

NOTES

## Frictional Properties of Polymer Langmuir–Blodgett Film for Poly(*N*-dodecylacrylamide)

Tokuji MIYASHITA,\* Xing-Dong LI, and Atsushi AOKI

*Department of Molecular Chemistry and Engineering, Faculty of Engineering,  
Tohoku University, Aramaki-Aoba, Aoba-ku, Sendai 980-77, Japan*

(Received May 19, 1995)

KEY WORDS Kinetic Friction Coefficient / Lubrication / Polymer  
Langmuir–Blodgett Films / Poly(*N*-dodecylacrylamide) /

Recently Langmuir-Blodgett (LB) films have received much attention from the viewpoint of functional ultrathin films. Since LB films are prepared by transferring the monolayer formed on the water surface successively to solid supports, uniform thin films with controlled thickness and well-defined molecular orientation have been provided. Many attempts to utilize the superior properties of LB film to functional organic devices have been carried out.<sup>1</sup>

We have continued to study the preparation of functional polymer LB films. Poly(*N*-dodecylacrylamide) (pDDA) forms the most stable condensed polymer monolayer with a high collapse pressure in poly(*N*-alkylacrylamides) on a water surface and the monolayer can be transferred to a solid support yielding a stable Y-type polymer LB film.<sup>2</sup> The thickness of pDDA monolayer is estimated to be 1.72 nm from X-ray diffraction analysis and a highly ordered structure is supported by measurement of FT-IR spectra.<sup>3</sup> In this paper, the frictional properties of pDDA LB monolayer and multilayers are investigated to utilize the pDDA LB film for an ultrathin lubrication film of hard-disk with higher storage density. A requirement for use in hard-disk with higher

storage density is that the separation between the head and magnetic layer must be kept to a minimum to avoid “spacing loss” in the recording process. LB films may possibly be applied to lubrication film of hard-disks. Frictional properties of LB films made of low molecular compounds such as stearic acid and so on have been studied.<sup>4–8</sup> There is, however, no report on LB films using polymer materials. Polymer LB films have higher thermal and mechanical stability compared with low molecular weight LB film.<sup>9</sup> We aim to demonstrate that polymer LB films have high performance for the surface modification. We report here that pDDA LB films are excellent lubricants.

### EXPERIMENTAL

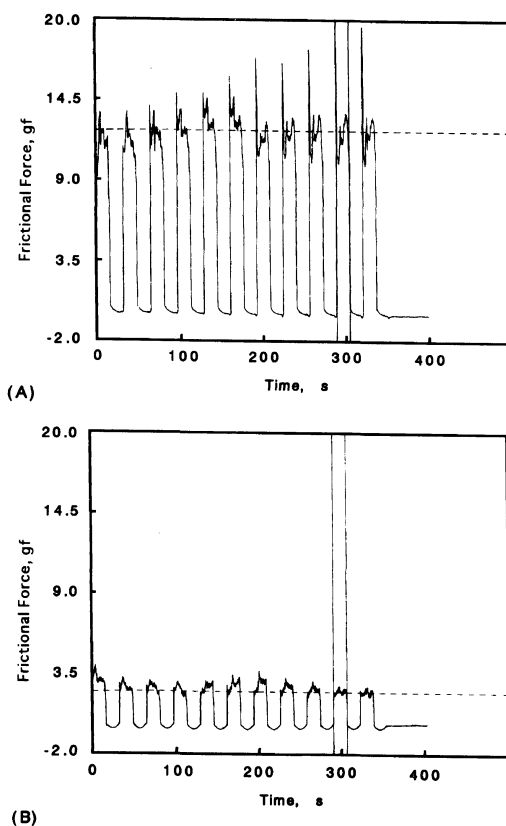
Fabrication of pDDA LB film and general properties are described in detail in the previous paper.<sup>2</sup> pDDA homopolymer was prepared by free radical polymerization in benzene at 60°C with AIBN initiator. A slide glass (Matsunami) was used as a deposition substrate. It was treated by dichlorodimethylsilane in chloroform solution before the deposition of pDDA LB films. This treatment made the glass surface

\* To whom correspondence should be addressed.

hydrophobic. The deposition of pDDA monolayers was carried out with a computer-controlled Langmuir trough (FSD-110, USI). A chloroform solution of pDDA polymer was spread on a water surface. The condensed monolayer on the water surface was transferred onto the hydrophobic slide glass at a surface pressure of  $30 \text{ mN m}^{-1}$  with a transfer ratio of unity by downward and upward strokes at a dipping speed of  $10 \text{ mm min}^{-1}$  at  $25^\circ\text{C}$ . Cast films of pDDA were prepared by pipetting a chloroform solution of pDDA and allowing the chloroform to evaporate at room temperature. Frictional force of the pDDA LB films and cast films of pDDA was measured with a back-to-forth sliding friction meter (HEIDON-14D, Shintoukagaku) using a sapphire tip consisting of a sphere with  $30 \text{ mm}$  radius at a sliding speed of  $1.0 \text{ mm s}^{-1}$  under various loading weights of 5, 10, and 20 g in eleven transits. The kinetic friction coefficients ( $f$ ) of the pDDA LB films were calculated by dividing the average value ( $F$ ) of these frictional forces during the tenth transit by loading weight ( $W$ ); i.e.,  $f = F/W$ .

