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Effect of Nano boron on braking performance of composite brake pads

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Abstract
Brake pads are formed by a combination of materials with different contents. Brake pads generally consist of binders, friction modifiers, lubricants and fillers materials. The particle size, chemical and structural properties of the brake pad materials affect the braking performance. In this study, usability of nano borax which is one of boron minerals as brake pad material was investigated. 3%, 6% and 9% nano borax was added to the composition to produce three different pads. The experiments were carried out using a pin-on disc. The tribological and physical characteristics of the pad were investigated. As a result; it is seen that the use of nano borax in brake pad composites has an important and beneficial effect on brake performance.

Keywords: brake pad, boron, wear, friction

Introduction

Braking system is used to slow down and stop of the vehicle. The brake system consists of a hydraulic unit, disc, brake pad and caliper parts. The brake pad slows and stops the vehicle by rubbing on the disc with the pedal pressure applied.

Brake pad is multicomponent composites including binder materials, fibers (reinforcing elements), solid lubricants, friction regulators, abrasives and fillers. When determining the friction material, it is desired to show high friction coefficient and good wear resistance. It is also desirable that it forms a good friction pair, does not damage the opposing material, and exhibits a constant and high friction coefficient under difficult thermal and mechanical influences [1, 2].

Mutlu *et al*. [3] showed that the use of boron derivatives in automotive brake pads improves the wear resistance. They also stated that the friction coefficient is smoothed when boric acid and borax are used together with copper powder.

In another study [4] researchers stated that the wear and friction properties of the brake pad sample containing 12% borax by mass are at optimum values.

Sugozu *et al*. [5] produced a pad containing nano-sized silicon carbide and studied its friction performance. The test results indicated that pads containing nano-silicon carbide provide significant improvements in wear performance.

Mutlu *et al*. [6] examined the effect of boric acid supplementation on tribological characteristics of pad. They stated that wear resistance was better in pad samples added boric acid.

In this study, the effect of use of nano-sized borax on brake pad friction materials on tribological properties was investigated. For this purpose, three different samples containing 3%, 6% and 9% nano borax by mass were produced by powder metallurgy method. The amount of borax in the composition was found to affect the performance characteristics of the pad composite.

2. Material and Method

Asbestos-free reinforcing materials were selected in the production of pad. During the production, the material ratio is based on the mass ratio. The powder contents of the pad sample are given in Table 1. The borax ratio of the produced samples was balanced with barite and coded as B3, B6 and B9 according to the amount of nano borax.

The powder materials listed in Table 1 were weighed with a precision scale of 0.001 g. The mixtures prepared in the determined ratios were mixed for 10 minutes at 300 rpm in the mixer to ensure homogeneity. The prepared mixture was transferred to a 25.4 mm diameter mold and held for 8 minutes under 8 MPa pressure and preformed. Then; the samples were subjected to hot pressing at 10 MPa pressure and 150ºC for 10 minutes.

Table 1: Produced brake pad contents (% by mass)

	B3	**B6**	**B9**
Phenolic resin	20	20	20
Steel wool	5	5	5
Alumina	8	8	8
Brass shavings	6	6	6
Cu particle	8	8	8
Cashew	8	8	8
Graphite	4	4	4
Borax	3	6	9
Barite	38	35	32

The experimental set given in Figure 1 was used to determine the friction coefficient-temperature characteristics of the pads. Experiment set can be transferred friction coefficient, brake force, hydraulic system pressure, pad surface temperature values to the computer during the experiment.

In the test apparatus, a load cell is used to measure the frictional force between the pad and the brake disc during rotation. Thus, due to the frictional force arising from the pressure applied to the brake pad during the rotation of the disc, the rotation force of the pad is also measured electronically, taking into consideration the desire of the pad to rotate with the disc. There is a speed adjuster to use the brake disc in the test setup at the desired speed. In order to carry out the tests in accordance with the standards, a non-contact (IR) thermometer was placed in the test device, which can receive data every second to determine the disk surface temperature and can operate in the range of -50 to 1000 ° C. A gray cast iron brake disc with 116 HB (41.86 HRA) hardness and 280 mm diameter were used in the tests [7].

Fig 1: Experiment set

The produced pads were placed on the test device with the help of shoes and operated at 0.7 MPa pressure at a speed of 3 m/s to ensure that the friction surfaces overlap until 95% of the sample surface touches the disk surface. Experiments were carried out at 1.05 MPa pad surface pressure and 6 m/s speed. The friction coefficient and time values obtained during the experiments are the arithmetic mean of the values obtained from the three samples produced with the same mixture and properties. Experiments for each sample were recorded for a total of 700 seconds at 1 second intervals under a pressure of 1.05 MPa at a speed of 6 m/s.
Rockwell hardness tester was used for hardness measurements of pads. In the hardness measurement process, a steel ball tip with a diameter of 2.5 mm was used as a sinking tip. The applied load was taken as 62.5 kgf (612.9 N). Hardness measurements were made on the friction surface of the samples. Because of the dimensions of the samples are Ø25.4×9 mm, they are calculated by taking values from the middle and near edges of the surface. The arithmetic mean of three sample results with the same content was taken for each sample. Density measurements of samples were determined by Archimedes principle [8].

