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Original Research Article

The effect of sintering time on the tribological properties of automotive brake pads

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ABSTRACT

In this study, the effect of sintering temperature on the physical, chemical and tribological effects of sintered automotive friction materials was investigated. Using the powder metallurgy method, 3 different samples were produced with the codes A_1, A_6 and A_{11}. Mixing, pressing and sintering processes were applied respectively as production steps. Mixing time is 90 minutes, speed is 15 rpm. The pressing pressure is 250 MPa and the duration is 1 min. The sintering temperature was 800 °C and the sintering time was 1, 6 and 11 hours, respectively. The sintering process was carried out in the sintering mold using Argon gas. As the sintering time increased, it was observed that there was an increase in the time-dependent friction coefficients of the samples. Increasing the sintering time also increased the density of the samples. As the sintering time increased, the gap in the sample decreased, as it provided better bonding of the dustsers.

Keywords: Brake pad, friction, sintering time, tribology.

1. Introduction

In an automobile, the brake system is used to stop the vehicle safely, as well as to ensure the safety and control of the passengers. It is one of the most important safety components of the car. Friction-based braking systems are a system used to convert kinetic energy into heat energy through friction between brake pads and rotor surfaces. This generated heat energy is collected on the brakes and then dispersed into the atmosphere [1-2].

Various material components have been used to make brake pads. But the main problem is that the brake pads are subject to wear, abnormal noise, fading, shortened service life and environmental problems. Some technical difficulties with this type of brake pad are to reduce the wear rate, noise, stopping distance of the vehicle and increase the friction coefficient to ensure that the brake pad is used for a longer period of time. Other challenges include increased heat resistance, service life and brake pad strength [3-4].

Friction materials are named differently according to the components they contain. For example, semi-metallic friction material contains more than 50% metal. As it reduces the metal ratio, it is called a low metal content brake pad. Low metal content friction materials are designed for slightly lower noise and comfort.

Low metal content friction materials have a friction coefficient in the range of 0.35-0.38, while semi-metallic friction materials have a friction coefficient of around 0.4. The link between components in sintered metal friction material, also known as metallic friction material, is created by the fusion of metal particles when heat and pressure are applied. To dissipate the high energy density, sintered metal is primarily used. The matrix material must transmit heat without breaking down. They often include different metal powders, including copper, iron, tin, lead, and others [5-7].

Automotive friction materials are enhanced with various metallic compounds to increase wear resistance and thermal strength. Different metals, including copper, steel, iron, brass, bronze, and aluminum, have been employed as friction material as fibers or particles. The thermal dissipation at the friction interface is improved by the use of metals, particularly copper or copper alloys. It is also well known that copper produces copper oxides at the friction surface, which helps to maintain the friction coefficient at high temperatures [9-10].

In order to have a high and stable friction coefficient at different sliding speeds and pressure conditions, the friction layer formed between the contact surfaces must have advanced properties that can provide high tribological performance at high temperatures without damaging the base material. Crack formation, wear and degradation processes on friction surfaces depend on physical parameters such as hardness, density and porosity. Therefore, the brake pad and friction layer must have the necessary hardness and properties. In addition to the material factor, manufacturing parameters can also play a decisive role in obtaining the desired properties [8].

Sintering is a heat treatment that brings the powder particles together at very high temperatures and enables the material to gain strength. This process can be brought about by solid-state atom transport events at temperatures below the melting point. If examined in microstructural dimensions, it can be seen that this bonding takes place through necking between particles. Thus, neck growth occurs. With this neck growth, changes in the properties of the material may occur. The production parameters, namely compaction pressure, sintering temperature, sintering time and sintering medium, affect the properties of the final product produced by powder metallurgy. As researchers realized that controlling sintering conditions resulted in products with controlled properties, they conducted several studies covering a wide variety of engineering materials to examine the effect of sintering conditions on the properties of powder metallurgy products [11-12].

