Investigation of Friction Performance Related to Use of Pinus Nigra Cone Powder in Automotive Brake Pads

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Abstract
This paper aims to investigation wear and friction properties of a new developed brake lining material, and the effect of pinus nigra cone dust on its performance. Hence, three different material samples were produced, examined and analyzed. The tribological properties of the first (without pinus nigra cone dust), second (containing 8% pinus nigra cone powder) and third (containing 12% pinus nigra cone powder) sample types were determined using pin-on disc type tester. Coefficient of friction, wear (mass loss) and friction surfaces were studied to evaluate the performance of the three brake linings. The friction surfaces of the brake linings were examined by scanning electron microscopy (SEM). Hardness tests of the samples were made on the Brinell tester. The densities of the samples were determined by Archimed scale method. The results indicated that the brake linings containing pinus nigra cone powder exhibited the better friction performance.

Keywords: Pinus nigra cone, brake pad, friction, wear

1. Introduction

Various braking systems have been developed in the vehicles, the most commonly used friction brake system developed brake systems today and the friction surface consists of fixed and rotating elements. The friction surface material of the fixed part is generally made of a combination of various materials.

Nowadays, asbestos based friction materials that threaten human health are tried to be produced instead of asbestos, friction materials which can perform high performance in wide working range and do not threaten human health. In recent years, studies on the use of waste products in brake pads have been included in the literature. Ikpambese et al. developed a non-asbestos free brake pads using palm kernel fibers and results show that palm kernel fibers can be used (Ikpambese et al., 2016). Idris et al. (2015) produced automotive brake pad using banana peels and the result obtained showed that the banana peels can be used in brake pad. Matejka et al. (2013) developed brake pads from hazelnut shells using different treatments.

The performance of the friction material is strongly affected by selection of the ingredients (Aleksendric et al., 2015, Sugozu et al., 2014). Many studies had already been made to investigate the effects of different materials on the friction performance of brake lining composites (Nesrine et al., 2014, Sugözü et al., 2018a, Hentati et al., 2014, Sugözü 2018, Cho et al., 2001, Sugozu et al., 2016, Filip et al., 2001). This study aims to use different binder materials as an alternative to phenolic resin. Three different friction materials were produced. In the first of the produced samples, the pinus niga cone powder does not contain. The second sample contains 12% by weight of phenolic resin and 8% by weight of pinus nigra cone powder. While in the third sample contains 8% by weight of phenolic resin and 12% by weight of pinus nigra cone powder.

2. Materials and Methods

In this paper, a new formulated brake lining material was developed using an addition of pinus nigra cone powder. The influence of pinus nigra cone powder on the brake's friction properties was especially examined. The friction materials investigated in this study were variations of a NAO (non-asbestos organic)-type material containing different ingredients including pinus nigra cone powder. Pinus nigra was obtained from Tarsus/Mersin in Turkey.

Three different samples were manufactured. These samples contained pinus nigra cone powder, phenolic resin, steel fibers, Al_2O_3, Cu particles, cashew, brass particles barite and graphite. Friction coefficient, temperature, time graphs were obtained to identify the friction characteristics. The brake lining samples were produced with conventional procedure. Detailed conditions can be found in the author's other study (Sugozu et al., 2018b). The compositions of the brake lining used in this study are shown in Table 1.

Table 1. Ingredients of the samples (weight %)

	KA-0	**KA-8**	**KA-12**
Cu particles	8	8	8
Steel fibers	15	15	15
Al_2O_3	5	5	5
Brass particles	5	5	5
Graphite	7	7	7
Barite	30	30	30
Cashew	10	10	10
Pinus nigra cone powder	0	8	12
Phenolic resin	20	12	8

Figure 1 shows a schematic view of the brake tester used in this study. Detailed conditions for brake tester can be found in the author's other study (Sugozu et al., 2018b). The braking tests were carried out at a pressure of 1.05 MPa, a velocity of 6 m/s and at temperatures from 50 °C to 400 °C for 500 s. The tests were repeated three times for each sample.

