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An Experimental Case Study on The Comparison of The Use of Micronized Quartz and Alumina in Brake Pads

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Brake pad, Vehicle, Coefficient of friction, Wear, Micronize quartz

Abstract: One of the crucial components of the brake system is the brake pads. Due to its importance in the sector, researchers have carried out many recent studies on this subject. In this study, two different brake pad samples were developed from alumina material and micronized quartz material as friction modifiers. Samples containing 12% alumina and micronized quartz were produced by hot molding method. The friction coefficient and wear rates were established in the brake pad tester in order to assess the performance of the created brake pad samples. Density, hardness, and microscopic analyses of the samples, which are other important parameters, were performed with Scanning electron microscopy. The average coefficient of friction was 0.35 in samples containing micronized quartz and 0.34 in samples containing alumina. The wear rates in both samples were obtained below the maximum desired wear rate from the brake pads. The experiments produced brake pad performance values with the desired characteristics, and it was found that micronized quartz material may be employed as an alternative to alumina in the composition of brake pads.

Fren Balatalarında Mikronize Kuvars ve Alümina Kullanımının Karşılaştırılması ile İlgili Deneysel Bir Vaka Çalışması

Anahtar Kelimeler
Fren balatası, Taşıt, Sürtünme katsayısı, Aşınma, Mikronize kuvars

Öz: Fren sisteminin en önemli bileşenlerinden biri fren balatalarıdır. Sektördeki öneminden dolayı araştırmacılar tarafından son yıllarda bu konu ile ilgili çok fazla çalışma yapılmaktadır. Yapılan bu çalışmada sürtünme düzenleyici olarak alümina malzemesi ve mikronize kuvars malzemesinden iki farklı fren balata numunesi geliştirilmiştir. %12 oranında alümina ve mikronize kuvars içeren numuneler sıcak kalıplama yöntemi ile üretilmiştir. Oluşturulan fren balatası numunelerinin performansını değerlendirmek için fren balatası test cihazında sürtünme katsayısı ve aşınma oranları belirlenmiştir. Numunelerin diğer önemli parametreleri olan yoğunluk, sertlik ve mikroskobik analizleri taramalı elektron mikroskobu ile gerçekleştirilmiştir. Mikronize kuvars içeren numunelerde ortalama sürtünme katsayısı 0.35 alümina içeren numunelerde ise 0.34 olarak elde edilmiştir. Her iki numunedeki aşınma oranları ise fren balatalarından istenilen azami aşınma oranının altında elde edilmiştir. Yapılan deneyler sonucunda fren balatalarından istenilen özelliklerde performans değerleri elde edilmiş olup, mikronize kuvars malzemesinin alümina yerine ikame olarak fren balatası içeriğinde kullanılabileceği belirlenmiştir.

1. INTRODUCTION

For people to continue their lives, they meet their food, drink, fuel, or energy needs by moving or transportation. They use different tools to meet these needs. Internal combustion engines working with different fuels or electric motors are used for these vehicles. The motion provided by the internal combustion engines is converted into kinetic energy at the wheels at different torques and speeds by the driveline. While vehicles are driven by various sources for acceleration, disc or drum-type brake systems have been developed for use in vehicles such as cars, trucks, or buses for safe deceleration. The brake pads, a crucial component of the brake system, transform kinetic energy into thermal energy that radiates to the environment, allowing the vehicle to be stopped or slowed down. The friction between the rotating disc or the brake lining pressing the drum determines how well the brake system works [1–4].

Besides the importance of moving the vehicle, stopping is also very important. Pads are important for the brake system to achieve the desired performance. Pads have a particular life due to their structure [5]. High temperatures occur due to the contact between the brake pad and the disc or drum. Under the resulting high temperature, minimum brake pad wear by transferring heat is desired [6]. One of the most crucial components of the brake system is the brake pads, which transfer the braking energy needed to slow down and stop the vehicle to the tires via a disc or drum. The brake pad wears down more quickly than the disc since it is the softer brake system component. Due to the characteristics of the components that make up the brake pad, the working environment, and environmental concerns, researchers are doing serious research. At the same time, the content and nature of the particles and the braking efficiency, should be controlled to ensure passenger safety. All these factors push scientists into a challenging and complex endeavor [7]. Although there are many options in the studies on brake pads, vehicle manufacturers should carefully select the appropriate pad material to ensure safety and optimum operation. This careful selection should also contribute to a stable coefficient of friction and less wear [8].

