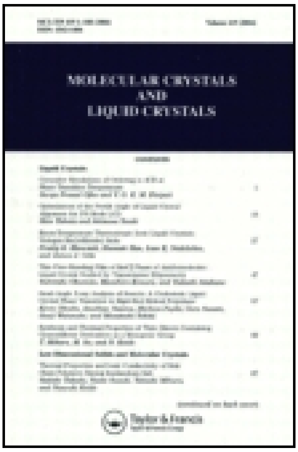

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Effect of the Rubbing Fabric for Surface Liquid Crystal Alignment on Various Orientation Films

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Effect of the Rubbing Fabric for Surface Liquid Crystal Alignment on Various Orientation Films

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We have studied the effect of the rubbing fabric for pretilt angle generation, polar anchoring strength (energy), and the surface order parameter in nematic liquid crystals (NLC), 4-cyano-4'-n-penthylbiphenyl (5CB), on rubbed polyimide (PI) surfaces. The pretilt angle of 5CB for nylon and rayon fabric is larger than that of cotton fabric in weak rubbing on rubbed PI surfaces. The polar anchoring energy and surface order parameter of 5CB for nylon fabric are larger than those of cotton fabric on rubbed PI surfaces. We suggest that the polar anchoring energy and surface order parameter of 5CB increase with hard rubbing fabric. Finally, we conclude that the polar anchoring energy of 5CB is strongly related to the surface order parameter on rubbed PI surfaces.

Keywords: Rubbing fabric, surface alignment, nematic liquid crystal, pretilt angle, extrapolation length, surface order parameter

1. INTRODUCTION

Uniform alignment of liquid crystals (LCs) on treated substrate surfaces is important in LC basic research and technology.[1] Most LC devices with pretilted homogeneous LC alignment are prepared using various surface alignment layers such as rubbed PI surfaces,[1–14] obliquely evaporated SiO surfaces,[15] PI Langmuir-Blodgett (LB) surfaces,[16,17] rubbed polystyrene (PS) surfaces,[18] and rubbed polypyrrole (PP) surfaces.[19]

The pretilt angle prevents the creation of disinclinations in LC cells. The pretilt angle is also very important in order to prevent stripe domains in super twisted nematic LC displays (STN-LCD).[20] and surface-stabilized ferroelectric liquid crystal displays (SSFLCD).[21] The generation of the pretilt angle in nematic LC (NLC) on various alignment layers by unidirectional rubbing was demonstrated and discussed by many

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investigators.[2–9,11–14,19] For aligning LC molecules, the rubbed polymer surfaces have been widely used, but the detailed mechanism of LC alignment by rubbing is not yet fully understood.

The anchoring energy (strength) between the LCs and the alignment layer on treated substrate surfaces is very important in understanding the LC alignment.[7,9,10,22–27] The effect of the rubbing fabric for the pretilt angle, anchoring energy, and surface order parameter on alignment layers by unidirectional rubbing is not yet reported.

Recently, we reported on the estimation of static electricity and induced optical retardation produced in alignment layers by rubbing with different rubbing fabrics.[28] It was demonstrated that the static electricity and the optical retardation produced in PI surface rubbed with nylon fabric were much larger than in those rubbed with cotton fabric.

In this paper, we report the effect of rubbing fabrics for pretilt angle generation, polar (out-of-plane tilt) anchoring energy, and the surface order parameter of 5CB for the three kinds of rubbing fabrics on various alignment layers.

2. EXPERIMENTAL

Four orientation films were investigated:

RN-305 (PI, Nissan Chemical Industries Co., Ltd.)
:highest polarization with alkyl-branchless;
RN-713 (PI, Nissan Chemicals Industries Co., Ltd.)
:medium polarization with alkyl-branched;
RN-722 (PI, Nissan Chemical Industries Co., Ltd.)
:with alkyl-branched and homeotropic alignment material;
HL-1110 (PA, Hitachi Chemical Co., Ltd.)
:highest polarization with alkyl-branchless.

