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Changes in friction coefficient by applying electric fields across liquid crystal lubricating films

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Experiments are described with a pin-on-disk-type friction testing machine in which a nematic liquid crystal, 4-pentyl-4'-cyanobiphenyl, is used as lubricant. Considerable changes in friction coefficient appear with application of low DC voltages across the lubricating film.

1. INTRODUCTION

Liquid crystals have been paid attention by researchers in various kinds of fields because of their many attractive properties. Recently, their application to display devices has been greatly successful, in which *optical* properties of liquid crystal thin films are changed with application of electric fields.

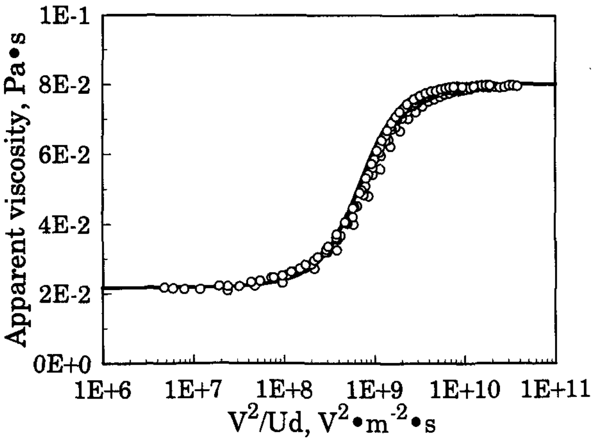

Fig. 1 Electrorheological effect of 5CB at 30 °C. Symbol: experimental, line: theoretical neglecting surface anchoring effect, V: voltage, U: velocity, d: film thickness[4,5].

The authors have been interested in the possibility of changes in *mechanical* properties of liquid crystal thin films by applying electric fields[1-5]. Actually, apparent viscosity of p-type nematic liquid crystals in a rotating viscometer significantly changes with electric fields[1,2,4,5] as shown in Fig. 1 for 4-pentyl-4'-cyanobiphenyl (5CB) in a nematic phase, for example. This phenomenon called the electrorheological effect makes us expect the application of liquid crystalline material to hydrodynamic lubrication as a *friction-coefficient-controllable lubricant.*

On the other hand, observation of friction coefficient in a *real* sliding system lubricated with a liquid crystal is also interesting[3]. In the present paper, experiments are described with a pin-on-disk-type friction testing machine in which 5CB is used as lubricant. Changes in friction coefficient by applying DC voltages across the lubricating film are discussed.

2. EXPERIMENTAL DETAILS

A schematic diagram of the pin-on-disk-type friction testing machine used in the present experiments is shown in Fig. 2. A bearing ball (diameter: 4.76 mm) made of SUJ2 steel was used for the pin specimen. A mirror-polished N-type Si wafer (diameter: 100 mm, thickness: 0.5 mm, specific resistance: 2 Ω•cm, crystallographic surface: (100)) was used as the disk specimen without any insulating coatings.

The pin was pressed on the disk with a load by a weight and a lever at a position with the distance 40 mm from the rotating axis of the disk, and the disk was rotated at a constant speed with a motor. Friction acting on the pin was measured by two strain gauges pasted on both sides of a leaf spring, whose signals were taken into a personal computer through an amplifier and an A/D converter. Environment temperature was controlled by a heater and was monitored with a thermocouple.

The disk was grounded and the pin was electrically isolated by an insulator. A voltage was applied between the specimens with a DC power supply.

Before installing the specimens, the steel ball, ball holders and wafer holders were washed thoroughly in acetone with an ultrasonic cleaner for 5 minutes and dried in a hot air stream. The Si wafer was used without any treatments since it was regarded as clean enough.

The specimens were mounted, 2 cm^3 of 5CB was poured on the Si wafer, and the pin was loaded. The disk was kept still for 5 minutes after the temperature reached the predetermined value, and it was rotated. The friction coefficient in a *quasi-stable* condition after a certain running-in period was determined.

In order to identify the position in the circular track on the disk, a trigger system was provided. When a marker fixed to the disk passed through the clearance of a photo-interrupter mounted on the base of the apparatus, a trigger signal was sent to the personal computer, which started the measurements of the friction.