In this study, metal-containing sintered automotive friction materials were produced by using powder metallurgy method. The effect of sintering time, which is one of the sintering parameters, on the automotive friction material, its mechanical, chemical and tribological properties was investigated.

2. Material and Methods

The amount, size and structural properties of the materials used in automotive friction materials have a great effect on the tribological properties of friction materials. The friction materials used in the study were produced by powder metallurgy method. First, the powders to be used to produce the automotive friction material were determined and mixed in the percentages given in Table 1. The articles and theses that are close to our study were examined, and the brake pad production parameters determined as a result of this are shown in Table 2 [14-16]. In addition, in a doctoral thesis, it was suggested that the pressing pressure of copper-based brake pads should be between 150-300 MPa and the sintering temperature in the range of 650-900 °C [17]. Powders; It was mixed in a V-Shape type mixing device at a speed of 90 min and 15 rpm. The powders mixed homogeneously were taken into a 1 inch^2 mold and pre-formed. The pressing pressure was 250 MPa and the pressing time was 1 min. The samples prepared after pressing were sintered in the sintering mold for 1, 6 and 11 hours, respectively, at 800 °C in the sintering furnace. Argon was used as inert gas during the sintering process.

Table 1. Proportion of mixed materials.

Ingredient	Weight (%)
Bronze Powder	40
Glass Fiber	5
Steel Wool	6
Barite	40
Graphite	6
Alumina	3

Table 2. Friction material production parameters.

Samples Code	A_1	A_6	A_{11}
Mixing Time (min)	90	90	90
Mixing Speed (rpm)	15	15	15
Pressing Pressure (MPa)	250	250	250
Pressing Time (min)	1	1	1
Sintering Temperature (°C)	800	800	800
Sintering Time (h)	1	6	11

Fig. 1. Pin on disc wear tester.

The mechanical, chemical and tribological properties of the produced samples were investigated. The wear friction test was performed on the pin-on disc tester shown in Fig. 1. The test parameters were determined by taking into account the characteristics of the device in the center where the friction-wear tests were carried out. In addition, the test parameters were determined by examining the articles close to our study [18-20]. Test conditions were determined as 400 rpm rotation speed, 0.2 m/s sliding speed, 11 mm radius, 1240 m distance, applied time 5400 s and applied force 10 N. Density values of the produced samples were determined according to the Archimedean principle. Density measurements were carried out in an experimental setup operating according to the Archimedes principle. Density measurement is shown in Equation 1. Three different density values were taken for each sample and the density of each sample was determined by taking the average. In the formula, m_h is the weight of the sample in air, m_s is the weight of the sample in water, and ρ is the density of the water. Since pure water was used during the measurements, ρ_{water} was taken as 1 g/cm^3.

$$Density = \frac{mh}{mh - ms} x\rho water \quad (1)$$

After the friction wear test for the produced friction materials, SEM and EDX analyzes were performed at Technology Application and Research Center (TUAM).

3. Results and Discussion

In the study, the effect of sintering temperature on automotive friction materials produced with the same content was investigated. A sintering time of 1, 6 and 11 hours was applied at 800 °C, respectively. In Fig. 2, the variation of friction coefficient of A_1, A_6 and A_{11} samples with time is shown. Friction coefficient values of the A_1 sample varied between 0.4 and 0.7. The average friction coefficient for the A_1 sample was determined as 0.52. When the time-dependent coefficient of friction graph is examined, there is a time-dependent decrease in the friction coefficient, especially after the 20th minute. The reason for this decrease in friction coefficient is; This can be explained by the fact that the alloy forming the friction layer, that is, the materials constituting the component, do not fit well with each other and the decrease in surface roughness strength due to the increase in temperature over time. When the friction coefficient time graph of the A_6 sample is examined, it is seen that the friction coefficient is more stable depending on time. Friction coefficient values varied between 0.55 and 0.85. The average friction coefficient for the A_6 sample was determined as 0.747. For the A_6 sample, there was an increase in the coefficient of friction up to the 20th minute, then a decrease until the 85th minute. A_{11} sample, which was sintered for 11 hours, reached the highest friction coefficient value. The average friction coefficient value for the A_{11} sample was determined as 0.833. Friction coefficient values varied between 0.55 and 0.9.

