EFFECT OF GRAPHITE ON THE TRIBOLOGICAL PROPERTIES OF BRAKE FRICTION MATERIALS

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ABSTRACT

An experimental investigation was carried out to examine the tribological behaviour of NAO (non-asbestos organic) type brake linings containing different volume ratios of graphite. Brake linings with increasing content of graphite (3%, 5% and 7% wt.) were prepared and slid against grey cast iron disc and their friction-wear properties were evaluated. The hardness and density of the samples were also determined. The friction coefficient (μ) was observed to decrease with increasing of graphite rate. The wear rate of tested brake linings decreases with increase in graphite rate. In particular, the brake lining containing higher concentrations of graphite showed better wear resistance.

Key Words: Graphite, Brake lining, Friction, Wear

1. INTRODUCTION

Polymer matrix composites are widely used in automotive, air, and railway transport systems as brake linings. Roughly more than 90% of these systems are of the type polymer matrix composite (PMC) brake pad against cast iron rotor. The friction materials used for the pad often contain more than 10 different ingredients, such as metals, ceramic fillers, aramid fibres, rubber, solid lubricants and phenolic resin, which are expected to fulfil specific functions. Since composition–property relationships are not known well enough, the formulation task is based on trial and error and thus is expensive and time consuming.

Among various ingredients for property modifiers, solid lubricants and abrasives are known as two-key ingredients to achieve outstanding brake performance [1,2]. Abrasives are added to control the level of friction effectiveness and to remove the pyrolyzed surface film on the disk surface. On the other hand, solid lubricants protect counter surfaces from excessive wear, and reduce noise and vibration induced by stick-slip at the friction interface. Typical abrasives used in the friction material are zirconium silicate, alumina, silicon carbide, mica, zirconium oxide, silicon oxide, quartz, iron oxides, etc. Solid lubricants used for commercial friction materials are graphite, molybdenum disulfide, antimony trisulfide, copper sulfide, calcium fluoride, etc. Special attentions have been given to the types and the relative amounts of solid lubricants and abrasives in the friction materials, since they affect the brake performance significantly. In particular, the selection of proper solid lubricants for better brake performance has been an important issue for friction material developers, since the solid lubricants decompose at elevated temperatures, resulting in unexpected friction characteristics. In order to accomplish friction stability at a wide temperature range, the commercial friction materials often contain two or more solid lubricants anticipating each of them as an effective solid lubricant at different temperature ranges. However, the role of the solid lubricants in the friction material is rarely found in the literature, although it is one of the most critical issues in developing a friction material with better performance. A few reports investigating the effect of solid lubricants on tribological properties of solid films coated on the metal substrates are available [3,4].

Solid lubricants in the brake lining are added in relatively small amounts but strongly affect various brake performance such as wear resistance, stopping distance, friction stability, torque variation, and noise propensity [5,6]. A large number of solid lubricants are currently available for brake linings. Graphite and MoS2 are frequently used in the commercial brake linings for better brake performance. Much effort has been made to investigate the effect of solid lubricants to improve friction and wear characteristics of brake linings. However, it is difficult to find the information about the role of solid lubricants on brake performance in the literature due to proprietary reasons.

The main objective of this work was to investigate the role of solid lubricant (graphite) on brake performance. The main emphasis was given to the complementary role of the solid lubricant (graphite) on various brake-related performance such as friction level, friction stability, and fade resistance.

2. EXPERIMENTAL PROCEDURE

Friction material specimens for this experiment were manufactured based on a typical non-asbestos organic (NAO) type formulation. The friction material specimens contained a binder, reinforcements, friction modifier, lubrication etc., as shown in Table 1, and they were fabricated using a typical manufacturing process for NAO brake pads [7]. Friction and wear characteristics of the specimens against to a disk made of cast iron were studied. The samples were produced by a conventional procedure for a dry formulation following dry-mixing, pre-forming and hot pressing. First, all components were weighed using a precision balance. The combinations were dry-mixed using a blender in order to achieve a homogeneous state ready for molding. Then the mixture was put into 25,4 mm diameter mold for pre-forming under 10000 kPa at room temperature for 2 min and molded at 180ºC under 15000 kPa for 10 min.

Table 1. The amount of ingredients used for friction materials (weight %)

Ingredients	G5	G10	G15
Phenolic resin	22	22	22
Steel Fibers	15	15	15
Cashew	10	10	10
Brass Particle	5	5	5
Al2O3	5	5	5
Cu particles	8	8	8
Barite	32	30	28
Graphite	3	5	7
Total	100	100	100

Friction material specimens were produced by a conventional procedure for a dry formulation following dry-mixing, pre-forming hot pressing, post-curing, scratching, and grinding. The size of the brake pad was approximately 25.4 x 10 mm (and had a slot in a vertical direction in the center). Three tests were run of each material for each test conditions and average values were reported here. A schematic diagram of the friction tester and its contact geometry has been previously published [8].

