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**Araştırma Makalesi / Research Article**

# Production of Vehicle Brake Lining with Andesite Powder Additives at Different Pressing Pressures and Determination of Their Effects on Braking Performance

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**ABSTRACT:** The purpose of braking systems is to stop or slow down the moving vehicle. Braking is achieved by converting kinetic energy into heat energy due to the friction created by the brake pads. Today, it is common to use disc brake systems on both front and rear wheels. Recently, serious studies have been carried out in different sectors to utilize industrial wastes, and it is aimed at bringing these waste products into the economy. For this purpose, using different materials in the brake pad contents is common. This study aims to utilize the waste powders resulting from the processing of andesite stone. The materials used in the brake pad samples were developed by the hot-pressing method at pressing pressures of 15, 20, 25, 30, 35, and 40 MPa. Friction coefficient, wear rate, density, hardness, and SEM analysis of the samples were performed. As a result of the study, the density and hardness of the lining samples increased with the increase in pressing pressure. The maximum friction coefficient was obtained in the 40 MPa sample, and the minimum wear rate was obtained in the 25 MPa sample. It was determined that the coefficient of friction and wear rate performances of the lining samples meet the desired properties for the lining. Using andesite dust waste material in the brake lining sector will contribute to the environment and economy.

**Keywords:** Brake Lining, Coefficient of Friction, Wear, Andesite, Vehicle Technology.

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## 1. INTRODUCTION

With recent technological developments, vehicle speeds have also increased due to the increase in engine power in vehicles. Vehicles can reach high speeds in a very short time. The system that ensures safe control of the vehicle at these high speeds is the brake system. The essential parts of the brake system are elements such as a pad, disc, caliper and hydraulic, etc. Braking occurs by converting kinetic energy into heat energy. In the brake system, operations such as stopping or slowing down vehicles are carried out by providing friction force between the disk caliper and the brake pad. Today, disc brakes are widely used in vehicles. During braking, friction-induced heat energy is released. This temperature increase adversely affects braking. There are various studies in the literature on lining content, tribological properties, service life, and production parameters to bring braking performance to desired levels. Some studies are given below.

In recent years, there has been much work on alternative friction materials to control friction, reduce the wear rate, and increase braking safety in studies on brake pads (Xiao et al., 2016). In the study by Boz, ceramic-based brake pads were produced at a sintering temperature of 820 °C at a pressure of 350 MPA. The density of the samples decreased as the amount of ceramic increased. The lead used in the content settled into the voids in the lining with the sintering temperature and caused a decrease in the volumetric area of the samples (Boz, 2003). In the study by Kurt and Boz, bronze material was used as a friction regulator. Bronze material increased the density value and contributed to the decrease in wear rate. It was stated that the friction coefficient increased with the amount of tin (Kurt and Boz, 2005). Yawas et al. investigated the effect of using periwinkle instead of asbestos material, which is harmful to health, in brake linings. 125 µm particle size sea shell was used with 35% resin. As a result of the test, it was determined that the desired performance values were met in the friction test with a decrease in wear rate (Yawas et al., 2016). In the study by Timur and Kılıç, a study was carried out to utilize marble wastes in brake pads. Marble powder was used as filler instead of barite. A friction coefficient between 0.30-0.53 was obtained in the samples. As a result, it was stated that marble dust wastes could be used as filler (Timur and Kılıç, 2013). Öktem et al. produced lining specimens with pet coke powder, readily available cheaply. As a result of the experiments, it was reported that pet coke material gave a stabilizing coefficient of friction, and specific wear rates improved (Öktem et al., 2021). In the study conducted by Ünaldı and Kuş, ecological brake pad samples were produced with miscanthus material as reinforcement material. The results obtained, it was stated that density values were affected by the mixing ratio factor while curing time and curing temperature were effective on porosity (Ünaldı and Kuş, 2018). Brake pad specimens were developed by Malak et al. with 5, 10, and 15% carbon fiber material. The maximum friction coefficient was obtained in the 15% carbon fiber sample. In addition, it was stated that carbon fiber can be used in brake pads as an alternative as the density and wear values decrease and surface roughness increases as the carbon fiber ratio increases (Malak et al., 2015). Sugözü et al. prepared three brake lining samples containing 4%, 8%, and 12% of ulexite and borax. The experimental studies determined that the frictional stability increased as the amount of ulexite and borax increased by mass (Sugözü et al., 2018). Başar et al. developed brake lining samples with 4%, 8%, and 12% colemanite and borax additives by hot pressing. They stated that the materials they developed are suitable for lining materials (Başar et al., 2018). Surajo et al. determined the effect of phenolic resin and fly ash on brake linings. As a result of the experiment, they determined that the coefficient of friction decreased with increasing the amount of phenolic resin in the sample content. In contrast, the friction coefficient increased with the amount of fly ash (Suojo et al., 2014). Pujari and Srikiran stated that 0-50% palm kernel, 0-15% Nile rose, and 0-10% wheat powder could be a substitute alternative for asbestos material. Using the Nile rose to increase the coefficient of friction and wheat powder to reduce the wear rate, and positive contributions were made to the coefficient of friction, noise pollution, and wear rates. It was stated that palm kernel, Nile rose, and wheat powder could be used as a substitute for asbestos (Pujari and Srikiran, 2019). In the study conducted by Yılmaz, in the investigation of the tribological efficiency of fly ash, it was stated that fly ash is generally a waste and can be found in abundance because it is obtained from the burning of coal and can be used as an alternative material in brake linings. According to the experimental results, it was stated that fly ash could be used instead of aluminum powder in the lining content and increases the coefficient of friction (Yılmaz, 2022). The study conducted by Güney and Mutlu aimed to comply with the standard by applying brake system tests according to the vehicles' usage and environmental conditions. TSE 555 and SAE J866 standards are used to determine the brake system's friction coefficient values at the disc/drum and lining interface. Thus, it was stated that the brake system parts evaluated within the framework of the standards directly affect the production methods (Güney and Mutlu, 2015).

