

Friction Performance of Eco-Friendly Cu-Free Brake Materials with Geopolymer Matrixes

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ABSTRACT

Besides elimination of copper, the eco-friendly brake materials are developed using geopolymer matrix and natural fibers to replace phenolic resin and synthetic fibers, respectively. The objectives are to diminish i) the amount of volatile organic compounds (VOCs) being released from the brake materials when subjected to temperatures higher than 300 °C; and ii) release the potentially hazardous wear debris particles to the environment. Brake materials were fabricated in university and tested using SAE J2430 test procedure and full scale automotive brake dynamometer (Dyno). Dyno test results indicate that the average friction level of the eco-friendly Cu-free materials ($\mu \sim 0.30$ to 0.33) was only slightly lower when compared to the baseline material containing Cu ($\mu \sim 0.35$). All tested materials have passed the Brake Effectiveness Evaluation Procedure (BEEP). The Dyno results show that all tested materials were resistant to thermal fade and the friction level slightly increased with the increased speed in the second effectiveness test. However, the wear rate of the Cu-free materials, as well as the corresponding disc wear, was higher than the wear of Cu-containing baseline material. A thorough SEM/EDX and XRD analyses revealed that the detected friction and wear performance can be ascribed to developed friction layer on surfaces of pad and disc.

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1. INTRODUCTION

Automotive brake materials usually are phenolic matrix composites, consisting of a combination of 5 to 30 ingredients for optimization of their performance [1]. It is necessary for automotive brake materials to meet the requirements of relatively high and stable friction level and low wear rate at any conditions of speeds, applied braking pressures and temperatures, snow and rain. The ingredients used for formulating brake pads are frequently categorized into four core classes: i) binders, ii) fillers, iii) friction modifiers, and iv) reinforcements [2, 3]. In general, phenolic resin is used as a binder to hold the ingredients firmly together. The functions of fillers are to fill the space to reduce the cost. Friction modifiers are the abrasives and/or solid lubricants. They are used in friction materials to attain desired friction level and friction stability. Finally, the reinforcement ingredients provide strength and wear resistance. Several thousands of different raw materials could be used when formulating brake materials. Understanding the role of individual components and optimal formulation of brake

materials always represent a challenge for scientists and researchers.

The raw materials used in the brake materials today may potentially have negative impacts on the environment, human, wildlife and agriculture. The brake wear debris that is generated from mechanical and chemical changes of raw materials in braking processes has different physical properties and chemistry when compared to the original raw materials used for formulation of pads [4]. In the recent years, researches showed that the wear debris released from certain brake materials can be toxic and can modify human DNA [5].

These environmental issues have received too little attention in the past years. According to Brake Pads Partnership (BPP), brake wear debris that is being released onto streets or into the air ends up into the waterways. The copper in the brake pad debris can be toxic to aquatic organisms. These bases of the food chain affect the health of entire ecosystems. In addition, copper is also harming salmon's sense of smell, making them vulnerable to predators and unable to find their spawning streams [6]. The goal of this study is to develop eco-friendly Cu-free brake friction materials without using and releasing hazardous constituents

Table 1. Brake formulations used in this study

	Weight Percent (%)			
	Commercial	Cu-free		
Constituent	Baseline	T30-13	T30-15	T30-16
Copper (Cu)	8.0	0.0	0.0	0.0
Antimony Trisulfide (Sb_2S_3)	3.6	0.0	0.0	0.0
Phenolic Resin	9.5	6.6	6.6	6.6
Geopolymer	0.0	2.9	2.9	2.9
Kevlar Fiber	3.4	0.0	0.0	0.0
Hemp Fiber	0.0	1.7	1.7	1.7
Lubricant 1	8.7	10.3	11.3	11.3
Abrasive 1	0.0	2.3	1.3	1.3
Organic 1	5.4	5.4	4.4	5.4
Organic 2	2.6	2.6	2.6	2.6
Ceramic 1	19.5	20.5	20.5	21.5
Abrasive 2	7.8	8.8	8.8	8.8
Ceramic 2	1.0	0.0	0.0	0.0
Ceramic 3	5.2	5.2	6.2	6.2
Ceramic 4	0.0	4.6	4.6	4.6
Lubricant 2	0.0	4.0	3.0	1.0
Filler	25.3	25.1	26.1	26.1

that are listed in the Washington State Senate Bill 6557 [7] and California State Senate Bill 346 [8]. These Cu-free brake materials should at least maintain desired friction performances using the J2430 full scale automotive brake dynamometer tests.

2. EXPERIMENTAL

2.1. Brake Samples

Four different types of brake samples were fabricated and tested on full scale automotive brake dynamometer (Link Engineering model 2584). The brake samples are Baseline, T13, T15 and T16. The Baseline sample contains 8 wt% of Copper (Cu) and 3.6 wt% of antimony trisulfide (Sb_2S_3). The eco-friendly Cu-free samples T13, T15 and T16 contain 0% of Cu and 0% of Sb_2S_3 . In addition, part of phenolic resin and all of the synthetic fibers were replaced by geopolymer matrix and natural hemp fibers, respectively.

Alternative non-hazardous constituents were selected based on material properties, and used in the brake formulations replacing Cu and Sb_2S_3 . [Table 1](#) lists the compositions of the brake samples.