The PI and polyamide (PA) films were coated on indium-tin-oxide (ITO) coated glass substrates by spin-coating. The PI films were imidized at 250°C for one hour. The PA was imidized at 150°C for one hour. The PI and PA films were rubbed with one of three fabrics using a machine equipped with a roller (Y_o-15-N, Yoshikawa Chemical Industries Co., Ltd.). The definition of the rubbing strength, RS, was given in previous papers:[8,9,11]

$$RS = NM(2\pi rn/v - 1), \tag{1}$$

where N is the number of times the substrates were rubbed ($N = 1$, in this work), M is the depth of the fibers of the fabric deformed due to the pressed contact (mm), n is the rotation rate of the drum (1000/60 s^{-1}), v is the translation speed of the substrate (7.0 mm/s), and r is the radius of the drum.

The LC was assembled in cells with antiparallel-rubbed surfaces for measuring the pretilt angle. The LC was assembled in cells with hybrid-structure (one side is planar and the other side is a homeotropic alignment layer) for measuring the polar anchoring energy and the surface order parameter. We used the hybrid-structure LC cell, because the polar anchoring energy of 5CB is very large on rubbed PI surfaces.[10]

The rubbing fabrics used were:

Cotton: with cellulose structure, natural fiber;
Rayon: with cellulose structure, synthetic fiber;
Nylon: with polyamide structure, synthetic fiber.

The LC layer was $60 \pm 0.5\,\mu m$. We used the crystal rotation method to measure the pretilt angle.[29] We used a microscope to observe the surface structure of fabrics. The magnifications of the microscope for the tip and surface of the fabric are × 300 and × 3.6, respectively. To measure the polar anchoring energy, we used the "high electric-field technique"[23,24,27] by Yokoyama *et al.* Figure 1 shows the experimental setup for measuring the optical retardation (R) and electrical capacitance (C). The light source is a He-Ne laser (632.8 nm) with 2-mW output power. The optical retardation measurement system consists of a polarizer, an acoustic modulator, and an analyzer and the output signal is detected by a photodiode. The electric capacitance of the LC cell is obtained by measuring the out-of-phase component of the current produced by changing the voltage applied to the cell. We evaluated the extrapolation length d_e by using the relationship between the measured values of the electric capacitance (C) and the optical retardation (R):[23,24,27]

$$\frac{R}{R_o} = \frac{I_o}{CV} - \frac{d_e}{d}, \quad \text{when} \quad V \gg 6V_{th}\,. \tag{2}$$

where I_o is a proportional constant depending on the LC materials; V and d stand for the applied voltage and LC medium thickness, respectively.

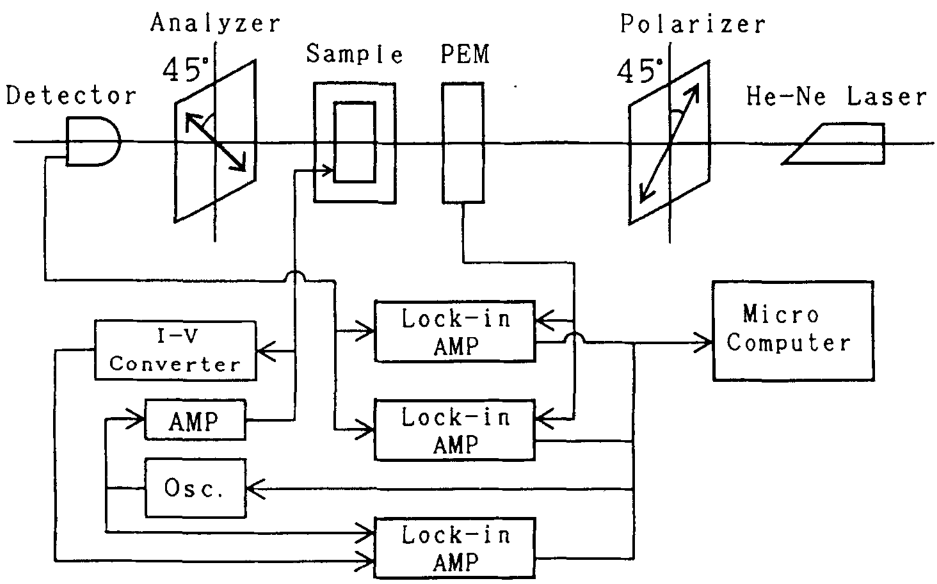


FIGURE 1 Experimental setup for measuring the optical retardation (R) and electrical capacitance (C).

