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Evaluation of the Effect of the Novolac Resin Ratio on the High-Temperature Performance of the Brake Pads

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Abstract

The resin is a widely used binder in the brake pads. Determining the optimum, resin ratio is important for the brake pad to show the best wear and braking performance. In this article, the impression of the novolac resin ratio (15% and 30%) on the performance of the brake pads at high temperatures was studied. Friction experiments of the brake pads were performed according to ASTM G99–95a test standard in Pin-on disc test device at 350 °C. The average friction coefficients obtained in the friction tests of 15% and 30% novolac resin samples at 500 rpm rotation speed, 350 °C temperature, and 10 N load were 0.151 and 0.308, respectively. With the increase in the novolac resin ratio, the hardness, density, and thermal conductivity of the brake pads have increased.

Keywords: Brake Pad; Novolac Resin; High Temperature; Friction Coefficient

Research Article

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1. Introduction

The brake pads have been accepted as one of the main components for a car's comprehensive performance. That's why the brake pads play an important role in determining characteristics such as stopping distance, the pedal feels, against disc wear, and brake-induced vibrations. Great efforts are being made to improve the performance of the brake pads, reduce their cost, and use different compositions [1-3]. A commercial brake pad as per usual contains more than 10 components These materials can be categorized as binders, fillers, solid lubricants, reinforcing fibers, abrasives, and friction adjusters for their role in determining the physical and tribological properties of the composite [4, 5]. The resins are used as binders in the brake pads due to their mechanical characteristics for example high hardness, compressive strength, medium heat resistance, creep resistance and very good wetting capacity, and low expense [6, 7]. The resin is widely used as a binder strongly influences important perspectives of the brake performance, for instance fading resistance, the pedal feels, wear resistance, and noise tendency, among others [8, 9]. Besides many advantages, the resins are brittle and hard. It breaks easily during the braking process; This causes heat decreases, heat expansion, and heat cracks in the composite brake pads. Cracks and voids that occur are potential safety problems for the braking process, particularly under hard working conditions [10]. For this reason, many studies have been carried out on the use of the resins, which are important components, in the brake pads. These; include studies such as the use of new types or modified resins, the determination of the resin ratio [6, 11, 12].

Sathyamoorthy et. al. [13] reported that studies on the common components and their effects on friction materials are needed to develop innovative formulations. They claimed that many synthetic and natural products were good alternatives to banned toxic substances such as asbestos and copper. There have been many studies on the use of environmentally friendly friction materials instead of traditional friction materials [14, 15]. Kim and Jang [11] produced the brake pad samples using the novolac resin and the modified novolac resin (10%, 20% and 30% the resin additives). According to the friction test results on the samples on the pad-on disc device, novolac resin gave more stable results than the modified novolac resin. The best values were obtained in samples containing equal amounts of aramid fiber and modified resin (20%). Wu et. al. [16] prepared samples containing 9.6%, 12%, and 24% pure resin and mixed resin (pure resin, benzoxazine resin, and nitrile butadiene rubber). A significant increase was observed in the friction coefficient and wear rate values of all samples when the braking temperatures increased to 200 °C or 250 °C. It was found that friction material based on P-B-N (9.6% pure resin, 9.6% Benzoxazine resin, and 4.8% Nitrile butadiene rubber) occupied a relatively higher glass-rubber transition temperature. It was determined that this stabilized the coefficient of friction and wear rate better under a relatively higher braking temperature. Bijwe et. al. [17] produced friction material using 5 different resins Alkylbenzene modified resin composite has proven to be the best in terms of strength, friction, fading, and recovery. But it was the weakest in wear performance. Gurunath and Bijwe [18] synthesized a new resin in their research and examined its tribological properties and added novolac type resin and newly synthesized resin to the friction material. The tests of the samples, whose resin ratio was determined as 10%, were carried out on a Krauss-type device. It was observed that the newly synthesized resin showed superior performance compared to the traditional resin. Additionally, to this resin being better as a binder in friction materials, the new resin also demonstrated other useful properties. These; very good shelf life, no emission of harmful volatile substances, near-zero shrinkage and void and things (like that). Hong et. al. [19] examined the wear mechanisms of the brake pad samples produced using straight phenolic resin, silicon modified phenolic resin, or boron-phosphorous modified phenolic resin. Tests of samples using 30% resin were evaluated up to temperatures above 400°C using the Krauss-type test device. The highest coefficient of friction was obtained between 200 and 350°C. It was found that the coefficient of friction decreased and the wear rate increased after 350 °C. Jo et. al. [20] examined the performance of binder resins in their studies. Resin, aromatic ring modified resin, silicon modified resin, alkyl modified resin, and acrylic modified resin were used in the test samples. A Resin ratio of 15% was used in the samples. Focusing on the thermal properties of the binder resin, its effects on the degree of friction, wear rate, and grain emission in brake applications were investigated. The results obtained from the tribo tests showed that the defect of the binder resin at high temperatures significantly affects the friction coefficient, wear rate, and brake emission of the brake pad. Shin et. al. [21] investigated the vibration of the brake friction materials with different weight average molar mass phenolic resins (16%) due to wear and friction. Friction tests were performed on a Krauss-type device. The higher weight average molecular masses (Mw = 2.2–6.1 kg/mol) phenolic resin friction material exhibited high friction and low wear rate. Also, friction material containing higher Mw resin showed improved performance in frictional vibration. In many studies on resin, new types of resin or modified resins have been used. In addition to the resin, the effects of different additive components were also investigated. However, it is seen that there are not enough studies to determine the amount of resin used in brake lining.