## RESULTS AND DISCUSSION

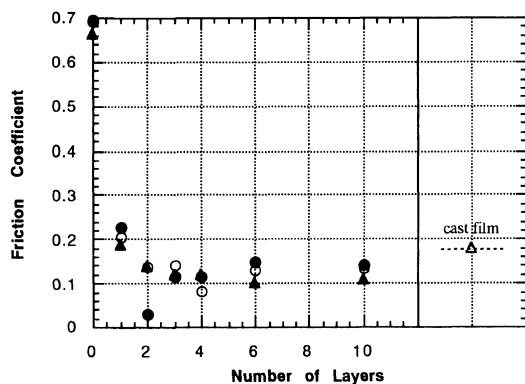
Figure 1 shows the frictional force response for pre-deposited glass substrate (A) and pDDA LB films on glass substrate with 2 layers (B) while the sapphire tip with a loading weight of 20 g was slid back-to-forth in the eleven times of transits. The average of the frictional force for the pre-deposited glass substrate is approximately 12 g at the tenth transit. The initial frictional force increases with the number of transits. The frictional force is also unstable during transit. These phenomena indicate that the sapphire tip with 20 g weight mechanically damages the pre-deposited glass substrate with increasing number of transits. The average of the frictional force for pDDA films with 2 layers on glass substrate is about 3 g, which becomes 4 times smaller than that of pre-deposited glass substrate. The frictional



**Figure 1.** Frictional force response to pre-deposited glass substrate (A) and pDDA LB films on a glass substrate with 2 layers (B): Loading weight, 20 g.

force is stable during transit. The frictional force is independent of the number of transits and keeps constant. It is clear that pDDA LB films provides significant protection against abrasion. It is noteworthy that the polymer LB films are stable against the number of transits compared with low molecular weight LB films such as stearic acid, where the frictional force increases with the number of transits because of the removal of LB films from substrates.<sup>4</sup> Thus pDDA LB films behave as lubricants and improve the frictional property.

Figure 2 shows the kinetic friction coefficients for pre-deposited glass substrates and pDDA LB films on glass substrates with 1–4, 6, and 10 layers. The kinetic friction coefficient is reduced by pDDA LB films whenever any



**Figure 2.** Kinetic friction coefficients of pDDA as a function of the number of layers. Loading weight, 20 g (closed circle); 10 g (opened circle); 5 g (closed triangle). Kinetic friction coefficient of cast film of pDDA with a loading weight, 20 g (opened triangle).

loading weight is used. The coefficients, however, indicate almost constant values even if the loading weight is changed. The kinetic friction coefficients measured in this study can be regarded as a constant physical parameter in the experimental range of the loading weight. One pDDA monolayer reduces the coefficient of kinetic friction from 0.7 for the pre-deposited glass substrate to 0.2. The coefficient for pDDA LB films with two layers shows the lowest value, 0.14 in this study. The coefficient remains approximately the same with increasing number of layers after the deposition of two layers LB films, as in the case of low molecular weight LB films.<sup>3-6</sup> This means that lubricating phenomena appear even at one monolayer of highly ordered ultrathin pDDA LB films

and that the lubricating performance of pDDA is enough at one monolayer. The coefficient (0.18) for the cast films of pDDA has a higher value than those of LB films with more than two layers. The highly ordered structure of LB films should make it better as a lubricant.

*Acknowledgments.* This work was partially supported by a Grant-in-Aid for Developmental Scientific Research (06555282) from the Ministry of Education, Science, and Culture of Japan. We thank Dr. Takao Iwayanagi and Miss Yuko Murakami, Hitach Research Laboratory, Hitachi, Ltd. for his helpful discussion and measurement of friction coefficient of polymer LB films.

## REFERENCES

1. A. Ulman, "An Introduction to Ultrathin Organic Films From Langmuir-Blodgett to Self-Assembly," Academic Press, New York, N.Y., 1991.
2. Y. Mizuta, M. Matsuda, and T. Miyashita, *Langmuir*, **9**, 1158 (1993).
3. T. Miyashita and T. Suwa, *Langmuir*, **10**, 3387 (1994).
4. F. P. Bowden and D. Tabor, "The Friction and Lubrication of Solids," Clarendon, Oxford, 1954.
5. V. Novotny and J. D. Swalen, *Langmuir*, **5**, 485 (1989).
6. J. Seto, T. Nagai, C. Ishimoto, and H. Watanabe, *Thin Solid Films*, **134**, 101 (1985).
7. E. Ando, Y. Goto, K. Morimoto, K. Ariga, and Y. Okahata, *Thin Solid Films*, **180**, 287 (1989).
8. M. Suzuki, Y. Saotome, and M. Yanagisawa, *Thin Solid Films*, **160**, 453 (1988).
9. T. Miyashita, *Prog. Polym. Sci.*, **18**, 263 (1993).