The brake pad is one of the essential parts of the brake system used to slow down or stop a moving vehicle. The industry's demand for the brake pad, a part that wears due to friction, is relatively high. Due to the number of manufacturers and differences in demand, product diversity in this sector is increasing daily. Brake pads of varying specifications are preferred according to the vehicle. Nowadays, especially in the direction of utilization of industrial wastes, there are many studies in brake lining and different sectors. In this study, samples with different pressure parameters were developed to contribute to the industry and scientific studies of the waste dust released due to andesite processing, which is used for various purposes, such as interior or exterior building cladding. In the developed samples, microscopic analyses of the worn surfaces and parameters that directly affect braking performance, such as friction coefficient and wear rate, were carried out. Instead of a material taken from nature directly to the production stage, industrial wastes generated by andesite processing were evaluated. Andesite is a material obtained by cooling underground lava above the ground, which has very high strength and can be used as a wear and friction regulator. While preparing the sample contents, care was taken to ensure that the other raw materials in the brake pads were harmless to biological life forms and the environment.

## 2. MATERIAL METHODS

### 2.1 Development of the samples

This study developed lining samples by applying the hot-pressing method at different pressure values of 15, 20, 25, 30, 35, and 40 MPa. In the developed samples, phenolic resin 20%, steel fiber 15%, alumina 6%, graphite 3%, cashew powder 6%, calcite 40%, and andesite powder 10% were used as a constant percentage by weight. The products were weighed on a precision balance of 0.001 g and then collected in a mixing container. They were mixed homogeneously in a mechanical mixer for 60 1/min for 15 minutes. In order to proceed to the next step in the production process, hot pressing, the mixture was added to each mold compartment shown in Figure 1.

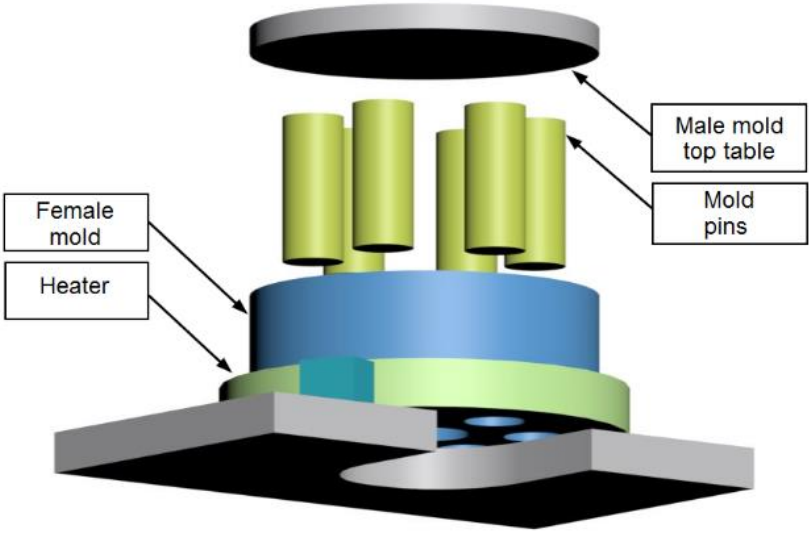


**Figure 1.** View of mold design.

The materials placed in the mold were shaped at 15, 20, 25, 30, 35, and 40 MPa pressing pressure at 150 °C for the time specified in Figure 2.

