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Impact of Boric acid and Colemanit addition on tribological behavior and braking performances of brake lining

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Abstract
Brake lining is formed as a result of combining different materials. The materials used in the brake lining are an important factor in the brake lining performance. In this study, boric acid and colemanite, one of the boron products with high temperature resistance, were used as brake lining materials. 1%, 3%, 5% and 7% boric acid and colemanite were added to the brake lining content. The tribological properties of the brake linings were examined with a pin-on disc tester. The friction performance increased as the boric acid and colemanite ratio increased in the brake lining content. As the boric acid and colemanite ratio increased, the hardness and density of the brake lining increased, and the wear resistance decreased.
Keywords: *Colemanite,Boric acid, brake lining, Tribology*

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I. Introduction

Brake lining materials can be broadly classified into four groups: binders, fibers, friction modifiers and fillers. Binders are adhesives in liquid or powder form with high oxidation resistance and thermal stability against high temperatures. Fibers are used as reinforcing materials or reinforcing materials. Friction modifiers are divided into two as abrasive and non-abrasive, and they serve to increase or improve the friction and mechanical properties of the brake linings. Filling materials are used to reduce the cost of the brake linings [1-3].

Although the usability of a wide variety of materials as brake friction materials has been investigated in the literature, studies on boron products are relatively few [4, 5]. In order to determine the effect of boron as a friction modifier on the performance of brake linings, they tried to determine the best combination in terms of friction performance in tests using different amounts of boron [6, 7]. The effects of borax and boric acid on brake liningswere investigated experimentally and it was stated that if boric acid and borax were added to the brake liningcomponent, it could be an alternative material meeting the properties of asbestos [8].

Boron is an important mineral used in many fields from the fertilizer industry to the pharmaceutical industry, from the chemical industry to the automobile industry, including the nuclear industry. Although the boron element has about 150 minerals, boric acid, borax, colemanite and ulexite are mostly used commercially [9].

Boron has a high melting temperature [9]. It can maintain its properties at high temperatures. Brake liningsoperate at high temperatures due to friction while the vehicle is stopped or slowed down. The ability of the brake liningto maintain its properties at high temperatures is an important factor in the deceleration of the vehicle [10].

In this study, boric acid and colemanite were used to increase the performance of brake liningsagainst the heat generated during braking. Boric acid and colemanite were added to the brake lining at rates of 1%, 3%, 5% and 7% by mass. The braking performance and tribological properties of the produced brake liningswere investigated.

II. Materials and Methods

2.1. Brake Lining Production

Automotive brake liningis a composite material formed by pulverizing and pressing materials with different properties. Its chemical and mechanical properties vary according to the proportions of the materials it contains. Therefore, in the design of a brake lining material, the determination of the materials that make up the composition and their proportions is a very important and complex issue. The production of the brake liningplays a role in the determination and change of the properties as much as its composition. Because material properties change during production and even if the compositions are the same, brake liningsproduced with different production parameters can exhibit very different properties [11].

The correct selection of the type, shape, size and amount of the materials used to form the brake liningcomposites play an important role in determining the wear and friction properties [12]. First of all, the materials that make up the brake liningsamples were determined. While determining the materials, the literature, cost and ease of supply were taken into consideration. The % mass amounts of the materials used are shown in Table 1.

Table 1. The materials used in the brake lining content and their ratios (% by mass).

	BC1	BC3	BC5	BC7
Phenolic Resin	20	20	20	20
Cashew	10	10	10	10
Alumina	5	5	5	5
Steel Wool	10	10	10	10
Brass Particle	7	7	7	7
Copper	5	5	5	5
Graphite	3	3	3	3
Barite	38	34	30	26
Boric Acid	1	3	5	7
Colemanite	1	3	5	7

The brake lining composition was prepared by weighing the powder materials, the ratios of which are given in Table 1, on a precision balance with an accuracy of 0.001 g.The prepared brake lining composition was transferred to the chamber of the mixing device.The brake lining in the chamber of the mixing device was mixed with a mixer at 120 revolutions and in 10 minutes to ensure the homogeneity of the mixtures.After the mixing process, it was poured into molds prepared for cold forming and shaped in a cold press to form the front shape of the brake lining at ambient temperature for 2 minutes at 80 bar pressure.

