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Tribological and mechanical behavior of boric acid and borax containing brake pad

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Abstract
Vehicle brake pads are formed as a result of combining different materials. In this study, boric acid and borax were used in vehicle brake pad content. Boric acid and borax were added to the pad content at 1%, 3%, 5% and 7%, and braking performance was compared. The braking performance of the produced pads was determined using a pin-on-disc friction test device. The specific wear rate, hardness and density values of the pad samples were determined. The brake pad containing 7% boric acid and borax achieved a braking performance close to the highest value among the values specified in the standards.
Keywords: *Boric acid, Borax, Brake pad, Friction performance*

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I. Introduction

The brake system is used to stop or slow down the vehicle. One of the most important safety and performance elements in automobiles is the brakes [1,2]. The braking system is a system that converts the kinetic energy obtained by the movement into heat by friction, which enables the movement to be stopped or taken under control [3]. One of the most important components of the brake system is the brake pad [4]. Asbestos-free organic brake pads have been developed and patented instead of asbestos-reinforced pads, which are prohibited in automotive brake pads due to their harm to human health [5]. As a result of rapid developments in automotive technology, vehicles that can reach very high speeds with higher acceleration are produced. Therefore, the use of new and different composite friction materials combined with each other in automotive brake pads has taken an important place in the development of material technology. Especially high coefficients of friction and good sliding properties are among the reasons for the use of friction materials. Friction materials are required to show a very stable and high coefficient of friction in different operating conditions such as variable load, temperature, speed in dry or wet environments. In addition, it is expected that the amount of wear will be low, the counter material will not be scratched and damaged, and there will be low noise during braking [6]. Environmental conditions, applied pressure and load, microstructure properties affect the tribological properties of the materials used in vehicle brake pads.Vehicle brake pads; It should exhibit properties such as stable and high coefficient of friction, low wear, low vibration and noise due to high wear resistance [7]. We can classify the materials used in vehicle brake pads as friction modifiers, abrasives, reinforcements and fillers [8].Vehicle brake pads are required to exhibit good friction performance due to the high temperature that occurs during braking. Studies on the search for materials that will preserve the properties of vehicle brake pads at high temperatures are increasing. In the literature researches, it has been seen that boron materials with high melting temperature are used in different areas [9-11].As a result of scientific and technological developments, it is seen that boron products are used in a wide range such as textile fibers, glass, nuclear applications, advanced magnets. In this sense, boron minerals have become a factor that closely concerns many sectors and technologies as raw materials. Considering Turkey's rich boron deposits, it is clearly seen that it should be used as an extremely important, vital and strategic resource [12]. In this study, the use of boric acid and borax materials, which are boron types, in vehicle brake pads was investigated. In this context, brake pads were produced by adding boric acid and borax at four different rates (1, 3, 5 and 7%) to the pad content. The tribological effect of brake pads produced with boric acid and borax was investigated.

II. Materials and Methods

In the production of the pads, non-asbestos reinforcement materials and components are selected to prevent thermal deterioration at high temperatures and to strengthen the mechanical and tribological properties of the pad. Mass ratio was taken as basis in determining material ratios during production. In Table 1, the materials that make up the pad content were weighed with an accuracy of 0.001 g and filled into the moving chamber of the powder mixer.

Table 1. The ratio of the materials used in the produced pad (% Mass)

	BX1	BX3	BX5	BX7
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
Borax	1	3	5	7

In order to ensure the homogeneity of the mixture prepared in certain proportions, it was mixed with a mixer at 120 rpm for 10 minutes. After mixing, it was poured into Ø25.4 mm molds prepared for cold forming and shaped in a cold press to form the preliminary shape of the pad at ambient temperature, 80 bar pressure for 2 minutes. The preformed pad samples were fired in a baking mold at 100 bar pressure and 150°C in 10 minutes by ventilating them at intervals of 60 seconds. Thus, it is ensured that the water in the material and the vapors and gases formed as a result of the reactions formed by the pad components as a result of the temperature are discharged. A special liquid was used to prevent the sample from sticking to the die punch surface. Finally, the samples removed from the mold were allowed to cool until they reached ambient temperature. Boric acid and borax were produced together and supplemented in four different ratios (1, 3, 5 and 7%). The samples were coded as BX1, BX3, BX5 and BX7, respectively.The experimental set, which can transfer the coefficient of friction, brake force, hydraulic system pressure, pad surface temperature values given in Figure 1 to the computer environment during the experiment, was used to determine the coefficient of friction and time characteristics of the samples, which were completed, depending on time.