Figure 1 show the disc test equipment used in this study. In order to define friction coefficients of automotive brake pad under different temperatures, a test device was designed and manufactured. The detailed test equipment is shown in Figure 1.

Using a real brake disc type tester, the friction coefficient characteristics of the pad next to the disc made of cast iron were investigated by changing the pad. The test sample was mounted on the hydraulic pressure and pressed against the flat surface of the rotating disc. Before performing the friction coefficient test, the surfaces of the test samples and the cast iron discs were ground with 320-grid sandpaper. The experiments were carried out a constant friction force. Braking tests were carried out under 1050 kPa pressure, 6 m/s velocity for 600 s. Electrical heater was used in order to achieve 400 °C in friction surface temperature. The friction coefficient values were stored in a databank. The tests were repeated three times for each sample. Friction coefficients-time graphs are obtained to identify the effect of these variables.

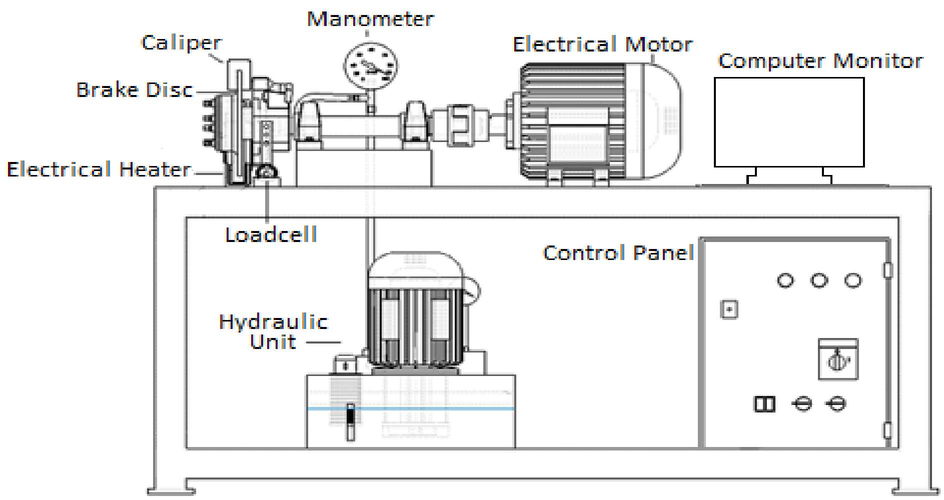

Figure 1. The disc test equipment used in this study

In the braking tests, 1050 kPa pressure was used and also friction coefficients were calculated for each second. In wear test, braking pads were tested 6 m/s sliding speed, 18.7 cm average frictional diameter and 3600 m path. By weighing the peaks to determine loss of mass in braking pads, wear amount was calculated for each experiment. A pad-on-disk test rig was used, and the counterface was cast iron. The gray cast iron disc specimens had a composition of Fe-3,40C-2,20Si-0,60Mn-0,15S-1,05P. Disc samples of 22.7 cm in diameter and 0.975 cm in thickness were obtained from a domestic company in Turkey. The roughness of cast iron disc was also Ra=1.40 μm. The Brinell hardness of the disc samples was 191.13 kgf/mm^2 using 5 mm ball and 1,471 kN (150 kgf) load. In order to understand the wear behavior of the samples, specific wear is determined to the mass method following the standard of TS 555 and calculated by the following equation:

$$V = \frac{m_1 - m_2}{2.\pi.R_d.n.f_m.\rho} \quad (1)$$

with V: Specific wear [cm^3 x Nm^{-1}], m_1: Mass of brake lining before testing [g], m_2: Mass of brake lining after testing [g], ρ: Density of brake lining [g x cm^{-3}], Rd: Radius of disc [m], fm: Average friction force [N], n: Total revolution [9].

In order to confirm uniform mixing and proper curing during manufacturing, the distribution of surface hardness was measured using a Brinell hardness tester. Hardness testing was carried out on a Brinell hardness testing machine using a 62.5 kgf load and 2,5 mm steel ball to determine the hardness variation as a function of braking pad compositions. The surface of the specimens was carefully prepared and each specimen was tested after production of each braking pad. At least five indentations were made from the center to the edge of the specimens to obtain an accurate value of the hardness for each specimen and an average value was obtained. Experimental scatter was at most ±2 HB.

3. RESULTS AND DISCUSSION

The coefficient of friction of the friction material changes as functions of numerous tribological parameters such as applied pressure, speed, temperature, and humidity. Therefore, the coefficient of friction for a commercial friction material is indicated as a code representing a range of the coefficient of friction according to the SAE recommended practice [10]. It is also known that the relative sensitivity of the tribological parameters on the COF is affected by the ingredients in the friction material and previous thermal history.