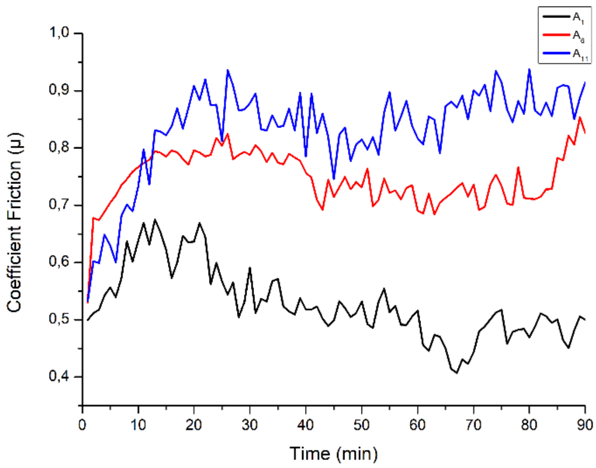


Fig. 2. Friction coefficient time graph of A_1, A_6 and A_{11} samples.

The average density values of the samples were determined by taking the average of the experiments performed 3 times with the density measurement kit. When Fig. 3 is examined; The sample with the lowest density is seen as A_1 and the sample with the highest density is seen as A_{11}. It was observed that the density of the samples increased with the increase of the sintering time. It is thought that the density of the sample increases as the porosity formed in the materials decreases with the increase of the sintering time [13].

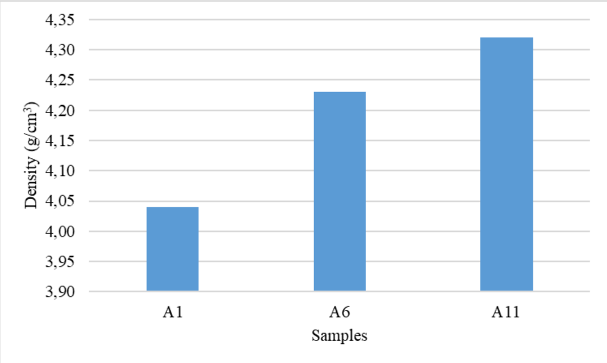


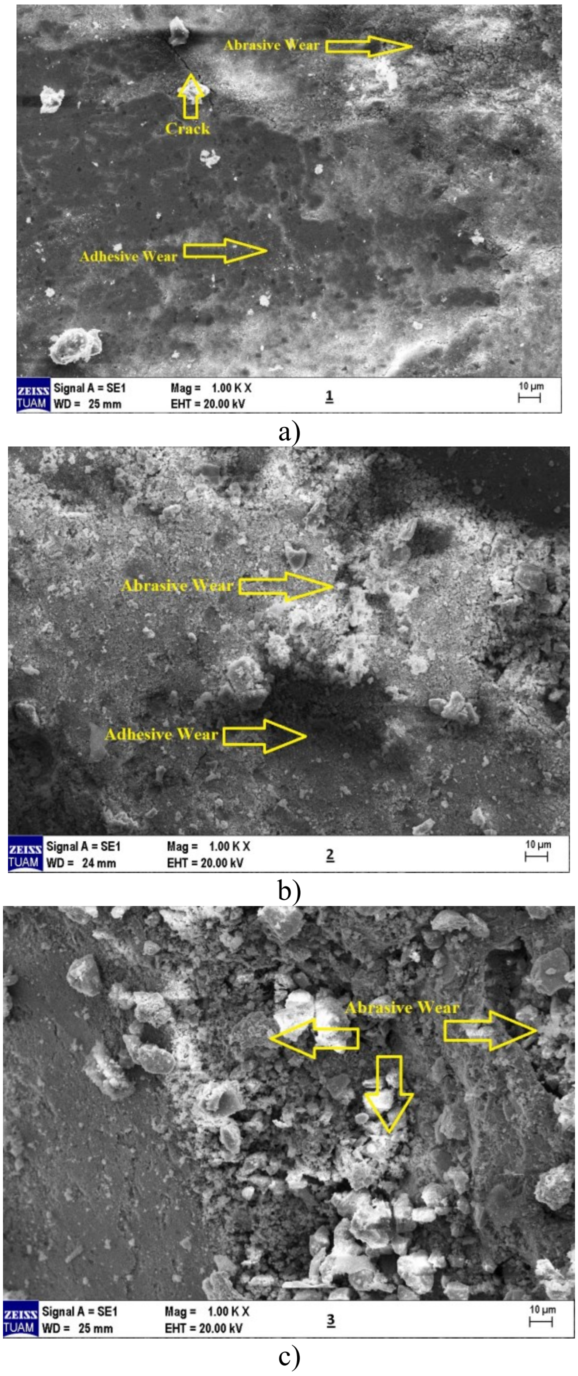
Fig. 3. Average density values of A_1, A_6 and A_{11} samples.

