# INVESTIGATION OF BRAKING PERFORMANCE AND THERMAL EFFECT OF SINTERING OF BRAKE PADS WITH $Al_2O_3$ ADDITIVE

by

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*Nowadays the improvement researches of pad materials, which are widely used in braking mechanisms of land vehicles, still maintain their popularity. In general, it has been proven by the studies that the material characteristics of the brake pads in composite structure vary greatly depending on the manufacturing parameters. In this study, the effects of sintering of $Al_2O_3$ added composite pads on braking performance via surface temperature were investigated. In this context, 50, 75, and 125 μm $Al_2O_3$ particles were added to the lining composition and the results were evaluated comparatively. The braking performances of the tested samples were evaluated in terms of pad wear, pad surface temperature and friction coefficient. As a result, it was observed that the braking performance of sintered $Al_2O_3$ additives in all three dimensions was better.*

Key words: *brake pad, braking performance, sintering, wear*

## Introduction

Asbestos was used as the most useful and effective material at the beginning of the pad production process. However, the use of asbestos was banned in brake linings, as in various fields, upon the recommendation of the World Health Organization, due to the damage it caused to both the environment and human health [1-4]. This ban has prompted researchers to investigate new materials that can replace asbestos. The performance expected from a brake pad is a regular amount of wear, a stable temperature on the pad surface and sufficient hardness. These research and development studies still continue today [5-7]. In this regard, many researchers are investigating organic or inorganic material compositions. When the literature on this subject is examined, it is observed that the changes in the amount and the additives in the lining material are mostly examined [8-11]. Because the brake pad is a composite material, it has opened up a lot of research areas for researchers [7, 8, 12, 13]. In general, in the production of brake pads, the method of homogeneously mixing the materials and binding resin in various proportions, and then pressing this composite mixture as cold or hot is applied. Although this manufacturing process may seem simple, it is not as easy as it seems to

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determine the effect of the added materials [14, 15]. In addition, every new invention and material in materials science directly affects pad production. That is, every newly found material is tested as a brake pad additive [3, 9, 13, 15-17]. When evaluated in this respect, it seems that the brake pad research will never end.

In this study, the effect of sintering, which is rarely taken into account in pad production, on braking performance was investigated. In addition, the contribution of $Al_2O_3$ in different sizes, which is thought to have a positive effect on the brake pad hardness, friction temperature, and amount of wear, is also examined.

## Material and method

The effect of the physical parameters measured in the experimental study on the target is important. Figure 1 shows the real view of the test set-up where the friction and wear tests are performed. In this study, it was aimed to experimentally determine the effect of sintering of 50-75-125 μm size $Al_2O_3$ particles on the braking performance of the lining. For this purpose, $Al_2O_3$, copper, brass stone, barite, graphite added linings were produced according to ISO 7629 and ISO 7881, and the tribological properties of the samples were determined and brake tests were carried out. In order for the test results to be reliable, the tests were repeated three times for each pad sample and the average of the results obtained was taken.

**Figure 1. Image of brake pad friction wear tester**

Standard air-cooled brake disc made of GG-20 gray cast iron hardness of 116 HB was used in the experiments. While the disc driven by the electric motor makes circular motion, the pad samples prepared are pressed by the braking force perpendicular to the disc surface. Brake force is measured from the load cell connected to the pad holder on the system. The values obtained are recorded and the friction coefficient is determined using these data, and the wear rate is calculated based on them. Based on these values, friction coefficient-temperature graphs were obtained. In the light of the data obtained, the basic parameters affecting the wear rate and friction coefficient are determined.

**Figure 2. Hydraulic unit**

In brake tests, friction forces are generally obtained by load cells. Load cells convert the physical value of the applied effect into an electronic signal when a load or force acts on them. In the experiments, a Zemic brand BM11-C3 model 50 kg load cell was used to determine the friction force. The loading process of the lining is done with a hydraulic unit and the pressure controls of the system are made with electro-hydraulic valves. The valves shown in fig. 2 are controlled by computerized microcontrollers.

In order to detect the changes in the temperature of the disc friction surface due to the effect of brake forces during the experiments, an infrared thermometer which located 2 cm away from the brake disc surface, operating between 0-700 °C and capable of instant data sharing to the computer was used.