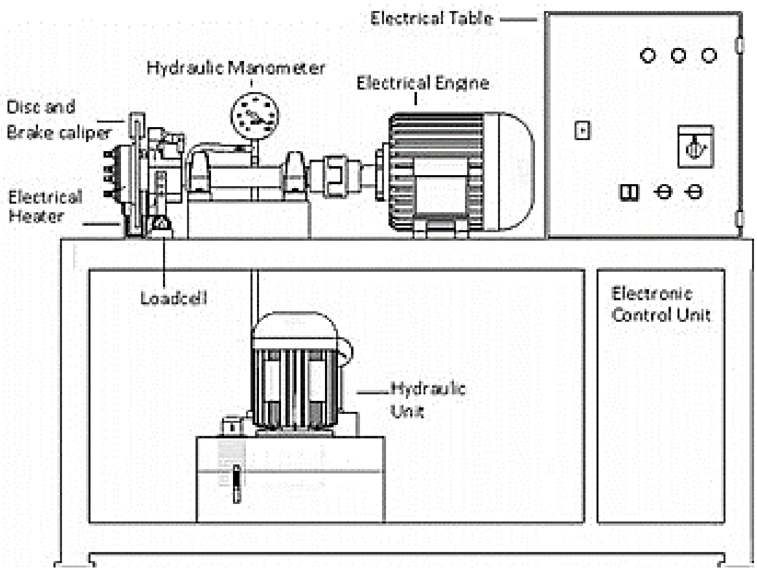


Figure 1. Schematic view of the brake tester

The friction coefficient was calculated by measuring under the stable pressures throughout the test 500 s. It was expressed as the mean value of the entire braking dependence during the friction-coefficient test. The specific wear rate was determined with the mass method following the Turkish Standard (1992) and British Standard (1968) and calculated with the following Equation (1):

$$V=(m_1-m_2)/(2.\pi.R.n.f_s.\rho) \quad (1)$$

where V is the specific wear rate (cm^3/Nm), m_1 and m_2 are the average weights of specimen before and after the test (g), ρ is the density of the brake lining (g/cm^3), R is the distance between the center of specimen and the center of the rotating disk (m), f_s is the average friction force (N) and n is the rev of the rotating disk (Sugozu et al., 2018b, TS 555 1992, British Standars 1968).

3. Results and Discussion

3.1 Effect of the temperature on the friction performance

Figures 2-4 show graphs of friction coefficients and temperature based on experimental study results. Figures 2-4 show the time-dependent friction coefficient and temperature graph of the brake lining samples used phenolic resin and pinus nigra cone powder as binder material. When the figures are examined, it is seen that the change in the friction coefficient depending on the time progresses steadily after 600 seconds in KA-0 coded sample and 500 seconds in KA-8 and KA-12 coded samples. The KA-8 code sample with a friction coefficient of 0.30 has the highest coefficient of friction. When Figure 2 and 3 are examined, the use of pinus nigra cone powder causes an increase in the friction coefficient, but as the amount of black pine cone increases and the amount of phenolic resin decreases, the wear due to friction in the brake pad samples also increases. Both the temperature value and the friction coefficient of the sample are high. Figure 3 and Figure 4 show changes in the friction coefficient and temperature depending on the time of the coded samples KA-8 and KA-12. When the shapes are examined, the highest temperature and friction coefficient is seen in the code sample KA-8. Anderson noted that the change in friction force is strongly influenced by the disk thickness variation, the temperature of the disk and the friction surface components (Mutlu et al., 2015).

Friction characteristics were formed after the development of the friction layer according to the characteristics of the constituents of the friction layer in all of the samples use of the pinus nigra cone powder (Fig 3-4). When the graphs were examined, there was less fluctuation in the KA-8 coded sample than KA-0 and KA-12 coded samples. The coefficient of friction tended to increase gradually with increasing internal temperature of the samples KA-8 and KA-12 (Fig. 3-4). This rise in the coefficient of friction can be explained as the improvement of the durability of the materials forming the friction layer against the friction surface, which is the opposite surface of the friction pair, as the temperature rises, that is, the constituent materials are well compatible with each other and therefore can create resistance to the friction surface.