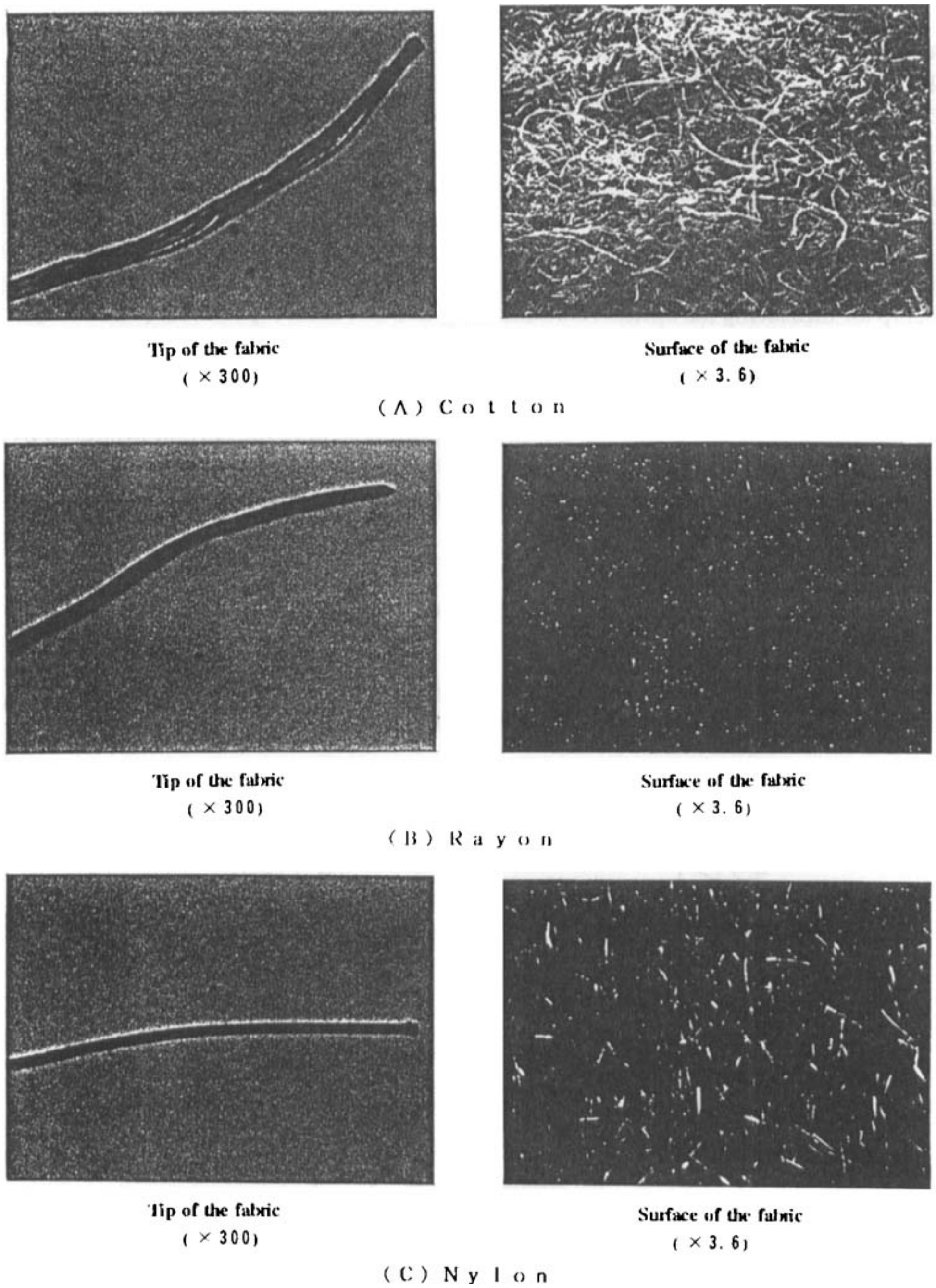


FIGURE 2 Microphotograph for tip and surface of the fabrics with a microscope. Fabrics are (a) cotton; (b) rayon; (c) nylon.

The polar anchoring energy A is obtained from the following relation:

$$A = K/d_e, \tag{3}$$

where K is the effective elastic constant which is given by $K = K_1 \cos^2 \theta_o + K_3 \sin^2 \theta_o$, where K_1, K_3, and θ_o stand for the elastic constant of the splay and bend deformation, and the pretilt angle, respectively. We used measured elastic constants in this work.