The brake lining samples, which had taken their shape as a result of cold forming, were fired in a baking mold at 100 bar pressure and 150 °C in 10 minutes by ventilating at intervals of 60 seconds. It is ensured that the vapors and gases formed as a result of the reactions formed by the brake lining components as a result of the temperature in the material are discharged. In order to ensure that the brake linings can be easily removed from the mold after cooking and pressing, hot water with granular soap was sprayed with compressed air as pulverized. Finally, the samples removed from the mold were allowed to cool until they reached ambient temperature.

In order to obtain the wear and friction coefficient properties of the samples, tests in accordance with TSE 555 (Highway Vehicles-Braking Systems-Pads-Friction Brakes) and TSE 9076 (Highway Vehicles-Braking Systems-Brake Pads-Evaluation of Friction Properties of Materials with Small Test Pieces) carried out [13, 14]. In order to make the brake liningsurface ready for the test according to the standard, it was lapped at 310 rpm, 700 kPa pressure and 100°C temperature limit until the surface contact of the brake liningwith the disc was 95%.

2.2. Experimental Setup

In order to determine the braking performance and tribological properties of the produced brake linings, the experimental set that can transfer the brake liningsurface temperature, brake force, hydraulic system pressure, friction coefficient data given in Figure 1 to the computer environment during the experiment was used. Information about the experimental device is given in detail in the authors' study [15, 16].

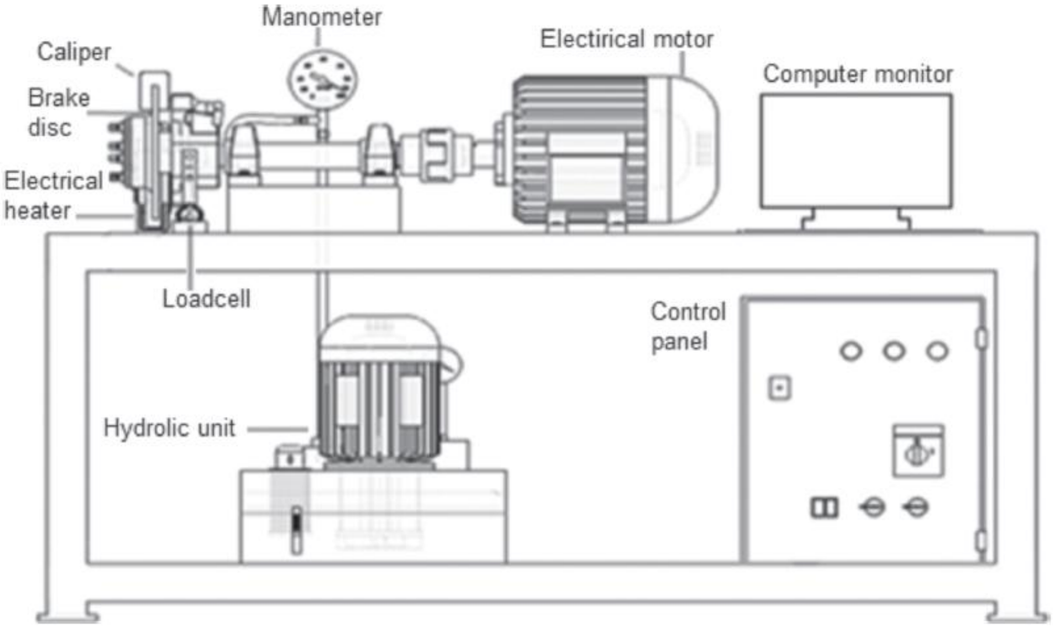

Figure 1. Brake liningtester schematic view [15, 16].

During the experiments, the friction surface temperature increases as a result of the friction of the brake lining against the brake disc. In order to examine the effect of temperature increase on the friction coefficient, the surface temperature of the disc was measured from a distance of about 2 cm from the friction surface of the brake lining to the disc with a non-contact (infrared) thermometer. A digital thermometer that can receive data every second is used for temperature measurement. Thanks to the device, the surface temperature of the disc was automatically transferred to the computer environment in seconds during the experiment [15, 16].

The produced brake liningswere tested on the experimental set, which is shown schematically in Figure 1 and has a gray cast iron disc with a hardness of 116 HB and a diameter of 280 mm. Tester; It is a computer-controlled device with software that stores brake liningsurface temperature, brake force, hydraulic system pressure, friction coefficient data.

