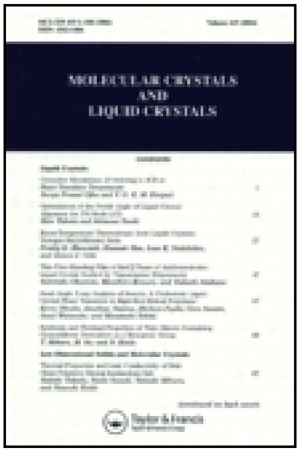

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RELATION AMONG MICRO-STRUCTURE OF RUBBING FIBER, SHAPE OF THE MICROGROOVE OF RUBBED POLYMER AND ITS ANCHORING STRENGTH

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Abstract To clarify the surface alignment mechanism of liquid crystal in detail, we have tried a simplified rubbing by using only one fiber, which we call "one-fiber-rubbing", and observed the microgroove. Then, we compared the curvature of microgroove structure observed by atomic force microscope (AFM) and friction force microscope (FFM) with that of the fiber observed by scanning erectron microscope (SEM). From the result, we confirmed that they agreed well with each other. Therefore, we concluded that the microgroove is formed by micro-structure of the fiber edge.

We also measured anchoring strength of the rubbed polymer surfaces with various pitch of the microgroove. From the result, we found that the anchoring strength is almost proprotional to the ratio of the total area of each microgroove in unit area.

INTRODUCTION

Alignment of liquid crystal induced by rubbing is not only interesting in physical chemistry but also important as a fundamental technology of production of liquid crystal devices. However, mechanism of the surface deformation and polymer alignment has not yet been clarified sufficiently. We have been studying the mechanism of liquid crystal alignment on the rubbed surfaces[1-4] and have developed a simple but reliable method of measuring azimuthal anchoring strength.[1-2] Also, we have defined the rubbing strength parameter as follows.[1-2]

$$L = N \cdot l \cdot \left(1 + \frac{2\pi rn}{60v}\right) \qquad (1)$$

where N is number of rubbing, l is the contact length between rubbing cloth and substrate (cm), r is the radius of rubbing roller (cm), n is roller rotation speed (r.p.m.) and v is substrate moving velocity (cm/sec.) as shown in fig.1.

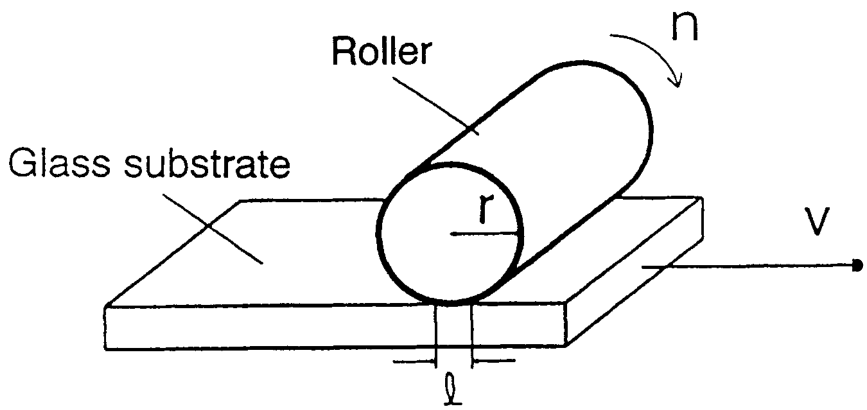


FIGURE 1 Rubbing parameters

Then we have examined the relation between the rubbing strngth parameter and the anchoring strength, and have found that the anchoring strength is proportional to the rubbing strength parameter. We have also clarified that the measured anchoring strength was two orders larger than a calculated value by Berreman's theory based on the liquid crystal distortion energy.[3] This result suggested that the Berreman's theory does not dominant factor of the liquid crystal alignment on the rubbed polymer surfaces. In order to clarify the alignment mechanism, we have simplified the rubbing by using only one fiber[4] (we call it as one-fiber-rubbing) and have observed and compared shape of the microgroove on the rubbed polymer surface with that of the rubbing fiber. Then, we made periodic microgrooves by repeating the one-fiber-rubbing, and we measured the anchoring strength of the surfaces to investigate the relation between the anchoring strength and the ratio of the total area of each microgroove in unit area.

