

The Role of Copper on the Friction and Wear Performance of Automotive Brake Friction Materials

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ABSTRACT

Copper has been regarded as one of the indispensable ingredients in the brake friction materials since it provides high thermal diffusivity at the sliding interface. However, the recent regulations against environmentally hazardous ingredients limit the use of copper in the commercial friction material and much effort has been made for the alternatives. In this work, the role of the cuprous ingredients such as copper fiber, copper powder, cupric oxide (CuO), and copper sulfide (CuS) are studied using the friction materials based on commercial formulations. The investigation was performed using a full inertial brake dynamometer and 1/5 scale dynamometer for brake performance and wear test. Results showed that the cuprous ingredients played a crucial role in maintaining the stable friction film at the friction interface, resulting in improved friction stability and reduced aggressiveness against counter disk. In particular, the addition of copper fiber or copper sulfide contributed to improved friction stability during effectiveness test. The test result also showed that the friction material containing 10 wt.% of cupric oxide exhibited better fade resistance without showing an abrupt decrease of friction coefficient during brake performance and wear tests. The addition of copper fiber showed better wear resistance compared to the friction material with cupric oxide, on the other hand, the increase of copper fiber showed an adverse effect in the wear resistance of the friction materials during wear tests up to 400°C.

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INTRODUCTION

Copper is an essential component in the non-steel type friction materials and widely used to improve brake performance at elevated temperatures. Various cuprous ingredients such as copper fiber/powder, brass fiber, bronze powder, cupric oxides, and copper sulfides have been used in the form of fibers or particles in the brake friction material. Copper has high ductility, high thermal conductivity, and low Mohs hardness so it is often used in the friction material industry as a solid lubricant for high temperature applications [1]. Copper is also known to maintain the friction level at the various braking conditions with different temperatures by producing cupric oxides at the friction interface. Therefore, cuprous ingredients are added to control the level of the friction coefficient while reducing the aggressiveness against counter disk surface [2].

However, the cuprous ingredients in the brake friction material have been responsible for the contamination of storm water and bay near metropolitan areas [3,4,5]. The recent issues concerning the public health of the brake friction material, therefore, may fundamentally modify the formulation and change the market trend significantly in the near future. The regulations against the copper use in the commercial brake friction material are recently legislated in the United States and they are summarized in Table 1 [6].

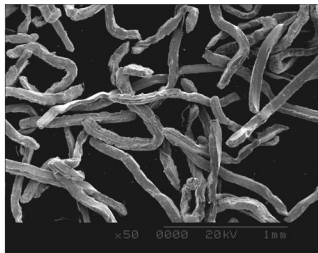
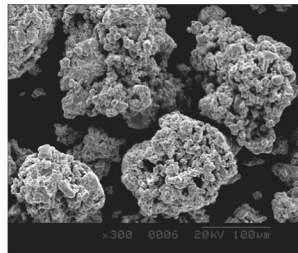
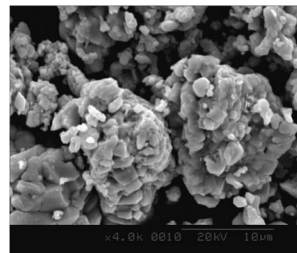
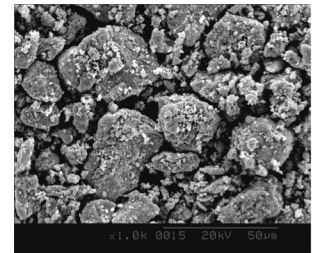
The role of cuprous ingredients in friction materials on braking performance and wear characteristics has not been widely reported due to the complicated interactions of various cuprous ingredients at the sliding interface and proprietary reasons. In this study, the effects of cuprous ingredients on the friction and wear characteristics were investigated using the brake friction materials based on a commercial

Table 1. Current regulation of copper content in the brake friction material

Classification		Washington (SSB6557)	California (SB 346)	New York (AB 10571)	Rhode Island (H7997)	Oregon (SB 341)
		Mar., 2010 confirmed	Oct., 2010 confirmed	May, 2010 draft submitted	May, 2010 draft submitted	Jan., 2011 introduction
Copper Content	5wt% ↓	Jan., 2021~	Jan., 2021~	Jan., 2020~	Jan., 2021~	Jan., 2021~
	0.5wt% ↓	Not yet decided	Jan., 2025~	Not yet decided	Not yet decided	Not yet decided

Table 2. Material properties and morphology of the cuprous ingredients used in this work

Cuprous ingredients	Density (g/cm ³)	Melting point (°C)	Mohs hardness	Morphology
Copper fiber	8.9	1,080	2.7	Aspect ratio (L/D) 2.2mm/0.2mm
Copper powder	8.2	1,080	2.7	Avg. particle dia. 240μm
Cupric oxide (CuO)	6.6	1,235	4	Avg. particle dia. 10μm
Copper sulfide (CuS)	4.5	1,100	1.5~2.0	Avg. particle dia. 28μm

**(a) copper fiber****(b) copper powder****(c) cupric oxide (CuO)****(d) copper sulfide (CuS)****Figure 1. SEM micrographs of the cuprous ingredients used in this work**

formulation, focusing on the friction stability, aggressiveness against counter surface, and wear characteristics at different temperatures.