3. RESULTS AND DISCUSSION

The observed friction coefficient with 5CB

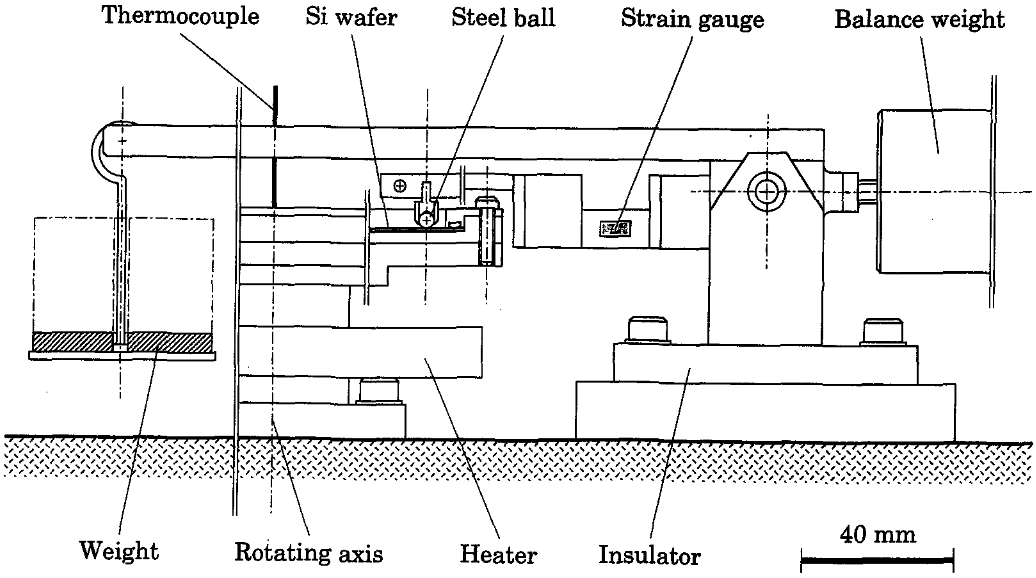

Fig. 2 Schematic diagram of the pin-on-disk-type friction testing machine.

is shown in Fig. 3 when the temperature was 25 °C (nematic phase), the load was 1 N, the sliding speed was 10 mm/s, and the disk was made the anode. The ordinates denote the friction coefficient obtained with the sampling frequency 100 Hz, and the abscissas denote the time after the personal computer received the trigger signal. Under