EXPERIMENT

In the experiment we used a main chain polymer AL1051 (Japan Synthetic Rubber Co., Ltd.), which was spin-coated on the glass. The rubbing cloths were nylon YO-15-N, rayon YA-20-R, cotton YA-25-C supplied by Yoshikawa Chemical Co., Ltd. As for fibers used for one-fiber-rubbing, we used a glassfiber or rubbing cloth treated as follows: all the fibers except only one were cut. The treated cloth was attached to the rubbing roller. In the case of the glassfiber, it is attached by silicon rubber. Fig.2 shows a schematic figure of the one-fiber-rubbing, where the substrate stage were moved perpendicular to the rubbing direction. The rotation speed of the roller was 400 r.p.m. and moving velocity of the substrate stage was 70.8 μ m/sec. Pressure length was 0.2mm unless specially mentioned. In the experiment of measuring the anchoring strength for the periodic microgrooves, the rotation speed of the roller was fixed to 300 r.p.m. and the moving velocity of the substrate stage was varied to get the desired ratio of the rubbed area.

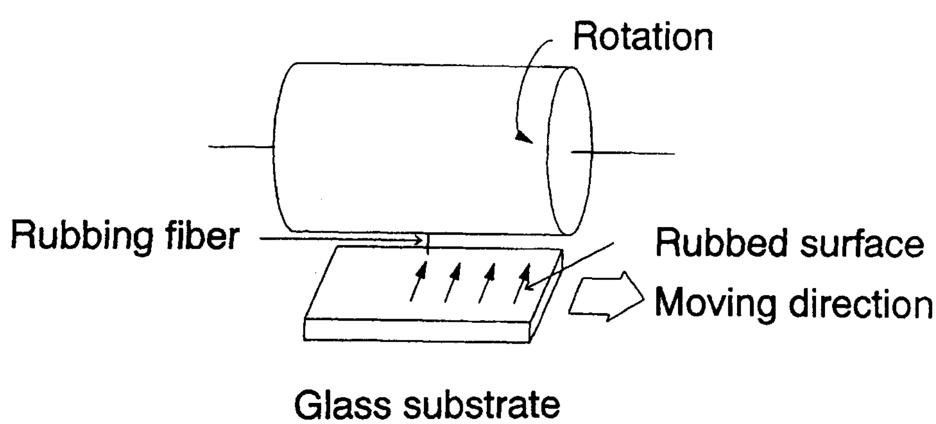
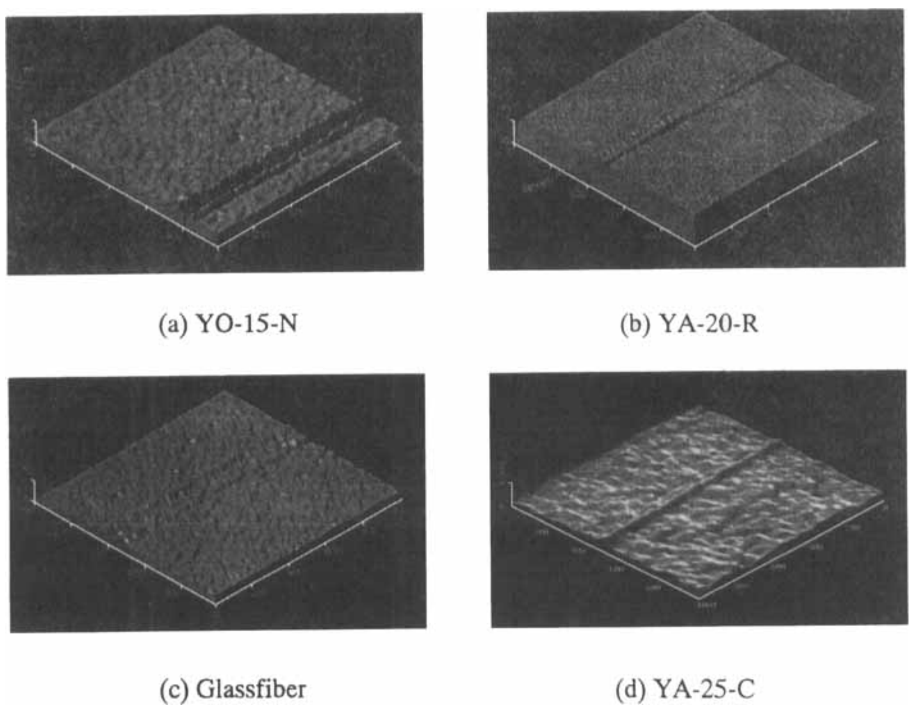


FIGURE 2 Simplified rubbing by using only one fiber (one-fiber-rubbing).