The coefficient of friction of the KI-0 coded sample decreased until 600 seconds. After 600 seconds, the coefficient of friction became stable with increasing temperature (Figure 2). The KA-0 coded sample exhibited a low but stable friction with temperature increase. The KA-8 coded sample has gradually increased in the coefficient of friction from the moment that the temperature starts to rise above 200 ºC after 500 seconds. The same is true for the code KA-12. It is thought here that the warming of the brake pad due to friction also improves the curing and binder properties of the pinus nigra cone powder in composition. When the sample with KA-0 code is examined (Figure 2), a decrease in the coefficient of friction is observed depending on the increase in temperature. When the samples shown in Figure 3 to Figure 4 are examined, an increase in the coefficient of friction is observed depending on the increase in temperature. It is generally emphasized in the literature that the coefficient of friction (μ) varies between 0.1 and 0.7, depending on the frictional force and the disk lining interface temperature (Mutlu et al., 2006). Figure 2 shows the temperature-time graph of the brake pad sample without pinus nigra cone powder.

Figures 3 and 4 show the coefficient of friction obtained from samples with pinus nigra cone powder-phenolic resin contents. Compared to Figures 2-4, it is seen that to use pinus nigra cone powder have a slight increase in friction coefficient. Comparing the figs, it is seen that a graph which shows a rise in the friction coefficients of the pinus nigra cone dust-doped samples increases as the temperature increases. There is a partial decline from 50th second to 500th degree with the increase in temperature in the sample of non-pinus nigra cones powder in the content, and there is a recovery afterwards.

Samples with KA-0 and KA-12 codes with low coefficient of friction exhibit low temperature curves as shown in Figures 2 and 4. The temperature curve of the KA-8 code sample, which exhibits the highest coefficient of friction, is also high.

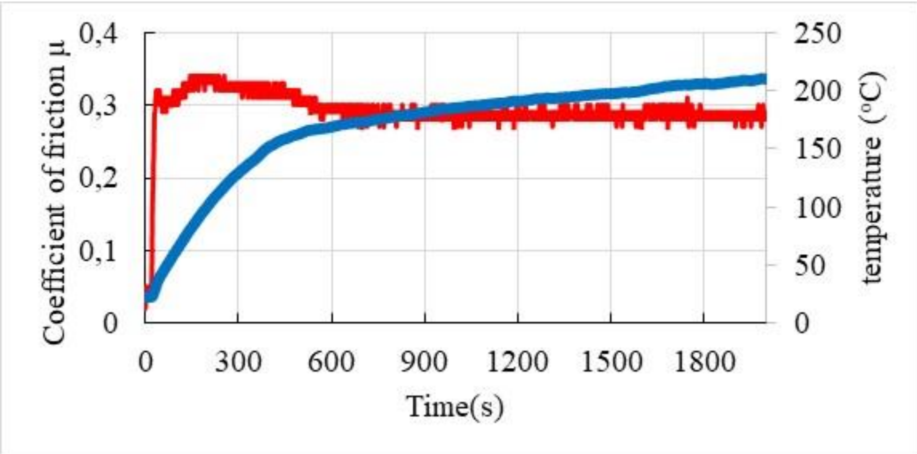


Figure 2. Change in the friction coefficient and the temperature as a function of time for sample KA-0