It is known that the resins can lose their properties at high temperatures, affect the performance of the brake lining and wear and affect the service life of the brake pad. In this study, new brake pads with novolac resin additives used in the different ratios were produced. The effect of the novolac resin ratio of the new formula of the brake pads on the friction coefficient of the brake pad at high temperatures was investigated. Friction tests were carried out at 350 °C in a pin on disc test device. Friction coefficient, hardness, density, thermal conductivity measurements, microstructure, and EDAX analyzes of the produced samples were made.

2. Material and Method

In the production of the brake pads, 15%, and 30% novolac resin was used. The effect of the novolac resin ratio on the performance of the brake pads at high temperatures has been investigated and 7 ingredients are used in the production of the new formulation of the brake pad. The sort and comparative quantities of the elements have been established by experimental observing and include the binder the resin, reinforcing fibers, solid lubricants, abrasives, fillers and friction modifiers. The samples with 15% and 30% of novolac resin were named FL_15 and FL_30, respectively. In the composition of the brake pad, except for the novolac resin, steel wool 10%, metal fiber 4%, Rock wool 10%, graphite 30%, talc 27%, and friction adjuster balance were used. After the ratios of the powders were adjusted, it was mixed in the mixer for 30 minutes. The prepared powders were produced by pressing with a hot press at 160 °C temperature, under 200 bar pressure, and for 25 minutes. Samples for experiments were prepared in 15mm in diameter and 25mm in length. Friction tests were performed in Turkyus brand Pin-on disc tester according to ASTM G99 standard. The friction test experiment setup is given in Figure 1. Each test was repeated three times. The results obtained were averaged. In friction experiments, rotation speed was determined as 500 rpm, speed 1309 m/s, total distance 800 m, and load 10 N. Friction tests were carried out at 350 °C. Gray cast iron disc with Ra 0.8, 55 HRC hardness was used in the experiments. By keeping the test parameters constant, the effect of the novolac resin ratio on friction performance was investigated under the same conditions. The hardness of the samples was measured with a Shore Durometer D device from 5 different parts of the sample and the average hardness values were obtained. The densities of the samples were calculated according to Archimedes' law. Redwag brand precision scales and a density measurement kits were used for density measurements. Microstructure images were obtained on FEI brand Quanta FEG 250 model SEM test device. The thermal conductivity of the samples was carried out on the C-Therm TCI thermal conductivity measuring device.

