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Effects of Boron minerals on the mechanical and tribological properties of brake friction materials

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Abstract
Brake liningsrise to high temperatures as a result of friction. The high temperature caused by friction causes brake weakening and extends the stopping distance of the vehicle as an undesirable situation. In this study, high temperature resistant boron minerals Colemanite, Ulexite, Borax and Boric Acid were used in brake lining content. Colemanite, Ulexite, Borax and Boric Acid have been added to the brake lining content at rates of 1%, 3%, 5% and 7% by mass. Friction and wear performances of the produced brake liningswere determined with a pin-on-disc tester. As the Bo mineral content increased, the friction performance of the brake lining increased positively. Depending on the increase in boron mineral, hardness and density values also increased. It has been determined that it is appropriate to use boron mineral in order to slow down the rate of increase of high temperature ratios caused by friction in brake linings.
Keywords: *Boron minerals,Colemanite, Ulexite, Borax, Boric Acid,Brake lining*

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I. Introduction

Boron, whose chemical symbol is "B", is a semiconductor element between metal and nonmetal with a melting point of 2190±20 °C [1].The degree of processing required to make boron compounds suitable for different industrial uses varies widely. Some industries use mineral concentrates, while others use refined Boron products [1-3].

The most important of these minerals in terms of boron industry are Colemanite, Ulexite, Borax and Boric Acid [2, 3]. Boron products are used in many fields such as space and air vehicles, military vehicles, missiles, radars, communication technologies, nano technologies and energy in addition to fields such as glass, chemistry and detergent, ceramic and polymeric materials, metallurgy and construction, food and agriculture [4]. Various boron products and chemical compounds obtained from boron minerals are consumed in fields such as electricity, medicine, cosmetics, fire-resistant materials, anti-corrosion materials, adhesives, plastics, explosives, hard materials, paints [5].

Due to its lightness, resistance to stretching and resistance to chemical effects; It is also used in plastics, industrial fiber production, tire and paper industry, agriculture, nuclear power plants, rocket fuels. It has an important place in the production of temperature-resistant glassware, qualified glasses to be used in electronics and space exploration, as it significantly reduces the expansion of the glass with temperature, provides resistance to vibration, high temperature and temperature shocks. Some Boron compounds have a high degree of hardness. (9 according to the Mohs ruler) [6, 7]. For this reason, it is used as an abrasive for cutting, sharpening and polishing metals and super alloys.

Since boron minerals retain their properties at high operating temperatures, their use in brake liningsoperating at high temperatures will positively affect the performance of the brake lining. In order for the vehicle to slow down or stop, the temperature increase caused by the friction of the brake lining to the disc will be controlled. Thus, depending on the temperature of the disc surface, the brake lining will be prevented from slipping on the disc surface and will positively affect the stopping distance of the vehicle.

In this study, Colemanite, Ulexite, Borax and Boric Acid powders, which are among the most important boron minerals, were used in brake lining at different rates (1%, 3%, 5% and 7%). The effect of the produced brake liningson the braking performance was investigated. The friction coefficient, wear rate, hardness, density and friction stability of the produced brake linings were determined.

II. Materials and Methods

Asbestos-free brake lining materials have been selected in the production of boron mineral added brake linings. The materials that make up the brake lining of the brake lining were determined as a result of the literature research and the products used by the brake lining manufacturers [8-11]. Mass ratio was taken as basis in the creation of the content that makes up the brake lining materials. The material contents and proportions that make up the brake lining content are given in Table 1. The boron mineral ratio of the produced brake linings was balanced with the filling material barite and coded as B1, B3, B5 and B7 according to the boron mineral and amount they contain. Except for the boron minerals and barite contained in the brake lining, the ratios of other materials are fixed.

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

	B1	B3	B5	B7
Phenolic Resin	20	20	20	20
Cashew	10	10	10	10
Alumina	5	5	5	5
Steel Wool	10	10	10	10
Brass Particle	5	5	5	5
Copper	5	5	5	5
Graphite	3	3	3	3
Barite	38	30	22	14
Colemanite	1	3	5	7
Ulexite	1	3	5	7
Borax	1	3	5	7
Boric Acid	1	3	5	7

The mixing ratios of the powder materials that make up the brake lining content were weighed with a balance with an accuracy of 0.001 g. The mixtures prepared at the determined ratios were mixed in the mixer at 300 rpm for 10 minutes to ensure their homogeneity. The prepared mixture was transferred to a mold with a diameter of 25.4 mm and pre-formed by keeping it under 8 MPa pressure for 2 minutes. Then, the samples were subjected to hot pressing process at 10 MPa pressure and 150ºC temperature for 10 minutes.