2.3. Test Conditions

The brake liningsamples produced were tested under 5 bar pressure at a speed of 3 m/s to ensure that the friction surfaces overlap until 95% of the sample surface comes into contact with the disc surface. The experiments were carried out at 7 bar brake liningsurface pressure and 616 rpm speed. The coefficient of friction, temperature and time values were recorded during the experiment. For each sample, the friction coefficient was recorded for 3600 seconds at 616 rpm, 7 bar pressure, 1 second intervals, and friction coefficient-time-temperature values were obtained. Thus, in TSE 555, the pressure applied to determine the friction coefficient of the brake liningswas applied as a constant, and the friction coefficient and time change were examined without being exposed to any external effects [13]. In order to determine the wear resistance, at the end of the experiment, the mass loss of each brake liningsample was determined by weighing the brake liningon a precision balance.

Hardness measurements of the brake liningswere made with a Rockwell (HRL) hardness measuring device. A steel ball with a diameter of 6.35 mm was used for the measurements. During the experiments, 10 kgf preload and 60 kgf full load were applied. The densities of the brake liningswere determined according to the Archimedes principle with the test method specified in the previous study of the authors.

III. Results and Discussion

One of the most important parameters affecting brake performance is the friction coefficient. Friction coefficient test results are used to understand various brake performances such as brake weakening, vibration, noise, stopping distance [17].Temperature and friction coefficient changes depending on the friction time of the brake linings are shown in Figure 2, Figure 3, Figure 4 and Figure 5. In the figures, the reason for the low friction coefficient at the beginning of the test is that the applied pressure acts gradually, not suddenly. Since the sudden pressure application will cause the brake liningsto be damaged, the pressure increase has been achieved gradually. In addition, at the beginning of the test, the brake lining is in the process of running in with the disc and the friction layers on which the friction force is effective have not yet formed [18]. One of the most important features required from brake liningsis that the change in the friction coefficient is at a minimum level due to the increase in the interface temperature due to the friction of the brake liningon the disc surface during braking.

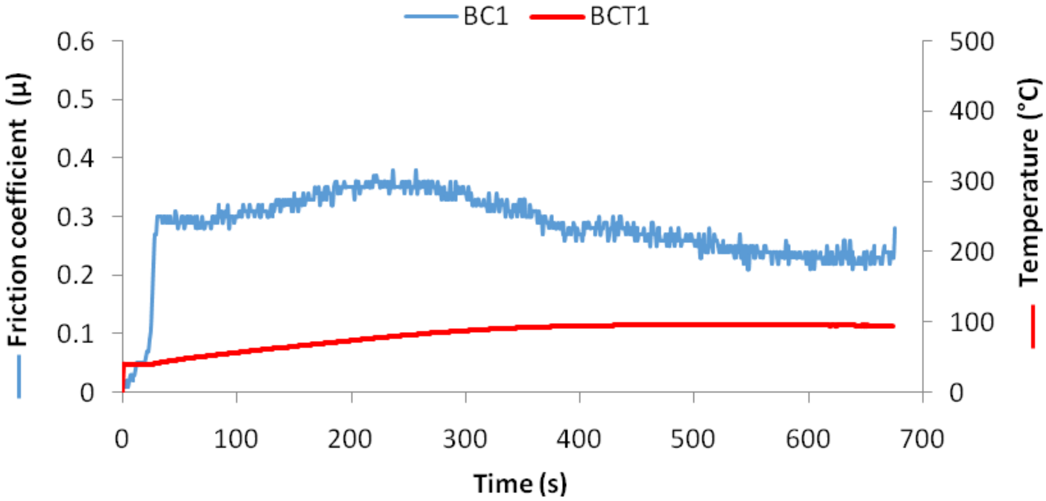

Figure 2. Friction coefficient-temperature-time variation of the brake lining containing 1% Boric Acid and Colemanite

Figure 2 shows the friction coefficient-temperature graph of the brake lining containing 1% Boric Acid and Colemanite over time. It was observed that the highest friction coefficient obtained during the tests was 0.38, and the highest temperature was 80°C. The average friction coefficient of the brake lining was calculated as 0.29 and the friction stability was calculated as 76%.