Figure 1. Computer controlled pin-on-disc test device

In the experimental setup, a load cell was used to measure the friction force between the pad and the brake disc during rotation. Thus, this turning force was measured electronically, taking into account the friction force of the pressure applied to the brake pad during the rotation of the disc, taking into account the desire of the pad 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 operate between -50°C and 1000°C, and which can receive data every second to determine the disc surface temperature was used.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 in the experiment.The pad tester was operated to ensure that the friction surfaces of the produced pad samples overlapped under 5 bar pressure at a speed of 3 m/s until 95% of the sample surface came into contact with the disc surface. The experiments were carried out at 7 bar pad surface pressure and 616 rpm speed. The coefficient of friction, temperature and time values were recorded during the experiment. The coefficient of friction for each sample was recorded for 600 seconds at 1 second intervals at 616 rpm, 7 bar pressure, and coefficient of friction-time values were obtained. Thus, in TSE 555 and TSE 9076, the applied pressure was applied to determine the coefficient of friction of the brake pads, and the coefficient of friction and time change were examined without being exposed to any external effects [13, 14]. At the end of the experiment of each pad sample, the pad was weighed on a precision scale and the mass loss was found.The coefficient of friction was determined according to TSE 555, taking into account the force applied to the pads and the friction force obtained from the test device [13]. Detailed information on the test procedure has been described in detail in the authors' previous work [15, 16].The hardness measurements of the samples were determined by the Rockwell hardness measurement method. During the hardness measurements, applied preload 10 N, full load 60 N and a 6.35 mm diameter steel ball tip were used as the penetrating tip. Hardness measurements were taken from the friction surface of the samples.Density measurements of the samples were determined using Archimedes' principle in water.

III. Results and Discussion

In this study, boric acid and borax added brake pads reinforced in the same amount by mass and in four different ratios were produced and its usability as a vehicle brake pad friction material was investigated. In order to determine the optimum ratio, four different ratios ranging from 1% to 7% were used. The mass increase of boric acid and borax powder in the friction materials in the brake pad samples was balanced by the reduction of barite, which had no effect on the coefficient of friction (Table 1). The graphs of the coefficient of friction of the samples over time are shown in Figure 2, Figure 3, Figure 4 and Figure 5. The best desired feature is that the change in the coefficient of friction is at a minimum level due to the increase in the interface temperature of the brake pads due to friction during braking [17, 18]. 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 minimal [19].

