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# Experimental study on friction properties of rubber material: Influence of surface roughness on sliding friction

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**Abstract**

This study investigated the influence of the surface roughness of rubber on sliding friction. The friction was measured by using textured specimens and plain (non-textured) specimens. Under a dry condition, the textured specimens, whose contact area was smaller than that of the plain ones, showed low coefficients of friction. Under a lubricated condition, the coefficients of friction of the textured specimens were higher in a low speed region, but those were lower in a higher speed region. Therefore, the lubrication conditions should be considered in the application of the texturing on rubber surface.


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*Keywords*: Rubber; Surface texture; Surface roughness; Coefficient of friction; Contact area

## 1. Introduction

In recent years, many studies have been made on surface texture on various materials to improve lubrication not only in hydrodynamic lubrication region but also in mixed lubrication region [1], [2]. However, less studies focusing on the surface texture on rubber have been reported compared to the surface texture on the hard materials such as metal, ceramics and so on. Recently, Kato et al. showed the effect of friction reduction due to the texture on rubber surface in hydrodynamic region [3]. Suzuki presented the test apparatus to measure the friction properties of rubbers with rough surface at low sliding speed under a lubricated condition [4]. This paper presented further investigation of the influence of surface roughness of rubber on sliding friction. Friction properties in both a dry condition and a lubricated condition were examined. The relation between friction properties and contact area was also discussed.

## 2. Experimental methods

As shown in Figure 1 (a), pin-on-disk sliding test was conducted to measure friction force between a rubber pin and a steel disk. The disks were made of steel and their arithmetic mean roughness (*Ra*) were 0.04 μm. The rubber

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specimen has a hemisphere shape as shown in Figure 1 (b). Two types of the rubber specimens, namely textured (12 μm *Rz*) and plain (2 μm *Rz*) specimens, were used.

Test conditions are listed in Table 1. The friction force was measured under a lubricated condition and a dry condition. Before and after the test, the contacting surface of the rubber specimen against a glass plate was observed by an optical microscope. The surface roughness of the contacting rubber specimen was also measured by the laser-scanning microscope with immersion method [5].

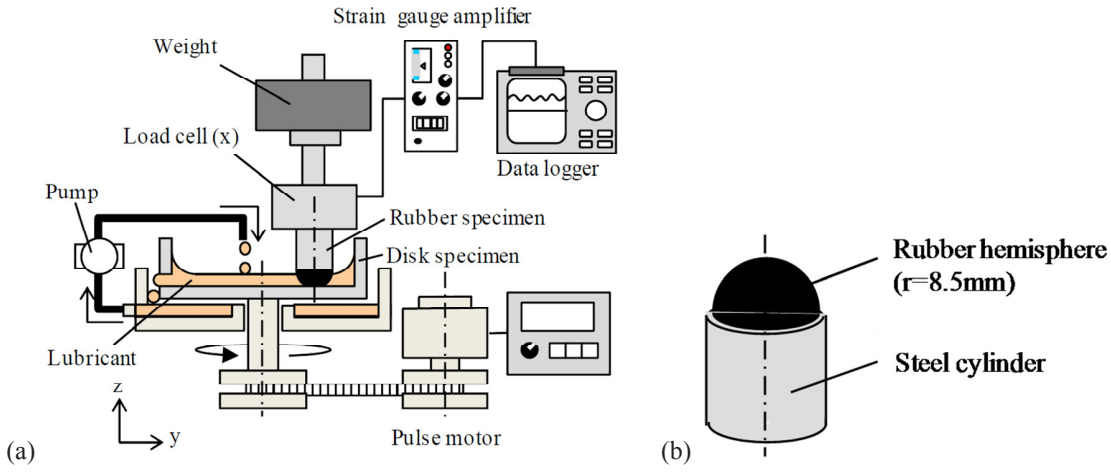



Fig. 1. Schematic of (a) pin-on-disk sliding test apparatus and (b) rubber specimen.

