Friction and Wear of Automotive Brake Lining Materials Containing Steel Wool

Banu SUGÖZÜ[1,*] Behcet DAĞHAN[2]

Abstract: *Investigations have been made to improve the braking performance with regard to manufacturing parameters and composition of brake pad materials. Automotive brake friction materials are multi-ingredient composites containing binder, fibers (reinforcements), solid lubricants, friction modifiers, abrasives and fillers. In this study the effect of steel wool used as fibers for brake lining materials on the tribological properties of brake linings is investigated. Three brake friction composites containing 5, 10 and 15 wt. % steel wool were prepared. The samples were produced by a conventional procedure for a dry formulation following dry-mixing, pre-forming and hot pressing. Friction and wear characteristics of the specimens were examined using a pin-on-disc-type wear tester. The physical properties such as hardness and density of samples were investigated. The results of tests showed that amount of steel wool on brake friction composites influenced the friction coefficient and specific wear ratio substantially.*

Keywords: Steel wool, Steel fibre, Brake lining, Friction, Wear

1 INTRODUCTION

Non-asbestos organic (NAO) friction materials are one of the important types of modern friction materials used in brakes. They are composed mainly of organic and mineral fibers. Most NAO formulations contain fewer amounts of metal fibers (steel wool) and they are called as low-metallic NAO [1].

Friction composites mainly consist of four classes of ingredients, viz. binder, fibres, fillers and friction modifiers. Fibres play a critical role in absorbing stresses generated at the braking interfaces while simultaneously retaining the integrity of the composite at elevated temperatures [2]. Metallic fibers or powders are very important constituents because of their special functions [3].

Metallic ingredients improve the specific function, such as resistance to fade, thermal conductivity, etc. Various metals such as copper, steel, iron, brass, bronze and aluminum have been used in the form of fibers or particles in the friction material and it is known that the type, morphology and hardness of the metallic ingredients can affect the friction and wear of friction materials [4].

Thermal conductivity (TC) of friction composites plays a vital role in the performance of the composites. Low TC renders the tribo-surface vulnerable for degradation of organic ingredients and affecting the braking capability adversely. Too high TC, on the other hand, results in adverse effect on brake-fluid [5].

Currently, steel fibers are often used in the friction material industry since steel fibers provide good wear resistance and maintain friction effectiveness at elevated temperature (fade resistance with fast recovery) [6]. However, steel fibers can induce excessive disk wear and large disk thickness variation (DTV), the main cause of brake vibration or judder. The aggressiveness of steel fibers against a brake rotor appears due to their high hardness and the metallic adhesion between steel and gray cast iron [7].

Bijwe and Kumar [5] studied optimization of steel wool contents in NAO friction composites for best combination of thermal conductivity and tribo-performance. They developed three friction composites using same ingredients in same proportion except steel wool and barite which were added in a complementary manner. The compositions containing 4, 8 and 12 wt.% of steel wool (and inert filler barite in 31, 27, and 23 wt.%) were developed as brake-pads and designated. They tested friction and wear behavior of the brake-pads on a Krauss type machine. They observed that with increasing metal contents, mechanical properties decreased, TC increased slowly and other important friction properties including fade resistance improved. Wear properties however, did not show any correlation with amount of steel wool, TC or mechanical properties.

Öztürk and co-workers [8] compared the effects of different kinds of fibers on the mechanical and tribological properties (in dry conditions) of a phenolic resin based friction material. They used series of fibers include rockwool, ceramic, E-glass and steel wool fibers in their study. They obtained highest friction coefficient and specific wear rate with E-glass and steel wool fiber reinforced composites, respectively.

The purpose of this study is to investigate the friction and wear properties of automotive brake lining materials containing steel wool. Hence, three different brake friction composites containing 5, 10 and 15 wt. % steel wool were prepared. All other ingredients were kept constant except steel wool. The physical properties such as density and hardness were measured. Friction-wear tests were carried out using a pin-on-disc type tribometer. All the friction materials were tested against a gray cast iron rotor disc.

2 EXPERIMENTAL

2.1 Fabrication of the composites

Three different types of brake lining specimens containing 5, 10 and 15 wt.% steel wool (Table 1) were produced by mixing, pre-forming and hot pressing. The prepared composites were designated as S5, S10 and S15.

Table 1. The composition of the brake lining specimens

Constituent	Weight percent (%)		
	S5	S10	S15
Phenolic resin	20	20	20
Steel wool	5	10	15
Cashew dust	10	10	10
Brass particles	5	5	5
Graphite	5	5	5
Copper particles	8	8	8
Alumina	8	8	8
Barite	39	34	29

All constituents were weighed were weighed with a sensitivity of 1 mg. The raw material ingredients were mixed in a mixer for 10 min until a uniform dispersion was obtained. The mix was pre-formed at room temperature under 8 MPa for 2 min and molded at 150°C under 10 MPa for 12 min.