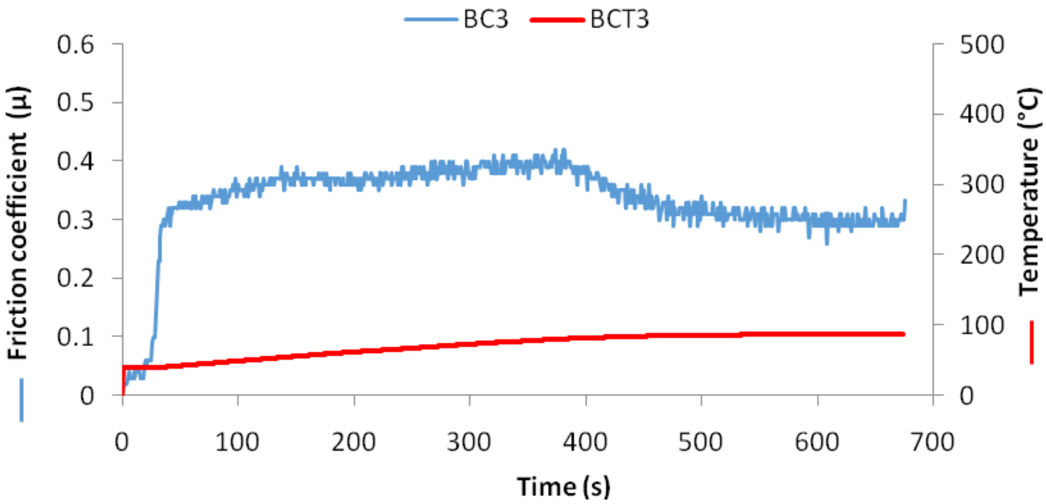

Figure 3. Friction coefficient-temperature-time variation of the brake lining containing 3% Boric Acid and Colemanite

The friction coefficient and time graph of the BC3 coded brake lining containing 3% Boric Acid and Colemanite are shown in Figure 3. During the tests, the highest temperature occurred at the interface between the disc and the brake lining was 88°C and the friction coefficient average was 0.33. It was observed that the highest friction coefficient value of the brake lining sample was 0.42, and the friction stability was 84%.

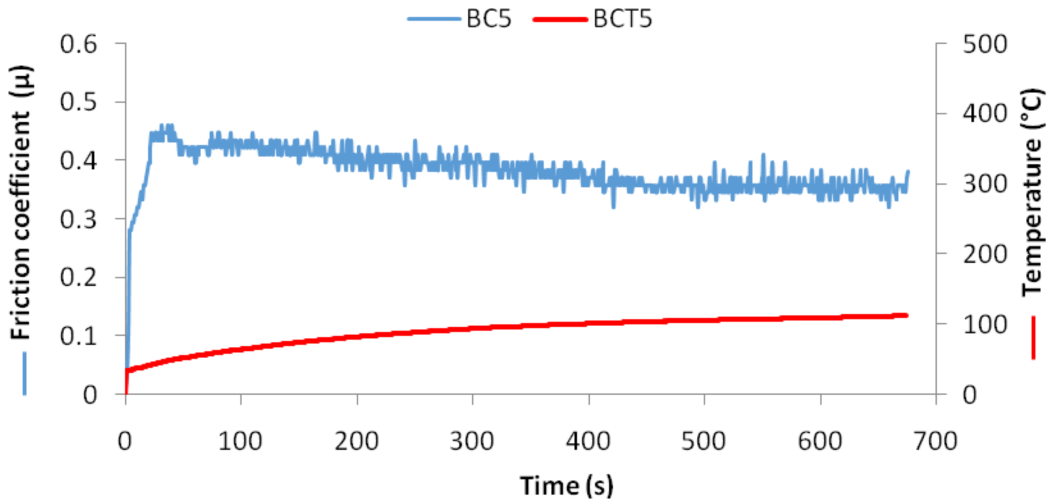

Figure 4. Friction coefficient-temperature-time variation of the brake lining containing 5% Boric Acid and Colemanite

Figure 4 shows the friction coefficient-temperature graph of the brake lining containing 5% Boric Acid and Colemanite over time. It was observed that the highest friction coefficient obtained during the tests was 0.47, and the highest temperature was 112°C. The average friction coefficient of the brake lining was calculated as 0.38, and the friction stability was calculated as 82%.