In order to determine the appropriate mixing ratios and mixing times in the first stage of the experimental studies, the average of the commercialized lining ratios and the values in the literature were taken into consideration to provide a good composition and a homogeneous mixture. The materials determined as constant ingredients were kept at the same mass proportions in all lining samples. After deciding the content of the lining samples, $Al_2O_3$ powders were passed through 50, 75, and 125 µm sieves and their particle sizes were separated. The powders obtained were prepared as a total of 20 g at the rates shown in tab. 1.

**Table 1. Physical composition of lining pads (mass%)**

| | 50 µm | 75 µm | 125 µm |
|---|---|---|---|
| Phenolic resin | 20 | 20 | 20 |
| Steel fibers | 12 | 12 | 12 |
| Brass particles | 8 | 8 | 8 |
| Graphite | 3 | 3 | 3 |
| Copper | 7 | 7 | 7 |
| Barite | 42 | 42 | 42 |
| $Al_2O_3$ | 8 | 8 | 8 |
| TOTAL | 100 | 100 | 100 |

Due to the different densities of each material in the lining sample, the lining mixture was mixed in a mixer at 300 rpm for 10 minutes. Thus, a homogeneous mixture was obtained. Afterwards, this homogeneous mixture was pressed under 100 bar pressure in cold mold for the first group experiments. On the other hand, 100 bar pressure was applied to the hot press molds of the lining samples prepared for the second group of experiments. At this stage, the samples were sintered in the molds at 150 °C for a total of 10 minutes, supported by a heater with a temperature-controlled thermostat sensitivity of ±5 °C in the upper and lower connections of the press. Granular soap was applied to the sintering molds in order for the samples to come out of the mold intact. After both pressing process, the samples removed from the die a 25.4 mm diameter cylindrical tablet. These dimensions were determined as 25.4 mm diameter and 6 mm thickness of test samples in accordance with the conditions specified in ISO 7629 standards. In addition, the samples were smoothed so that no traces were left on their surfaces before they were attached to the test device. The specific wear rate was determined with the mass method following the ISO 7629 and calculated with [1]:

$$V = \frac{1}{2\pi R_d} \frac{m_1 - m_2}{r f_m \rho} \tag{1}$$

where $V$ is the specific wear, $m_1$ [g] – the mass of the brake pad before the testing, $m_2$ [g] – the mass of the brake pad after the testing, $R_d$ [m] – the disc radius, $f_m$ [N] – the average force of friction, $n$ – the revolutions per minute [rpm], and $\rho$ [kgmm$^{-3}$] – the density of the brake pad.

In the pad abrasion tests, 45 °C was determined as the starting temperature. It was ensured that 95% of the surface of the pad samples came into contact with the brake disc at 7 bar pressure. Then, sanding, cleaning and cooling processes of the lining samples were carried out.

The wear level was determined by traveling 10800 m for a period of 1800 seconds at a speed of 616 rpm at 10.5 bar pressure.

## Results and discussion

In this study, the effect of sintering of pad samples with different grain sizes of $Al_2O_3$ particles on braking performance was evaluated comparatively. For the braking performance, primarily the friction coefficient and the pad surface temperature are taken into consideration. In addition, the density, wear rate and surface hardness of the linings were also evaluated.