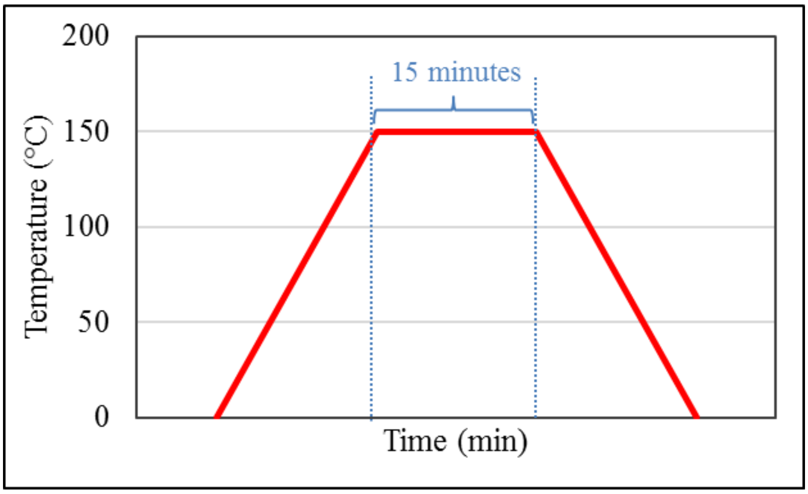


**Figure 2.** Temperature-duration graph under production conditions.

The production method was developed based on the studies in the literature (Yavuz, 2023; Yavuz and Bayrakceken, 2022). In order to apply an initial pressure value of 15 MPa, the ceramic resistance heater in Figure 1 around the mold was activated until it reached a temperature of 150 °C. A hydraulic press kept the pressure values stable during the heating period. When the mold temperature reached 150 °C, it waited for 15 minutes. The heating process of the resistance was stopped by keeping the pressure constant. The mold temperature was allowed to drop to 75 °C. Brake pad samples were carefully removed from the mold.

### 2.2 Density and Hardness Measurement

According to Archimedes' principle, density values were calculated according to Equation 1 with a density measurement kit on a precision balance. According to Archimedes' principle, weight measurements of 3 samples in each series were performed in air and water. The density value was obtained by using the average values of the samples whose measurements were completed.

$$\rho_b = \frac{g_h}{g_h - g_s} \rho_s \quad (1)$$

In the above equation;
$\rho_b$= Density of the lining sample (g/cm$^3$)
$g_h$= Weight of the pad sample in air (g)
$g_s$= Weight of the pad sample in water (g)
$\rho_s$= Density of pure water (g/cm$^3$)

Hardness measurements were performed with the Shore D device that is used for composite, resin, and plastic materials in accordance with ASTM D2240 (ASTM D2240-15 2021) standard. The average values of five points on three pad surfaces in each series gave hardness results (Figure 3).

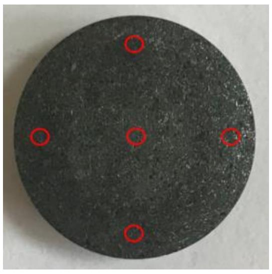

**Figure 3.** Hardness measurement points.

### 2.3 Coefficient of friction and wear rate

The specimens were tested by the brake pad tester shown in Figure 4. The brake pad tester uses a vertically positioned electric motor. The brake disc used in vehicles is used in the device, and the brake disc can be moved in the desired speed ranges. Load cells are used for friction force and applied load measurement. The brake pads apply load to the load cells by friction.

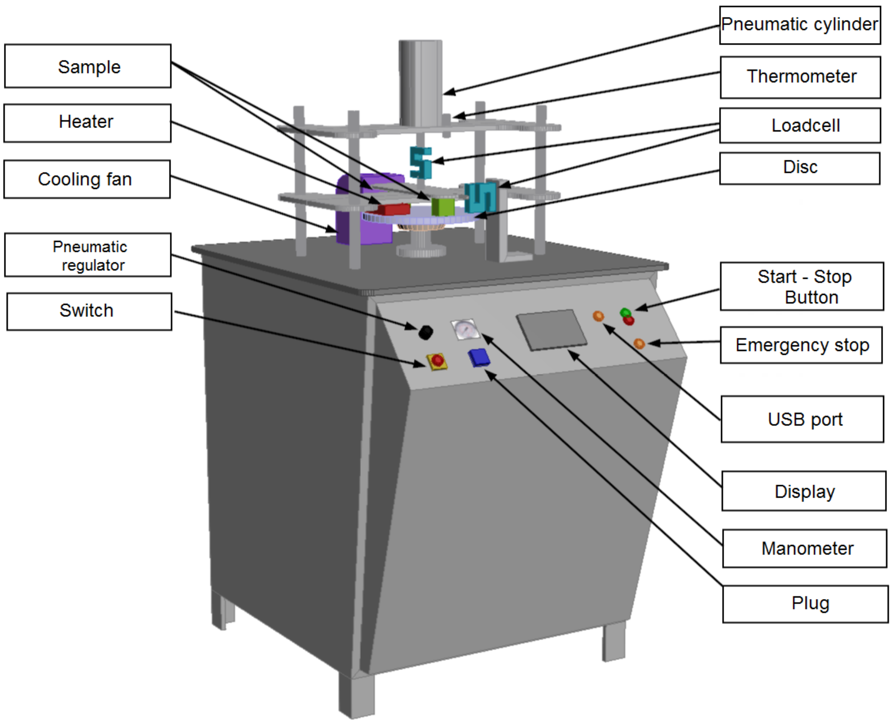


**Figure 4.** Test device design view.

With the other load cell located between the pneumatic cylinder and the pad samples, the loads applied to the pads were recorded on the control panel. The temperature value formed on the disk surface is recorded with a non-contact thermometer. According to the measurement results, the coefficient of friction was calculated by Equation 2.

