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The Rolling-Sliding Friction of Rubber and the Behavior of Contact Area

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Rolling-sliding friction was investigated for three SBR (styrene-butadiene rubber) specimens including silica-filled, HAF carbon black-filled, and SAF carbon black-filled SBR. When a rubber wheel was rolled against a glass disk, the coefficient of friction varied with the slip ratios. The coefficient of friction for the silica-filled SBR showed the highest value of the rubber specimens examined under various slip ratios. The contact areas of silica-filled SBR were larger than those of the carbon black-filled SBRs, as indicated the modulus of the silica-filled SBR showing the lowest value. The contact area during rolling-sliding friction was always smaller than those during the static contact. The friction force at the unit contact area for the silica-filled SBR under braking and driving was higher than those of carbon black-filled SBRs.

Keywords : Friction force, Rolling-sliding friction, Contact area, Rubber, SBRs, Slip ratio

1. INTRODUCTION

Rolling-sliding friction is important for automobile tires and rubber rollers[1-2]. The relationships between the coefficient of friction for SBRs (styrene-butadiene rubbers) and the slip ratio were examined under braking and driving. The influence of fillers such as silica and carbon black on the rolling-sliding friction of SBR was also examined. The contact surface was observed through a mating glass disk, and the behavior of the contact region was also analyzed.

2. EXPERIMENTAL

In the experiments, a rubber wheel was rolled against a mating glass disk, as shown in Figure 1. The friction force was measured in terms of the torque of a driving shaft. The coefficient of friction between the rubber wheel and the mating glass was examined under various slip ratios. The rubber wheels were 62mm in diameter and 12.2mm thick. The diameter of the mating glass disk was 250mm and its thickness was 8mm. The rubber wheel was driven by one motor and the mating glass disk was driven by another one. The diameter of the mating glass disk track was 200mm. The three rubber specimens, such as silica-, HAF carbon black-, and SAF carbon black-filled SBR, were used. The mixture formulation of SBR compounds and their mechanical properties are shown in Table 1 and Table 2, respectively. In order to finish the periphery of the rubber wheel prior to the experiments, the rubber wheel was rubbed against abrasive paper CC#1000. The experiments were carried out at sliding speeds from 0 to 40mm/s, applied loads of 9.8N, and room temperature of 23°C. To measure the braking force, the speed of the mating glass disk track was fixed at 40mm/s, and the peripheral speed of the rubber wheel was then varied from 0 to 40 mm/s. On the other hand, in the driving experiments, the peripheral speed of the rubber wheel was fixed at 40mm/s, and the speed of a rubber wheel track was then varied from 0 to 40 mm/s. The contact area was observed via a CCD camera through the mating glass disk. The pictures taken by the CCD camera were recorded and transferred to the bitmap data in a personal computer. Then the contact areas were calculated based on those data.

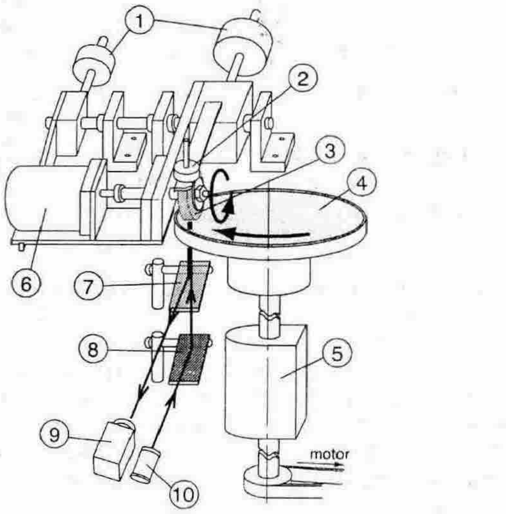

Fig. 1 Schematic diagram of the experimental apparatus: 1. counter balance, 2. weight, 3. rubber specimen, 4. glass disk, 5. toruque meter, 6. reversible motor, 7. half mirror, 8. mirror, 9. CCD camera, 10 light source.

3. RESULTS AND DISCUSSION

Figure 2 shows the relationship between the coefficient of friction for the silica-filled and the carbon black-filled SBRs and slip ratio s. The comparison between the rolling-sliding friction and the sliding friction for the silica-filled SBR is also shown in Figure 3.

The slip ratios s_B, s_D are defined as

$$s_B=(v_g-v_r)/v_g > 0 \quad \text{(braking)} \tag{1}$$

$$s_D=(v_g-v_r)/v_r < 0 \quad \text{(driving)}, \tag{2}$$

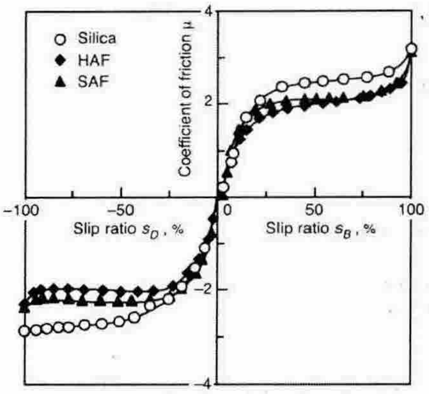

Fig. 2 The relationship between the coefficient of friction and slip ratio.