The features that the lining material should have are high coefficient of friction, low wear rate, high heat dissipation rate, good resistance to water swelling, dimensional stability at high temperature, high tensile, compressive and shear strength, and low absorption to water and oil [2]. The physical properties of the unsintered/sintered composite brake pad samples were determined as indicated in tab. 2. When the density change of the pads is examined, it is observed that the pad density increases depending on the increasing particle size in both sintered and unsintered samples. However, when compared according to all three particle sizes, it is seen that the density of sintered samples is lower. When the density change of the pads is examined, it is seen that the pad density increases depending on the increasing particle size in both sintered and unsintered samples. However, when compared according to all three particle sizes, it is seen that the density of sintered samples is lower. It is necessary to considered the method of calculating the density of the brake pads. Because the density calculation is determined according to the classical method of overflowing water. In this case, the sintering temperature initially filled the binder resin and other additives into the pores. Therefore, the density of the sintered samples, which gained a more non-porous structure, was lower. Also, tab. 2 shows that the hardness values of the sintered samples are higher than the unsintered samples. The highest hardness value in sintered samples was 26 HB in 125 μm grain size, while the hardness of the unsintered sample in the same grain size was 24 HB. This two-unit hardness difference was preserved in all three grain sizes. In the sintered samples, the hardness increase occurred as a result of various chemical interactions occurring in the composite structure with the effect of heat treatment. Although the sintered samples had higher values in terms of hardness, the contrary, was observed in terms of wear resistance. The wear resistance of the sintered samples was lower than the unsintered samples in all three grain sizes. There is a relationship between material hardness and wear resistance under normal conditions. However, it is difficult to determine this relationship in composite materials. Because there are more physical bindings than chemical compositions in the production of composite materials. Therefore, while taking hardness measurements from the sample, the probe of the device may have come across the hard particles in the sample. In addition, sintering may occur more in sintered samples as a result of embrittlement of the lining surface. It can be considered that this reduces the wear resistance of the sintered samples. When tab. 2 is evaluated in terms of friction coefficient, the average friction coefficient decreased when the particle size increased

**Table 2. Average friction properties of unsintered/sintered $Al_2O_3$ additive brake pad**

| Grain Size | Density [gcm$^{-3}$] | | Hardness [HB] | | Wear resistant | | Friction coefficient | | Temperature [°C] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unsintered | Sintered | Unsintered | Sintered | Unsintered | Sintered | Unsintered | Sintered | Unsintered | Sintered |
| 50 μm | 2.46 | 2.36 | 20 | 22 | 0.234 | 0.211 | 0.284 | 0.322 | 154.5 | 177.5 |
| 75 μm | 2.51 | 2.40 | 22 | 24 | 0.213 | 0.201 | 0.281 | 0.299 | 167.2 | 140.5 |
| 125 μm | 2.56 | 2.46 | 24 | 26 | 0.184 | 0.155 | 0.279 | 0.282 | 138.5 | 208.2 |

in both sintered and unsintered lining samples. However, higher friction coefficient is observed in all three grain sizes in sintered samples. It can be argued that the temperature applied during sintering changes the tribological properties of the binder resin and other heat-affected additives.

Unfortunately, significant changes in friction coefficient, density, hardness and wear resistance with the sintering of the linings could not be observed at the average surface temperatures. For this, it would be a more accurate approach to handle the time-dependent coefficient of friction and temperature changes.

The friction coefficient and surface temperature values in tab. 2 were the average of the values recorded up to 670 seconds. Figure 3 shows the instantaneous friction coefficient and surface temperature variation of the brake pad samples. In addition, the graphs in fig. 3