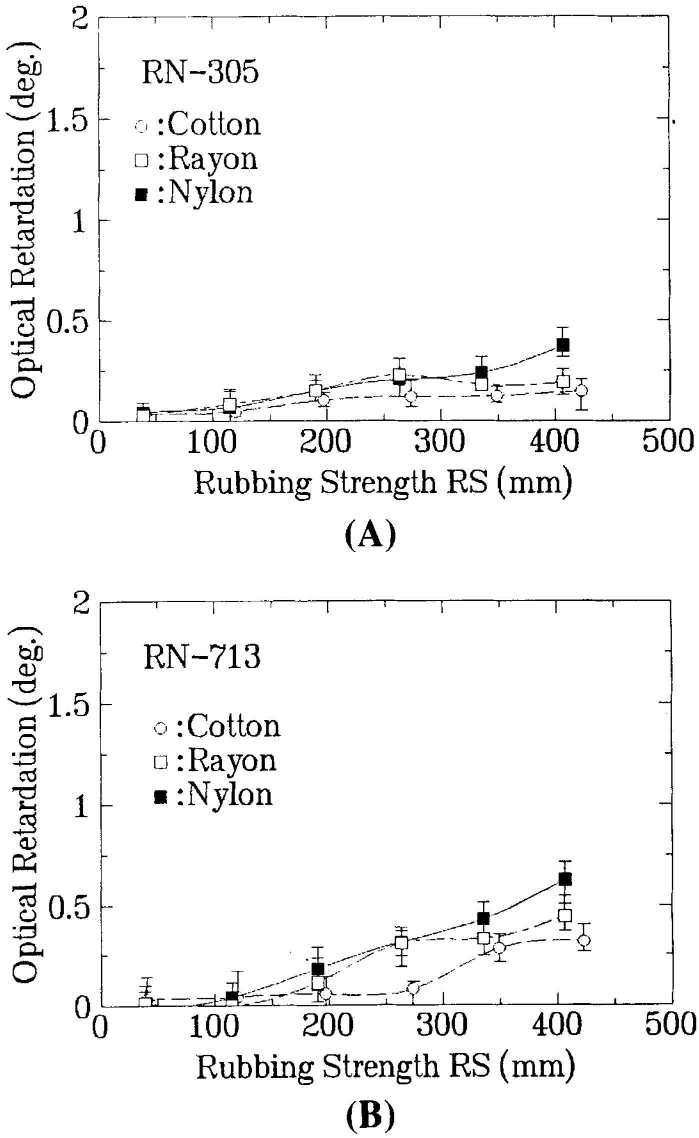
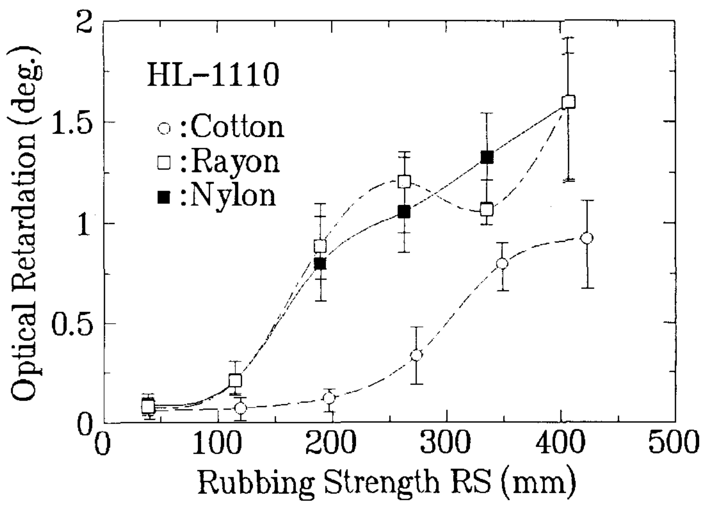


FIGURE 3 The induced optical retardation on alignment films for the three kinds of the rubbing fabrics as a function of RS. (a) RN-305; (b) RN-713; (c) HL-1110.



