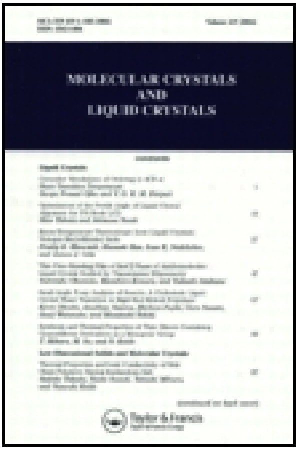

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On the Possibility of Controlling the Surface Alignment Properties of Liquid Crystal using the Amount of Frictional Work Generated During Rubbing

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In order to improve the stability of the rubbing process, the authors have employed a new parameter – the amount of frictional work W – as a rubbing controlling parameter instead of rubbing strength L which has been used in the past. The applicability of this new parameter to control the surface alignment properties of liquid crystal is experimentally confirmed. The relationship between surface alignment properties, including anchoring energy (azimuthal direction) and pretilt angle, and rubbing condition parameters is investigated, and it is proven that by using the amount of frictional work, anchoring energy and pretilt angle under various rubbing conditions can be summarized uniformly. It is also shown that differences in anchoring energy as a result of using different kinds of rubbing cloth can be cancelled by using the amount of frictional work as a reference parameter.

Keywords: Alignment property; Anchoring energy; Pretilt angle; Amount of frictional work; rub; rubbing cloth

1. BACKGROUND AND PURPOSE

Processing technology for liquid crystal surface alignment is indispensable in the manufacture of liquid crystal display. Being the most widely applied technology for mass-production of display, the rubbing method is a liquid crystal alignment technique that utilizes friction. The advantage of the rubbing method is that it is possible to process at high speeds and with large areas. However, the rubbing method is from experience, the quantitative control of the rubbing process in manufacturing is rarely completed. In order to produce high-quality liquid crystal displays it is necessary to control the alignment distribution with high accuracy.

Many researchers have conducted investigations in order to determine the controlling parameter in the rubbing process. Uchida[1] proposed the parameter of rubbing strength L, which is the length that rubbing cloth passes one arbitrary point of alignment film during rubbing. Under constant filament indentation conditions, the rubbing strength L exhibits a linear relationship with anchoring energy. Kato[2] proposed the parameter of amount of frictional work W, which is able to express all of the rubbing conditions (Expression (1)) and present the possibility of a correlation with anchoring energy. However in Kato's proposal, the amount of frictional work is calculated from a filament deformation model, so the real frictional work cannot be obtained because the frictional coefficient generated between the alignment film and rubbing cloth is not gained.

$$W = F_x \times L = \mu \times F_z \times Nl(1 + \frac{2\pi rn}{60v}) \qquad (1)$$

Here:
F_x: Frictional force applied to alignment film during rubbing, N
F_z: Normal load applied to alignment film during rubbing, N
L: Rubbing strength, mm; r: Radius of roller, mm
n: Roller rotation velocity, min^{-1}; v: Stage feed speed, mms^{-1}
N: Cycles of rubbing, cycle; l: Contact length, mm
μ : Frictional coefficient

Based on these previous findings, the main purpose of this study is to confirm that the alignment properties of liquid crystal can be controlled by using the amount of frictional work generated during rubbing.

2. EXPERIMENTAL APPARATUS AND CONDITIONS

Figure 1 shows the detailed photograph of the rubbing machine used in this experiment. A feature of this particular apparatus is that it can measure the normal load and frictional force applied to an alignment film during rubbing in real time. From expression (1), the amount of frictional work generated on the alignment film during rubbing can be calculated using measured frictional force. Rubbing conditions are shown in the figures for each experiment.

3. EXPERIMENTAL RESULTS

3-1. Relationships between surface alignment properties and rubbing parameters

The relationships between anchoring energy and each of the rubbing parameters were investigated. It can be shown that anchoring energy increases with increasing the roller rotation velocity and filament indentation. However, it can be shown that anchoring energy decreases with increasing stage feed speed. The relationships of rubbing parameters to pretilt angle were also investigated. In this case, pretilt angle exhibits the same relationships as anchoring energy; increasing with roller rotation velocity and filament indentation and decreasing with increasing stage feed speed.