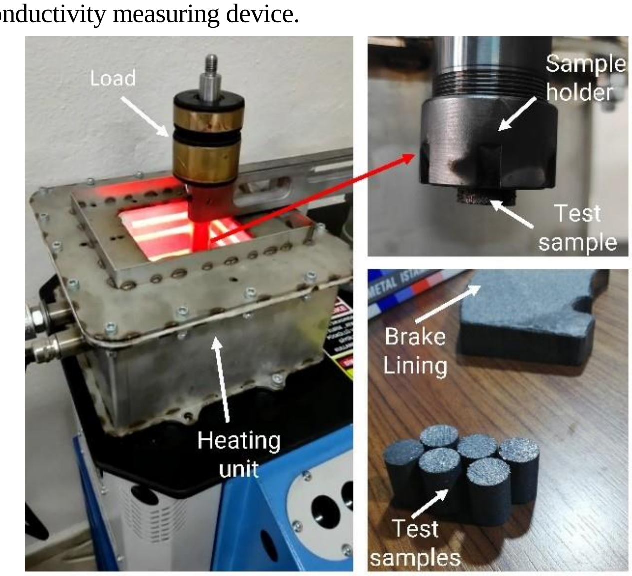

Fig. 1. Pin-on disc test device and experimental design

3. Results and Discussion

3.1. Microstructure analysis

Microstructure images of FL_15 and FL_30 the brake pads produced using different ratios of the novolac resin were examined. The microstructure images of the samples are given in Figure 2. The binding resin is thought to have a significant role in braking performance because it keeps the components together as a matrix in a compound. In the content of brake pads, the phenolic resin has long been used because of its excellent heat resistance and comparatively lowly manufacturing expense. However, the recent high require to brake performance requires enhanced frictional stability and wear resistance at higher temperatures. Many studies are carried out on binder resin to meet the demands for a short braking distance and reduced brake pad wear in braking applications at high temperatures [20, 22]. Figure 2a shows the microstructure of the FL_15 sample. It is seen that the novolac resin and other components are homogeneously distributed in the matrix. It is also seen that the novolac resin successfully binds the matrix components together. In Figure 2b, it is seen that the novolac resin spreads more clearly in the FL_30 sample. In addition, it is seen that the structure is less porous as the amount of resin increases. This reduced the phenolic resin porosity by flowing and filling the pores during hot molding [22].