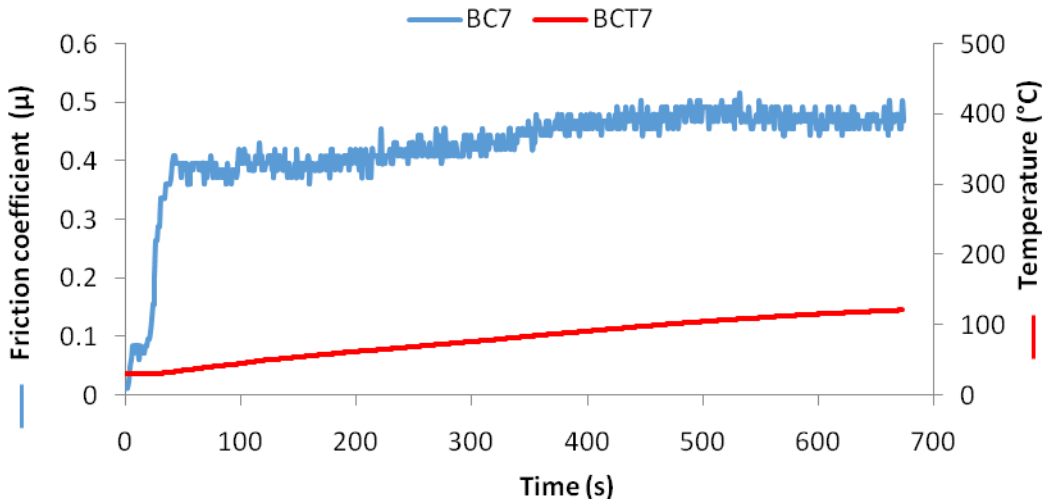

Figure 5. Friction coefficient-temperature-time variation of the brake lining containing 7% Boric Acid and Colemanite

Figure 5 shows the friction coefficient and temperature graph of the brake lining containing 7% Boric acid and colemanite over time. The highest friction coefficient obtained in the tests was 0.51, the highest temperature occurring between the disc and the brake lining was 121°C. The frictional stability was calculated as 82%. In the literature, it is stated that the friction stability (%) value should be as high as possible and close to 100, and the slope and fluctuations of the obtained curve should be low [19, 20].

Table 2. Test results of the produced brake linings

Sample code	Specific wear ratio (cm^3/Nm)	Density (g/cm^3)	Rockwell hardness (HRL)	Average friction coefficient (μ)	Friction stability (%)
BC1	$1{,}22x10^{-6}$	2,16	72	0,29	76
BC3	$1{,}73x10^{-6}$	2,21	79	0,33	78
BC5	$1{,}93x10^{-6}$	2,36	84	0,38	80
BC7	$2{,}32x10^{-6}$	2,56	89	0,42	82

The specific wear rate and friction coefficient of the brake lining are important parameters that affect the brake performance. It is desirable for a brake lining to have a low specific wear rate and a high coefficient of friction.According to the TSE 555 standard, the friction coefficient of the brake liningsshould not be less than 0.25 [13]. When Table 4 is examined, it is seen that the sample with the highest average friction coefficient is the BC7 coded brake lining containing 7% Boric acid and Colemanite by mass. In addition, it has been determined that there is a direct proportionality between the hardness and density of the brake linings. The relationship between hardness and density is consistent with the literature [21, 22].

IV. Conclusions

In this study, the usability of boric acid and colemanite in brake lining content was investigated. For this purpose, four different brake liningscontaining 1%, 3%, 5% and 7% Boric acid and Colemanite by mass were produced. A full scale brake liningtester was used for the wear and friction tests of the brake linings. The results obtained from the tests are summarized below;

- Brake liningsproduced according to friction and wear test results can be applied in the industry, comply with the literature and comply with the TSE 555 standard.
- As the ratio of Boric acid and Colemanite in the brake lining content increased, the frictional stability also increased.
- The highest brake lining performance was seen in the lining sample containing 7% Boric acid and Colemanite.
- As the boric acid and colemanite ratio increased, the brake lining density and hardness increased.
- As the boric acid and colemanite ratio increased, no sudden increases in disc surface temperature were observed. The disc surface temperature increased stably and was below the standard values. This has increased the braking performance positively.
- When the characteristics of the brake lining samples were examined, it was concluded that there was a direct proportionality between the hardness and density of the samples and this ratio was compatible with the literature.

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