$$\mu = \frac{f}{F} \quad (2)$$

In the equation above;
μ: Coefficient of friction
$f$: Friction force read on a dynamometer
F: Compressive force applied to test specimen

The specimen surfaces were sanded with 320-grit sandpaper, and the specimens were prepared for the test. The brake pad standard states that the sliding speed should be between 6 m/s and 8 m/s, and the compression pressure should be 1 ± 0.02 MPa (*TS555*, 2019). In this study, the disk speed was 6 m/s, and the pressure applied to the specimen was 1 ± 0.02 MPa. In the lining tester, experiments were carried out at a sliding distance of 8 km after a 2.8 km run to acclimatize the specimen surfaces to the disk surface. The coefficient of friction temperature plots were generated to cover the operating period after the break-in run.

Before and after the experiment, the weight of the samples was weighed on a precision balance and was used to calculate the wear rate which was determined according to Equation 3.

$$W_a = \frac{\Delta G}{SMd} \quad (3)$$

In the equation above;
$W_a$: Wear rate
ΔG: Weight loss
S: Sliding distance
M: Loading weight
d: Density of the abrasion material

### 2.4 Sem analysis

Before SEM analysis, the sample surfaces were coated with a carbon using a flash coating device. SEM analysis was performed on the LEO brand 1430 VP model scanning electron microscope (SEM) device attached with RÖNTEC QX2 (EDX – Energy Dispersive X-ray Spectroscopy) detector.

## 3. RESULTS AND DISCUSSION

### 3.1 Density measurements

Figure 5 shows the density values of the lining samples produced in this study. The densities of the specimens increased proportionally as the molding pressures were increased. The lowest density value in the lining samples was produced under 15 MPa pressure whereas the most dense lining was produced at 40 MPa compaction pressure. With the increase in molding pressure, the distance between the compacted powders is reduced and hence the sizes of the voids between the powders decrease dramatically, therefore, the density of the lining samples increases accordingly.

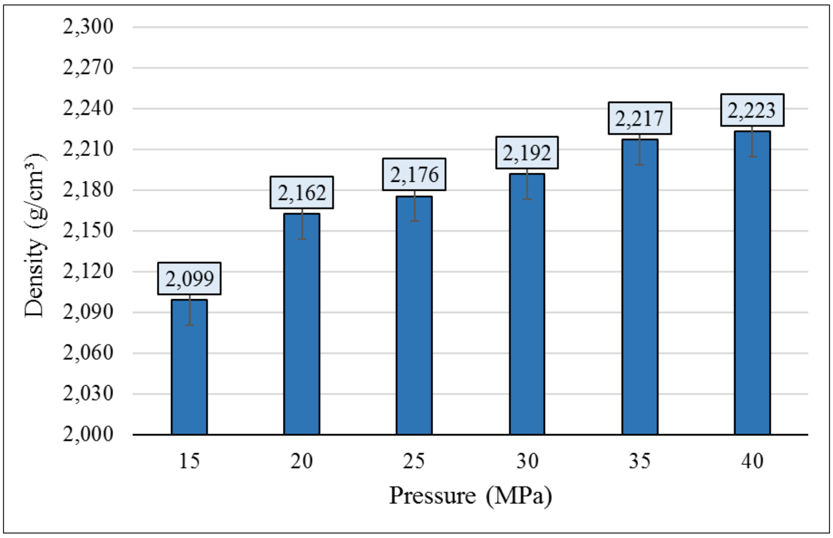


**Figure 5.** Density values.

### 3.2 Coefficient of Friction

Friction coefficient graphs and explanations for all specimens are given under this heading. When the graphs are examined, it is determined that the temperature values increase with increasing sliding distance and remain partially constant after the 7000 m sliding distance. This is an expected behavior from friction pairs. This study reached a point where heat equilibrium was reached after almost a 7000 m sliding distance. In the experiments carried out, temperature values were above 100 °C towards the last stage of the experiment. Rising temperature values are an essential variable in friction coefficient performance. In the experiments conducted for all samples, performance was not negatively affected, even at very high temperatures. Figure 6 shows the friction curve of the lining sample produced under 15 MPa pressure. As a result of the experiment, the average coefficient of friction is 0.34, and the maximum temperature of the disc friction surface is 135.9 °C.