Table 1. Test conditions

| | |
|---|---|
| Rubber material | ACM (Acrylic rubber ) |
| Hardness ISO 7619-1 | 61 |
| Lubricant | poly-α-olefin |
| Kinematic viscosity @ 23ºC, $mm^2/s$ | 66 |
| Temperature, ºC | 23±2 |
| Sliding speed, m/s | 0.004~1 |
| Normal load, N | 1.0, 3.0 |
| Average contact pressure, MPa | 0.3, 0.4 |

## 3. Test results

Table 2 shows the 3D surface roughness of the rubber specimens under a non-contact condition and contact conditions at an average contact pressure of 0.3 and 0.4 MPa. The surface roughness of the textured specimen was larger than that of the plain one in the non-contact condition. In the contact conditions, the surface roughness of the textured specimen decreased as the average contact pressure increased, but the textured specimen had still larger roughness than the plain one.

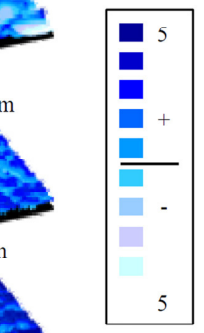
Figure 2 shows the relation between the coefficients of friction and the normal loads. The coefficients of friction of the textured specimens were lower than those of the plain ones at each normal load under a dry condition. However, the coefficients of friction of textured specimens were higher than those of the plain ones under a lubricated condition.

The relationship between the coefficients of friction and sliding speed are shown in Figure 3. As the sliding speed increased, the coefficients of friction decreased to reach a minimum value, then increased gradually. The friction

properties of the plain specimens reached the minimum friction at a lower speed as compared to the textured specimens. The coefficients of friction of the textured specimens were higher than those of the plain ones at the speed lower than 0.1m/s, nevertheless the textured specimens showed lower friction in the dry condition. As compared at the speed higher than 0.1 m/s, the textured specimen showed lower friction. The results obtained at the normal load of 1N and 3N showed almost the same tendencies.

Table 2. 3D surface roughness under contact with a flat glass

| Average contact pressure | Plain | Textured |
|---|---|---|
| 0MPa (non-contact) | 1024μm, 768μm<br>*Rz*: 2μm | *Rz*: 10μm |
| 0.3MPa | *Rz*: 2μm | *Rz*: 8μm |
| 0.4MPa | *Rz*: 2μm | *Rz*: 6μm |




*The roughness indication in this report is based on ISO 4287: 1997.

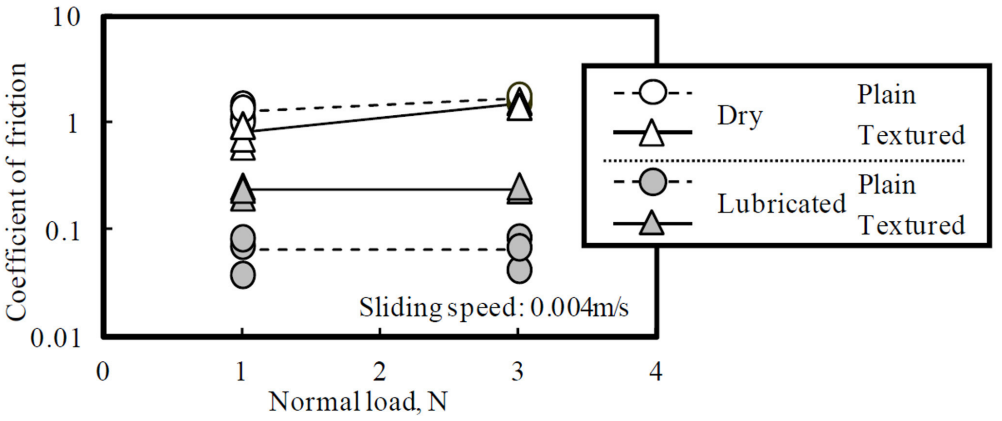



Fig. 2. Relation between the coefficients of friction and the normal loads.

