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Effect of Humidity on Friction Characteristics of Automotive Friction Materials

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Abstract : The effects of humidity on friction performance of automotive brake materials were studied using a pad-on-disk type friction tester. Three different friction materials based on a simple formulation were investigated by changing the solid lubricant, graphite, MoS_2, and Sb_2S_3. Friction materials without solid lubricants were also examined to study the effect of other ingredients in the matrix on humidity. The friction material containing graphite was strongly affected by the humidity showing lower friction coefficient at high humidity level than other conditions. On the other hand, the friction material containing MoS_2 exhibited higher friction coefficient at initial stage under high humidity level. The friction material without solid lubricant or with Sb_2S_3 was not affected by humidity conditions. However, the friction material containing barite showed strong speed dependence.

Key words : Friction material, humidity, solid lubricant, friction characteristics, friction coefficient, drag test

Introduction

Friction materials for an automotive brake system are multi-component composite materials containing more than 10 ingredients. This is because the friction material has to show stable friction levels on various braking conditions and has to be non-aggressive against cast iron rotors. The performance of the friction material is strongly affected by the selection of the ingredients and the manufacturing condition [1]. The friction performance at the friction interface is, therefore, strongly affected by the ingredients in the friction material and directly related to the brake performance such as fade resistance, noise, and judder during braking [2,3].

Among various ingredients currently used to produce brake friction materials, solid lubricants play important roles in reducing the wear of the friction couple, optimizing the level of the friction force, and diminishing the noise propensity during brake applications. Solid lubricants in the brake friction material show different friction characteristics according to the load, temperature, speed, and humidity. In particular, they play a crucial role in developing the transfer film (friction film) on the rotor surface. Solid lubricants for brake friction materials comprise graphite, MoS_2, Sb_2S_3, ZnS, CuS, and etc. In general, more than one type of solid lubricants are used to manufacture brake friction materials and the detailed information about the type and the relative amount of the solid lubricant in a commercial product is classified as a proprietary information [1,4]. The effects of humidity on the lubrication properties of solid lubricant are reported by several authors. Savage *et al.* [5] reported that a small amount of water vapor improves the wear resistance of graphite-based materials. They showed that wear resistance of the graphite can be changed by the effective molecular size and by the relative humidity level in the atmosphere. Bowen and Tabor [6,7] also reported that the water molecules easily reacted with sulfur atoms in the MoS_2 layers and result in a significant change in friction properties. However, the effect of humidity on friction properties has seldom been reported in the case of friction materials.

In this study, we investigated the effect of humidity on the friction performance of the brake friction material. We examined the friction characteristics of six different friction materials containing different amount of ingredients using a pad-on-disk type friction tester with an environmental chamber.

Experiments

In this study, a basic formulation containing only 7 ingredients was used to simplify the interpretation of the test results. The formulation was shown in the Table 1. The specimens 1, 2 and 3 contained 8 vol.% of solid lubricants (Graphite, MoS_2, and Sb_2S_3, respectively) and the amounts of other ingredients were fixed. In the case of the specimen 4 the solid lubricant was

Table 1. Raw material ingredients used in this work [vol. %]

Raw materials	1	2	3	4	A	B
Phenolic resin	20	20	20	20	20	20
Aramid fiber	6	6	6	6	6	6
Potassium titanate	20	20	20	20	0	74
Barite	46	46	46	54	74	0
Graphite	8	0	0	0	0	0
MoS_2	0	8	0	0	0	0
Sb_2S_3	0	0	8	0	0	0