2.2 Characterizations

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 (The surface of the specimens was carefully prepared using SiC papers from coarse (180 grid) to fine (1.200 grid), and each specimen was tested after production). 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 [9]. Therefore, it was concluded that the alloys the braking pads were homogeneous.

The densities of samples were measured by Archimedes' method.

2.3 Temperature measurement

Counter disc temperature was measured during the tests by using non-contacting infrared (IR) thermometer. The thermometer is placed at approximately 2 cm away from the trailing edge of the brake lining samples.

2.4 Friction and wear tests

The pin-on-disc type test device shown in the Figure 1 schematically was used to examine the friction and wear properties of the developed composites. As a rotor, the disc made of cast iron was used. The data of the friction coefficients and specific wear rates of friction materials were obtained.

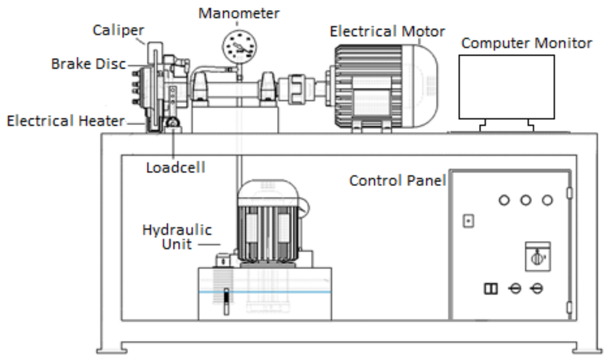

Fig. 1. Schematic of brake friction test equipment [10]

For each sample, three friction test procedures were applied and the average of these three tests was recorded. The test machine uses a pearlitic gray cast iron disc (diameter of 180 mm, thickness of 38 mm) and a brake lining test sample with 25 mm diameter. The test sample was mounted on the load arm and pressed against the flat surface of the rotating disc. The rotating cast iron disc moved with a constant sliding speed of v = 6 m/s for 10 min and the temperature was increased from 50°C to around 350°C. Before performing the friction testing, the surfaces of the test samples and the cast iron discs were ground with 320-grid sandpaper. The normal load was varied to achieve a constant friction force. The friction coefficient was calculated by measuring normal and tangential pressures every 5 s throughout the test of 10 min. From the values of the normal load applied on the pin f_n and the frictional frictional force f_s measured by the pin-on-disc type test device, the friction coefficient μ is calculated as follow:

$$\mu = \frac{f_s}{f_n} \tag{1}$$

The weight and thickness of two pads and a disc for each sample were taken before and after the friction test. To obtain average thickness, six measurements (three at the beginning and three at the end) were taken at different locations on the pads and disc before and after the friction test.

Specific wear rate was determined in accordance to a TSE 555 [11] standard by using the following equation:

$$V = \frac{1}{2.\pi.R} \cdot \frac{m_1 - m_2}{n.f_s.\rho} \tag{2}$$

where V is the specific wear rate (cm^3/Nm), R is the distance between centers of the sample and the rotating disc (m), m_1 and m_2 are the average specimen weights before and after the test (g), respectively, n is the rotating number of disk, ρ is the density of the brake lining (g/cm^3) and f_s is the average frictional force (N).

Friction stability (%) was determined by using the following equation [12]:

$$FS = (\mu_{avg}/\mu_{max}) \times 100 \tag{3}$$

3 RESULTS AND DISCUSSION

Fig. 2, Fig. 3 and Fig. 4 show the changes in the coefficient of friction related to the time.

The friction coefficient varied significantly in the initial stage of testing, as the size of the contact area increased and the friction layer was developed on the surface [13].

In brake linings, heat is generated due to friction during braking. This heat increases the interface temperature and this, in turn, decreases friction coefficient. Therefore, the decrease in the friction coefficient should be minimum for an effective braking [14-16].