(C)

FIGURE 3 *(Continued)*

We determined the surface order parameter of 5CB by measuring the temperature dependence of the residual optical retardation at above the clearing temperature (35.3°C) on rubbed PI surfaces.[30,31]

RESULTS AND DISCUSSION

Figure 2(a), (b), and (c) shows the microphotograph for the tip and surface of the fabrics with a microscope for three kinds of the fabrics. It is shown that the surface structure of nylon and rayon fabric is uniform, whereas that of cotton fabric is not. We consider that nylon and rayon fabrics are very hard compared with cotton fabric. The surface structure of the rayon fabric is almost the same as that of nylon.

Figure 3(a), (b), and (c) shows the induced optical retardation on alignment layers for the three kinds of the rubbing fabrics as a function of RS. The induced optical retardation increases with the RS for all three rubbing fabrics on rubbed PI (RN-305) surfaces. The induced optical retardation for nylon fabric is larger than that of cotton fabric. The induced optical retardation on rubbed PI (RN-713) and PA (HL-1110) surfaces increases with the RS for all three rubbing fabrics (Fig. 3(b) and (c)). Also, the induced optical retardation for nylon fabric is larger than that of cotton fabric. Therefore, the induced optical retardation for nylon and rayon fabrics is lager than that of cotton fabric on all three alignment layers. From these results, we suggest that the induced optical retardation increases with hard rubbing fabric on alignment layers, because of increased orientation of the PI polymer chain. We also suggest that the polymer chains are oriented by the mechanical stress and elevated surface temperature produced by rubbing.

Figure 4(a), (b), and (c) shows the pretilt angles for the three kinds of rubbing fabrics as a function of RS. In Figure 4(a), the pretilt angle of 5CB increases with the RS for all three kinds of the rubbing fabrics on PI (RN-305) surfaces. It is shown that the pretilt angle of 5CB for nylon and rayon fabrics is larger than that of cotton fabric. Figure 4(b) shows that the pretilt angle increases rapidly at RS = 180 mm and decreases slowly with the RS for nylon and rayon fabrics on PI (RN-713) surfaces. The pretilt angle of

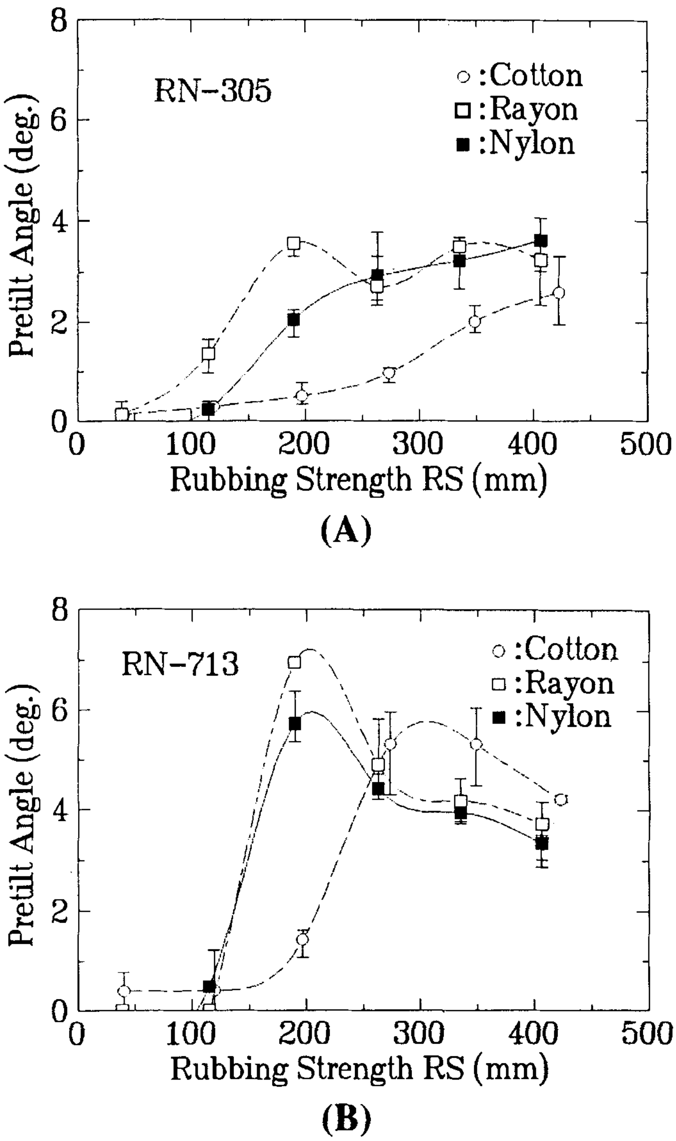
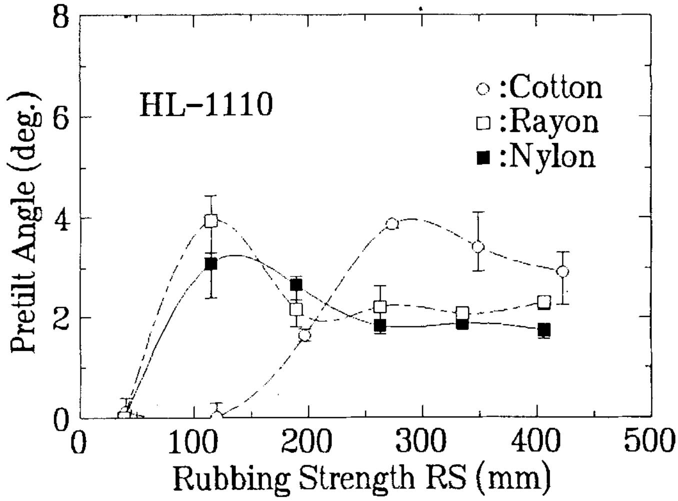