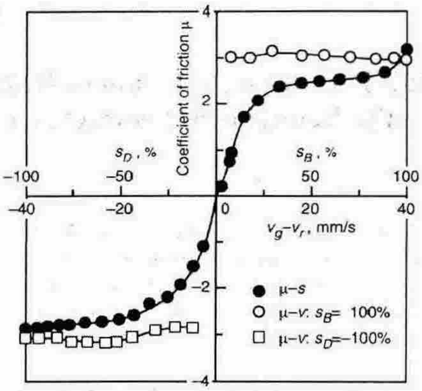

Fig. 3 The relationship between the coefficient of friction for the SBR-silica and slip ratio (μ-*s* curve). The coefficients of friction are also plotted against the relative speed of the glass disk and the rubber wheel (μ-*s* curves, s_B=100% or s_D= −100%).

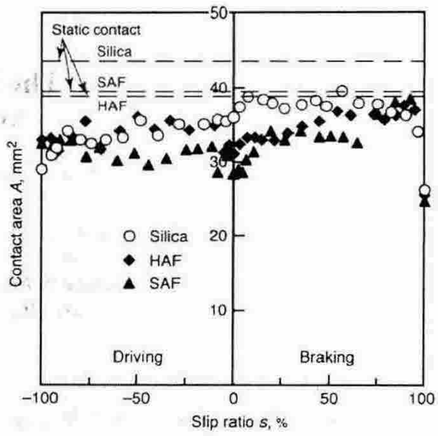

Fig. 4 The relationship between the contact area and slip ratio.

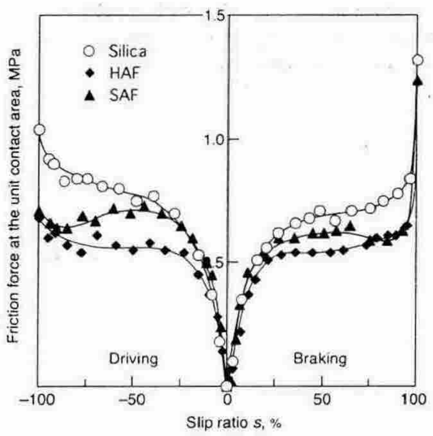

Fig. 5 The relationship between the friction force at the unit contact area and slip ratio.

Table 2 Mechanical properties of rubber specimens.

Specimen	SBR-silica	SBR-HAF	SBR-SAF
M100, MPa	2.0	2.5	2.3
M300, MPa	8.4	11.8	9.9
T_B, MPa	20.1	22.9	25.6
E_B, %	528	515	583
Hardness JIS(A)	61	61	62
tanδ	0.187	0.265	0.320
E', MPa	6.53	6.87	8.14
E", MPa	1.22	1.82	2.60

Table 1 Compound formulation of rubber specimens (phr).

Specimen	SBR-silica	SBR-HAF	SBR-SAF
SBR1502	100	100	100
Silica	50		
Carbon black HAF		50	
Carbon black SAF		50	
Si-69	4		
DEG	2.7		
ZnO	3		
Stearic acid	1	1	1
Antioxidant	1	1	1
Process oil	15	15	15
TBBS	1	1	1
DPG	0.5		
Sulfur	2	2	2
Total(phr)	180.2	173	173

where v_r denotes the peripheral speed of the rubber wheel, and v_g denotes the track speed of the mating glass disk.

As shown in Figuer 2, it was found that the friction increased with the increment of the slip ratio in the rolling-sliding. The coefficient of friction of the silica-filled SBR was highest in the rubber specimens examined under various slip ratios. In the simple sliding, the coefficients of friction under braking and driving changed slightly at sliding speed examined (Fig. 3).

Figure 4 shows the contact areas under static and rolling-sliding contact between the rubber wheel and the mating glass disk. The static contact areas of the silica-filled SBR were larger than those of the carbon black-filled SBRs, because the modulus of the silica-filled SBR showed the lowest value. The contact areas during rolling-sliding friction were always smaller than those during the static contact. The contact area under a slip ratio of 100% during braking showed the smallest value.

Figure 5 shows the friction force at the unit contact area obtained from the data of Figures 2 and 4. Under braking and driving, the friction force at the unit contact area for the silica-filled SBR was the highest among the SBR specimens examined. Under a 100% slip ratio, the highest friction force at the unit contact area was also seen for the silica-filled SBR is shown in Figure 5.

4. CONCLUSIONS

The rolling-sliding friction experiments were performed using a wheel made of rubber such as silica- and carbon black-filled SBRs, and a glass disk. In the experiments the contact area was also observed. Based on the experiments, the following conclusions were drawn:

(1) In the experiments, the silica-filled SBR showed the highest coefficient of friction in the rubber specimens examined under various slip ratios.

(2) The contact areas during rolling-sliding friction were always smaller than those during static contact. The contact area under a slip ratio of 100% during braking showed the smallest value. Among the SBR specimens examined, the highest friction force at the unit contact area was observed for the silica-filled SBR.

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