EXPERIMENTS

CUPROUS INGREDIENTS

Four different cuprous ingredients such as copper fiber, copper powder, cupric oxide (CuO), and copper sulfide (CuS) were used in this study. Material properties and morphology of the cuprous ingredients are listed in [Table 2](#). The cuprous materials used in this work were industrial grade for commercial brake friction materials, and they exhibited some distribution in length and diameter. [Fig. 1](#) shows the SEM micrographs of cuprous ingredients used in this work.

NON-STEEL FORMULATION OF THE FRICTION MATERIALS

Friction materials investigated in this study were manufactured based on a commercial non-steel type formulation (non-asbestos organic, NAO) for compact segment vehicles. The friction materials contained a binder, reinforcements, friction modifiers, and space fillers as shown

in [Table 3](#), and they were fabricated using a typical manufacturing process for NAO brake pads. In order to examine the effect of the cuprous ingredients, four different friction materials (CuF, CuP, CuO, and CuS) were manufactured by changing the type of cuprous ingredients. Based on a commercial formulation, a basic set of the friction material specimens was produced with 10 wt.% copper or 4 wt.% CuS or CuO. Other ingredients were not changed and the deviation from different cuprous ingredient was balanced by space fillers. In order to investigate the friction characteristics as a function of the content of the cuprous ingredients, six different friction materials (CuF3/5/10 and CuO3/5/10) were manufactured by changing the amount of copper fiber or cupric oxide.

The physical and thermal properties of friction materials such as surface hardness, specific gravity, compressibility, and thermal transfer temperature were measured to confirm the effect of the type and amount of cuprous ingredients on those properties after fabrication. Compressibility was measured from the change of friction material thickness under the maximum applied pressure of 16 MPa, and thermal conductivity was obtained by measuring the temperature on

Table 3. Non-steel formulation of the friction material specimens

Raw materials [wt.%]		Cu-free	CuF	CuP	CuO	CuS	CuF3	CuF5	CuF10	CuO3	CuO5	CuO10
Cuprous ingredients	Copper fiber	0	10	0	0	0	3	5	10	0	0	0
	Copper powder	0	0	10	0	0	0	0	0	0	0	0
	Cupric oxide (CuO)	0	0	0	4	0	0	0	0	3	5	10
	Copper sulfide (CuS)	0	0	0	0	4	0	0	0	0	0	0
Binder		8	8					8				
Reinforcement		15	15					15				
Friction modifier		55	55					55				
Space filler		22	12~18					12~19				

Table 4. Wear test procedures used in this work

Section	Initial velocity (kph)	Braking temp. (°C)	Deceleration (G)	Braking applications
Burnish	80	100	0.3	250
Wear test	50	100	0.3	250
	50	150	0.3	250
	50	200	0.3	250
	50	250	0.3	250
	60	300	0.3	250
	60	350	0.3	250
	65	400	0.3	250

the backing plate after heating the friction material surface for 10 min. at 400°C.

BRAKE PERFORMANCE & WEAR TEST

A full scale inertial brake dynamometer was used to investigate brake performance. The JASO C406 P1 test mode was used to analyze brake performance for passenger car. The brake performance test procedure consists of a standard burnishing procedure, effectiveness tests, fade tests, and recovery tests to examine the friction coefficient level, friction stability at different speeds and deceleration, and aggressiveness against counter disk surface.

The wear characteristics of the friction material were investigated using a scale (1/5) dynamometer. The size of a friction material specimen was 45×18×5 mm, and two pieces of friction material were pressed against the counter disk surface during sliding (total apparent contact area=1,620mm²). The wear test mode consists of a standard burnish and wear procedure in the braking temperature range between 100 and 400°C. The wear test was repeated 250 times at each braking condition. The wear amount of friction material specimen was obtained by measuring the thickness change after each wear test. The detailed test procedure is shown in [Table 4](#).

RESULTS AND DISCUSSION

EFFECT OF THE CUPROUS INGREDIENTS ON PHYSICAL PROPERTIES

Physical property measurement after fabrication was carried out to investigate the effect of cuprous ingredients. [Table 5](#) shows the physical properties of the friction materials studied in this work. The surface hardness of the friction material was in the range of 80~90 HRR (Rockwell hardness R-scale) and the compressibility (the change of friction material thickness under the applied pressure of 16 MPa) was in the range of 132~149 µm. The results suggested that the type and amount of cuprous ingredients showed little effect on the hardness and compressibility of friction materials. In the case of the specific gravity, on the other hand, the measured data was strongly affected by the type of the cuprous ingredients in the friction materials. This result is attributed to the intrinsic density difference of the cuprous materials ([Table 2](#)). Also, the specific gravity of friction materials was increased with the content of copper fiber or cupric oxide.

Thermal transfer temperature was measured to investigate the thermal diffusivity with the type and amount of cuprous ingredients in the friction materials. The transfer temperature was obtained by detecting the temperature of the backing