

Effect of steel fiber addition on the mechanical and tribological behavior of the composite brake pad materials

H Yanar¹, G Purcek^{1,3} and H H Ayar²

¹ Department of Mechanical Engineering, Karadeniz Technical University, 61080, Trabzon, TURKEY

² Metisafe® Cleanroom and Biosafety Systems, 06980, Ankara, TURKEY

Abstract. Effect of steel fiber addition on the friction and wear characteristics and mechanical properties of non-asbestos composites brake pad material was investigated. For this purpose, the content of steel fiber was added in the range of 0 - 20 wt.% with changing the rock fiber of the matrix structure. The matrix has also phenolic binder resin, cashew nut shell liquid, aramid pulp, magnetite, rubber and graphite. Friction behavior of the samples prepared from the mixture were tested using a pin-on-disk type test configuration according to the NF F 11-292 French standard. It was observed that coefficient of friction (CoF) of composite samples increased with increasing steel fiber content. After 5wt.% steel fiber addition, the CoF of composite did not significantly change. Although the steel fiber addition caused a significant increase in the CoF of the composite, no significant change can be observed in the specific wear rate with steel fiber addition up to 15wt.%, above which it increased significantly. On the other hand, steel fiber addition to the composite matrix deteriorated the mechanical properties, but improved the fade resistance of the sample.

1. Introduction

Kinetic energy of the vehicle is converted to the heat energy at the interface of brake pad and disc/wheel during the braking application. The characteristics of the brake pad/shoes used as friction material in trains and automotive are directly affecting the braking performance of the vehicles. Therefore, it is expected that the brake pads should have an effective friction and wear performance at all stressing conditions such as high temperature and high speed. In last decades, these commercial products have been started to be produced from the composite materials where many ingredients are combined to achieve the desired requirements for the properties of the friction materials [1]. These ingredients used are collected in four groups: fibers, solid lubricants, friction modifier and space filler [2]. In recent years, the effects of types and amounts of these ingredients on the friction and wear performance of friction materials have been extensively studied by the researchers [3-6]. However, increasing demand to produce faster and more powerful vehicles has also dramatically changed the desired performance outputs from the brake friction materials. Therefore, these friction materials used need to be continuously improved.

Fibers are generally added to the brake pad matrix to increase its mechanical strength and thermal stability. Especially after asbestos fiber was banned, many different types of fiber have been added into the brake pad structure, and their tribological and mechanical effects have been comprehensively investigated [3, 7-10]. Among them, metal fibers seem to be more attractive due to their high thermal conductivity properties. Therefore, this research has attempted to examine the effect of steel fiber addition on the friction characteristic and mechanical properties of non-asbestos brake pad composite.



2. Experimental Procedure

All composite samples consist of eight constituents; binder (phenolic resin), filler (barite), fiber (steel wool, rockwool and kevlar), lubricant (graphite) and friction modifier (cashew nut shell liquid (CNSL)) and abrasive (magnetite). Steel fiber added between 0 wt.% - 20 wt.% was replaced by an equal amount of rock fiber into the matrix structure. All ingredients were mixed for 5 min in a high-speed mixer to ensure macroscopic homogenization of the mixture. Subsequently, ~10 g of the mixture was compressed under the pressure of 50 bar into a compression mold pre-heated to 90 °C. Temperature of the mold was then increased to 150 °C, and the samples were cured in the mold under a pressure of 50 bar for 10 min. Finally, post-curing was carried out by using a small size electrical furnace at 200 °C for 20 min to achieve curing all of the resin into the matrix.

Surface hardness of the test samples was measured by using a Rockwell hardness tester according to ASTM D785-65 standard with a 19.3 mm ball-indenter under the maximum load of 60 kg. This method is described as RSX. The compressive strength and elastic modulus (E) of the samples was determined using a tension/compression test machine (Instron 3382) with cylindrical test samples having the diameter of 20 mm and the thickness of 20 mm. Three samples of each composition were tested to estimate the repeatability of the results.