3. Results and Discussion

Three different composites containing 3%, 6% and 9% nano borax were produced massively, provided that the other materials forming the pad composition remained constant. As stated in TS 555, a total of 15 samples were produced by considering the arithmetic average of the results obtained from five test pieces with the same content. The time dependent friction coefficient-temperature graphs of the samples are shown in Figure 2, Figure 3 and Figure 4.
When the graphs are examined, the lowest friction coefficient is given as B3 coded sample containing 3% nano borax with 0.32 and the highest friction coefficient is B9 coded sample containing 0.43 with 9% nano borax by mass. In the literature, it is emphasized that the friction coefficient (µ) ranges from 0.1 to 0.7 depending on the friction force and disc-pad interface temperature [9].

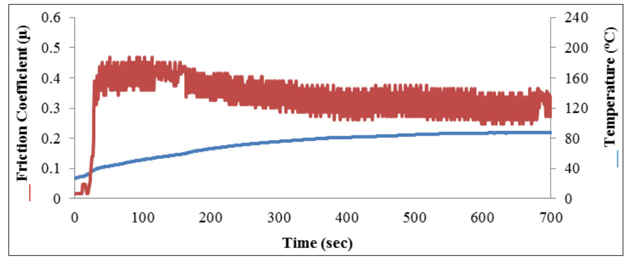

Fig 2: Friction coefficient-temperature-time graph of 3% nano borax brake pad sample

Figure 2 shows the time-varying friction coefficient variation of the B3 coded sample containing 3% nano borax by mass. The temperature at the disc interface with the pad was measured as minimum 25 °C and maximum 88 °C. The average friction coefficient was 0.33 and the friction stability was 72%.

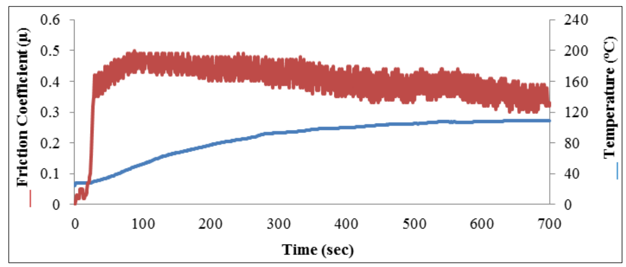

Fig 3: Friction coefficient-temperature-time graph of 6% nano borax sample

Figure 3 shows the change in friction coefficient of the sample coded B6 with 6% nano borax by mass. The temperature of the pad and the disc interface is 25°C minimum and 109 °C maximum. The average friction coefficient was 0.39 and the friction stability was 80%.

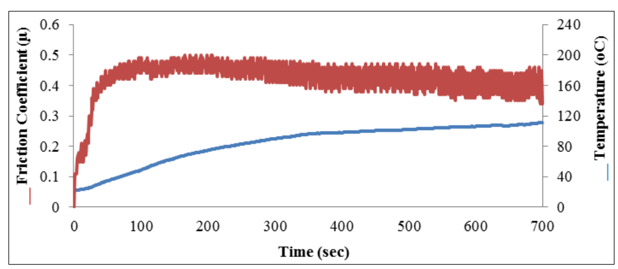

Fig 4: Friction coefficient-temperature-time graph of 9% nano borax sample

Figure 4 shows the change in friction coefficient with time of B9 coded sample containing 9% nano borax by mass. The minimum temperature of the pad and disc interface is 25 °C and the maximum is 111 °C. The average friction coefficient was 0.43 and the friction stability was 88%.
Ostermeyer [10] stated that interfacial temperature decreases due to the increase in the friction coefficient in the study regarding the dynamics of the friction coefficient. When the graphs are examined, there is a continuous change in the friction coefficient. Anderson [11] stated that this is due to the periodic continuous change of heat into the contact areas on the disk surface during friction. This effect results in a constant change in the friction coefficient. Stachowiak and Batchelor [12] explain this situation

by the coalescence and growth of the roughnesses on the surface of the friction pairs. In this case, a release state of adhesion is repeated continuously, which results in a continuous increase and decrease in the friction coefficient.

One of the most important features of the brake pads is that the change in the friction coefficient is minimal due to the increase in the interface temperature that is released due to friction during braking [13,14]. Friction stability (%) value should be as high as possible and close to 100, the slope and fluctuations of the obtained curve should be minimum [15]. 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. It is desirable to have high friction stability in brake pad materials. Figure 5 shows the friction stability (%) of samples containing nano borax. The highest friction stability value was observed in the sample containing 9 % nano borax by mass.

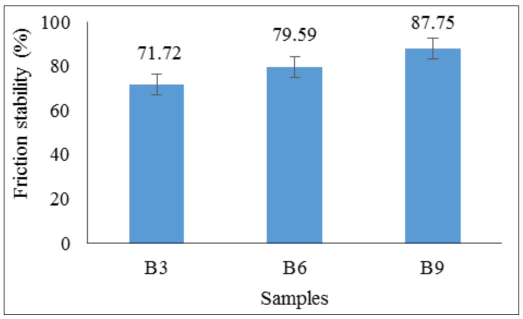

Fig 5: Friction stability of pad samples (%)

The tribological and physical properties such as hardness and density of the samples containing nano borax are given in Table 2 and Table 3. Accordingly, it was found that the average friction coefficient of the samples with high hardness was higher.

