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Effect of process for manufacturing a brake lining on tribological properties: an experimental study for hot pressing pressure

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Abstract
Production of composite brake linings; mixing, cold and hot pressing (molding) and heat treatment steps. The aim of this study is to investigate the effect of hot-pressing pressure on friction performance in the production of composite brake linings. As the pressure applied during the hot-pressing step increases, the density of the product increases as the gap between the materials forming the product decreases. Therefore, the pressing pressure, which is one of the production parameters, is very important for the friction performance of composite brake lining materials. In this study, composite brake lining samples having the same content were produced by applying three different hot-pressing pressures such as 8000, 13000, 18000 kPa and friction performances were examined. The friction coefficients of the samples with 13000 and 18000 kPa pressing pressure were low. The most suitable pressing pressure was determined as 8000 kPa.

Keywords: brake lining, composite materials, wear, friction

1. Introduction
With the development of automotive technology, motor forces, movement speeds and acceleration capabilities of vehicles have increased relatively in the past. This has increased the importance of reliably controlling the movement of vehicles. The most important safety feature of a car is the brake system. Systems that convert motion energy into heat through friction, which stop or control movement, are called braking systems. Expected from the brake system; the vehicle is stopped safely under different conditions. The most important indicator of braking performance is the short distance between braking and stopping. This is possible with the maximum deceleration acceleration.

Brake linings have an important role in ensuring the safety of the vehicle while driving. The brake lining should be able to repeat its performance over a wide range of speeds, pressures and temperatures under all conditions and without re-use. It must be resistant to oxidation and high resistance to cracking and thermal fatigue due to the temperature increase during friction. It should have sufficient strength against pressure and shear stress applied during use, should be easy to manufacture and be suitable for continuous production of the same quality and the heat conduction should be low [1, 4].

In the studies conducted on brake linings, the effect of the relationship between components on tribological properties such as friction and wear were investigated [5, 6]. There is a change in the average friction coefficient at all temperatures depending on the rate of asbestos. For the same initial speed and surface pressure, the friction coefficient decreases with increasing temperature and braking time increases. From this it is concluded that the reinforcing material is effective in changing the friction coefficient [7, 8]. Although they play a very important role in determining the friction performance in studies affecting friction, information about the role of many substances such as abrasives, solid lubricants and other additives in friction performance is limited [9, 10]. Because of the commercial importance and registration of friction materials, it is quite difficult to find the contents of friction materials in the literature [11]. Significant improvements have been made in brake linings with high friction coefficient, good wear resistance and thermal resistance. The improvement in tribological properties of composites depends on composite formulation, production and working parameters [12]. Multiple powder contents are used in the brake lining composition. Homogeneous distribution of these constituent powders should be ensured. Homogeneous distribution of the component, pressing pressure will affect the density of the brake lining plays an important role in friction performance.

In this study, to examine the effect of hot-pressing pressure, which is one of the lining production parameters, on the brake lining, mixtures with the same contents were pressed at three different pressures and samples were produced and tested for friction coefficient tester to determine the friction performance. Thus, the effect of hot-pressing pressure on wear and friction coefficient was investigated.

2. Material and Method
There are many parameters that affect the friction performance during the production of brake linings. One of these parameters is the hot-pressing pressure which is one of the lining productions stages. In order to investigate the effect of pressing pressure on friction and wear, three samples of the same composition were produced by applying three different pressures, with the other production parameters being the same. The materials used for the brake lining samples are given in Table 1. The developed brake linings consist of eight ingredients. Accordingly, phenolic resin as binder, steel wool as fiber, alumina as abrasive, copper particle and brass shavings as thermal conductor, graphite as solid lubricant, barite as space filler and, cashew as friction modifiers were used.