A specific pin-on-disc type test system designed according to the NF F 11-292 French standard was used to perform two types of friction and wear tests (Figure 1). The sample size for friction test was 20 mm in diameter and 15 mm in thickness. The counter disc was made of AISI 52100 steel with the surface roughness (Ra) of 0.05 mm and hardness of 55-58 HRC. The disc was rotated at the speed of 2800 rpm corresponding to the sliding speed of 26 m s⁻¹ (95km. h⁻¹). The 80 kg normal load (corresponds to about 0.8 MPa) was applied to the samples by means of hydraulic cylinder for 20 s and then removed for 150 s for periodic braking test. This is called as one braking cycle and this was repeated 15 times for each brake pad sample. The second type of friction test (drag test) was performed to analyze the fade behavior of non-asbestos composite brake pad samples. The same normal load was applied to the samples until the temperature of the disc surface reached to about 400 °C. During the test, coefficient of friction (CoF) and temperature of disc surface were recorded. The weight loss was determined using a microbalance with an accuracy of 0.1mg. The specific wear rate (*Q*) of the samples was determined by using the Equation 1 given below. The worn surface of samples was also analyzed using a scanning electron microscope (SEM) in order to clarify the morphological features of the worn surfaces.

$$Q = m \text{ (g)} \cdot 10^6 \cdot [X \cdot F \text{ (N)} \cdot V \text{ (m} \cdot \text{s}^{-1}) \cdot \mu \cdot t \text{ (s)} \cdot \rho \text{ (g} \cdot \text{cm}^3)]^{-1} \quad (1)$$

Where;

Q: Specific wear rate (cm³. (MJ)⁻¹)

m: Weight Loss (g)

X: Number of braking period

F: Applied Normal Load (N)

V: Test speed (m. s⁻¹)

μ: Average coefficient of friction

t: Braking time in one period (s)

ρ: Density of sample (g.cm⁻³)

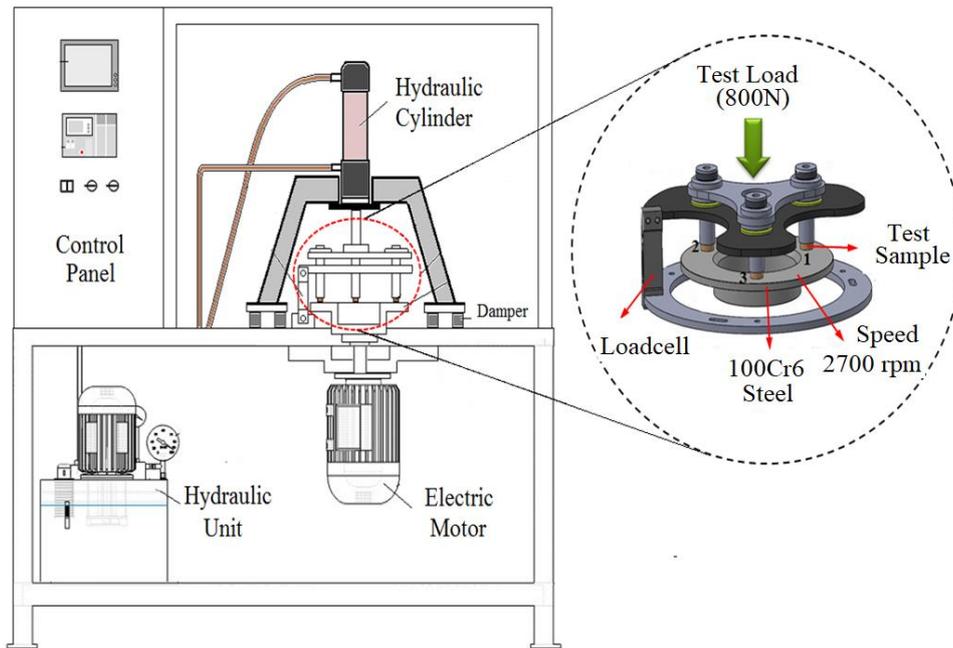


Figure 1. A schematic view of the pin-on-disc type friction and wear test rig used in the current study.