Then, we observed the polymer surface by using the scanning probe microscope SPA 300 and SFA 300 (Seiko Instruments Inc.) in atomic force microscope (AFM) and friction force microscope (FFM) mode. The measurement area was 1 μ m square and the scanning speed was 2 μ m/sec. The micro-structure of the fiber was observed by using the scanning erectron microscope S-800 (Hitachi, Ltd.). We made liquid crystal cells by using substrates rubbed by the avobe mentioned one-fiber-rubbing as well as those rubbed with the ordinary rubbing cloths, and measured their anchoring strength by the torque balance method.[1-2] Liquid crystal used in these experiment was GR-41 of Chisso Corp.

RESULT AND CONSIDERATION

Fig.3 shows the polymer surface treated by the one-fiber-rubbing. From this figure, we confirmed that the microgroove was formed by the fiber itself instead of dust particle as was supposed sometimes by several researchers.



(a) YO-15-N (b) YA-20-R

(c) Glassfiber (d) YA-25-C

FIGURE 3 The polymer surface structure treated by the one-fiber-rubbing using four different fibers.

Table 1 shows the diameter of the fibers and the width and the depth of the microgroove measured by AFM.

TABLE 1 Diameter of four kinds of fibers and width and depth of the microgroove.

		Fiber	micro groove	
	Pressure length(mm)	Diameter(μ m)	Width (nm)	Depth (nm)
YO-15-N	0.2	12	57	2.10
	0.2	12	29	0.79
	0.2	12	40	0.83
	0.3	12	48	0.35
	0.4	12	31	0.81
	0.4	12	26	0.72
YA-20-R	0.2	12	77	0.43
	0.4	12	74	0.47
Glassfiber	0.2	9.5	130	0.40
	0.2	9.5	143	0.61
	0.2	9.5	203	0.80
YA-25-C	0.2	9.6~16	68	0.56
	0.2	9.6~16	33	0.16
	0.3	9.6~16	89	1.09

It is seen from Table 1 that the width of the microgroove is different from fiber to fiber and is much smaller than the fiber diameter. Therefore, we first approximate that the fiber contacts the polymer surface at very narrow area. In this case, the cross section of the microgroove is supposed to coinside with that of the fiber. If we assume the fiber has simple cylindrical structure, we can estimate the depth of the microgroove as a function of its width. The relation is shown in Fig.4 (a)~(c). The measured results for various fibers are also plotted in the same figure.