FIGURE 4 Pretilt angles for the three kinds of the rubbing fabrics on three alignment layers as a function of RS. (a) RN-205; (b) RN-713; (c) HL-1110.



(C)

FIGURE 4 *(Continued)*

5CB for cotton fabric increases rapidly at 280 mm and decreases with the RS on PI (RN-713) surfaces. The pretilt angle of 5CB for nylon and rayon fabrics is larger than that of cotton fabric in weak rubbing on PI (RN-713) surfaces. Figure 4(c) shows that the pretilt angle of 5CB for nylon and rayon fabrics increases rapidly at $RS = 100$ mm and saturates on PA (HL-1110) surfaces. The pretilt angle of 5CB for cotton fabric increases with the *RS* and decreases at $RS = 300$ mm on PA (HL-1110) film. From these results, we suggest that the pretilt angle of 5CB increases with hard rubbing fabric and weak rubbing. Therefore, we conclude that the generation of the pretilt angle of 5CB depends strongly on the hardness of the rubbing fabric.

Figure 5 shows the temperature dependence of the extrapolation length d_e of 5CB on rubbed PI surfaces with different rubbing fabrics. We measured the extrapolation length d_e of 5CB for nylon and cotton fabric. From results of the induced optical retardation and pretilt angle generation, we consider that the characterization of rayon fabric is similar to nylon fabric. The extrapolation length d_e of 5CB for nylon fabric does not vary up to the clearing point, but the extrapolation length d_e for cotton fabric increases with increasing temperature. It is shown that the polar anchoring energy of 5CB for nylon fabric is larger than that of cotton fabric on PI film. Thus, the polar anchoring energy of 5CB increases with hard rubbing fabric.

In Figure 6, we show the residual optical retardation of 5CB at above the clearing temperature T_c (35.3°C) for different rubbing fabrics on rubbed PI surfaces. It is shown that the residual optical retardation of 5CB for nylon fabric at above the clearing temperature is observed, but no residual optical retardation is observed for cotton fabric. We consider that the residual optical retardation of 5CB at above the clearing temperature coincides with the anisotropy on the surface. The residual retardation of 5CB on alignment layers is related to the surface order parameter.[25,26]

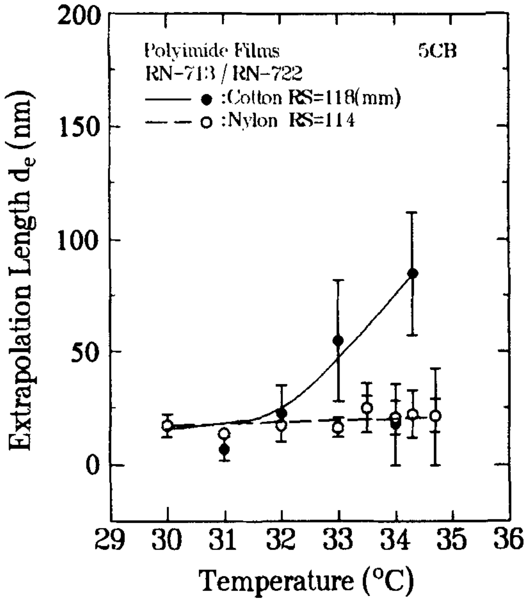


FIGURE 5 Temperature dependence of the extrapolation length d_e of 5CB on rubbed PI surfaces with different rubbing fabrics.