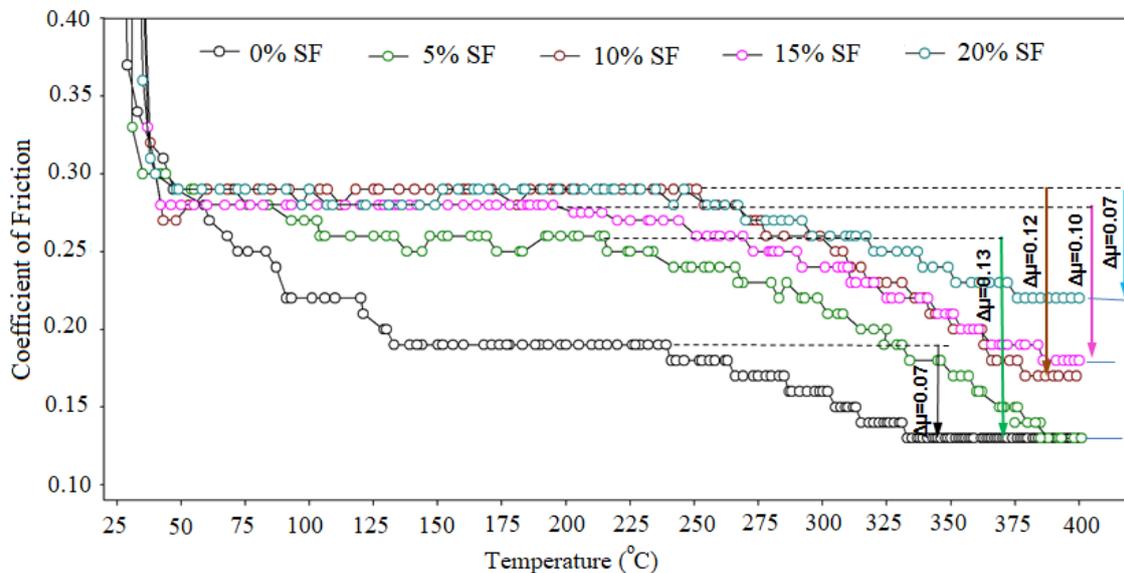
3. Results and Discussion

Table I shows the average CoF, specific wear rate, hardness, compressive strength and modulus of elasticity of all composite samples with or without steel fiber addition. Change in the amount of steel fiber affected the physical and mechanical properties of a friction material. As seen, the average CoF of composite samples increased from 0.20 (S1 base sample) to approximately 0.30 (S5 sample) with increasing the steel fiber content in the matrix structure. This is mainly because of the breakdown of the stable friction film (secondary plateaus) formed on the sliding surfaces of composite samples. Addition of 5wt.% steel fiber significantly increased the CoF of S1 sample, above which it did not cause a significant change in the CoF. The addition of steel fiber had no significant effect on the specific wear rate up to 15wt.%, above which it increased significantly. This unexpected increase is attributed to the instability of CoF. Addition steel fibre also affected the key mechanical properties of the samples. Steel fibre addition to the brake pad composite decreased generally the hardness and compressive strength of brake pad sample. However, 5% steel fibre addition into the matrix structure significantly increased the modulus of elasticity of the base sample (S1). The E values were measured to be 770 MPa and 1100 MPa for the S1 and S2 samples, respectively. This could be due to the better binding capacity of steel fibre with the resin rather than rock wool fibres. The further increasing of steel fibre content in the matrix had a reducing effect on the E of composite brake pad samples. This is expected result since an increment in the amount of steel fibre in the composite's matrix is balanced only by decreasing the amount of rock wool having lower density than the steel fibre. It contributes to the formation of a more porous and void structure [11,12].