Table 1: Produced brake lining contents (wt. %)

Raw materials	Amount
Phenolic resin	15
Steel wool	10
Brass shavings	4
Alumina	3
Cu particle	15
Cashew	8
Graphite	10
Barite	35

The produced samples were coded as P8, P13 and P18 according to the hot pressure to which they were subjected. Before starting production, powder materials were weighed with 0.001 g precision scales. The sample content was then mixed for 10 minutes to ensure homogeneity of the prepared mixture. The prepared mixture was transferred to 25.4 mm diameter mold and pre-formed under 10000 kPa pressure. Afterwards, hot-pressing was applied to samples for 10 minutes at a temperature of 150ºC and three different pressures of 8000, 13000 and 15000 kPa. During the pressing process, ventilation was performed at 60 second intervals. Thus, the steam and gases formed as a result of the temperature were provided to be discharged to the outside. The brake lining production parameters are given in Table 2. The friction, wear, density and hardness characteristics of the samples were examined.

Table 2: Production parameters of brake lining samples

Operations	Production Parameter	P8	P13	P18
Mixing	Time (min)	10		
Cold Forming	Time (min)	2		
	Temperature (ºC)	Ambient temperature		
	Pressure (kPa)	10000		
Hot Pressing	Time (min)	10		
	Temperature (°C)	150		
	Pressure (kPa)	8000	13000	18000

The friction tester shown in Figure 1 that examine the friction coefficient, brake force, hydraulic system pressure, brake lining surface temperature values were used to determine the frictional characteristics of the samples.

Fig 1: Test device

Loadcell was used to measure the friction force between the brake lining and brake disc during rotation. Thus, the rotational force was measured electronically, taking into account the rotation of the brake lining with the disc due to the frictional force arising from the pressure applied to the brake lining during the rotation of the disc. An inverter was available to use the brake disc in the test set at the desired speed. The device has a 7.5 kW, 1400 rpm three-phase electric motor to rotate the disc. The transmission shaft of the electric motor was supplied with a Ø 30 mm transmission shaft. Two UCP 209 bearings placed on this shaft prevent the shaft from oscillating. The circular motion transmitted from the electric motor was provided to rotate the disc between 100-1400 rpm over the shaft owing to the inverter. The speed of the electric motor could be easily controlled with computer program. Pressure could be applied to the brake disc at desired values owing to the hydraulic system in the test device.

An infrared thermometer that can receive data every second to determine the surface temperature of the disc and can operate in the range of -50 to 1000ºC was placed in the test apparatus. A gray cast iron brake disc with 116 HB (41.86 HRA) hardness and 280 mm diameter was used in the test operations.

The produced brake linings were operated at a speed of 3 m/s under a pressure of 250 kPa until 95% of the sample surface contacted the disc surface in order to ensure that the friction surfaces overlap. The experiments were carried out at 1050 kPa lining surface pressure and 6 m/s speed. The friction coefficient values taken during the experiments are the arithmetic mean of the values obtained from the three samples produced with the same mixture and properties. The friction coefficient for each sample was recorded at 1 sec intervals under a pressure of 1050 kPa at a speed of 6 m/s. In the wear tests, the brake lining samples were subjected 10800 m (10.8 km) sliding distance under 1050 kPa pressure. These values were converted into friction coefficient-time plotsAt the end of the tests, the mass loss of each brake lining sample was found by weighing on the precision scale. The specific wear rate was calculated with the formula below according to TS 9076 [13, 14].

$$V = \frac{m_1 - m_2}{2 \times \pi \times R_d \times n \times f_s \times \rho}$$

where; the specific wear rate V (cm^3/Nm), R_d the distance between the center of the brake lining and the center of the disc (m), m_1 and m_2 respectively the pre-test and post-test mass of the brake lining (g), n the total number of rotations of the disc during the test, ρ the density of the brake lining (g/cm^3) and f_s mean friction force (N).

Rockwell hardness tester was used to determine the hardness of brake linings. 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 [15].

3. Results and Discussion

In this study, composite brake lining samples with the same content were produced and the effect of hot press pressure which is one of the brake lining production parameters on friction performance was investigated.