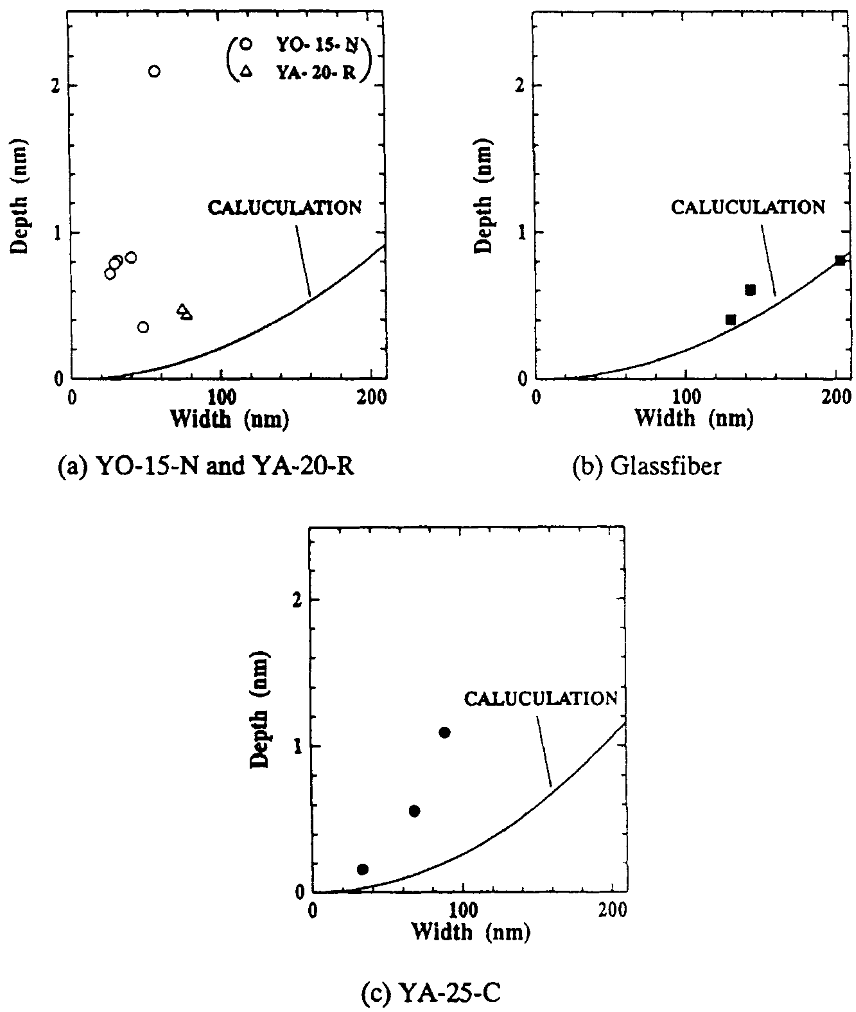


FIGURE 4 The calucurated value and the measurement value of depth of the microgroove as a function of width.

It is found from this figure that the actual depth are larger than the caluculated value except the case of the glassfiber. From the avobe mentioned result, it is suposed that these fibers do not have simple cylindrical structure but have micro-structure at least at the edge of the fiber. Therefore, we have observed the fibers by SEM and have confirmed that these fibers have micro-structure as shown in Fig.5 and Table 2.

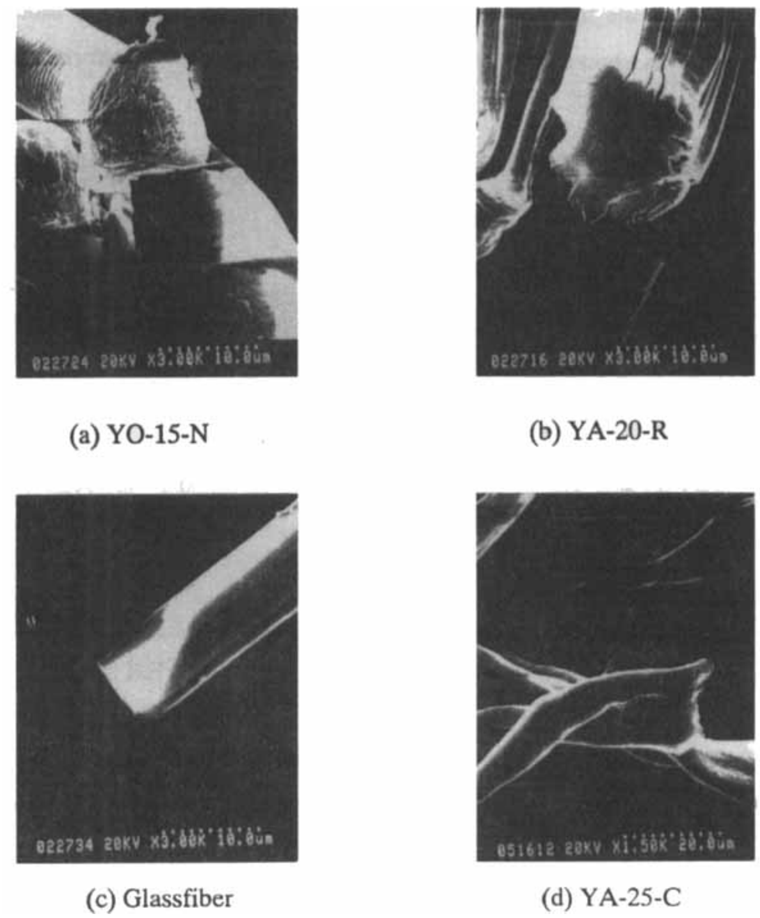
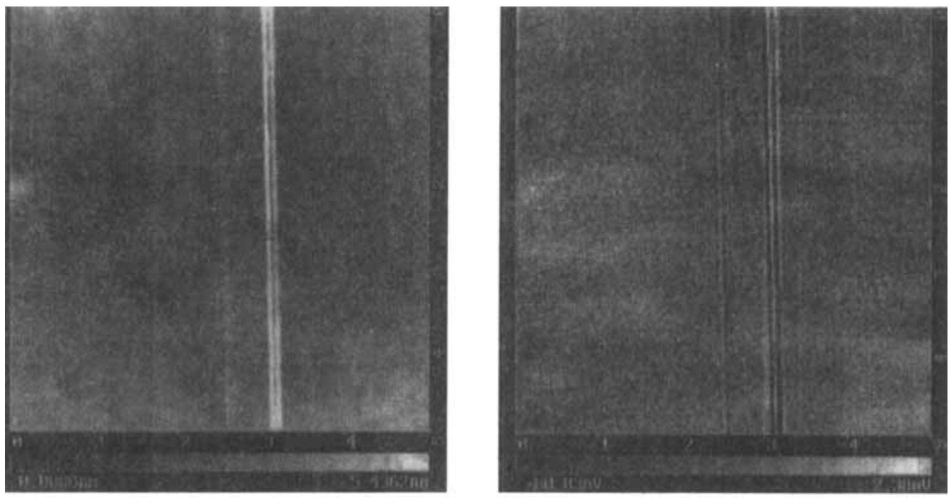


