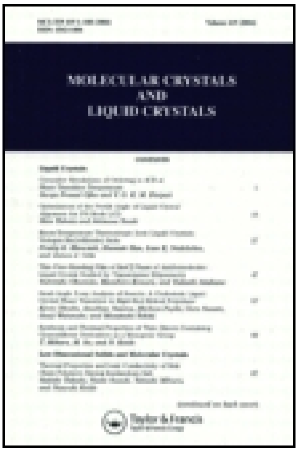

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Constrained Liquid Crystals and Polymer Networks: A Texture Study of Elasticity and Ordering

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CONSTRAINED LIQUID CRYSTALS AND POLYMER NETWORKS: A TEXTURE STUDY OF ELASTICITY AND ORDERING

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Abstract Nematic liquid crystals confined to cylindrical cavities, and polymer networks constrained by the presence of an oriented liquid crystal, are studied. Frank elastic theory is used to predict stable nematic structures and to calculate their corresponding interference patterns (textures) for structures observed with a polarizing microscope. The comparison of theoretical and experimental textures are used to investigate nematic ordering which result in the measurement of the bend-to-splay (K_{33}/K_{11}) bulk elastic constant ratio, the saddle-splay-to-splay (K_{24}/K_{11}) surface elastic constant ratio, and the degree of orientational order of polymer networks induced by the nematic liquid crystal during the formation of these networks.

INTRODUCTION

It was first disclosed in the early 1970s by Cladis and Kleman[1] and Meyer[2] that the nematic director field in a cylindrical cavity with homeotropic-type surface boundary conditions was a continuous structure where the nematic director escapes along the cylinder axis to avoid a line disclination as presented in Figure 1 (a). Optical studies[3] of nematic liquid crystal confined in capillary tubes later revealed the existence of singular point defects along the cylinder axis due to the existence of two energetically equivalent configurations with opposite directions of bend as shown in Figure 1 (b). It was not until the 1990s when the work on cylindrically confined liquid crystal was revitalized.[4] The saddle-splay surface elastic constant (K_{24}) and the molecular anchoring strength (W_θ) were found to play an important role in the stability of the escaped-radial director field in submicrometer cavities, and their values were measured with deuterium nuclear magnetic resonance.[4] The aim of this short contribution is to demonstrate that a careful texture analysis of nematic liquid crystals confined to supramicrometer capillary tubes, in conjunction with predictions of Frank elastic theory, lead to the determination of bulk and surface elastic constants, as well as the molecular anchoring strength. Furthermore, we show that textures can be used to study the ordering of polymer networks within these configurations.

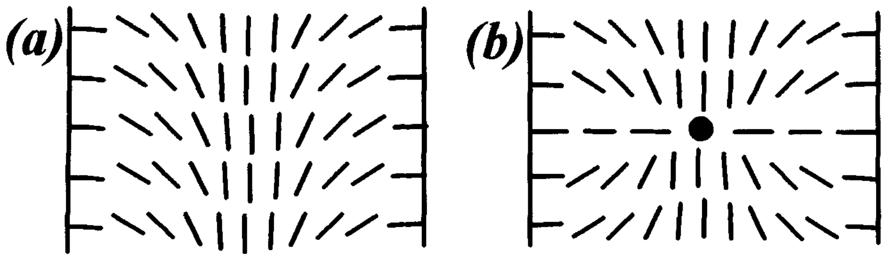

FIGURE 1 The continuous escaped-radial director configuration (a) and one with a singular point defect (b).

EXPERIMENTAL

Capillary tubes of radii ranging from 5 to 200 μm were treated with lecithin, and filled with a nematic liquid crystal. The lecithin promotes homeotropic surface anchoring. The tubes are then surrounded by a glycerin matrix with an index of refraction that matches that of the glass of the capillary tubes. The samples are placed between crossed polarizers of an optical microscope and illuminated with either a mercury lamp (λ_o=435 nm) or sodium lamp (λ_o=589 nm). For the polymer network studies, a small amount of diacrylate monomer (2% by wt.) and photoinitiator (0.5 % by wt.) were dissolved into the nematic liquid crystal prior to filling the lecithin treated capillaries. This solution is then filled into the capillary and photopolymerized with a ultra violet radiation source for approximately 40 minutes. These dispersion samples are then studied in the isotropic phase using an optical polarizing microscope equipped with a white light source.

MICROSCOPE TEXTURES

The observed optical polarizing microscope textures were simulated using the same method as employed by Ondris-Crawford and et. al[5] and Xu et. al.[6] The textures are calculated for the incident light wave vector $\mathbf{k}_o$ being perpendicular to the symmetry axis of the escaped-radial configuration. The computer simulated texture is sensitive to the extraordinary index of refraction, n_e, the ordinary index of refraction, n_o, the wavelength of the incident light, λ_o, the radius of the capillary, R, the orientation of the initial polarization vector with respect to the cylinder axis, α_o, the ratio K_{33}/K_{11}, and the surface parameter σ is defined[4] as RW_θ/K_{11}-K_{24}/K_{11}-1. The values of n_e, n_o, λ_o, and R are independently measured, while K_{33}/K_{11} and σ are used as fitting parameters.