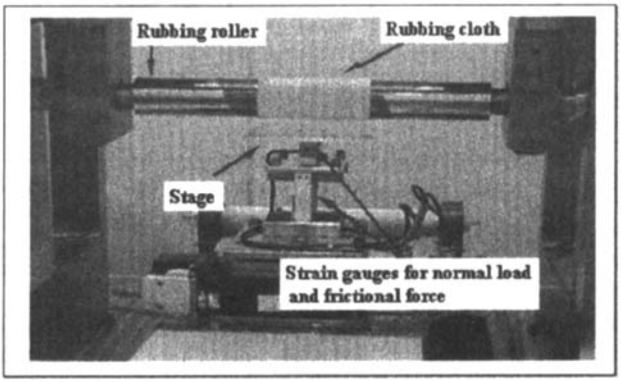

Fig. 1. Photograph detailing the parts of rubbing machine

3-2. Relationship between alignment properties and amount of frictional work

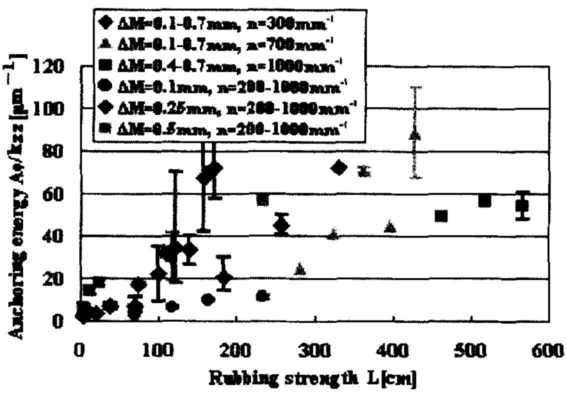

Fig. 2. Relationship between anchoring energy and rubbing strength

Figure 2 shows the relationship of anchoring energies obtained under various rubbing conditions to rubbing strength. Anchoring energy can be seen to vary significantly in respect to rubbing strength under different filament indentation conditions. However, by applying the amount of frictional work, anchoring energy can be well modeled for all rubbing conditions (figure 3).

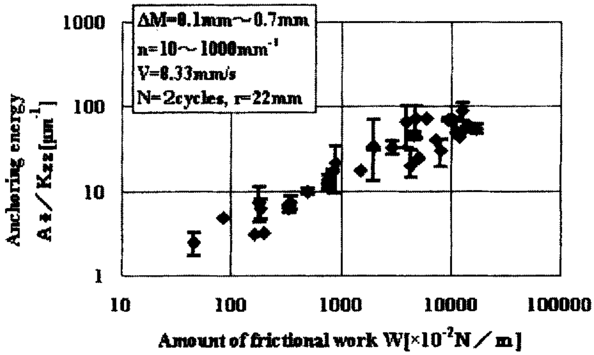

Fig. 3. Relationship between anchoring energy and amount of frictional work

Figure 4 shows the relationship between pretilt angle under various rubbing conditions and the amount of frictional work. Pretilt angle appears to be proportional to frictional work. It can be seen that in order to achieve stable pretilt angles, it is necessary to apply sufficient frictional work to the alignment film.

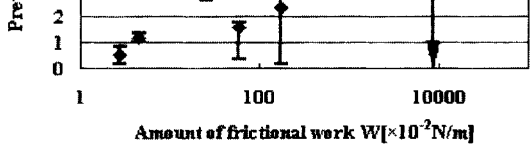

Fig. 4. Relationship between pretilt angle and the amount of frictional work

3-3. Influence of rubbing cloth type on anchoring energy

Figure 5 shows the anchoring energies produced using two kinds of rubbing cloths (R-18 and R-18C) under identical rubbing conditions (as shown). It can be seen that using the R-18C rubbing cloth can produce a higher anchoring energy than using R-18.