Figure 2 shows the friction coefficient-time graph of the brake lining samples. When the friction coefficient-time graph is examined, the friction coefficient value of P18 coded sample is lower than P8 and P13 coded samples. The surface temperature increased as a result of the reduction of the gaps between the materials forming the component and the formation of a larger friction surface with the effect of production pressure in the sample coded P18. Therefore, the binding agents forming the component cannot be better retained on the friction surface due to the loosening by the effect of temperature and caused a lower friction coefficient than P13.

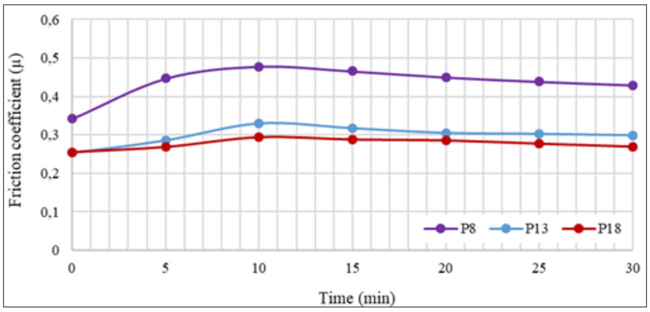

Fig 2: Friction coefficient-time graph of brake lining sample

When the graph is examined, the lowest friction coefficient is given as P18 coded sample with 0.27 and the highest friction coefficient is P8 coded sample with 0.43 with. 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-brake lining interface temperature [16].

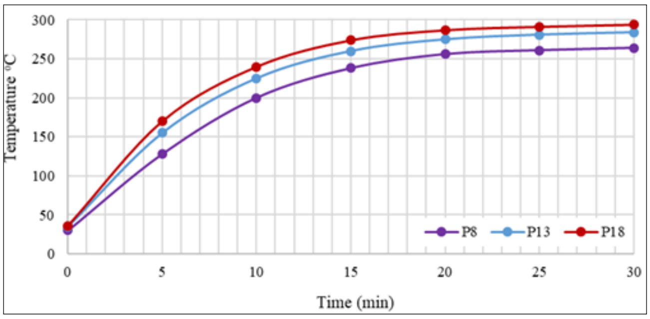

Fig 3: Temperature-time graph of brake lining sample

The temperature increase was faster in the sample with high hot-pressing pressure. It increased the contact area of the brake lining to the disc surface. The P18 brake lining sample had a negative effect on the friction coefficient because it was pressed at more pressure than the P13 and P8 brake lining sample.

One of the most important features of the brake linings 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 [17, 18]. Friction stability (%) value should be as high as possible and close to 100, the slope and fluctuations of the obtained curve should be minimum [19].

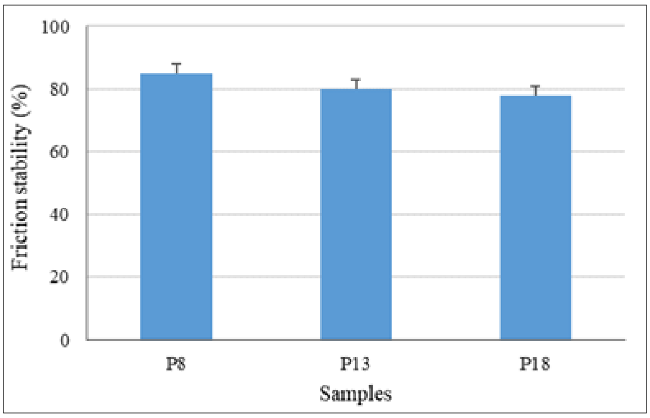

Fig 3: Friction stability of brake lining samples (%)

Figure 3 shows the friction stability (%) of samples. When the friction test results were examined, it was seen that the temperature occurring at the interface of the brake lining and the disc directly affected the friction stability. It is desirable to have high friction stability in brake lining materials [20].