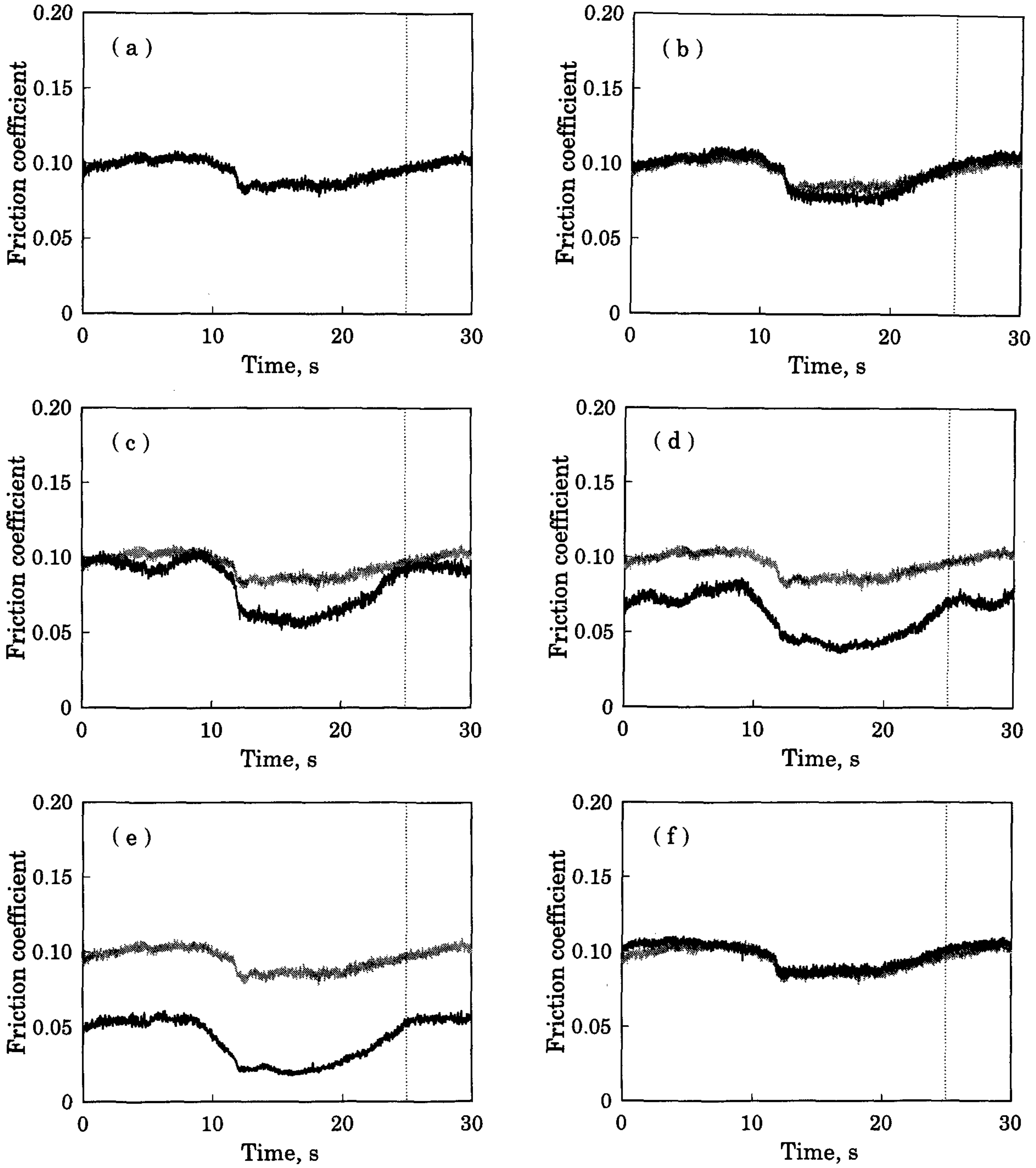

Fig. 3 Friction coefficient with 5CB as lubricant. Temperature: 25 °C, load: 1 N, sliding speed: 10 mm/s, voltage: DC (a) 0 V, (b) 0.5 V, (c) 1.0 V, (d) 1.5 V, (e) 5.0 V, (f) 0 V, anode: disk.

these conditions, the maximum Hertzian contact pressure reaches 1 GPa, and the rotating period of the disk becomes about 25 s shown by perpendicular dashed lines in the graphs.

Figure 3 (a) shows the friction coefficient without voltage. It did not become constant but was disturbed around a low value 0.094 with short-period and long-period fluctuations. The latter period is that of a rotation of the disk, which seems to be dependent on the *local* difference of physical or chemical properties of the disk specimen.

The changes in the friction coefficient with DC voltages are shown in Fig. 3 (b) - (e) where the applied voltages are 0.5 V, 1.0 V, 1.5 V, 5.0 V, respectively. Although the friction coefficient little changed with DC 0.5 V, it clearly decreased around the time 15 s with DC 1.0 V. In the case with DC 1.5 V, the effect of the voltage appeared in all the locations of a rotation of the disk, and the decrease in friction coefficient was more marked with DC 5.0 V.

After these tests, the friction coefficient was measured again without voltage, Fig. 3 (f). The friction coefficient trace almost coincides with that before the test with voltages, which shows that the decrease in the friction coefficient by applying voltage is essentially reversible.

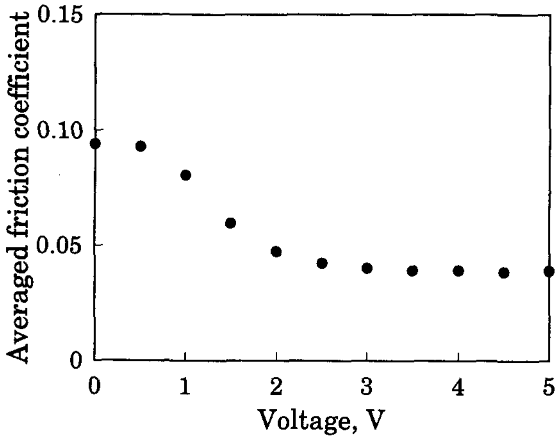

Fig. 4 Change in the averaged friction coefficient with DC voltage.

To evaluate these changes in the friction coefficient more quantitatively, an averaged friction coefficient is introduced, which is defined by the averaged value of all the friction coefficient data in a rotating period of the disk taken into the personal computer. Figure 4 shows a change in the averaged friction coefficient with applied voltage. While the averaged friction coefficient decreases with increasing the voltage as seen in Fig. 3, it seems to have a limiting value about 0.039. In the case with DC 5.0 V, a decrease in the averaged friction coefficient of 58 % is caused with application of the voltage.

4. CONCLUSION

The friction coefficient with a nematic liquid crystal 5CB as lubricant considerably decreases with application of DC voltages. The phenomenon is expected to be a *tribological tool* for *active control of friction coefficient,* together with the electrorheological effect of liquid crystal.

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