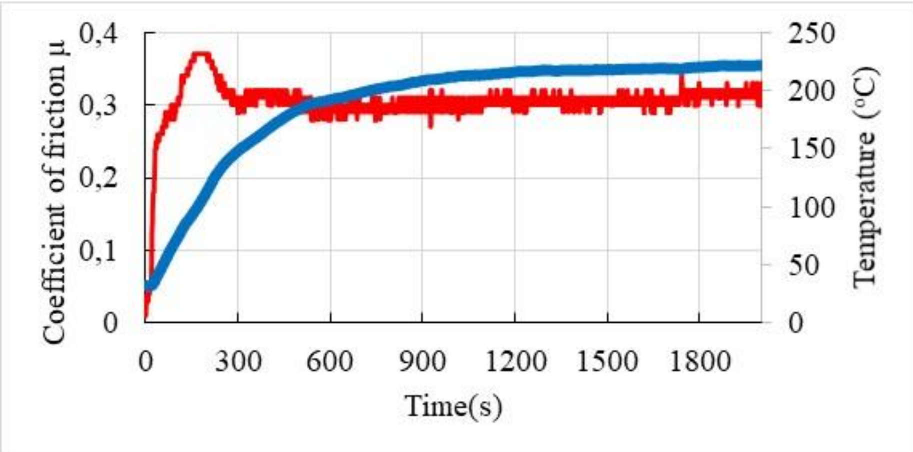


Figure 3. Change in the friction coefficient and the temperature as a function of time for sample KA-8

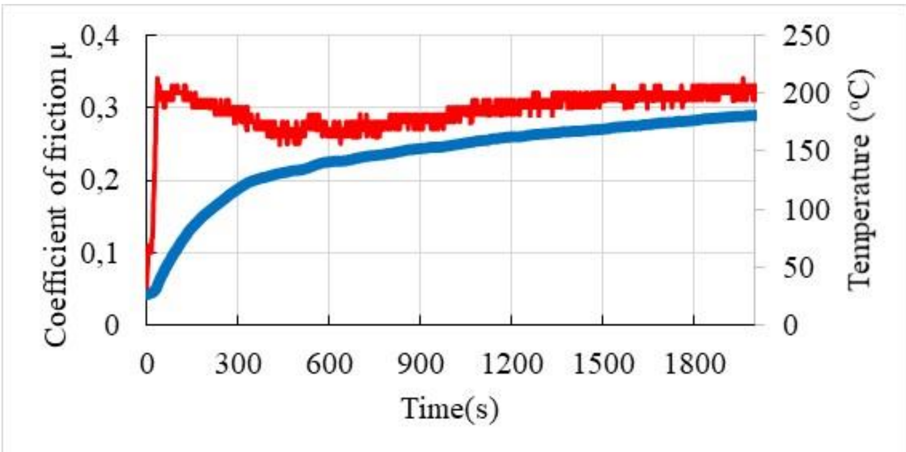
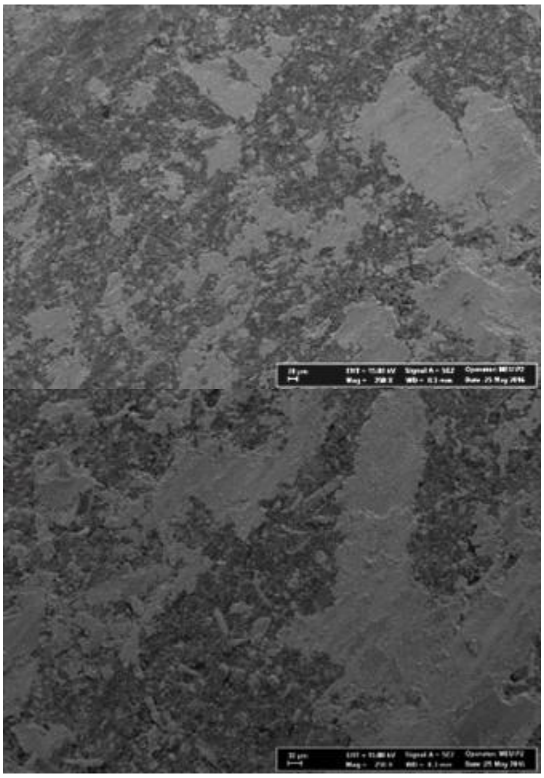