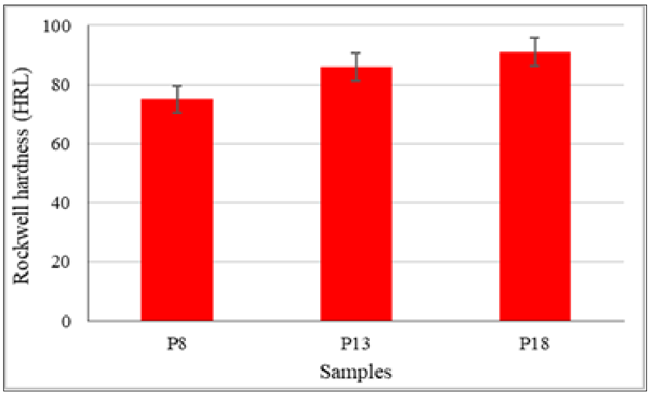

Fig 4: The Rockwell hardness values of the samples

Figure 4 shows the Rockwell hardness values (HRL) of samples. Increased pressure ratio increased the hardness of the brake lining sample. Increased hardness caused the temperature to rise due to friction between the brake lining and the contact surface. With the increase in temperature, the brake lining formed fade on the disc surface and decreased the friction value.

Increased production pressure in the samples produced was effective in increasing the material density and hardness. The homogeneous distribution of the component and minimization of the gaps in the sample by increasing the pressing pressure caused the hardness value in the sample to increase.

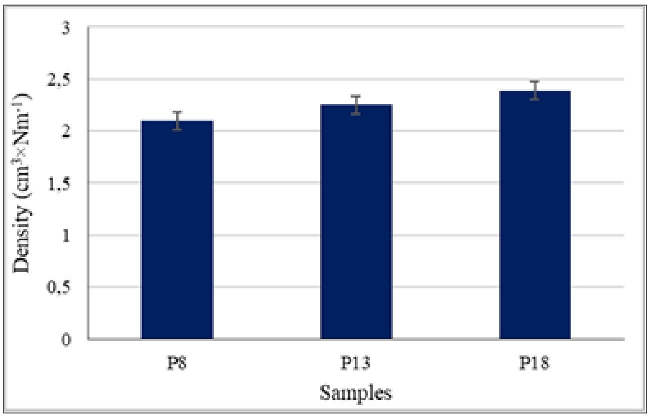

Fig 5: The density values of the samples

Figure 5 shows the density values of samples. As the pressure applied to the samples increased, the density of samples increased and friction coefficients decreased. The density levels obtained are among the recommended values for brake lining application [21].

Table 3: Tribological characteristics of the brake lining samples

Sample code	Friction coefficient [µ]	Specific wear ratio [$cm^3 \times Nm^{-1}$]
P8	0,43	0,139 x10^{-6}
P13	0,30	0,105 x10^{-6}
P18	0,27	0,085 x10^{-6}

As seen in Table 3, P13 and P18 coded samples showed less wear when looking at the amount of wear per unit area. It is stated in the studies that the friction coefficient is proportional to the amount of wear [22]. The samples with high friction coefficient have higher wear, as anticipated. As a result of the studies, the P8 coded sample subjected to 8000 kPa hot pressing pressure had better friction performance. When the specific wear values were examined, the wear at the P8 coded sample with a pressing pressure of 8000 kPa was higher and the wear at the P13 and P18 coded sample with a pressing pressure of 13000 kPa and 18000 kPa was less (Table 3). As the pressure increases, the gaps between the materials forming the component are reduced, so that the particles are held closer together.

4. Conclusions

In this study, the effect of hot-pressing pressure, which is one of the brake lining production parameters on friction performance was investigated. Brake lining with the same content was produced at three different hot-pressing pressure. As a result of the experiments; the following conclusions were obtained:

- The friction performance of the lining produced at high pressing pressure was negatively affected.
- In the lining with high pressing pressure, the temperature increase was faster due to time.
- The increase in pressure was effective in increasing the material density and hardness.
- Increased pressure ratio increased the hardness of the brake linings. This caused the temperature to rise due to friction between the brake lining and the disc surface.
- High hardness caused fade formation on the disc surface of the brake lining and decreased the friction coefficient.
- It was observed that the temperature occurring at the interface of the disc and the brake lining directly affects the friction stability.
- The wear resistance of the brake lining produced at high pressure was found to be better.

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