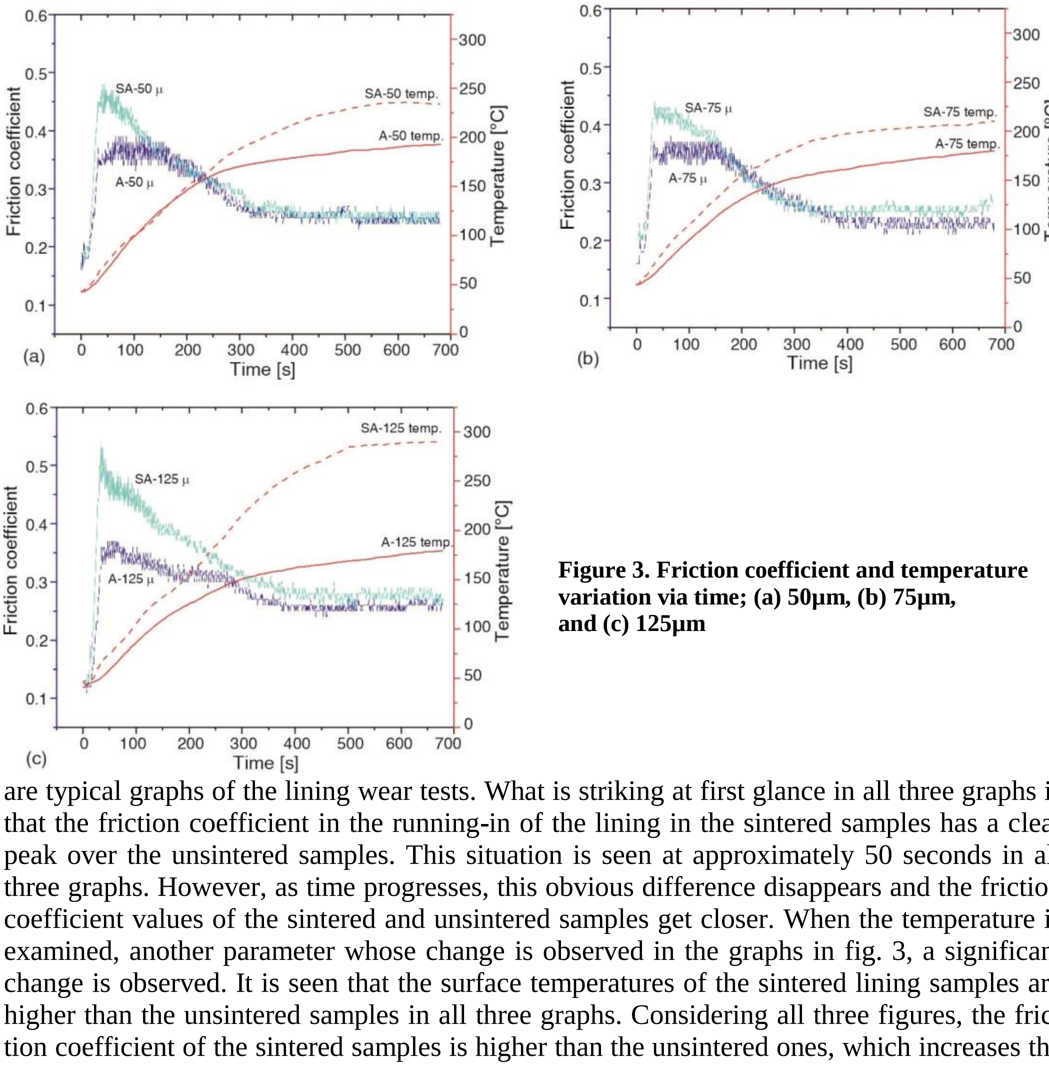


**Figure 3. Friction coefficient and temperature variation via time; (a) 50µm, (b) 75µm, and (c) 125µm**

are typical graphs of the lining wear tests. What is striking at first glance in all three graphs is that the friction coefficient in the running-in of the lining in the sintered samples has a clear peak over the unsintered samples. This situation is seen at approximately 50 seconds in all three graphs. However, as time progresses, this obvious difference disappears and the friction coefficient values of the sintered and unsintered samples get closer. When the temperature is examined, another parameter whose change is observed in the graphs in fig. 3, a significant change is observed. It is seen that the surface temperatures of the sintered lining samples are higher than the unsintered samples in all three graphs. Considering all three figures, the friction coefficient of the sintered samples is higher than the unsintered ones, which increases the friction energy between the disc and the lining. Therefore, higher surface temperatures have emerged on the sintered lining surface due to the increased friction coefficient [18]. While the surface temperatures of the lining samples showed an obvious increase about 300 seconds, they became horizontal in the time interval after 300 seconds. The fact that the pad and disc surfaces transition a regular wear phase after 300 seconds explains this situation. It is already possible to see this typical curve in similar studies [19, 20].

## Conclusion

In the study, the effect of sintering of $Al_2O_3$ powders on the braking performance and the surface temperature of the pads was investigated. In the experimental study, time dependent friction coefficient and temperature changes were measured. The following results were obtained in the study carried out to determine the wear resistance, hardness, and surface temperatures of the samples during braking.

When the study was evaluated as a whole, it was observed that the surface temperatures of the sintered linings were higher than the unsintered ones.

Similarly, higher friction coefficients were obtained in sintered linings.

On the other hand, while a decrease is observed in the density and wear resistance of the sintered linings, there is an increase in the surface hardness.

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