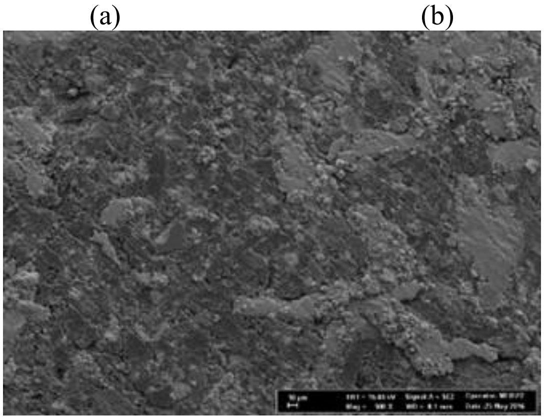
Figure 4. Change in the friction coefficient and the temperature as a function of time for sample KA-12

3.2 Microstructural characterization of friction surfaces

Figure 5 shows SEM photographs taken to determine the characteristics of the friction surface formed after the experiments in which the friction performance of brake pads with pinus nigra cone powder were determined. When looking at the photographs, they seem that there are traces of scratching that show abrasive wear with micro crack, micro-cavities and coated friction layers showing adhesive wear. It is also understood that the component-forming materials on the friction surfaces formed actively participate in the friction.



(a) (b)



(c)

Figure 5. SEM micrographs of brake-pad samples with the KA code
(a) KA-0 (b) KA-8 (c) KA-12

SEM photograph of the KA-0-coded sample with 20% by mass of phenolic resin as binder is shown in Figure (a). This sample exhibited a friction coefficient average of 0.29. Micro voids formed by the particles that are broken loose from the sample are visible in the picture. Short scratches and color differences on the friction surface indicate that adhesion and abrasive wear have occurred.

The SEM photograph of the sample with the code KA-8 is shown in Figure (b). This sample contains, as binder, 12% phenolic resin and 8% pinus nigra cone powder. The sample has the highest coefficient of

friction with a coefficient of friction of 0.30. It appears that scratches on the surface of the sample show very pronounced adherent abrasion and abrasive wear, resulting in micro voids. It has been observed that the hard and large particles that hold onto the disk surface are not much in the friction layer.
It is seen that abrasive abrasion occurs on the friction surface in the SEM photograph of the sample with the code KA-12 shown in Figure (c). In this sample, it has a friction coefficient average of 0.29, such as the KA-0 code sample. The clusters resulting from the barite in the context are visible. On the surface of these particles, which are seen as dark and light gray color, it is thought that the materials which are put on these particles after the friction from other friction regions cause adhesion wear. It is understood from the scratches formed on the friction surfaces that the materials on the friction surface try to hold onto the opposite surface.

3.3 Wear behaviour

The hardness, density and specific wear rate of the samples are shown in Table 2. When the tables were examined, the coefficient of friction of KA coded samples was 0.30, and the wear amount averages were $1.64x10^{-6}$. Component forming materials may have a hard structure, which may result in high hardness values. However, if the binder holding the component-forming materials and the content orientation are generally inadequate, rapid detachment of the component-forming particles from the main structure during small forces during friction may result in high wear rates.

Table 2. Typical characteristics of the brake pads used in this study

Sample code	Mean coefficient of friction	Density (g/cm^3)	Brinell Hardness (HB)	Specific wear rate (cm^3/Nm)
KA-0	0.29	2.225	28	1.691×10^{-6}
KA-8	0.30	2.305	30	1.525×10^{-6}
KA-12	0.29	2.253	29	1.737×10^{-6}

4. Conclusions

In this study, the performance of the pinus nigra cone powder as a binder material in automotive brake pads was investigated experimentally. From the present work, the following conclusions can be drawn:
• The highest friction coefficient and the lowest specific wear rate were obtained in the sample containing 8 wt.% pinus nigra cone.
• Temperature occured on lining contact surface during the friction test affected friction stabilities of the samples.
• The experimental results have shown that the friction layer, with the use of pinus nigra cone powder significantly improved the overall performance.
• The result of this research indicates that pinus nigra cone powder can be used as a replacement for binder in brake pad manufacture.

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