In order to determine the braking performance of the brake linings, a computer-controlled experiment set, which can transfer the friction coefficient, brake force, hydraulic system pressure, brake lining surface temperature values, which are schematically displayed in Figure 1, to the computer environment during the experiment was used.

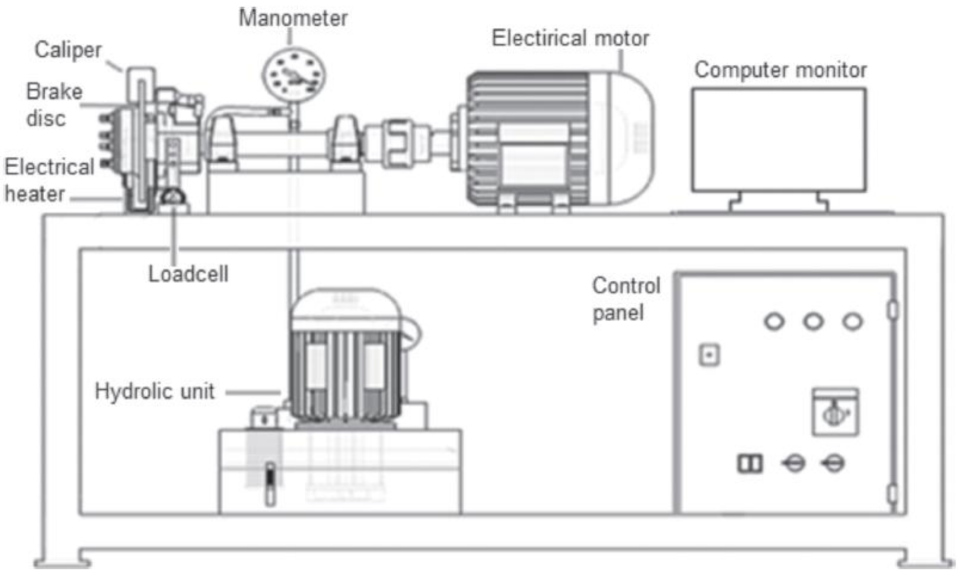

Figure 1. Schematic view of the computer-controlled brake lining tester [8]

In the experimental setup, a load cell was used to measure the friction force between the brake lining and the brake disc during rotation. Thus, the rotational force was measured electronically, taking into account the friction force arising from the pressure applied to the brake lining during the rotation of the disc, taking into account the desire of the brake lining to rotate together with the disc. There is a speed adjuster so that the brake disc in the experimental setup can be used at the desired speed and revolutions. In order to carry out the experiments in accordance with the standards, a non-contact (IR) thermometer, which can receive data every second and can operate between -50 and 1000°C, was placed in the experimental setup to determine the disc surface temperature. A brake disc made of gray cast iron with a hardness of 116 HB (41.86 HRA) and a diameter of 280 mm was used [9].Detailed information about the experimental set is given in the authors' work [10, 11].

The produced brake linings were placed in the test device with the help of shoes and operated at a speed of 3 m/s under 0.7 MPa pressure until 95% of the sample surface came into contact with the disc surface to ensure that the friction surfaces overlap. The experiments were carried out at 1.05 MPa brake lining surface pressure and 6 m/s speed. The friction coefficient and time values taken during the experiments are the arithmetic average of the values taken from three samples produced with the same mixture and properties. The coefficient of friction for each sample was recorded for approximately 700 seconds at 1 second intervals at a pressure of 1.05 MPa at a speed of 6 m/s.

Considering the force applied to the brake linings and the friction force obtained from the test device, the friction coefficient was calculated with the formula specified in TSE 555 [12].The hardness measurements of the brake linings were determined by the Rockwell L (HRL) hardness measurement method. During the hardness measurements, a preload of 10 kgf and a full load of 60 kgf were applied with a 6.35 mm diameter steel ball as the penetrating tip. Hardness measurements were taken from the friction surface of the brake linings. Calculated by taking the values from the middle and near the edge of the brake linings. Measurement values were taken from different regions for each sample and their arithmetic average was taken [13]. Density measurements of the samples were determined using Archimedes' principle in water.