Brake pads, a vital component of the automobile brake system, are fixed to the steel support pieces facing the brake disc. When it is desired to reduce or stop the vehicle's speed, the pads are brought into contact with the disc with an outward force when the brake is applied. Safety and comfort in cars are of great importance for passengers and drivers. Brake pads produced from unsuitable materials do not meet the desired performance criteria. The heat generated during braking causes deterioration of the structural integrity of the components that make up the lining composite, which is called fading, and causes losses during friction. In addition, these conditions cause an increase in the wear rate and cause malfunctions. All of these elements may have a detrimental effect on the performance and longevity of brake pads. It is essential to create materials with the mechanical, tribological, thermal, and physical characteristics anticipated of brake pads. The use of locally available materials is often encouraged. In addition, they do not contain environmentally friendly asbestos-type substances harmful to health, as well as provide the desired functional properties [9,10].

Working conditions are another factor that is expected to be known or estimated in order to be able to produce brake pads at the desired criteria [2]. High temperatures occur due to the interaction of the contact surface between the lining and the disc or drum. For the brake pad to perform its duty without being worn, it must absorb the heat rapidly. Brake pad friction materials are generally developed by combining different materials to provide the desired performance and appropriate wear criteria [6]. A new composition content and production parameters in brake pad development significantly impact performance improvement [1,11].

Because brake friction materials for vehicles fulfill complex requirements, selecting ingredients and optimizing the recipe are essential to improve the performance of the materials [12]. Brake pads, called polymeric composites, are considered a good choice in terms of cost and performance [13]. With dozens of different materials used in the brake pad, braking performance, environmentally friendly and stable friction coefficient, and high wear resistance are provided [14]. Developed countries also prohibit the use of asbestos-causing lining ingredients [15–17]. The developed brake pad content consists of the following ingredients [18]:

- Abrasives,
- Friction modifiers,
- Fillers,
- Fiber-like reinforcements,
- Phenolic resins, mainly used as binders

Materials that affect the thermal resistance, which prevents the heat generated by braking from damaging the brake pad composite, are also added to the brake pad content [19]. In addition to the materials employed, the production of composite materials using various production techniques is very effective in aspects affecting the tribological performance of the brake friction material, such as density, hardness, surface roughness, braking performance, strength, and brake pad service life [20,21]. In order to allow the driver to brake comfortably, a perfect brake pad should have a consistent coefficient of friction and low wear rate unaffected by speed, pressure, or environmental conditions [22,23]. Determining the tribological behavior of brake pads in the automotive industry is very important.[24]. In order to determine the tribological behavior of brake pads, disc wear tests are usually performed on the pin in a laboratory setting [7,25].

Two separate brake pad samples were developed for this study. The effects of micronized quartz on the brake pad content and the tribological performance of automobile brake pad samples produced from alumina material used extensively as a friction modifier were investigated comparatively.

2. MATERIAL AND METHOD

Table 1 gives the composition ratios by weight of the materials that make up the brake pad composites and the production method. Brake pad samples were produced in mixtures containing 12% alumina and 12% micronized quartz. AL12 code refers to brake pad sample containing alumina, and MQ12 code refers to brake pad sample containing micronized quartz. Brake pad samples were produced in three stages according to the production method specified in Table 1 [26]. In the first stage, the materials that make up the brake pad samples were weighed on a precision scale. In the second stage, they were mixed at 60 l/min for 15 minutes. In the third step, the mixture was hot pressed under the pressing conditions given in the third step of Table 1. The lining samples taken out of the mold after hot pressing have a diameter of 25 mm and a height of approximately 11 mm.

Using the Archimedes principle, the density measuring kit calculated the densities of the brake pad sample productions. The samples were tested in the brake pad testing apparatus under the conditions listed in Table 2 to ascertain the friction coefficient and wear rate. Using the equations in Table 2, the brake pads' friction coefficient and wear rate were computed.

Table 1. Brake pad sample content (% by weight) and production method

Sample \ Material	Resin	Steel fiber	Brass powder	Graphite	Barite	Cashew	Alumina	Micronize quartz
AL12	19	15	7	7	35	5	12	-
MQ12	19	15	7	7	35	5	-	12
Production Method								
Step 1	Weighing of materials with an accuracy of 0.001 g							
Step 2	60 1/min, 15 min kinetic type mixing							
Step 3	25 MPa, 20 min. 150 °C hot molding							

The hardness values of the brake pad samples for each sample were carried out in the Shore D durometer hardness measuring device, which is used for hardness measurement in ASTM D2240 [29] standard.

Scanning electron microscopy (SEM) microscopic analyses (LEO 1430 VP) were performed at 1000X magnification.