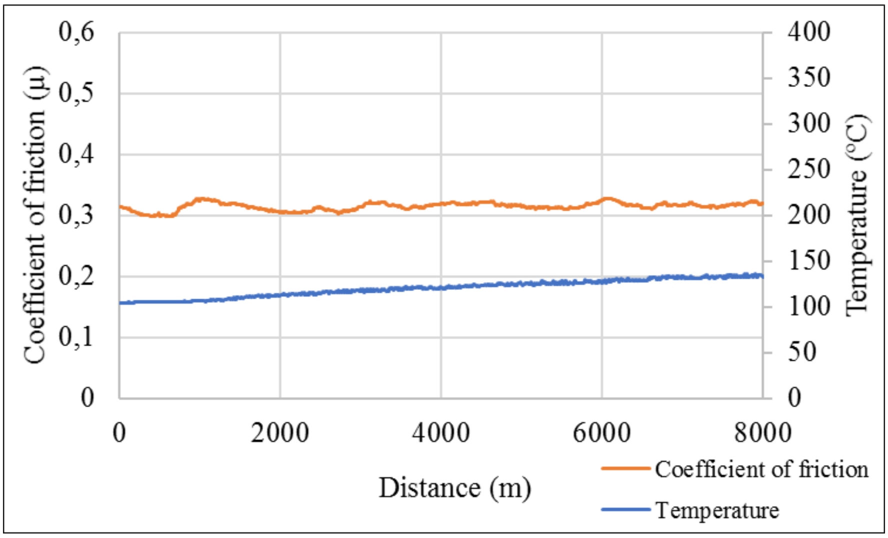


**Figure 6.** 15 MPa friction coefficient and temperature graph.

Figure 7 shows the friction graph of the lining sample produced under 20 MPa pressure. As a result of the experiment, the average coefficient of friction is 0.34, and the maximum temperature of the disc friction surface is 189.8°C.

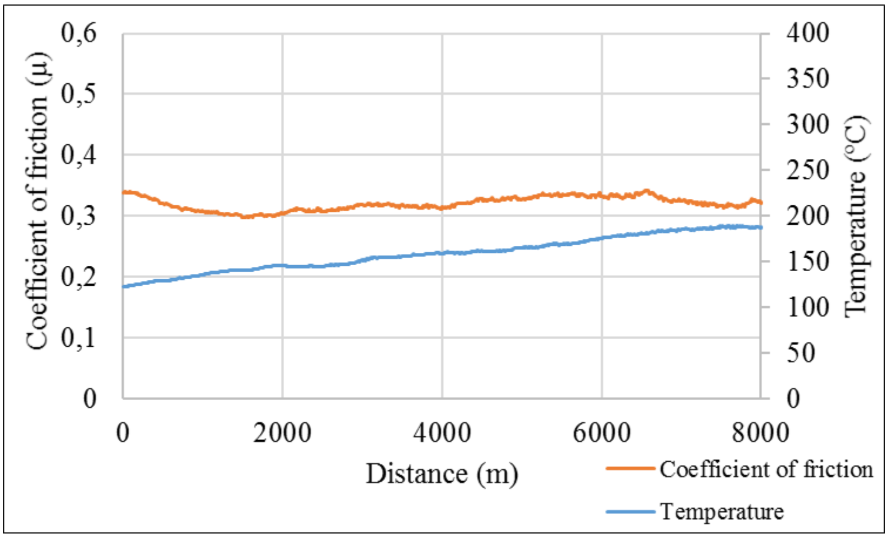


**Figure 7.** 20 MPa friction coefficient and temperature graph.

Figure 8 shows the friction graph of the lining sample produced under 25 MPa pressure. As a result of the experiment, the average coefficient of friction is 0.35, and the maximum temperature of the disc friction surface is 167.1°C.

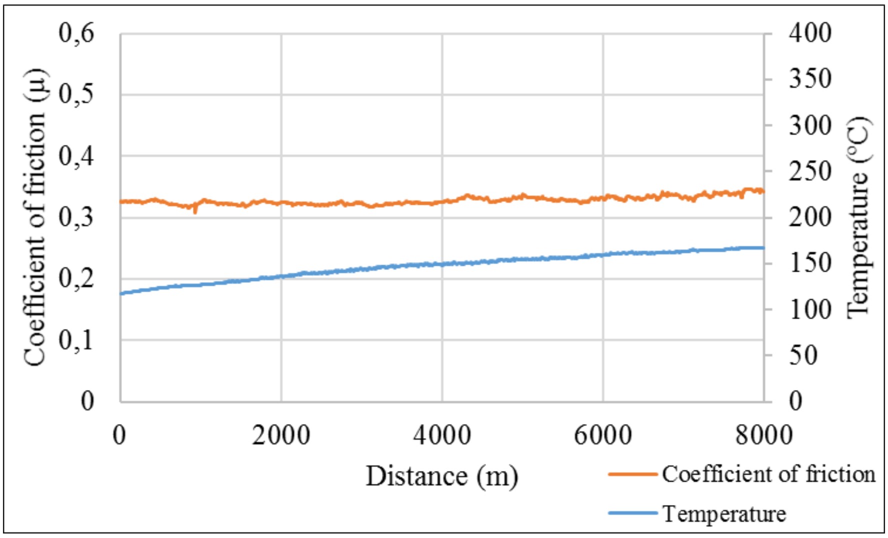


**Figure 8.** 25 MPa friction coefficient and temperature graph.

The friction graph of the lining sample produced under 30 MPa pressure is shown in Figure 9. As a result of the experiment, the average coefficient of friction is 0.35, and the maximum temperature of the disc friction surface is 189.7°C.