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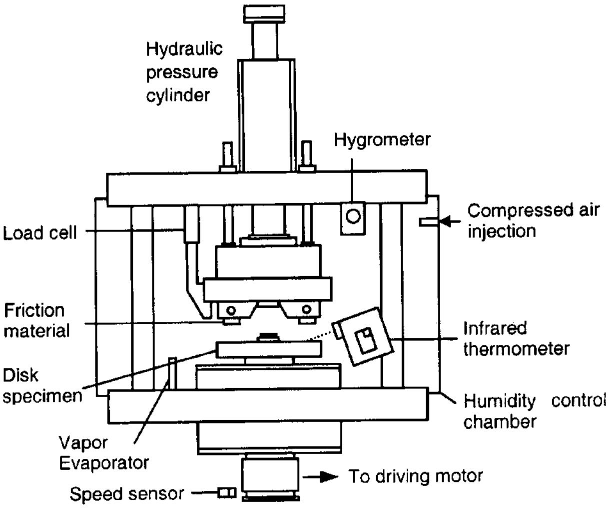

Fig. 1. A schematic diagram of the pad-on-disk type friction tester.

replaced by $BaSO_4$ (barite) for comparison with specimen 1, 2, and 3. In addition, the specimens A and B were manufactured to compare humidity effects of the two important filler materials (barite and potassium titanate) on friction performance. The friction materials were manufactured by dry mixing, pre-forming, hot pressing, and heat treatment. The detailed manufacturing condition can be found in the previous publication [8]. The specimen was produced in a disk shape using a hot mounting press (diameter: 50 mm, thickness: 5 mm) and the disk was cut into a size of 10 mm × 10 mm × 5 mm to be installed in the friction tester. Gray cast iron rotor was used as a counter surface and the rotor was 60 mm in diameter and 25 mm in thickness. The composition of the gray iron rotor was reported in a previous publication and omitted in this paper [1].

A pad-on-disk type friction tester was used for this work and the friction test was carried out in a closed humidity chamber. A schematic diagram of the friction tester was shown in the Fig. 1. The friction test was performed after a burnishing process to ensure the uniform contact between the friction material specimen and the rotor surface. Friction test segments was performed in a drag mode. Table 2 showed the detailed test procedure employed in this work. The friction tests in a drag mode were carried out in three different relative humidity levels; low humidity (15-20% RH), medium humidity (50-60% RH), and high humidity (90-95% RH). Humidity control was performed using a water vaporizer and by blowing dry compressed air into the chamber. The test was carried out for 600 sec at initial friction temperature of 35°C. The friction temperature was measured on a rotor surface using an infra-red thermometer (3M IR-16, accuracy: ±1% of reading) and the coefficient of friction was obtained by measuring the friction force under constant pressure condition.

Table 2. Friction test procedure

1. BURNISHING: 1.5 MPa, 300 rpm (70 cm/sec), 2 min.
2. DRAG TEST: IBT (initial brake rotor temperature: 35°C, 10 min. drag)

Humidity condition	LRH	MRH	HRH
Speed \ Pressure		2 MPa	
300 rpm*	TEST 1	TEST 2	TEST 3
600 rpm*	TEST 4	TEST 5	TEST 6
900 rpm*	TEST 7	TEST 8	TEST 9

*100 rpm ≈ 23.3 cm/sec

Results and Discussion

Humidity effects on friction characteristics

Humidity effects on friction characteristics were investigated at 600 rpm (100 rpm = 23.3 cm/sec) and 2 MPa of applied pressure (test mode 5 in Table 3). A new set of friction material specimens was used for each test in order to prevent the effects from accumulated thermal history. The initial run-out of the disk rotor was maintained at less than 1 μm. Fig. 2 showed the changes of friction coefficient and rotor temperature during friction test at different humidity conditions. The specimen without solid lubricant (specimen 4) showed small changes regardless of temperature increase or differences in relative humidity, indicating that the solid lubricant was a crucial ingredient on determining the friction stability at elevated temperatures. The specimen 1 containing graphite showed not much difference in the change of the coefficient of friction at low (15-20% RH) humidity and medium (50-60% RH) humidity conditions. On the other hand, at high humidity condition (90-95% RH), the coefficient of friction was lower than other two cases throughout the drag, suggesting that water molecules were adsorbed on the graphite and reduced the sliding resistance of the graphite layers. This was because the bonding strength between carbon layers parallel to the basal plane of the graphite crystal was decreased due to the adsorbed water molecules [9,10]. The initial increase of the friction coefficient in the Fig. 2 was appeared due to the increase of the contact area at the sliding interface between pad and rotor surfaces in the early stage of sliding. The decrease of the friction coefficient after the maximum value was exhibited due to the high temperature fading phenomena. Fading represents the loss of friction force during braking at elevated temperatures and is normally caused by the decomposition of ingredients, resulting in a reduction of friction resistance at the sliding interface.