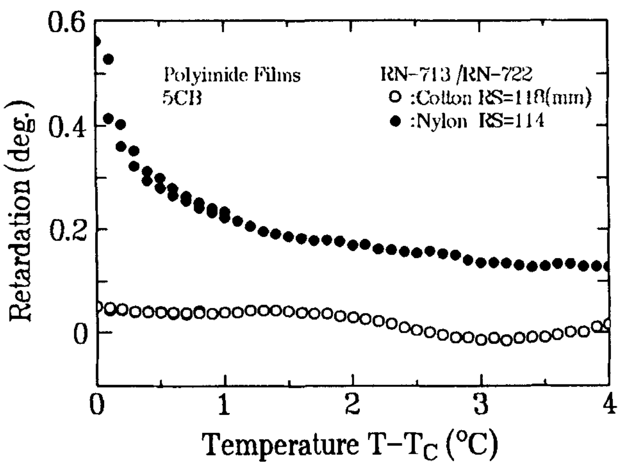


FIGURE 6 The residual optical retardation of 5CB at above the clearing temperature (T_c = 35.3°C) for different rubbing fabrics on rubbed PI surfaces.

The surface order parameter of 5CB for different rubbing fabrics on rubbed PI surfaces as a function of *RS* is shown in Figure 7. It is shown that the surface order parameter for nylon fabric increases rapidly at *RS* = 120 mm and saturates, but that for cotton fabric is about 0 for wide-range RS. From these results, we suggest that the surface order parameter of 5CB increases with hard rubbing fabric on rubbed PI

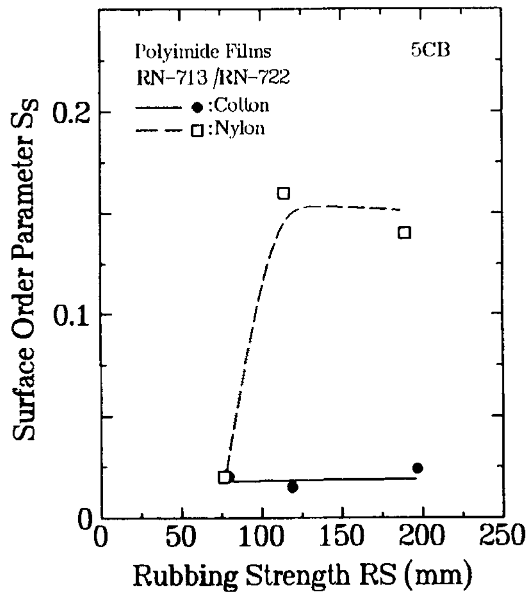


FIGURE 7 Surface order parameter of 5CB for different rubbing fabrics on rubbed PI surfaces as a function of RS.

surfaces. It is considered that the surface order parameter is increased by increasing the orientation of polymer chain with hard rubbing fabric. Consequently, the polar anchoring energy and surface order parameter of 5CB for nylon fabric are larger than those for cotton fabric. From these results, we obtained that the rubbing fabric effect on pretilt angle, polar anchoring energy, and the surface order parameter are clearly observed. Finally, we obtained that the polar anchoring energy of 5CB increases with increasing the surface order parameter on rubbed PI surfaces. Therefore, the polar anchoring energy of 5CB is strongly related to the surface order parameter on rubbed PI surfaces.

4. CONCLUSION

We investigated the effect of the rubbing fabric for LC alignment in NLC, 5CB, on various alignment layers. We suggest that the polar anchoring energy and surface order parameter of 5CB increase with hard rubbing fabric on alignment layers. We also conclude that the polar anchoring energy of 5CB is strongly related to the surface order parameter on rubbed PI surfaces.

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