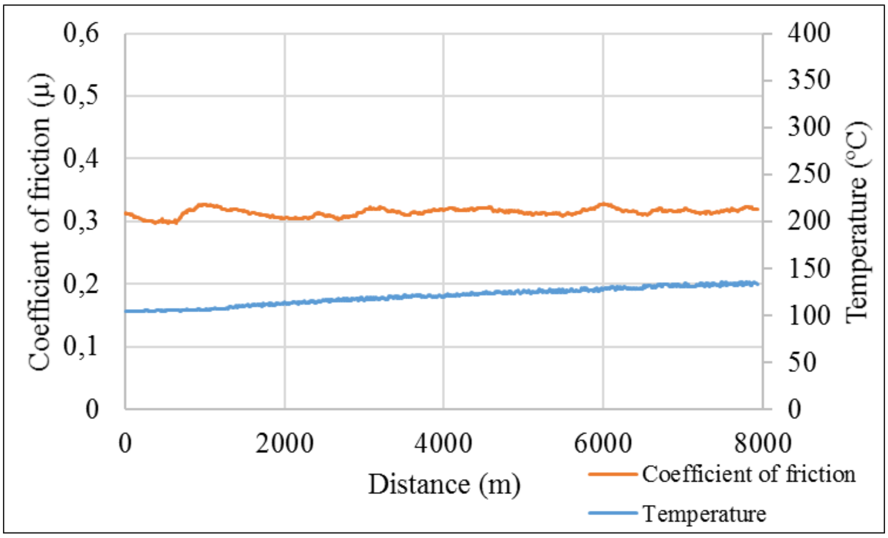


**Figure 9.** 30 MPa friction coefficient and temperature graph.

Figure 10 shows the friction graph of the lining sample produced under 35 MPa pressure. As a result of the experiment, the average coefficient of friction is 0.33, and the maximum temperature of the disc friction surface is 218.1°C.

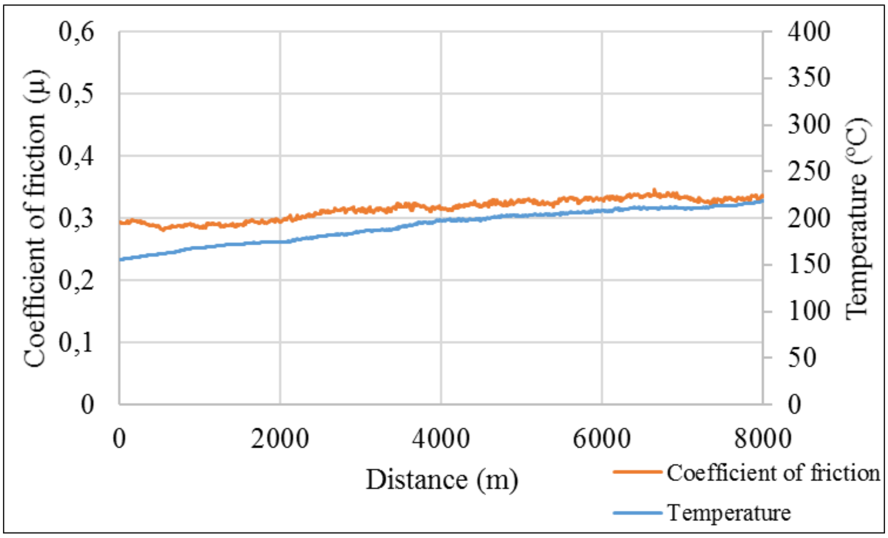


**Figure 10.** 35 MPa friction coefficient and temperature graph.

Figure 11 shows the friction graph of the lining sample produced under 40 MPa pressure. As a result of the experiment, the average coefficient of friction is 0.37, and the maximum temperature of the disc friction surface is 206.7°C.