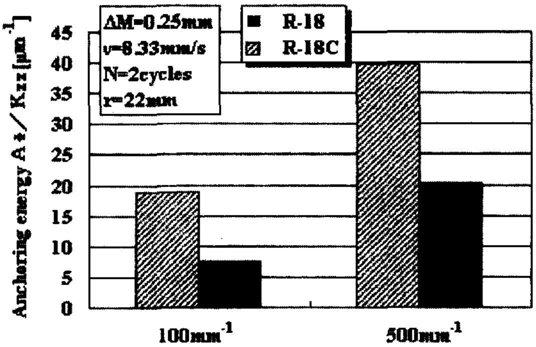

Fig. 5. Influence of rubbing cloth type on anchoring energy

Figures 6 shows the influence of rubbing cloth type on the normal load and frictional forces applied to the alignment film. It can be seen that using R-18C produces a larger normal load on alignment film than by using R-18 for the same filament indentation. In this figure, the rate of normal load increase with increasing filament indentation indicates the relative strength of the rubbing cloths. Hence, the relative strength of R-18C is stronger than R-18. Figure 6 also shows that R-18C applies a higher friction force on alignment film than R-18. For this reason, R-18C can produce larger anchoring energies than R-18.

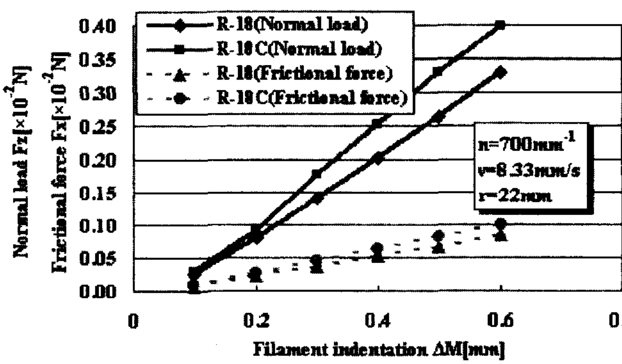

Fig. 6. Influence of rubbing cloth type on normal load and frictional forces

4. DISCUSSION

The normal load is applied to the alignment film during rubbing by the deformation of the filaments in the rubbing cloth. In other words, the normal load can be considered to be the sum of reactive forces from the deformation of single filaments[2]. In this model, a filament can be assumed to be a flexible bar. The deformation model of this flexible bar[3] is presented in figure 7.

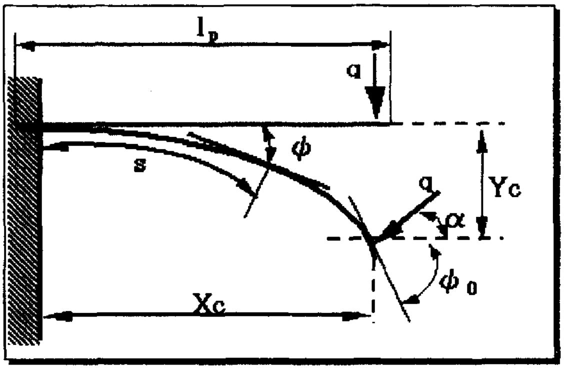

Fig. 7 The deformation model of flexible bar[3]

The model in figure 7 has length l_p, elastic modulus E, second end face moment I and normal load q, which is always normal to the free edge of the bar. The coordinate system along the bar is shown as s, and the angular displacement of s is φ. Thus, the moment that acts on the beam can be shown as

$$EI(\frac{d\varphi}{ds}) = q\sin(\alpha)(X_c - X) + q\cos(\alpha)(Y_c - Y) \qquad (2)$$

From analysis of R. Frisch-Fay[3], the normal load q that is applied by the bar in the model can be obtained. The vertical pressure P_n applied to the alignment film can be considered to be the sum of q, and is expressed by

$$P_n = 0.31C\rho(\frac{\Delta M}{l_p^3})Ed^4 \qquad (3)$$

Here: ΔM: Filament indentation, mm — ρ : Filament density, filament/cm^2

d: Filament diameter, mm — E: Elastic modulus, Gpa

l_p: Filament length, mm — C: Constant

The normal loads applied to the alignment film by R-18 and R-18C are calculated from expression (3) and shown in figure 8. For comparison, the measured experimental values are also plotted. As can be seen, the values calculated from expression (3) and the measured values correspond quite closely.