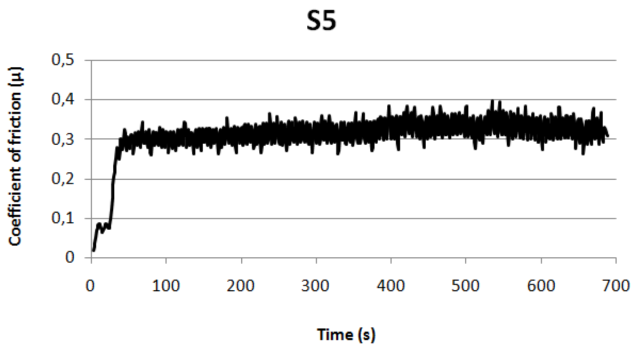

Fig. 2. The change of friction coefficient as a function of time for S5 sample

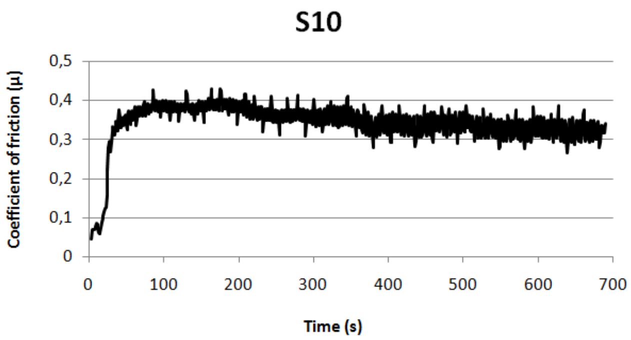

Fig. 3. The change of friction coefficient as a function of time for S10 sample

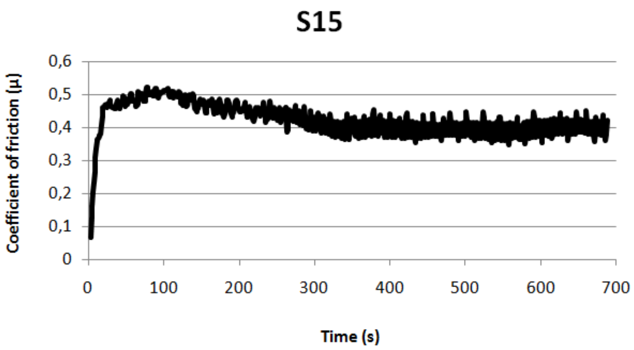

Fig. 4. The change of friction coefficient as a function of time for S15 sample

Composites without metal contents show low μ and the metallic fillers in general enhance the μ of composites [3]. When friction test results are examined, it is seen that the average coefficient of friction of the specimen containing 15 wt.% steel wool is 0.441.

The highest temperature occurred between the brake specimen and the disc were measured as 83.2 °C, 95.9 °C and 107.1 °C for S5, S10 and S15 respectively, in friction tests.

Figures 4 shows that specimen S15 exhibited the largest fluctuations in friction coefficient compared to the other specimens. Anderson [4] attributed these fluctuations to non-homogenous heat load on lining contact surface. That is because heat toward the center of the disc from the contact surfaces changes during the test period. Therefore, the friction coefficient changes continuously due to this effect. Stachowiak and Batchelor [17] explained this by sticking of the friction surfaces. The sticking surface slips after a while due to the relative movement and therefore, this, in turn, results in changes in the friction coefficient.

The sample containing 15 wt.% steel wool showed the highest values of μ while the sample containing 5 wt.% steel wool showed the lowest values of μ. The average coefficient of friction, specific wear rates and friction stabilities of samples are given in Table 2.

Table 2. Friction properties of the specimens

Sample	Average coefficient of friction (μ_{ort})	Specific wear rate (cm^3/Nm)	Friction Stability (%)
S5	0.311	1.731×10^{-6}	75.6
S10	0.343	1.549×10^{-6}	76.2
S15	0.441	1.207×10^{-6}	66.9

It is stated in the literature that the friction coefficient (μ) generally varies between 0.1 and 0.7 depending on friction force and disc-lining interface temperature [18].

As can be seen from Table 2, an increase in average coefficient of friction of the specimen with increasing steel wool amount is observed.

Temperature occurred on lining contact surface during the friction test affected friction stabilities of the samples. Magnitude of % friction stability should be as high as possible and near to 100. Slope and undulations in the curve should be minimum [12].

No wearing cannot be expected from brake linings. Even if very high wear resistant materials are used, this results in wear on the counter surface. Therefore, a variation of the friction coefficient with the temperatures is considered to be much more important than the wear resistance in the friction materials [15].

Table 3 contains physical properties such as density and hardness. The properties are correlated in general. If hardness is high, density increases and specific wear rate decreases.

Table 3. Physical properties of the specimens

Sample	Density (g/cm^3)	Brinell hardness (HB)
S5	2.113	35
S10	2.201	41
S15	2.209	43

4 CONCLUSIONS

In this study, the effect of steel wool amount on tribological properties of brake lining is experimentally analyzed and the following conclusions can be drawn:

- Steel wool amount added to the brake lining materials influenced wear and friction behaviors of brake linings.
- In the specimens, the specific wear rate decreased with increasing density and hardness.
- If steel wool amount of the samples high, average coefficient of friction tends to be high.
- Temperature occurred on lining contact surface during the friction test affected friction stabilities of the samples.
- The highest friction coefficient was obtained in the sample called S15.
- The highest wear was obtained in the sample called S5.