The observed optical interference pattern for the liquid crystal compound ZLI-2583-100 in a R=100 μm tube, illuminated by sodium light, is presented in Figure 2 (a) for the α_o=45° orientation. The value of K_{33}/K_{11} in the simulation (see Figure 2(b)) was varied until the interference fringe number and position corresponded to the experimental observations. A value of K_{33}/K_{11} =0.75±0.04 was determined. Since R is large, the value of σ is also large placing us into the strong anchoring limit;[4] therefore, K_{33}/K_{11} is the only fitting parameter. A detailed analysis of the interference patterns has recently been published which provides a more accurate measure of K_{33}/K_{11}.[7]

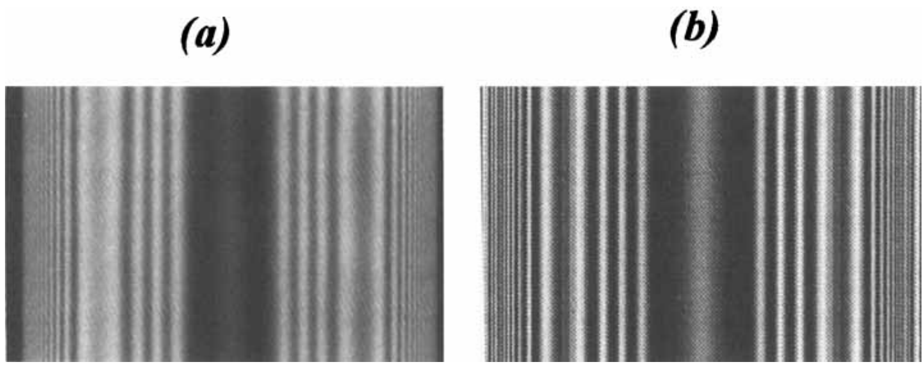

Figure 2 Microscope texture photographs (a) directly compared to simulations (b) for the escaped-radial configuration in a R=100 μm tube for K_{33}/K_{11}=0.75.

The observed optical interference patterns for the liquid crystal compound 5CB in a R=10 μm tube illuminated with a mercury light source is presented in Figure 3 for the α_o=45° orientation. Using a previously measured value of K_{33}/K_{11}=1.4,[7] the interference pattern is solely sensitive to σ. The value of σ was varied in the simulation until the interference fringe number and position coincided with the experimental observations. The parameter σ has two unknowns, K_{24} and W_θ, so the interference pattern was also fitted for other capillary tube sizes in order to determine both K_{24} and W_θ.[8] The value of W_θ was determined to be $(6.6\pm3.0)\times10^{-6}$ J/m^2 using $K_{11}=6.0\times10^{-12}$ J/m, and K_{24}/K_{11}=3.1±4.0. The large error bars on this preliminary determined ratio K_{24}/K_{11} are indicative of relatively strong anchoring (σ>10). This optical estimate of K_{24}/K_{11} is consistent with earlier measurements of K_{24}/K_{11}[4,9] and stability considerations.[8]

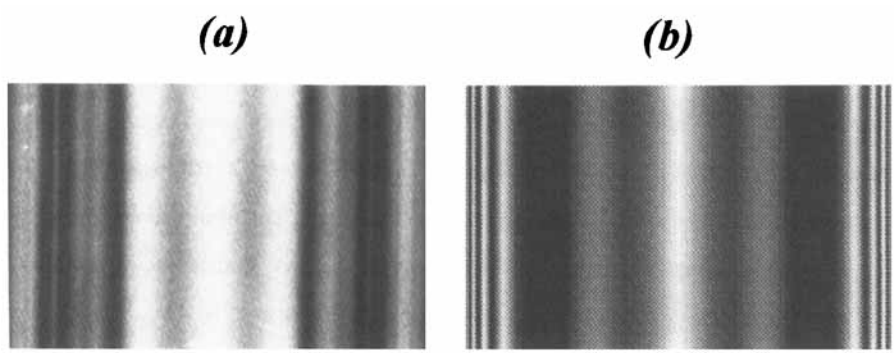

Figure 3 Microscope texture photographs (a) directly compared to simulations (b) for the escaped-radial configuration in a R=10 μm tube where σ=3.1.

We have also used the escaped-radial configuration to prepare aligned polymer networks. After photopolymerization of the dissolved diacrylate monomer, the microscope textures of the quenched escaped-radial configuration were studied when the bulk liquid crystal was in the isotropic phase (see Figure 4 for the α_o=45° orientation). The textures reveal that the network completely and indefinitely memorizes the nematic director field and even order parameters where the polarization took place. A detailed study of the birefringence of the polymer network is in progress.[10]

We have demonstrated the usefulness of studying microscope textures of liquid crystals confined to capillary tubes of various sizes. Important material and surface parameters can be extracted by comparing observed textures of the escaped-radial configuration to simulated textures predicted from Frank elastic theory. We have also demonstrated that the escaped-radial configuration can be stored in a polymer network.

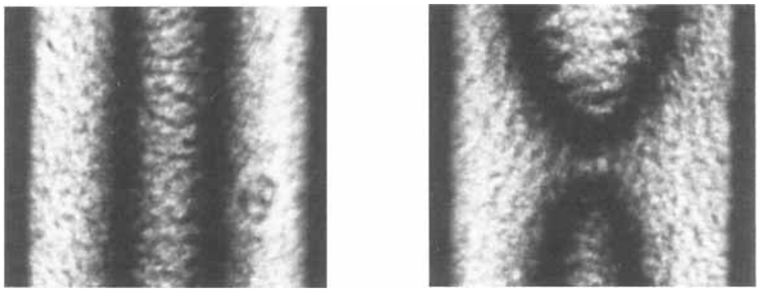

Figure 4 Microscope textures of the escaped-radial configuration stored in a polymer network in a R=100 μm capillary tube when the liquid crystal is above the nematic-isotropic transition temperature. A white light source was used. See Color Plate V.

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