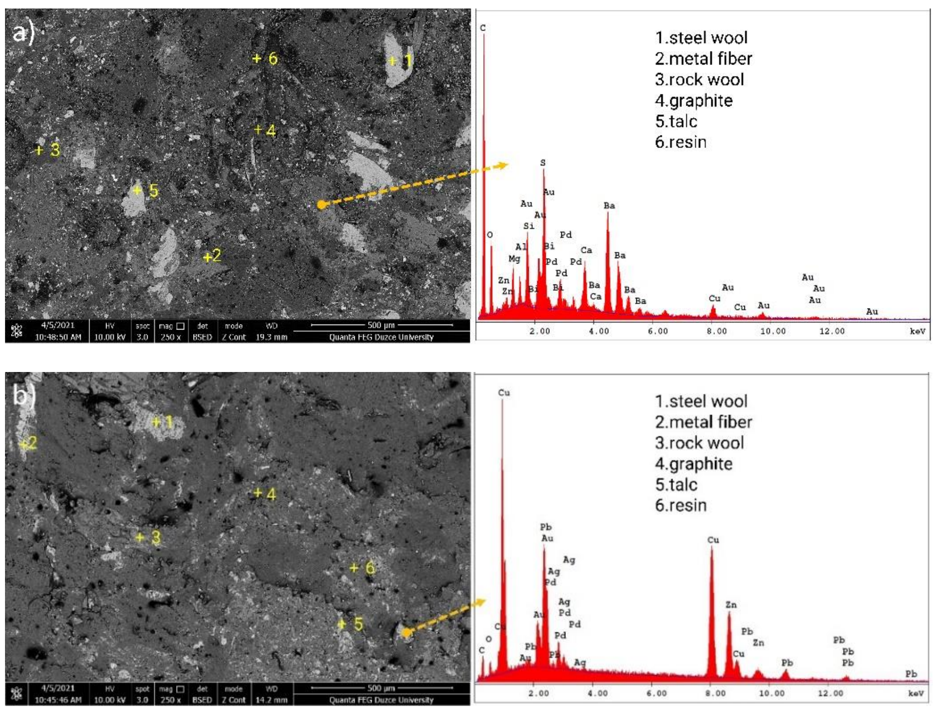

Fig. 2. Microstructure images of the brake pads produced using the novolac resin, a) FL_15 sample, b) FL_30 sample.

3.2. Density, Hardness and Thermal Conductivity

Densities of FL_15 and FL_30 samples are 2.57 gr/cm3 and 2.81 gr/cm3, respectively. Generally, higher density contributes to higher hardness [23, 24]. Tightly pressed samples have a higher density. Higher density and hardness lead to a decrease in porosity [13, 25, 26]. It is seen that the density increases depending on the novolac resin ratio. The ratio of resin used as a binder melted during hot pressing and increased the density of the sample by filling the pores. The density of the brake pads is an important parameter in the brake pads, together with their friction wear and braking performance. The density of brake pads can vary depending on the composition, powder sizes, molding method and heat treatment applied. The properties and ratios of materials used as additives affect the density of the brake pads [27-29]. While the brake pad is being produced, the resin melted with the help of heat fills the pores, reducing porosity and contributing to the increase of density [22].

The hardness of FL_15 and FL_30 samples was measured at 80 shore D and 83 shore D, respectively. There are several determinants affecting the hardness of brake pads, for example, the properties of the components that make up the brake pad, the production process, and the particle size of the components [30]. The hardness of the samples increased with the increase in the amount of the novolac resin. This is by the reason of the fact that the novolac resin is a thermosetting polymer and shows high strength after curing [22].

The thermal conductivity of the brake pads plays a very important role in the brake pad life. The thermal conductivity makes the tribo surface woundable to the descent of organic compounds and adversely affects the braking capacity [18]. Thermally decomposing components and subsequent damage to the contact friction interface areas determine the fading performance of friction materials [31]. Too high thermal conductivity has a negative effect on the brake fluid, creating porous braking, while too low thermal conductivity results in higher degradation in organic components, so the thermal conductivity must be optimized for better performance [23]. The thermal conductivity of FL_15 and FL_30 samples were measured as 0.145 W/mK 0.378 W/mK, respectively. With the increase in the amount of the novolac resin, the thermal conductivity of the samples also increased. With a 30% resin additive, the thermal conductivity of the FL_30 sample increased by 160.6% compared to the FL_15 sample. This increase is in parallel with the hardness and density of the sample. Increasing the amount of novolac resin resulted in a less porous structure in the samples. It can be said that thermal conductivity increases due to the decrease in porosity and the increase in density.

3.3. Friction coefficient

The processes and interactions caused by friction in the brake are still poorly understood today [32]. For this reason, the friction behavior of every new brake pad produced is investigated in detail. The number, ratio, type of components that make up the content and the production procedure affect the friction coefficient. In this study, the effect of 15% and 30% of novolac resin ratio on friction properties was investigated. The average friction coefficient graph obtained in the friction tests performed at 500 rpm rotation speed, 350 °C temperature, and load under 10 N of FL_15 and FL_30 samples are given in Figure 3.

