{10}$$

2.8. The spectral dispersion curves of fibers

For studying one of the most important characteristics for rayon acetate fiber, optical and dielectric dispersion, we use the main values of refractive indices at different values of wavelength λ in Cauchy' equation [27]:

$$n_\lambda = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \cdots \tag{11}$$

where A, B and C are known as Cauchy coefficients which characterizing the fiber materials. However, in the transparency region of