FIGURE 5 Micro-strcture of four kinds of fibers.

TABLE 2 The features of four kinds of fibers.

	Edge	Surface
YO-15-N	Wide, Protuberant	Uneven
YA-20-R	Uneven, Puckery	Cactoid
Glassfiber	Smooth	Smooth
YA-25-C	Uneven	Stringy

Then, we compared the curvature of the micro-structure of the fiber with the cross section of the microgroove. In this study, we used AFM and FFM to measure the depth and width of the microgrooves, respectively, because FFM gives much clearer image than AFM as shown in Fig.6 but does not give qualitative imformation on the depth.



(a) AFM mode (b) FFM mode

FIGURE 6 Rubbed polymer surface obtained by the AFM mode and the FFM mode.

Then, we calucurated the curvature of microgroove structure R by using the following equation

$$R = T + \frac{W^2}{4T} \tag{2}$$

where T and W are respectively depth and width of the microgroove. Fig. 7 shows the comparison between the curvature of the micro-structure of the fiber edge and that of the cross section of the microgroove. We confirmed from these result that they agree well to each other.

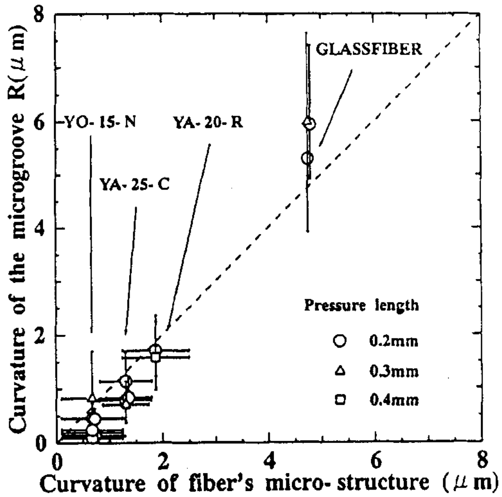
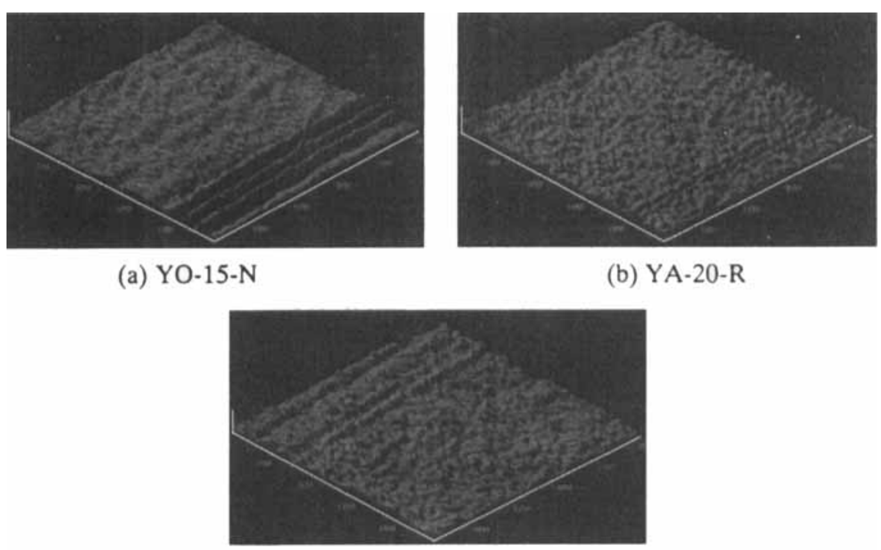


FIGURE 7 Comparison of the curvature between microgrooves and fibers.