Table 1. Friction, wear and mechanical properties of composite samples including different amount of steel fiber

	Steel Fibre Content (wt %)	Average CoF (periodic braking)	Specific Wear Rate ($\text{cm}^3 (\text{MJ})^{-1}$)	Hardness (HRX)	Elastic Modulus (MPa)	Compressive Strength (MPa)
S1	0	0.205	0.026	60±0.7	770 ± 32.7	86±2.9
S2	5	0.263	0.023	61±1.2	1100 ± 64.1	83±5.1
S3	10	0.277	0.024	59±1.3	915 ± 35.0	80±2.6
S4	15	0.273	0.026	57±2.1	713 ± 47.2	76±5.3
S5	20	0.290	0.038	56±3.3	675 ± 41.8	72±4.4

The changes in the CoF of all samples with surface temperature of the disc during continuous braking tests are shown in Fig. 1. The CoF of the base sample (S1) continuously decreased up to 120 °C and then remained constant to be 0.19 in-between 120 °C to 250 °C. After then, the CoF decreased again down to 0.14 level at about 400 °C. However, this change in the CoF with generated temperature was slightly different in the sample having steel fiber. It is important to note that the CoF of the samples having steel fiber did not drop below the 0.25 level until the disc surface reached to about 250 °C, above which the CoF started decreasing. Such a decrease in the CoF ($\Delta\mu$) at high temperature is known as the fade. The fade values were obtained as 0.13, 0.12, 0.10 and 0.07 for the S2, S3, S4 and S5 samples, respectively. These results show that the fade value decreases with increasing the steel fiber content in the matrix due to the increased thermal conductivity of the composite sample [12].

**Figure 2.** Variation of CoF with disc surface temperature during the continuous braking tests for the composite samples including different amount of steel fibre.

SEM images taken from the worn surfaces of brake pads after the fade (drag) tests are shown in Figure 3. In general, the worn surfaces of composite samples with and without steel fibre have different features. Worn surface of the S1 sample is almost fully covered with secondary plateaus (Figure 3 (b) and (c)). These secondary plateaus are formed by degradation of organic materials such as phenolic resin, CNSL and kevlar at the elevated braking temperature [11]. The secondary plateaus covering

almost the entire surface of the S1 composite (Figure 3 (c)) are responsible for the lowest CoF and the highest degree of fade achieved in this sample (Figure 2). Distribution of primary and secondary plateaus on the worn surface varied according to the steel fibre content in the matrix structure. The areas covered by the primary plateaus (indicated by yellow arrows) on the worn surface of samples increased by increasing steel fibre content in the matrix. This resulted in an increase in the CoF of composite sample. On the other hand, pores and void (indicated by red arrow) were observed around the steel fiber on the worn surface of friction materials. This leads to poor bonding of steel fibers to the structure and reduced the mechanical properties and wear resistance of composite sample.