REFERENCES

[1] Tomášek, V., Kratošová, G., Yun, R., Fan, Y., & Lu, Y. (2009). Effects of alumina in nonmetallic brake friction materials on friction performance. *Journal of materials science*, vol. 44(1), ISSN 0022-2461 p.266-273.

[2] Bhabani, K., Satapathy, B. K., Bijwe, J., (2006). Composite friction materials based on organic fibres: Sensitivity of friction and wear to operating variables. *Composites Part A: Applied Science and Manufacturing*, vol. *37*(10), ISSN 1359-835X p.1557-1567.

[3] Kumar, M., Bijwe, J., (2010). Role of different metallic fillers in non-asbestos organic (NAO) friction composites for controlling sensitivity of coefficient of friction to load and speed. *Tribology International*, vol. *43*(5), ISSN 0301-679X p. 965-974.

[4] Anderson, A.E. (1992). Friction, lubrication and wear technology. *ASM Handbook*, Vol. 18, p. 569-577.

[5] Bijwe, J., Kumar, M., (2007). Optimization of steel wool contents in non-asbestos organic (NAO) friction composites for best combination of thermal conductivity and tribo-performance. *Wear*, vol. *263*(7), ISSN 0043-1648 p.1243-1248.

[6] Anderson, A.E., (1987). Friction materials performance issue, in: Proceedings of Fibers in Friction Materials Symposium, Friction Materials Standard Institute, p.2-57.

[7] Jang, H., Ko, K., Kim, S. J., Basch, R. H., & Fash, J. W. (2004). The effect of metal fibers on the friction performance of automotive brake friction materials.*Wear*, vol. *256*(3), ISSN 0043-1648 p.406-414.

[8] Bülent Öztürk, Fazlı Arslan, Sultan Öztürk, (2013). Effects of Different Kinds of Fibers on Mechanical and Tribological Properties of Brake Friction Materials. *Tribology Transactions.*,vol. 56:4, ISSN 1040-2004 p.536-545.

[9] İlker Sugozu, İbrahim Mutlu, Kezban Banu Sugozu, (2016). The effect of Colemanite on the friction performance of automotive brake friction materials. *Industrial Lubrication and Tribology*, vol. *68*(1) ISSN: 0036-8792 p.92-98.

[10] Sugözü, I. (2015). Investigation of using rice husk dust and ulexite in automotive brake pads. *Materials Testing*, vol. 57(10), ISSN 0025-5300 p. 877-882.

[11] TS 555 (1992) Highway Vehicles - Brake System – Brake Pads for Friction Brake, TSE, Ankara, Turkey

[12] Bijwe, J., Aranganathan, N., Sharma, S., Dureja, N., & Kumar, R. (2012). Nano-abrasives in friction materials-influence on tribological properties. *Wear*, vol. 296(1), ISSN 0043-1648 p. 693-701.

[13] Filip, P., Weiss, Z. and Rafaja, D., (2002). On friction layer formation in polymer matrix composite materials for brake applications, *Wear*, vol. 252, ISSN 0043-1648 p. 189-198.

[14] Boz, M. and Kurt, A. (2006). The influence of stibium tri sulfut content on friction-wear behaviour of bronze-based friction materials. *Technology ZKU*, vol. 9, p. 79-90.

[15] Boz, M. and Kurt, A. (2007). The effect of Al2O3 on the friction performance of automotive brake friction materials. *Tribology International*, vol. 40, ISSN 0301-679X, p. 1161-1169.

[16] Tabor, D. (1996). Friction as a dissipated process. *Friction of Organic Polymers in Fundamentals of Friction, Macrosc Microsc Process*, Vol. 220 No. 3.

[17] Stachowiak, G.W. and Batchelor, A.W. (2001). *Engineering Tribology*, Heineman, Boston, MA, pp. 36-44.

[18] Ravikiran, A. and Jahanmir, S. (2001). Effect of contact pressure and load on wear of alumina. *Wear*, Vol. 251, ISSN 0043-1648, p. 980-984.

Authors addresses

[1]Banu Sugözü, Friction and Wear of Automotive Brake Lining Materials Containing Steel Wool, Institute of Natural and Applied Sciences, Selcuk University, Konya, Turkey, banusugozu@gmail.com

[2]Behcet Dağhan, Friction and Wear of Automotive Brake Lining Materials Containing Steel Wool, Department of Mechanical Engineering, Faculty of Engineering, Selcuk University, Konya, Turkey, bdaghan@selcuk.edu.tr

Contact person

* *Banu Sugözü, Institute of Natural and Applied Sciences, Selcuk University, Konya, Turkey, banusugozu@gmail.com*