III. Results and Discussion

Provided that other materials constituting the brake lining composition remain constant, 4 different composite brake linings containing boron minerals (Colemanite, Ulexite, Borax and Boric Acid) by mass 1%, 3%, 5% and 7% were produced. As stated in TSE 555 [12], a total of 20 brake lining samples were produced considering the arithmetic average of the results obtained from 5 test pieces with the same content in the experiments. The time-dependent friction coefficient-temperature graphs of the samples are shown in Figure 2, Figure 3, Figure 4 and Figure 5.When the graphs are examined, the average lowest friction coefficient was 0.39 in the B1 coded sample containing 1% boron minerals (Colemanite, Ulexite, Borax and Boric Acid) by mass, while the B7 coded sample containing 7% boron minerals by mass gave the highest average friction coefficient 0.50.

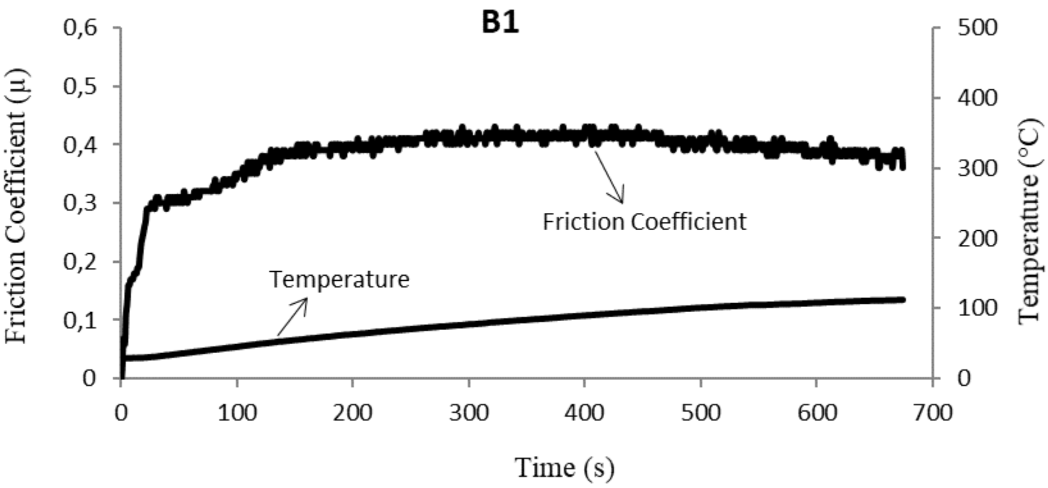

Figure 2. Friction coefficient-temperature graph of the brake lining containing 1% boron minerals

Figure 2 shows the friction coefficient-temperature change depending on time of the B1 coded brake lining containing 1% boron minerals by mass. The temperature occurring at the interface between the brake lining and the disc is 25°C at the lowest and 112°C at the highest. Average friction coefficient value is 0.38 and friction stability is 86%.