Table 2: Tribological characteristics of the brake pad samples

Sample code	Friction coefficient [μ]	Specific wear ratio [$cm^3 \times Nm^{-1}$]
B3	0,33	0,344 x10^{-6}
B6	0,39	0,461 x10^{-6}
B9	0,43	0,543 x10^{-6}

The friction coefficient and specific wear rate of the brake friction materials are important parameters that affect the brake performance. In terms of braking performance, it is desired that the friction coefficient is high and the specific wear rate is low. According to TS 555 standard, the friction coefficient of brake pads should not be less than 0.25 [16]. The wear of the brake pads is predictable. Even if very high-strength materials are used to prevent wear on the pad contents, this will cause the opposite surface to wear. Therefore, the choice of abrasives is one of the most important aspects in a pad formulation to increase abrasion resistance. The wear mechanisms of the friction materials are extremely complex because various interactions and mechanisms work simultaneously during braking from the disc and pad surface. These dynamic processes depend on the composition of the contacting surfaces, depending on operating parameters such as load, speed and in particular interface temperature.

Table 3: Physical characteristics of the brake pad samples

Sample code	Density [$g \times cm^{-3}$]	Rockwell hardness [HRL]	Friction stability [%]
B3	2,13	89	71,72
B6	2,19	91	79,59
B9	2,25	93	87,75

The nano borax content used in the pad content increased the density and hardness values. The density levels obtained are among the recommended values for brake pad application [17]. When nano borax content increased, friction stability improved. High friction stability indicates that the friction coefficient of the pad is high.

Brake friction materials are subjected to many complex wear mechanisms such as wear, adhesion, fatigue and friction. The mechanisms during the wear of the friction materials are extremely complex, because many interactions and mechanisms operate simultaneously during friction on both surfaces. In the literature, wear correlations are mostly determined by surface topography studied by SEM rather than by mechanical or physical properties [18, 19]. The SEM microstructures of the worn surfaces of the pads are shown in Figure 6.

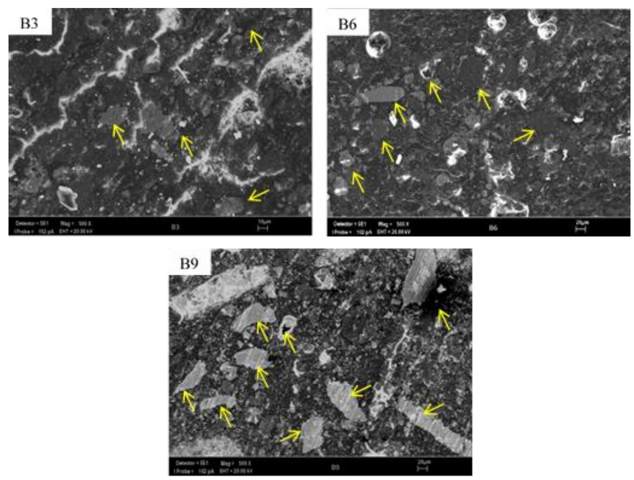

Fig 6: SEM morphologies of frictional surface of pad samples

In general, SEM images show that there are micro cracks, micro and macro gaps, coated friction layers showing adhesive wear and scratched friction marks showing abrasive wear. Compression of wear residues at the friction interface is the cause of friction film formation. The lines in the slip direction on the pad surface indicate the presence of the friction film. The wear and friction characteristics of brake pad depend on the formation, growth and disintegration of contact plateaus, shape adaptation and thermal-induced deformation [20-25]. Compression of wear residues on the friction surface is the cause of friction film formation [26-30]. It is also understood that the materials forming the pad content on the friction surfaces are actively involved in the friction. As the result of the fact that the hard and large particles that will provide adhesion on the disc surface is not present in the friction layer, the 3% nano borax pad sample (B3) exhibits low friction coefficient, 9% nano borax content pad (B9) has high amount of wear layers on the SEM images and the friction coefficient is as high as 43%. It was concluded that the values caused. Due to the increase in the amount of nano borax, the adhesive wear, which causes the formation of friction layer, has increased.

4. Conclusions

Composite brake pads containing nano borax in different ratios were developed and tribological and physical properties were evaluated according to industrial standards. Based on the experimental results, the following conclusions were obtained:

- In the friction tests of pads, the tribological properties of B9 coded sample containing 9% nano borax were seen to give better results than the samples containing 3% and 6% nano borax.
- It was observed that the temperature occurring at the interface of the disc and the pad directly affects the friction stability.
- Due to the increase in the amount of nano borax, friction layer formation increased and friction coefficient showed a more stable condition.
- The density and hardness of the pads increased due to the increased amount of nano borax.
- Developed nano borax-containing pads were found in the desired friction coefficient range (0.30-0.50) according to industrial application.

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