In the case of the specimen containing MoS_2 as a solid lubricant, initial levels of the coefficient of friction showed difference in terms of humidity conditions [Fig. 2(b)]. However, the friction coefficient did not change much with humidity condition after approximately 200 sec in this case. This result was based on the fact that the bond strength of molecular layers parallel to the basal plane of an MoS_2 molecule became stronger with humidity at a low temperature range, but the extra strength due to water molecules was disappeared at elevated temperatures due to evaporation of water molecules. The lower coefficient of friction of the

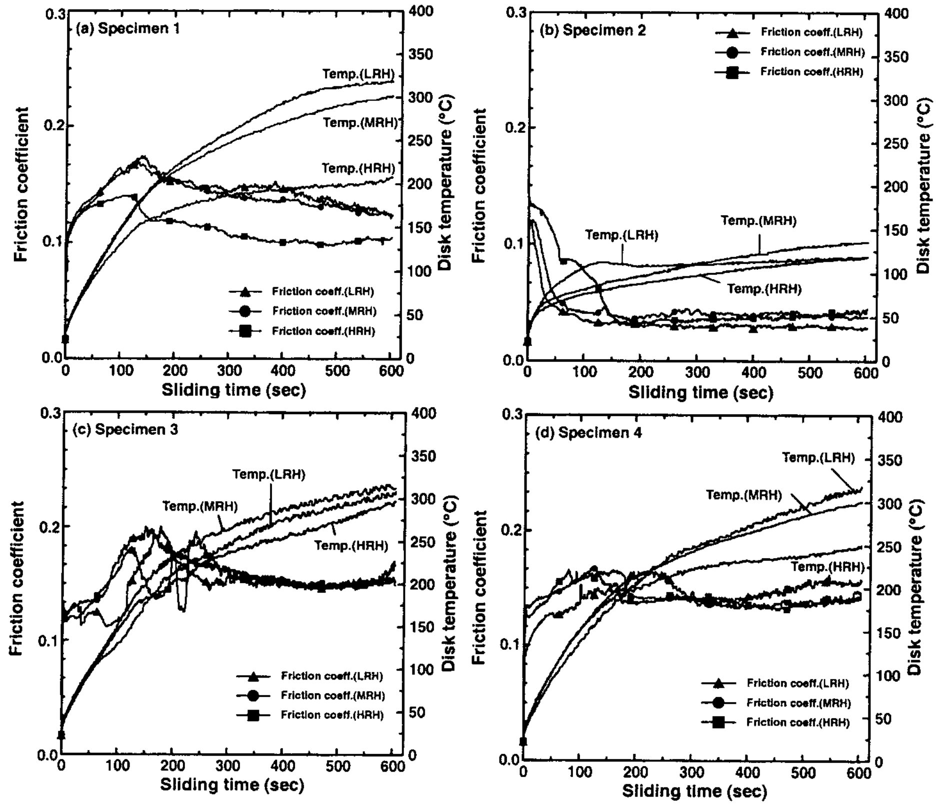

Fig. 2. The variation of friction coefficient and disk temperature as a function of time at three different humidity conditions.