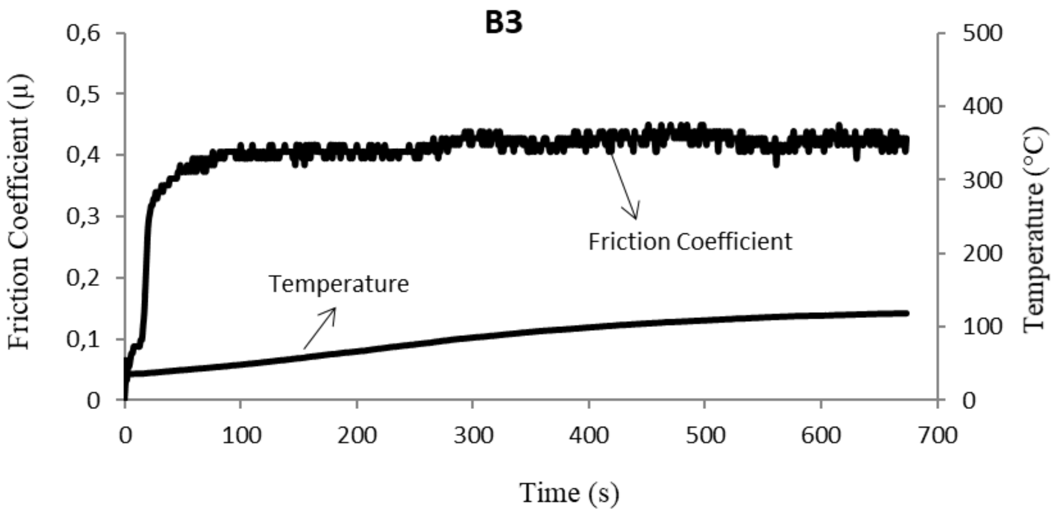

Figure 3. Friction coefficient-temperature graph of the brake lining containing 3% boron minerals

Figure 3 shows the friction coefficient-temperature variation of the B3 coded brake lining containing 3% by mass of boron minerals. The temperature occurring at the interface between the brake lining and the disc is 25°C at the lowest and 114°C at the highest. Average friction coefficient value is 0.41 and friction stability is 91%.

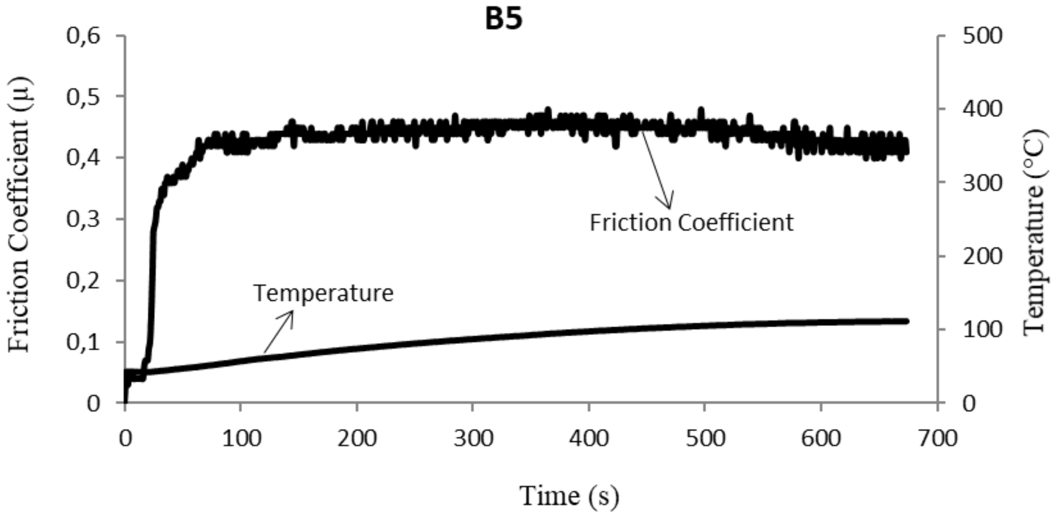

Figure 4. Friction coefficient-temperature graph of the brake lining containing 5% boron minerals

Figure 4 shows the friction coefficient-temperature variation of the B5 coded brake lining containing 5% by mass of boron minerals. The temperature occurring at the interface between the brake lining and the disc is 25°C at the lowest and 117°C at the highest. Average friction coefficient value is 0.43 and friction stability is 90%.