2.2. Sample Preparations

All constituents were weighed accurately using a precise analytical balance and added into the Stephan Machinery Co. vertical mixer (model 2786) and mixed for 12 minutes. Then, the mixture was loaded into a mold (model D748) which fits the 1999 Ford Crown Victoria test assembly on the full scale automotive brake dynamometer (Dyno). The mixture was hot pressed inside the mold for 15 minutes at 177 °C. The pressure of the hot press was released several times during the molding process to release gases generated in the cross

linking reaction of phenolic resin. After the brake samples were released from the mold, the brake samples were subsequently post cured in a preheated furnace (Fisher Scientific Isotemp) at 180 °C for four hours.

2.3. Friction Tests - Full Scale Automotive Brake Dynamometer (Dyno)

All brake samples were tested on the single-ended inertial type Dyno as shown in [Fig. 1](#), using the SAE J2430 standard test procedure list in [Table 2](#). The SAE J2430 test procedure includes sequences of instrument checks, burnish, effectiveness, fade, hot performance, cooling, recovery ramp, re-burnish, and second effectiveness.

Original equipment manufacturer cast iron discs and calipers were used in the tests. The temperature of the friction surface was recorded by a K-type thermocouple embedded 1 mm below the friction surface of the friction materials (pads). The thickness (at eight locations) and weight of the inboard and outboard pads were measured prior to and after each test.

3. RESULTS AND DISCUSSIONS

3.1. Full Scale Automotive Brake Dynamometer (Dyno) Results

The Dyno test results of the Baseline and T16 brake samples are shown in [Figs. 2](#) and [3](#). The Dyno results are plotted with torque, pressure, temperature, effectiveness and speed versus stop numbers of different sections in the SAE J2430 procedure. The average effectiveness of the Baseline, T13, T15 and T16 brake samples are 0.35, 0.33, 0.30 and 0.33, respectively. None of the tested brake samples exhibited thermal fade.

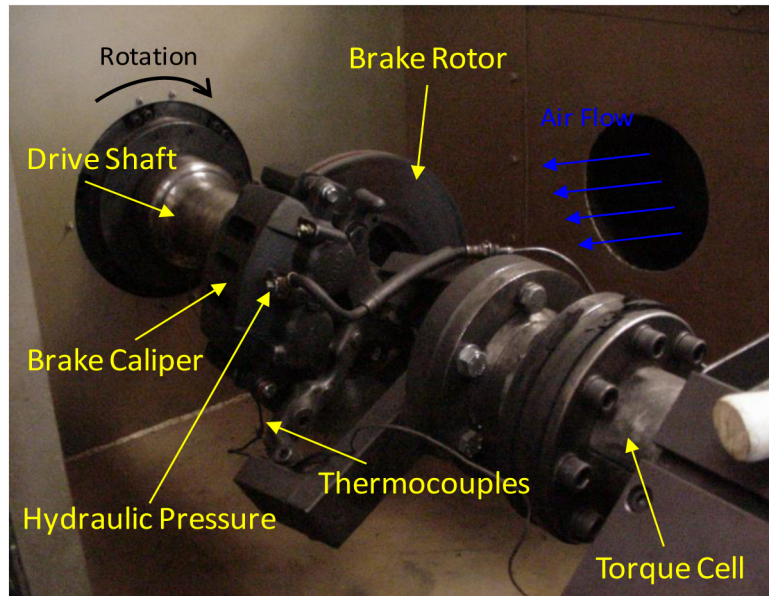


Fig. 1. Test assembly of the single-ended inertial type full scale automotive brake dynamometer

Table 2. SAE J2430 standard test procedure

Section Number	Test Section	Number Stops	Initial Speed (km/h)	Release Speed (km/h)	Deceleration (m/s ²)	Pedal Force Pressure (N)	Initial Temp. (°C)	Cycle Time (s)
2	Instrument Check - Torq. Control	5	50	3	3.14	-	100	-
3	Instrument Check - Torq. Control	5	100	3	3.14	-	100	-
4	Instrument Check - Pres. Control	3	50	3	-	75	100	-
5	Instrument Check - Ramp	5	50	3	7.85	-	100	-
6	Instrument Check - Ramp	5	100	3	7.85	-	100	-
7	Burnish	200	80	3	3.14	-	-	97
8	Post Burnish - Ramp	5	50	3	7.85	-	100	-
9	Post Burnish - Ramp	5	100	3	7.85	-	100	-
10	Post Burnish - Cold Effectiveness	6	100	3	6.38	-	100	-
11	Fade	15	120	56	3.14	-	-	45
12	Hot Effectiveness	2	100	3	-	500	-	30
14	Cooling	4	50	3	3.14	-	-	120
15	Recovery Ramp	2	100	3	7.85	-	-	60
16	Reburnish	35	80	3	3.14	-	-	97
17	Final Ramp	5	50	3	7.85	-	100	-
18	Final Ramp	5	100	3	7.85	-	100	-
19	Final Ramp	5	160	3	7.85	-	100	-

Based on the recorded SAE J2430 Dyno test results, all tested brake samples have passed the Brake Effectiveness Evaluation Procedure (BEEP) [17]. Table 3 lists the BEEP criteria and the tested values that were calculated from the results of SAE J2430 Dyno tests. The BEEP results clearly show that the T13, T15 and T16 brake samples exhibit slightly lower friction levels when compared to the Baseline brake sample.

All tested brake samples exhibit similar pattern of effectiveness in the Fade section. There are 15 brake engagements in the Fade section. The first stop engagement was started at 25 °C. The following stop engagements were applied with a cycle time of 45 seconds. The temperature of the sample went up to 325 °C as shown in Fig. 4. As the pad temperature increases, all tested samples do not show sign of thermal fade. The effectiveness of brake samples starts ~0.30, and then went up to 0.50 when the temperature was above 150°C. The effectiveness dropped to ~0.38 as the pad temperature kept increasing to 325 °C.