Table 2. Test method of brake pad samples and formulas used

Test Method and formulas		
The friction coefficient and wear rate test conditions	Six m/s disc speed, 1 MPa loading pressure, and 1800 min. test duration	
Coefficient of friction	$\mu = \frac{f}{F}$ [27]	μ = $Coefficient\ of\ friction$ $f = Frictional\ force\ [N]$ $F = Sample\ pressing\ force\ [N]$
Wear rate	$W_a = \frac{\Delta G}{S.M.d}$ [28]	$Wa = Wear\ rate\ [cm^3/Nm]$ $\Delta G = Mass\ loss\ [g]$ $S = Sliding\ distance\ [m]$ $M = Loading\ weight\ [N]$ $d = Sample\ density\ [g/cm^3]$

3. RESULTS AND DISCUSSION

Determined characteristic values of brake lining samples are given in Table 3. The density value of the brake lining sample containing micronized quartz was lower than the sample containing alumina due to the high density of the alumina material. (Alumina density: 3.92 g/cm^3 [30], Quartz density: 2.65 g/cm^3 [31])

The hardness of the micronized quartz sample was higher than that of alumina. The hardness values are similar to the studies in the literature [32,33]. Although the average friction coefficient is close to one another, the sample containing micronized quartz has a friction coefficient of 0.35.

Table 3. Characteristics of brake pad samples

Brake pad \ Property	Density (g/cm^3)	Hardness (Shore D)	The average coefficient of friction (μ)	Wear rate (X10^{-7} cm^3/Nm)
AL12	2.602	91.6	0.34	0.144
MQ12	2.598	94.9	0.35	0.242

The coefficient of friction and wear rate are significant factors in determining the adequacy of the brake system when evaluating the performance of developed brake pad samples. The structure of the components that make up the brake pad, the test circumstances, and the pressure applied to the brake pad samples all affect these numbers [6]. The friction coefficient and wear rate graphs of the brake pad samples, depending on the test period, are shown in Figure 1 for the AL12 sample and Figure 2 for the MQ12 sample. In Figure 1 and Figure 2, friction coefficient and temperature values are increasing during 100 min. slip from the first stage of the test in both brake pad samples. At the same time, the friction coefficient decreased for both samples from approximately 100 min. to 400 min. sliding time, the temperature values became more stable. After 400 min. of sliding time, the friction coefficient values of the brake pad samples showed a more stable state. When comparing the samples, the micronized quartz sample showed a slightly more unstable state than the alumina sample. The reason why the Micronized Quartz sample is more unstable maybe because it is harder than the samples formed with alumina. However, both samples provided the desired performance criteria for brake pad samples.

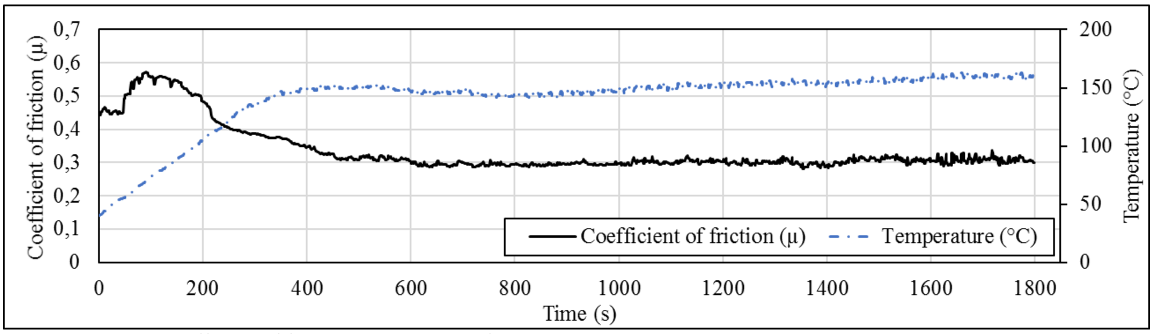

Figure 1. Time-dependent coefficient of friction and wear rate of AL12 brake pad sample

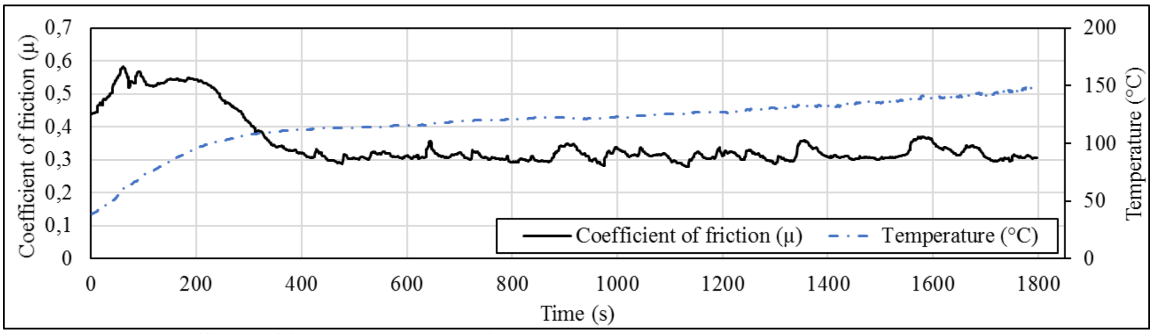

Figure 2. Time-dependent coefficient of friction and wear rate of MQ12 brake pad sample