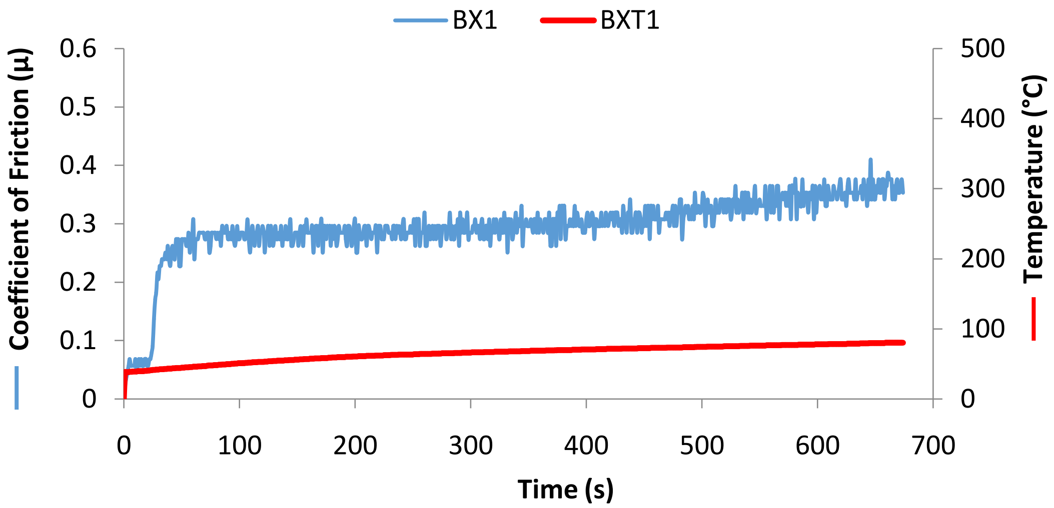

Figure 2. Time-dependent coefficient of friction-temperature graph of BX1 sample

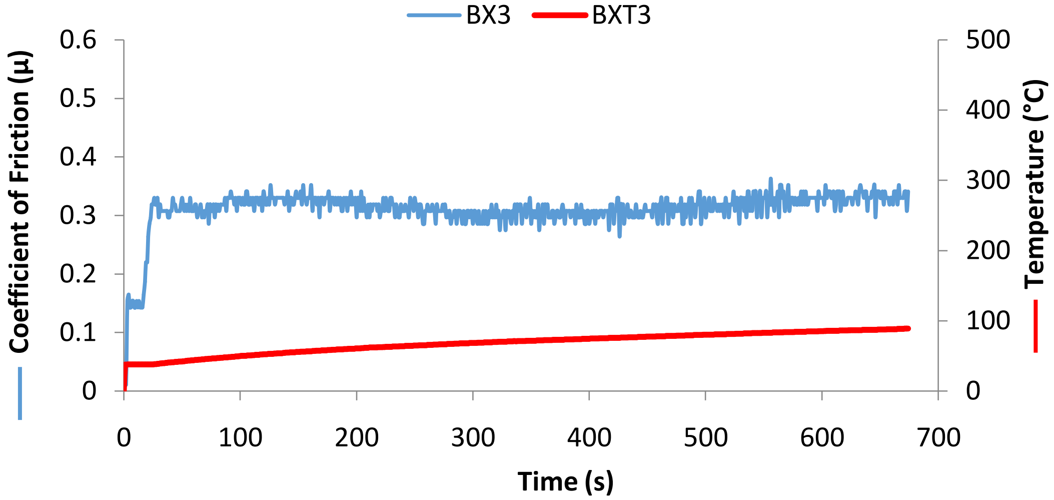

Figure 3. Time-dependent coefficient of friction-temperature graph of BX3 sample

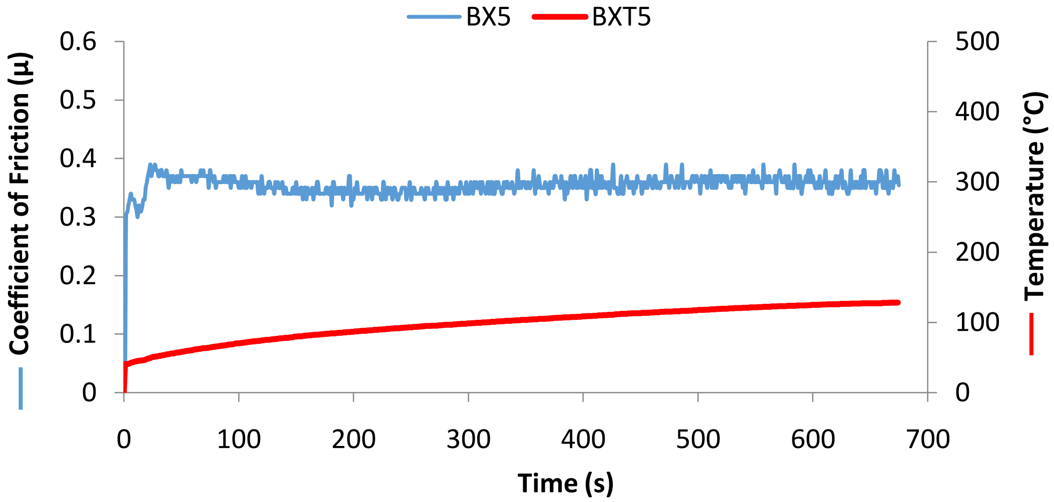

Figure 4. Time-dependent coefficient of friction-temperature graph of BX5 sample

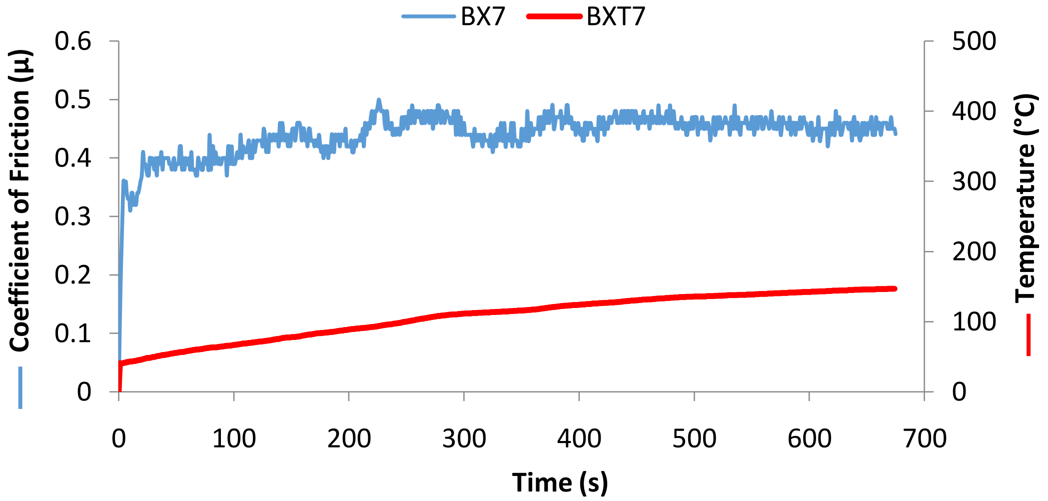

Figure 5. Time-dependent coefficient of friction-temperature graph of BX7 sample

When the graphics are examined; while the lowest average coefficient of friction value was 0.29 in the BX1 coded sample, the highest average coefficient of friction was 0.44 in the BX7 coded sample.Figure 2 shows the variation of the coefficient of friction of the BX1 coded sample over time. The temperature occurring at the interface between the pad and the disc is 37°C at the lowest and 80°C at the highest. Average coefficient of friction value is 0.29 and friction stability is 70%. Figure 3 shows the variation of the coefficient of friction of the BX3 coded sample over time. The temperature occurring at the interface between the pad and the disc is 37°C at the lowest and 89°C at the highest. Average coefficient of friction value is 0.32 and friction stability is 71%. Figure 4 shows the variation of the coefficient of friction of the BX5 coded sample over time. The temperature occurring at the interface between the pad and the disc is 37°C at the lowest and 128°C at the highest. Average coefficient of friction value is 0.35 and friction stability is 78%. Figure 5 shows the variation of the coefficient of friction of the BX7 coded sample over time. The temperature occurring at the interface between the pad and the disc is 37°C at the lowest and 146°C at the highest.Average coefficient of friction value is 0.44 and friction stability is 73%.When the figures are examined, it is seen that there is a fluctuating continuous change in the form of a small decrease in the coefficient of friction during the development of the friction layer. It has been stated that the reason for this situation is the periodic constant change of temperature towards the inside of the contact areas on the disc surface during friction [20]. Due to this effect, a constant change in the coefficient of friction occurs. In addition, this situation is explained by the coalescence and growth of the roughness on the surface of the friction pairs [21]. In this case, an adhesion and a release state is constantly repeated, resulting in a continuous increase and decrease in the coefficient of friction.
Average coefficient of friction, specific wear rate, hardness, density and friction stability of the samples produced as friction material are given in Table 2.