Then, we compare the shape of microgroove formed by the one-fiber-rubbing with that formed by the ordinaly rubbing using the usual rubbing cloths. The latter is shown in Fig. 8.



(a) YO-15-N (b) YA-20-R

(c) Glassfiber

FIGURE 8 The structures of polymer surface rubbed by the ordinary rubbing cloths.

It was confirmed from Fig.3 and Fig.8 that the both microgrooves formed by the same fiber have almost the same shape. Therefore, we concluded that the structure of microgroove by ordinary rubbing is formed by the micro-structure of the fiber edge.

For the next step, we have studied the difference among the fibers, especically focussing on the shape of microgrooves and anchoring strength of liquid crystal alignment. As shown in Table 1, width of the microgrooves differ according to the types of the fiber. Then we have measured the anchoring strength of the polymer surfaces rubbedd by the ordinary rubbing cloths. The results are shown in Fig.9, where the anchoring strength is normalized by twist elastic constant K_{22} of the liquid crystal GR-41 for convenience.

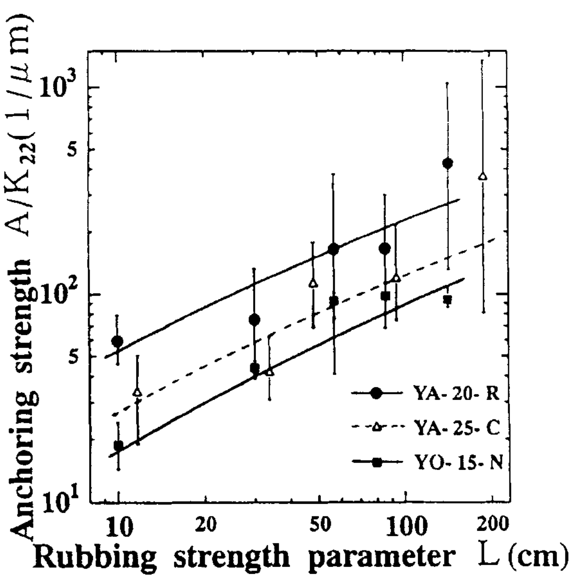


FIGURE 9 The anchoring strength normarized by K_{22} for the polymer surfaces rubbed by the ordinary rubbing cloths.

It is found from this figure and Table 1, that the wider the width of microgroove is, the larger the anchoring strength becomes. This fact suggests us that the anchoring strength becomes larger acccording to increase of the ratio of the total area of each microgroove in unit area. In order to confirm this fact more clearly, we rubbed the polymer surface by the one-fiber-rubbing method, changing pitch of microgroove by changing the moving velocity of the substrate as shown in Fig.2. The result is shown in Fig.10.

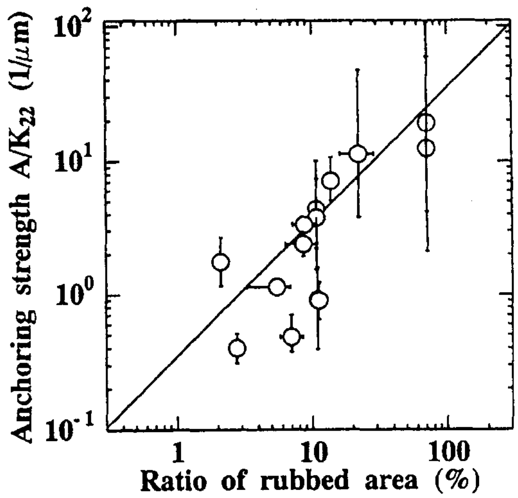


FIGURE 10 The relation between the ratio of the total area of each microgroove in unit area and the anchoring strength.

It is confirmed from this figure that the anchoring strength is almost proprortional to the ratio of the total area of each microgroove in unit area. From this fact, it is considered that rubbing strength parameter deffined by equation (1) has strong correlation with the ratio of tha total area of each microgroove in unit area.

CONCLUSION

In order to analyse the mechanism of the rubbing and liquid crystal alignment, we have examined by the one-fiber rubbing. Then we have observed the shape of the microgroove in detail by using AFM and FFM. From this result, we found that the microgroove is formed by the micro-structure of the fiber edge. We also found that the anchoring strength is almost proportional to the ratio of the total area of each microgroove in unit area.

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