SEM wear photos of the samples are shown in Fig. 4. When Fig. 4 (a) is examined, it is seen that approximately 30% abrasive and 70% adhesive wear has occurred in the sample. In Fig. 4 (b), the sample tried to show adhesive wear and the particles breaking off from the abrasive zone damaged the adhesive zone. When Fig. 4 (c) is examined, the overall sample showed abrasive wear. When Fig. 4 is examined in general, it is seen that abrasive wear occurs in the samples as the sintering time increases. In addition, it is clearly seen that the increase in sintering time increases the deformation in the wear zones.

Overall, Fig. 4 shows that abrasive wear is the predominant type of wear in the samples, and that the sintering time has an impact on the amount of deformation in the wear zones. The results of this experiment suggest that longer sintering times can lead to increased abrasive wear and deformation in the wear zones.

It is seen that the cracks in the samples decrease with the increase of the sintering time. When Fig. 5 (a) was examined, dust particles were seen. In Fig. 5 (b) and (c) samples, the structure became homogeneous after long-term sintering results. It was determined that 1-hour sintering time for sample a was insufficient to obtain a homogeneous structure without cracks.

The most likely reason for this behavior is that the sintering process of the sample is incomplete. During sintering, the particles are heated and heated until they fuse together and become denser. This process takes time and requires a certain temperature and duration to complete. When the sintering time is insufficient, the particles are not completely fused together and the structure remains porous and weak, leading to cracks. Additionally, the dust particles observed in Fig. 5 (a) suggest that the sintering time is insufficient, as the particles have not melted, and the structure is not yet homogeneous.



c)

Fig. 4. SEM wear images of A_1 (a), A_6 (b) and A_{11} (c) samples.