Therefore, expression (3) is effective for evaluating the relative characteristics of rubbing cloth.

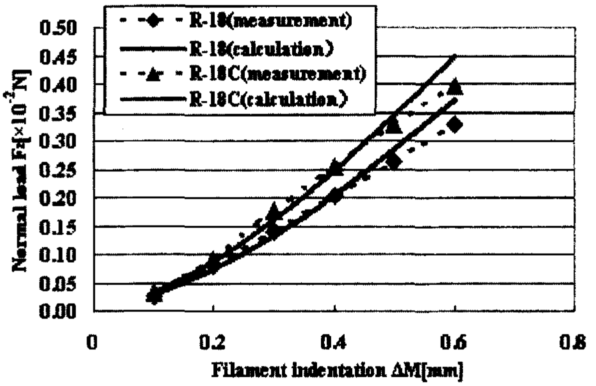

Fig. 8. Comparison of calculated and measured normal load

It has been shown that the normal load applied to the alignment film during rubbing depends on filament diameter, length, density and elastic modulus. In particular, the normal load is influenced strongly by the length and diameter of the filaments.

Figure 9 shows the relationship between the anchoring energy produced using the two rubbing cloths (R-18 and R-18C) and rubbing strength. It can be seen that the anchoring energies of each rubbing cloth type are well separated in reference to rubbing strength. However, by applying the amount of frictional work to the horizontal axis, the difference in anchoring energy due to rubbing cloth type can be cancelled (figure 10).

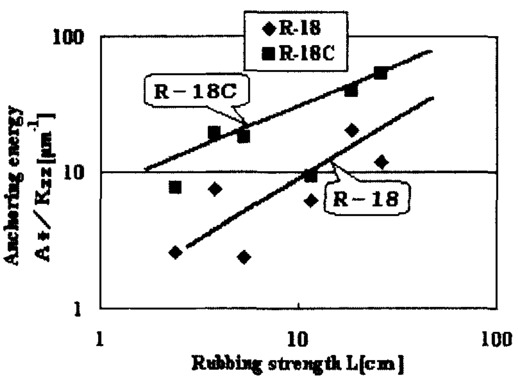

Fig. 9. Relationship between anchoring energy for two kinds of rubbing cloth (R-18 and R-18C) and rubbing strength L.

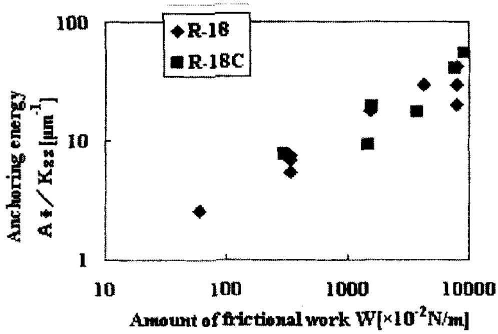

Fig. 10. Relationship between anchoring energy for two kinds of rubbing cloth (R-18 and R-18C) and amount of frictional work

Therefore, it has been confirmed that using the amount of frictional work W as a rubbing controlling parameter is more effective than using the rubbing strength L.

5. CONCLUSION

By using the amount of frictional work, the surface alignment properties of liquid crystal under various rubbing conditions can be summarized uniformly, even for different rubbing cloth types. It has been proven that the amount of frictional work can be successfully used as a controlling parameter for the control of the surface alignment properties of liquid crystal.

6. ACKNOWLEDGEMENT

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