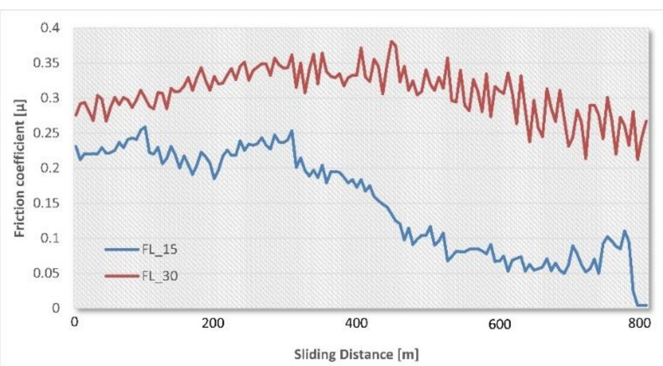

Fig. 3. The average friction coefficient graph of FL_15 and FL_30 samples (at 500 rpm rotation speed, 350 °C temperature and load under 10 N).

According to Figure 3; the average friction coefficients of FL_15 and FL_30 samples are 0.151 and 0.308, respectively at 350 °C temperature. Since the same friction is expected under different braking conditions, the variation in the coefficient of friction under different conditions should be minimal [33]. Increasing the novolac resin ratio increased the friction coefficient. The relationship between temperature and friction coefficient is known to be complex [34]. The surface temperature of a tribo pair increases significantly during severe braking, repetitive braking, speed control, frequent starting, and stopping. Thus, it will cause less fading. This causes an increase in the average temperature of the braking surface and a decrease in braking efficiency or friction coefficient. The brake fade; is the loss of the brake efficiencies as an outcome of high temperature in the brake pad, generally under severe braking conditions. Resistance to fade is one of the most important performance parameters for the choosing of friction material. Therefore, when adapting the composition of friction material, it becomes mandatory to estimate the newly designed material for its resistance to fading [6]. Due to the thermal expansion and heterogeneity of the brake pad materials, contact is highly unstable. Actual and visible contact areas differ significantly [8]. The kinetic energy that increases with the increase of friction heat at high speeds degrades the polymeric components and causes a decrease in the friction coefficient [25]. The change in porosity with increasing resin ratio affected the actual contact area of the brake samples. This is reflected in the friction coefficient results. With increasing sliding distances, fade is less in FL_30 samples. Sudden fade occurred at approximately 300 m friction distance in FL_15 samples. It is seen that increasing the amount of resin contributes positively to Fade.

4. Conclusion

In the study where we investigated the effect of 15% and 30% novolac resin amount on the performance of the brake lining at a temperature of 350 °C, the following results were obtained.

•According to the microstructure samples; it has been found that the novolac resin and other components are homogeneously distributed in the matrix, and the novolac resin successfully holds the matrix components together. It is seen that novolac resin spreads more clearly in the 30% sample than in the 15% sample.

•Densities of samples containing 30% and 15% novolac resin are 2.57 gr/cm3 and 2.81 gr/cm3, respectively. The increase in the novolac resin ratio caused the density of the samples to increase.

•Increasing the novolac resin ratio increased the hardness of the samples. The hardness of the samples containing 30% and 15% novolac resin was determined as 80 shore D and 83 shore D, respectively.

•The thermal conductivity of the samples containing 30% and 15% novolac resin was measured as 0.145 W / mK 0.378 W / mK, respectively. With the increase in the ratio of resin, the thermal conductivity of the samples also increased. With a 30% novolac resin additive, the thermal conductivity of the sample increased by 160.6% compared to the 15% sample.

•Average friction coefficients of samples containing 30% and 15% novolac resin were obtained in the friction tests performed at 500 rpm rotation speed, 350 °C temperature, and under 10 N load, respectively, 0.151 and 0.308. The change in porosity with increasing resin ratio affected the actual contact area of the brake samples. This is reflected in the friction coefficient results.

•New compositions can be produced with different amounts of resin in future work. In addition, friction tests can be performed at different temperatures.

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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