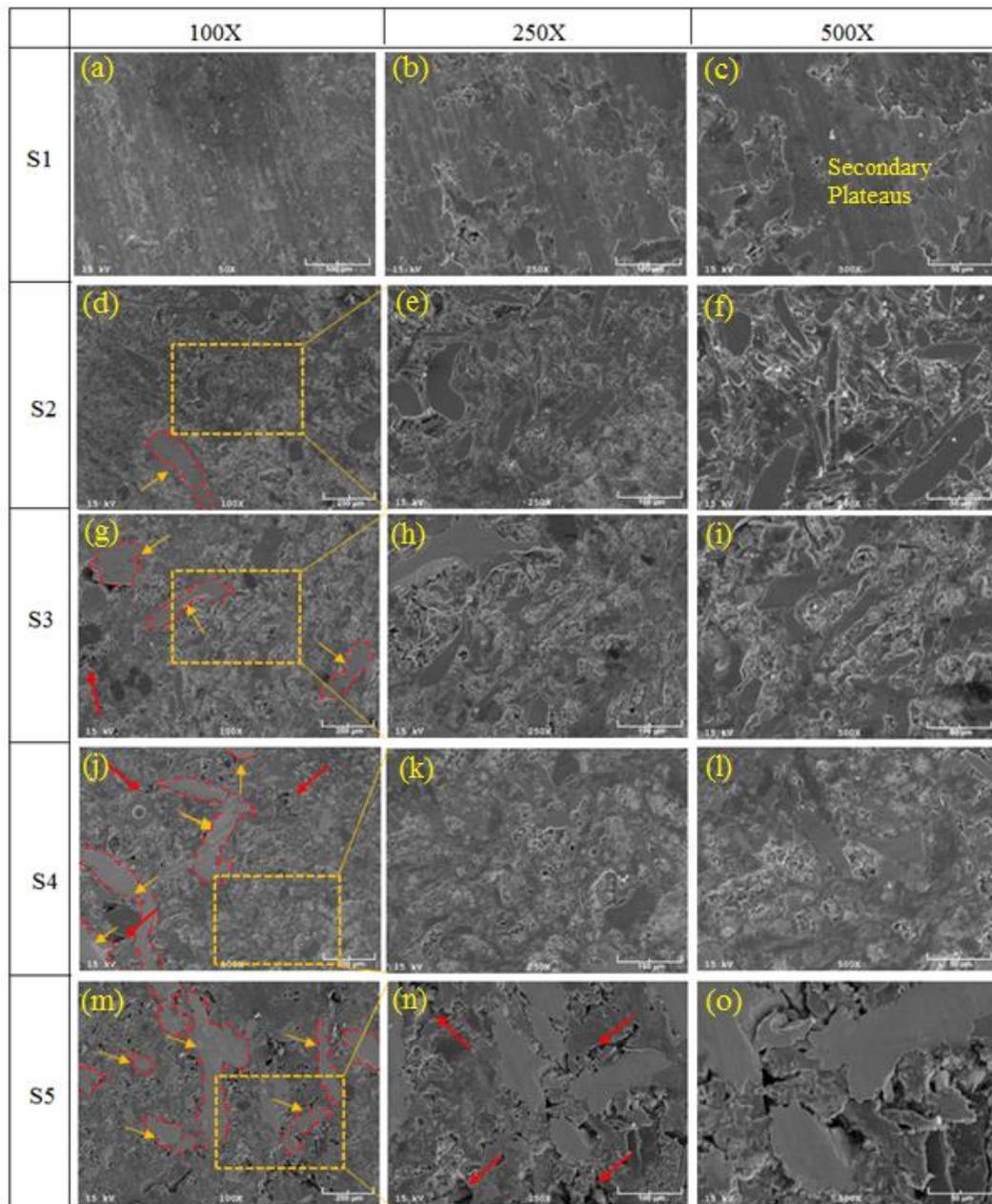


Figure 3. SEM images of worn surface of composite sample having different amount of steel fiber.

4. Conclusions

Steel fibre addition increases the CoF of non-asbestos composites including phenolic binder resin, cashew nut shell liquid, aramid pulp, magnetite, rubber and graphite. The CoF values increased from 0.20 for the sample having 0 wt.% steel fiber (S1) to about 0.30 for the sample having 20 wt.% steel fiber (S5). However, steel fiber addition does not considerably effect of the specific wear rate of the composite sample. Steel fiber addition to the brake pad composite decreases generally the hardness, modules of elasticity and compressive strength of sample. The fade resistance of the sample increases by increasing steel fiber content in the brake pad matrix structure.

5. References

- [1] Cho M H, Kim S J, Kim D and Jang H 2005 *Wear* 258 1682-87.
- [2] Lu Y 2006 *Compos. Sci. Technol.* 23 591-98.
- [3] Jang H, Ko S, Kim S J, Bash R H and Fash J W 2004 *Wear* 256 406-14.
- [4] Hong U S, Jung S L, Cho K H, Cho M H, Kim S J and Jang H 2009 *Wear* 266 739-44.
- [5] Dureja N, Bijve J and Gurunath P V 2009 *J. Reinf. Plast. Comp.* 28 489-97.
- [6] Cho M H, Ju J, Kim S J and Jang H 2006 *Wear* 260 855-60.
- [7] Singh T, Patnaik A, Chauhan R and Rishiraj A 2015 *JKSUS* 29 183-90.
- [8] Ho S C, Chern Lin J H and Ju C P 2005 *Wear* 258 861-69.
- [9] Aranganathan N, Mahale V and Bijwe J 2016 *Wear* 354-355 69-77.
- [10] Öztürk B, Arslan F and Öztürk B 2013 *Tribol T.* 56 536-45.
- [11] Bijwe J and Kumar M 2007 *Wear* 263 1243-48.
- [12] Kumar M and Bijwe J 2013 *Wear* 303 569-83.