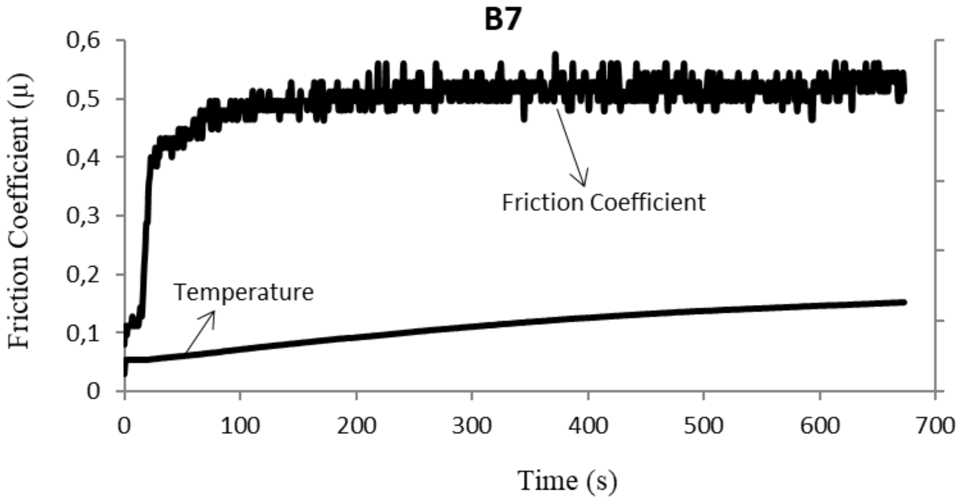

Figure 5. Friction coefficient-temperature graph of the brake lining containing 7% boron minerals

Figure 5 shows the friction coefficient-temperature variation of the B7 coded brake lining containing 7% boron minerals by mass, depending on time. The temperature occurring at the interface between the brake liningand the disc is 25°C at the lowest and 127°C at the highest. Average friction coefficient value is 0.50 and friction stability is 90%.In the literature, it is stated that after the friction coefficient increases, it will continue to be stable and decrease after a while depending on the increase in the interface temperature of the disc and the brake lining.When the figures are examined, a fluctuating continuous change is seen in the friction coefficient. It has been stated that this is due to the periodic constant change of temperature towards the inside of the contact areas on the disc surface during friction [14]. Due to this effect, a constant change in the coefficient of friction occurs. In addition, this situation is explained by the merger and growth of the roughness on the surface of the friction pairs [15]. In this case, an adhesion and a release state is constantly repeated, resulting in a continuous fluctuating change in the coefficient of friction.When the friction test results were examined, it was seen that the temperature occurring at the interface of the brake liningand the disc directly affected the friction stability. High frictional stability is required for brake lining materials. The highest friction stability value was seen in the brake liningscontaining 5% and 7% boron minerals by mass.

The friction properties and physical properties such as hardness and density of the brake linings containing the boron minerals Colemanite, Ulexite, Borax and Boric Acid are given in Table 2.

Table 2. Tribological and mechanical properties of brake linings

Sample code	Specific wear ratio ($x10^{-6}$) (cm^3/Nm)	Density (g/cm^3)	Rockwell hardness (HRL)	Average friction coefficient (μ)	Frictional stability (%)
B1	1,88	2,36	81	0,39	86
B3	1,95	2,57	87	0,41	89
B5	2,16	2,85	90	0,43	90
B7	2,34	3,12	95	0,50	90

Accordingly, it was observed that the average friction coefficient values of the brake liningswith high hardness were also higher. It was determined that as the boron minerals increased, the density and astringency of the brake lining increased. Friction stability showed close values to each other. Boron minerals prevented the sudden increase in the temperature of the disc and brake lining interface. This is due to the high operating temperature of the boron minerals added to the brake lining content.When the wear rates of the brake linings containing the boron minerals Colemanite, Ulexite, Borax and Boric Acid were examined, it was seen that they were compatible with the literature [16-19]. As boron minerals increased, the friction coefficient increased, which caused an increase in temperature due to surface friction. When the wear rates of the brake liningswere examined, it was observed that there was an average of 7% difference. It is normal for the brake liningwear amount to increase due to the increase in the friction coefficient.

IV. Conclusions

In this study, the effect of the use of boron minerals in Colemanite, Ulexite, Borax and Boric Acid on vehicle brake linings on tribological properties was investigated. For this purpose, four different brake linings containing 1%, 2%, 5% and 7% boron minerals by mass, Colemanite, Ulexite, Borax and Boric Acid, were produced by powder metallurgy method. It has been observed that the amount of boron mineral in the composition affects the performance properties of the brake lining composite. It has been determined that the friction coefficient of the brake liningsvaries between 0.4 and 0.5 depending on the friction force and the disc-brake lininginterface temperature. It has been observed that the temperature occurring at the interface between the sample brake liningsand the disc directly affects the frictional stability. Connections were determined between the physical properties of the samples. Accordingly, density is directly proportional to hardness. In addition, an increase in the average friction coefficient of the brake liningswith high hardness was determined. The results obtained from the friction-wear tests were found to be in line with the literature and in accordance with TSE 555.

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