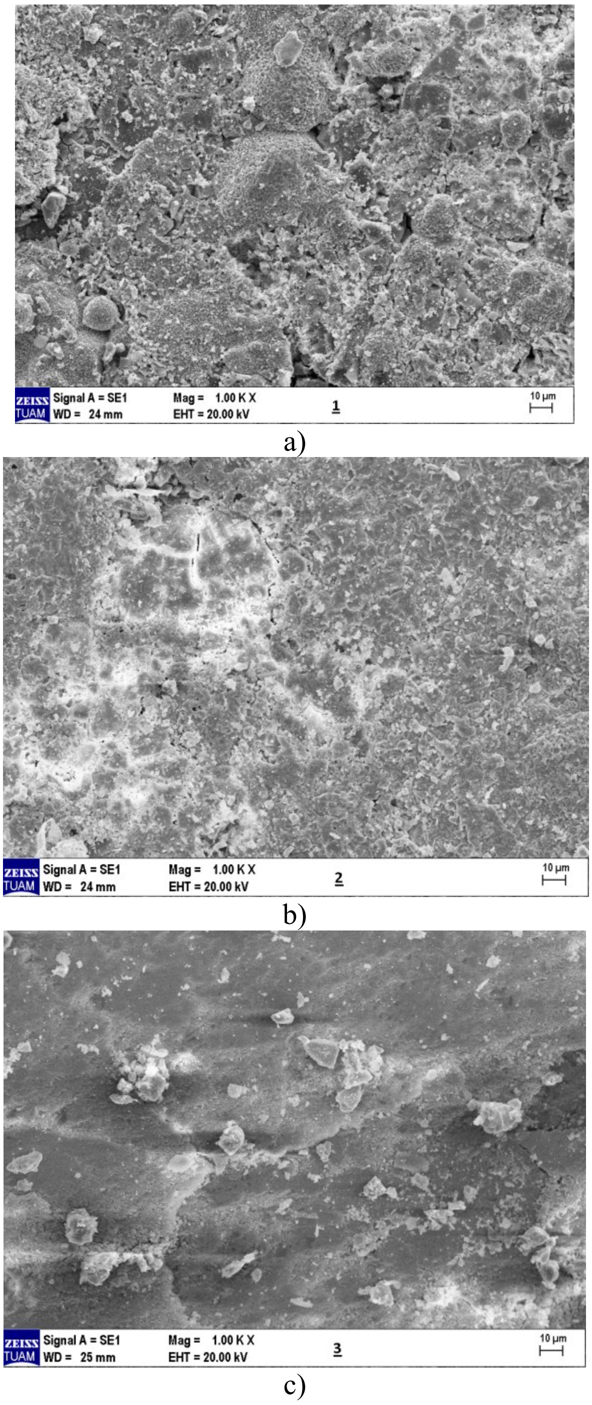


Fig. 5. SEM development images A_1 (a), A_6 (b) and A_{11} (c) samples.

In Table 3, the results obtained as a result of the experiments are compared. According to the results obtained, it was observed that the density of the samples increased as the sintering time increased. Similarly, the increase in sintering time increased the friction coefficient of the samples. As a result of the 1-hour sintering time, a homogeneous structure could not be formed in the A_1 sample. A partial homogeneous structure was formed in the A_1 sample. When the SEM images of the A_6 and A_{11} samples sintered for 6 and 11 hours were examined, it was observed that a homogeneous structure was formed.

Table 3. Comparison of obtained results.

Samples	**A_1**	**A_6**	**A_{11}**
Sintering Time (h)	1	6	11
Density (g/cm^3)	4.04	4.23	4.32
Average Friction Coefficient	0.52	0.747	0.833
Homogeneity of Samples	PH	H	H

*P.H: Partial Homogeneity, *H: Homogeneity

4. Conclusions

In this study, the effect of sintering temperature on the physical, chemical and tribological effects of automotive friction material was investigated. The following results have been obtained;

* As the sintering temperature increased, the friction coefficients of the samples increased. While the A_1 sample had the lowest friction coefficient with 0.52, the A_{11} sample had the highest friction coefficient with 0.833.

* The friction coefficient time graph of the A_6 sample sintered for 6 hours was generally more stable than the other samples.

* Increasing the sintering time increased the density of the samples. The sample with the highest density was the A_{11} sample, which was sintered for 11 hours.

* As the sintering time increases, the combination of the samples in the structure and the decrease of the voids appear more clearly.

* With the increase of the sintering time, the cracks in the samples decreased and the dust particles became homogeneous.

* In order to expand the study, the tests can be repeated by optimizing the proportions of the materials used in production.

CRediT authorship contribution statement

Furkan Akbulut: Literature review, Experimental study, Results and discussion, Writing.

İbrahim Mutlu: Supervision, Writing - review & editing, Conclusions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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