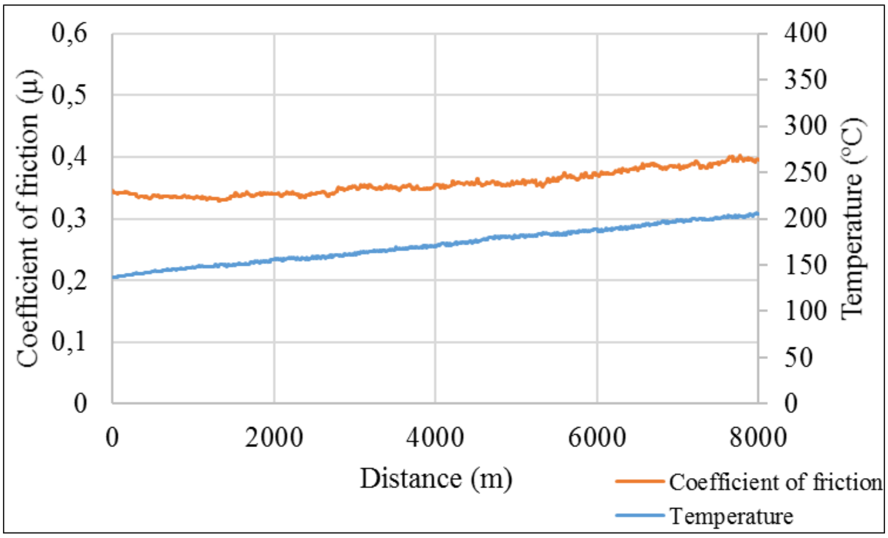


**Figure 11.** 40 MPa friction coefficient and temperature graph.

Table 1 shows the average coefficient of friction values of the brake pads. The average friction coefficients of the samples between 15-35 MPa varied between 0.33 and 0.35, and the values were very close to each other. The maximum coefficient of friction is desired for brake pads, and the highest value was obtained in the sample produced at 40 MPa. In the brake pad standard (*TS555*, 2019), the friction coefficient range for disc brakes is between 0.20-0.70, depending on the temperature. The coefficient of friction of all specimens is within these values.

**Table 1.** Average coefficients of friction.

| Pressure | 15 | 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|
| Coefficient of friction | 0,34 | 0,34 | 0,35 | 0,35 | 0,33 | 0,37 |

### 3.3 Wear Rates

The wear rates measured in all samples were similar to studies conducted in the literature (Sugözü et al., 2018). The wear phenomenon in brake pads is very complex, and the wear rate values of the developed pads were measured as 0.18 - 0.28 X $10^{-7}$ cm³/Nm. According to the brake pad standard (TS555, 2019), the wear rate should be 1X$10^{-7}$ cm³/Nm at 200°C and 1.5X$10^{-7}$ cm³/Nm at 250°C. The maximum temperature obtained in the samples varies depending on the coefficient of friction increase and between 135.9 and 218.1 °C. According to brake pad standards, the wear rate values suit brake pads.

**Table 2.** Wear Rates

| Pressure | 15 | 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|
| Wear rate (X$10^{-7}$cm³/Nm) | 0,28 | 0,25 | 0,18 | 0,28 | 0,25 | 0,24 |

### 3.4 Hardness measurements

Shore D hardness measurement values are shown in Figure 12. It is observed that the hardness values of the pads produced under 15 and 40 MPa pressure are close to each other. The sample produced at 40 MPa pressure had the highest hardness value, while the sample produced at 15 MPa pressure had the lowest. As the pressure values increased, the gap between the particles of the materials forming the specimens decreased, which increased hardness values. Hardness values were similar to studies conducted in the literature (Yavuz and Bayrakceken, 2022).

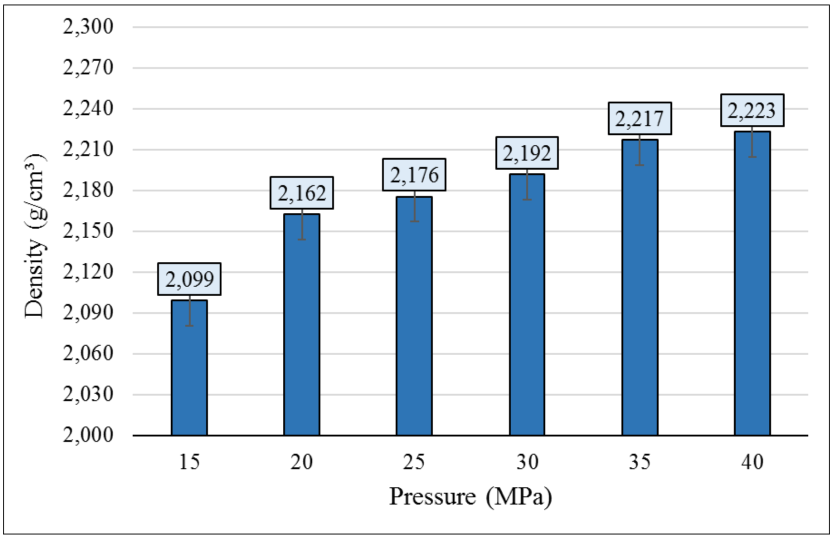


**Figure 12.** Shore D hardness measurements.

### 3.5 SEM analysis

When the SEM images obtained on the wear surfaces of the samples as a result of 1000X magnification in Figure 13 are examined, the friction layers formed after the test are identified. It is desirable that the friction layers have a large area in brake pads and the friction surface has a large area in all brake pad samples. The 30 MPa brake pad specimen in Figure 8 shows intense scratches in the friction layer. The intense scratches in this specimen are considered to be caused by abrasive hard particles.

## 4. CONCLUSIONS

This study prepared a recipe consisting of powdered materials from the processing of andesite stone and other materials that make up the brake pad structure. With these materials forming the samples, lining samples were produced at different pressure parameters of 15, 20, 25, 30, 35, and 40 MPa. The lining samples were analyzed for wear rate, friction coefficient, density, hardness, and SEM analysis. As a result of the measurements and tests, the following results were determined.