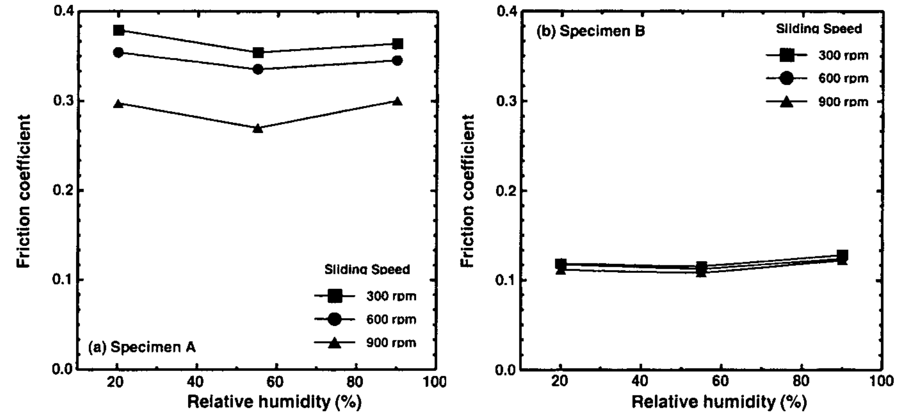

Fig. 3. The change of average friction coefficient as a function of relative humidity levels for (a) specimen A and (b) specimen B at different sliding speeds.

specimen 2 than specimen 1 [in Fig. 2(a) and (b)] seemed due to the inherent difference in the friction properties of the two solid lubricants.

The friction material containing Sb_2S_3 as a solid lubricant showed no systematic trend with different humidity conditions. The coefficient of friction showed strong oscillations at the temperature range below 250°C. This indicated that Sb_2S_3 was oxidized at the temperature range below 250°C, showing erratic friction behavior due to transitional states oxides since the most of the Sb_2S_3 was converted to Sb_2O_3 and Sb_2O_5 at this temperature range. The TGA (thermogravimetric analysis) of the Sb_2S_3 indicated that the oxidation of the Sb_2S_3 began near 250°C and ended near 400°C [4]. However, the erratic friction oscillation was observed below 250° in the Fig. 2(c) because the temperature measured during this experiment was a bulk temperature and the flash temperature at the friction interface was higher than the measured values. The steady friction coefficient at higher temperature appeared due to the transformation of the antimony oxides into Sb_2O_4. At temperatures over 250°C, the Sb_2O_4 played an important role as a high temperature solid lubricant since Sb_2O_4 was stable at high temperatures [11]. Therefore, in the case of Sb_2S_3, no systematic effect from the different humidity levels was observed.

Effect of humidity on sliding friction of fillers

In general, fillers were considered as inert materials during sliding at various friction conditions. In order to confirm the inertness of the filler materials on humidity, we also investigated friction characteristics at different humidity by changing the relative amounts of fillers (potassium titanate and barite: specimen A and B in Table 1). Specimen A contains only barite and specimen B contained only potassium titanate as a filler and the amounts of phenolic resin and aramid fiber were fixed.

Fig. 3 showed the average friction coefficient measured at 3 different levels of humidity conditions and 3 different sliding speeds. The figure indicated that both fillers were not affected by the change of the humidity levels suggesting they were quite inert on humidity. However, the coefficient of friction was changed as a function of a sliding speed in the case of using barite as a filler. This was an interesting result although we did not focus on the effect of sliding speed in this study in the beginning. The change of the friction coefficient with sliding speed suggested that barite (granular particles) is more aggressive than potassium titanate (whiskers). It is know that the speed dependency of the coefficient of friction is strongly related to the stick-slip phenomena, resulting in anti-fading phenomena during braking [12]. Therefore, this result shed light on the possible effect from the barite on the friction characteristics, in particular, on speed dependency of the friction coefficient. Further systematic investigations of the effect of the amount, shape, and composition of barite on the speed dependency of friction materials were strongly recommended.

Conclusions

Effects of humidity of brake friction materials were studied by examining the friction characteristics during sliding at different humidity conditions. Friction materials containing graphite showed low coefficient of friction at high humidity and fade was observed at relatively low sliding temperature. On the other hand, the friction materials containing MoS_2 showed humidity effect in the early stage of sliding and showed no difference after the early stage. Friction material specimens with Sb_2S_3 or without solid lubricants did not show any influence from humidity. Filler materials (barite and potassium titanate) were not affected by the humidity level. However, the friction material containing barite showed strong speed dependence.

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