Table 2. The characteristics of the pad samples

Sample code	Specific wear ratio (x10^{-6}) (cm^3/Nm)	Density (g/cm^3)	Rockwell hardness (HRL)	Average coefficient of friction (μ)	Frictional stability (%)
BX1	1,36	2,07	69	0,29	70
BX3	1,66	2,12	73	0,32	71
BX5	1,74	2,19	79	0,35	78
BX7	2,36	2,21	82	0,44	73

When the friction test results were examined, it was seen that the temperature occurring at the interface of the pad and the disc directly affected the friction stability. High frictional stability is required for brake pad materials. When Table 2 is examined, it is not seen that the friction stability of the produced pad samples is between 70 and 80%.In the literature, it is seen that the coefficient of friction (μ) varies between 0.3 and 0.7, depending on the friction force and the temperature of the disc-pad interface [22]. The results obtained from the friction wear tests were found to be in line with the literature studies and in accordance with TSE 555. The wear rate of the BX1 coded pad used as friction material is 1.36x10^{-6} cm^3/Nm, the wear rate of the BX3 coded pad is 1.66x10^{-6} cm^3/Nm, the wear rate of the BX5 coded pad is 1.74x10^{-6} cm^3/Nm and the BX7 coded pad 2.36x$10^{-6}$$cm^3$/Nm was found. It has been determined that there is a direct proportional relationship between the density and hardness values of the pads.

IV. Conclusions

In this study, new pads were produced by adding boric acid and borax powder in different ratios (1%, 3%, 5%, 7%) to the pad content and the friction wear behavior of the produced pads was investigated.

- In the friction performance tests of BX1, BX3, BX5 and BX7 coded pads, it was seen that the BX7 coded pad gave the highest result, while the BX1 coded pad gave the lowest performance.
- In the friction performance tests of BX1, BX3, BX5 and BX7 coded pads, the highest wear was observed in BX7 coded pad and the lowest wear was observed in BX1 coded pad. It has been determined that the amount of wear is proportional to the coefficient of friction.

- As the amount of boric acid and borax in the pad increased, friction performance increased positively.
- The amount of boric acid and borax added to the pad content caused an increase in the density and hardness.
- It has been observed that the temperature occurring at the interface between the pad samples and the disc directly affects the friction stability.
- It can be said that the performance tests of the pads produced by adding boric acid and borax powder are compatible with the literature studies and can be used as a pad material according to the TSE 555 standard.

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