- When the post-test density values are examined, the density and pressure values were measured in direct proportion to the lowest 15 MPa and the highest 40 MPa pressure in the lining samples.
- According to the results of hardness values, the average Shore D value was determined as 96.07. According to the samples, the hardness value increased in direct proportion to the increase in production pressure and density.
- A stable coefficient of friction is desirable for braking performance. In all of the samples, a stable situation was observed in the friction coefficient graphs.
- The maximum coefficient of friction was obtained as 0.37 for the 40 MPa sample, and the average friction coefficient for all samples is within the desired limits. Wear rate value differences are close and within the desired values.

In this study, brake lining samples were developed from andesite powder, considered industrial waste, and results were obtained at the desired performance values. Using this material as industrial waste will contribute to recycling and material costs.

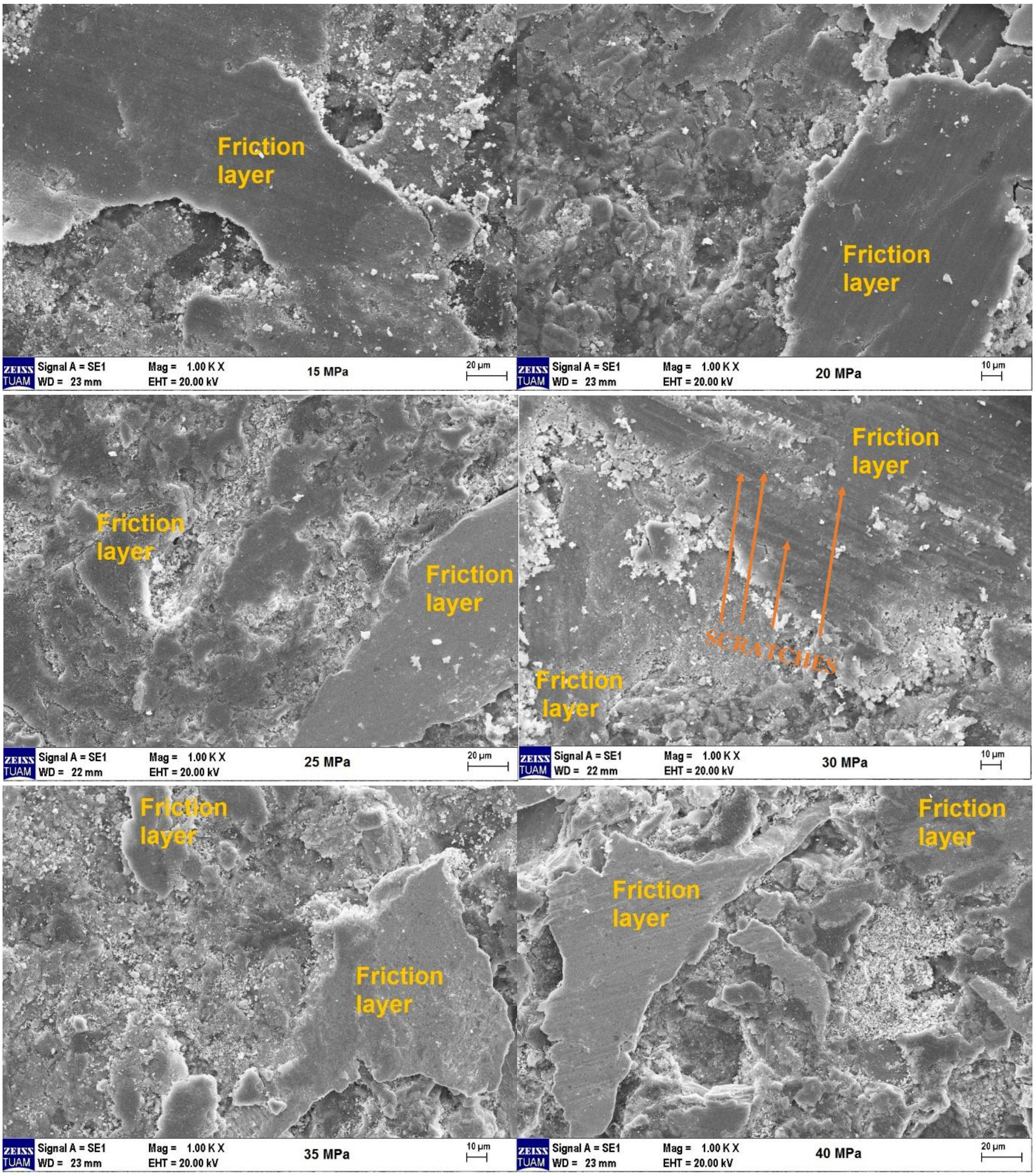

**Figure 13.** SEM images.

## 5. ACKNOWLEDGEMENTS

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## 6. CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

## 7. AUTHOR CONTRIBUTION

Hüseyin Bayrakçeken, Muhammet Ziya Güven, and Hicri Yavuz contributed to the Determination of the Conceptual Design Processes of the Study, Data Analysis and Interpretation, and the Creation of the Article Draft. In addition, Critical Review of Intellectual Content Hüseyin Bayrakçeken and Hicri Yavuz Data Analysis and Interpretation Muhammet Ziya Güven contributed. Final Approval and Full Responsibility belong to Muhammet Ziya Güven.

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