The composite brake disc and brake pad wear characteristics are identical. The material of the brake disc is abrasively affected by brake pad wear [34]. Brake pad wear is a complicated phenomenon resulting from numerous interactions and friction mechanisms. As a result of plastic deformation, the temperature rise brought on by the friction between the brake pad and the disc during braking leads to wear. Mass loss of brake pad composites also happens due to the development of pits and cracks brought on by loading and vibration [8]. According to the lining standard used in the friction brakes of TS555 road vehicles, the average friction coefficient should be between 0.20-0.70 up to an operating temperature of 200 °C, and the wear rate should be $1X10^{-7}$ cm^3/Nm or less [27]. The produced brake pad samples' average friction coefficient and wear rate fall within these bounds.

SEM microscopic images of brake pad samples are given in Figure 3. For brake pad samples, microscopic images of worn surfaces are seen as an essential tool in evaluating surface morphology [11].

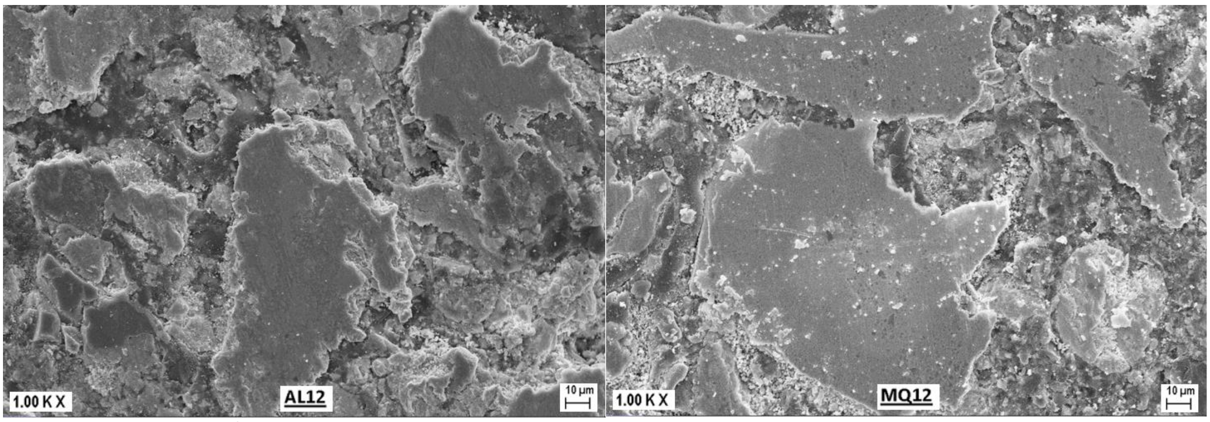

Figure 3. Microscope images of brake pad samples

In Figure 3, the smooth surfaces in the brake pad samples are contact plateaus. Contact plateaus consist of heat-resistant fibers, other friction modifiers, and thermally stable compounds. These plateaus are first covered with tribo film during braking, which resists high temperatures by cutting the atoms in the graphite structure. The light-colored parts on the edges of the contact surfaces are back transfer patches. Retransfer patches are less stable components that degrade during braking. Back transfer patches are caused by a hot spot on the contact surface or adhesion in the fading cycle. The contact surfaces that resist the wear movement contribute to forming a back-transfer patch by ensuring the adhesion of the wearing parts [8,23].

4. CONCLUSIONS

In this study, samples containing 12% alumina and 12% micronized quartz were produced as friction modifiers. The produced brake pad sample density, hardness, and tribological performance were assessed. SEM microscopic examinations were done on the worn surfaces of the brake pad samples whose tribological performance was assessed. The following results were obtained from the experiments.

- The density of the samples containing micronized quartz in brake lining samples was lower.
- The micronized quartz brake pad samples had a higher wear rate than the alumina brake pad samples. For both samples, the wear rate is at its best.
- The average friction coefficient, one of the essential properties sought for brake pads, was obtained at an optimum value of 0.34 in the sample containing alumina and 0.35 in the sample containing micronized quartz.
- The hardness of the brake pad samples was found to be 91.6 Shore D in the sample containing alumina and 94.9 Shore D in the sample containing micronized quartz, similar to the studies in the literature.
- In the SEM analysis of brake pad samples, contact surfaces, and back transfer patches, which are the light-colored parts on the edges of these surfaces, were determined.

When all the results were evaluated, it was determined that the use of micronized quartz material instead of alumina material, which is often used as a friction-regulating material in brake pads by the researchers, meets the desired performance parameters of the brake pads.

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