Obtained friction coefficient (μ) properties of tested samples are shown in Figure 2. The friction coefficient varied significantly in the initial stage of testing, since the size of the contact area increased and the friction layer was developed on the surface [11-13].

The figure demonstrates that the coefficient of friction can be changed considerably under braking conditions. The burnish procedure shows that the coefficient of friction is increased after approximately 150th second. The substantial change of the friction coefficient in the initial burnishing stage is attributed to the gradual change of apparent contact area at the friction interface and the physicochemical change of fresh friction materials. The stabilized values of the coefficient of friction at the end of the burnish were 0.67, 0.59, and 0.58 for friction materials G5, G10, and G15, respectively.

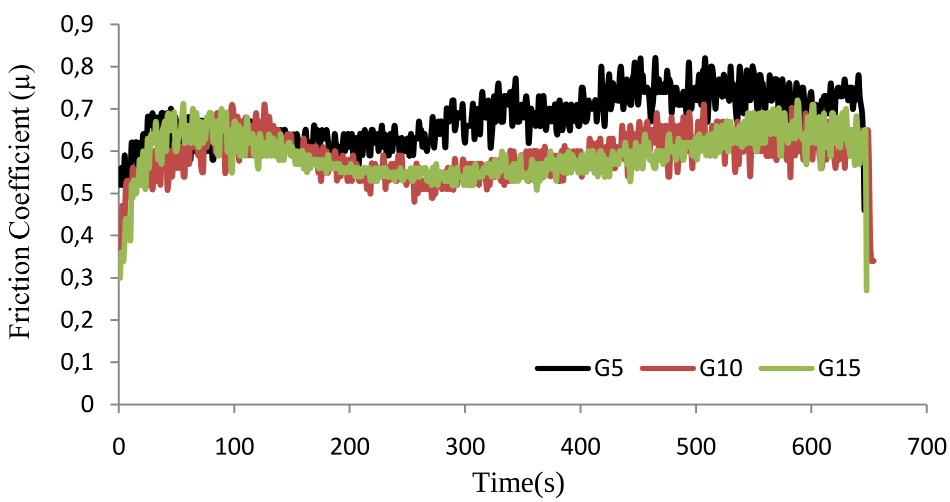

Figure 2. The change of friction coefficient for samples

It is seen from this figure that μ was firstly increased in all samples after it slowly decreased. There is an increase in μ between 0th ÷100th second which degrades slightly after 100th second. When Figure 2 is examined, it is seen that the 3% graphite (G5) added specimen resulted in friction coefficient of 0.67 while the 7% graphite (G15) added specimen resulted in 0.58 at 0th ÷ 600th second. Rapid increase or decrease in μ has lead to a rapid increase in temperature on the surface of friction. Ostermeyer also reported that friction coefficient decreases with increase in interface temperature [14].

Table 2 presents the mean coefficient of friction, hardness, density and specific wear of the sample during the tests for 600 seconds. The friction coefficient of surface material couple is desired to be high and stable. As apparent from Table 2, since wear was very small, wear was measured before and after friction test, and wear rates were calculated as a mean value of the weight reduction in three samples.

Table 2. Typical characteristics of the brake pad

Sample code	Brinell hardness (HB)	Density [$g \times cm^{-3}$]	Specific wear ratio ($x10^{-6}$) [$cm^3 \times Nm^{-1}$]	Friction coefficient
G5	40,9072	2,039055	0,33	0,67
G10	45,0022	2,162963	0,277	0,591
G15	55,31925	2,20053	0,272	0,589

Finally, less wear is observed with the samples where additive graphite material rate is 5%, 7% compared to the other sample. But its coefficient of friction is lower than G5 (3%). Therefore, more graphite (lubricant) material negatively contributes to the coefficient of friction in brake pads, but positively contributes to the wear resistance in brake pads. Table 2 shows the variation in specific wear rates with increasing graphite rate for all specimens investigated. The specific wear rate is increased with increasing graphite rate as expected.

4. CONCLUSIONS

Tribological properties of three different friction materials G5, G10, and G15 containing 3 wt.% graphite, 5 wt.% graphite and 7 wt.% respectively, were investigated using a brake dynamometer. Important results obtained from this work can be summarized as follows:

- It was observed that the addition of the graphite powder in the samples decreased coefficient of friction.
- The highest friction coefficient was obtained in the samples containing graphite in the range of 3% due to an increase in the temperature during friction.
- The addition of 5%, 7% graphite powder to the samples decreased the friction coefficient.
- The highest wear was obtained in the sample containing 3% graphite, wear resistance of the samples increased with increasing the amount of graphite.

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