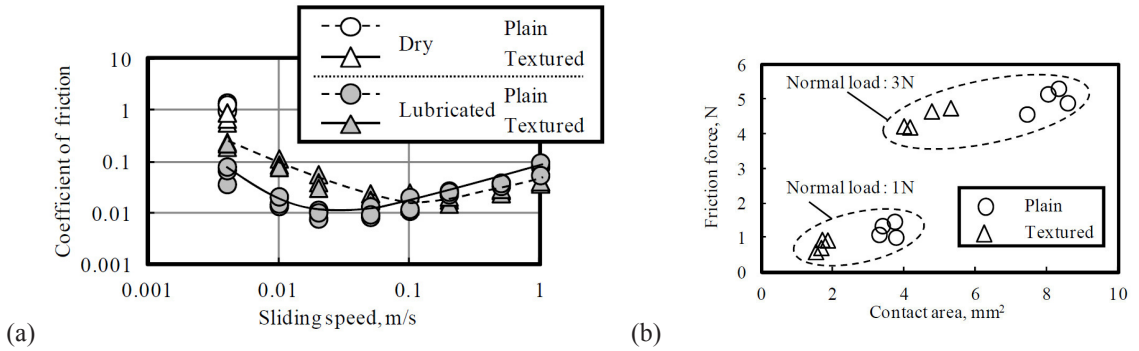


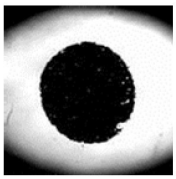
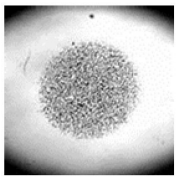
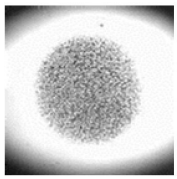
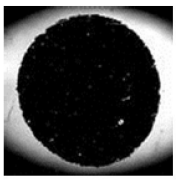
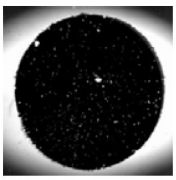
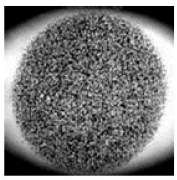
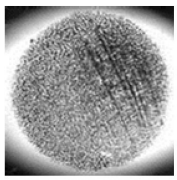

Fig. 3. Coefficients of friction and sliding speed at a normal load of (a) 1N and (b) 3N.

## 4. Discussions

Table 3 shows the static observation images of contact area in the dry condition. Contact area, which was the black color in the image, was estimated from binarized images. Figure 4 shows the relationship between the friction force and the contact area. The contact area of the textured specimens was approximately half of that of plain ones. Smaller contact area must be related to the low friction of the textured specimens in the dry condition (Figure 2). The observation in dynamic condition should be addressed in the future work.

In the lubricated condition, the fact that the coefficients of friction of the textured specimens were higher than those of the plain one at the low speed region suggests that the contact friction between the rubber asperities and the disk surface increased remarkably. On the other hand, it is suggests that the low coefficients of friction of the textured specimens at the high speed region were caused by enhancing the formation of the fluid film and the micro cavitations due to the rubber surface roughness [6]. Further studies are needed to explore the effects of the texture in the lubricated conditions.

Table 3. Static observation images of contact area in the dry condition

| Normal load | Plain | | Textured | |
|---|---|---|---|---|
| | Before test | After test | Before test | After test |
| 1N |  |  |  |  |
| 3N |  |  |  |  |
| 2mm ⟷ | | | | |

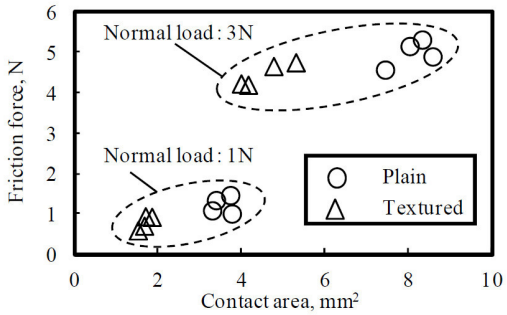



Fig. 4. Relationship between the friction force and the contact area in the dry condition.

## 5. Conclusion

The results are summarized as follows:

(1)Under a dry condition, the coefficients of friction of the textured specimens were lower than those of the plain ones.

(2)Under a lubricated condition, compared with the plain specimens, the coefficients of friction of the textured ones were higher at sliding speed slower than 0.1 m/s, but those were lower at the speed faster than 0.1 m/s

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