Scientific Research and Essays Vol. 6(23), pp. 4893-4904, 16 October, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE10.1072
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

Investigation of using natural zeolite in brake pad

Ahmet Keskin

Abant İzzet Baysal University, Vocational School, Bolu, Turkey. E-mail: keskin_a@ibu.edu.tr, ahmkeskin@gmail.com.
Tel: +90 374 2701452. Fax: +90 374 2701459.

Accepted 19 September, 2011

Brake pads in automobiles are made of composite materials composed of more than ten different ingredients. The choice of the friction material has an important impact on a vehicle's braking performance. Drivers expect the brake system to stop the automobile under all possible conditions. In the present study, natural zeolite was used as a new material in brake pad. Zeolite has a silica ingredient which gives the pad materials a ceramic like behavior. Zeolite is ground to obtain the dust. Different amount of zeolite is used in the mix of other regular ingredients in brake pad. Newly formulated brake pad material with seven different ingredients has been tested under Friction Assessment and Screening Test (FAST). In this experimental study, the change of friction coefficient, the temperature of friction surface and the amount of wear were measured. In addition, micro-structural characterizations of braking pads were carried out using scanning electron microscopy (SEM).

Key word: Brake pad, composite materials, friction coefficient, zeolite, tribology.

INTRODUCTION

The materials used in the automotive brakes are known as friction materials. Friction materials used in automotive sector are approximately formulated a century ago. A characteristic friction material is a multi component polymer matrix composite whose formulation is generally developed by experimental studies. The friction coefficient should be moderately high, but most significantly must be durable during the braking process. It should have a stable level, independence of temperature, humidity, age, degree of wear and corrosion, existence of dirt and water spray from the road, etc (Filip et al., 2002). Frictional braking systems must be designed in such a way that a constant coefficient of friction is maintained over a wide range of stressing conditions (Severin and Musiol, 1995). Wear of the brake pad is inevitable, but should be minimized as far as possible. For automotive and many other industrial applications, polymer matrix composites (PMC) are used as pads and cast iron or steel discs as counterparts. The performance of the brake is mainly controlled by the composition and microstructure of the pad material. Industrial pads usually contain a large number of different constituents like ceramic particles and fibers, minerals, metallic chips, solid lubricants and elastomers in a matrix material such as phenolic resin. A description of more than 100 formulations of patented friction materials was presented by Newman (1978). Up to now, the development of new friction materials has been done empirically, starting from well-known base compositions which have been successively optimized by adding friction modifiers (Österle et al., 2001). One of the key requirements in developing composites and other advanced materials for the brake pads is the generation of a good understanding of the relationships between composition and structure. Another key requirement is the application of this understanding to develop a material with the desired properties. A third key requirement is to understand the new material's failure mechanisms (Pasto et al., 1999).

Previous studies carried out by earlier researchers have found that there are four failure modes operative during braking: i) chemical changes (Jacko, 1977), ii) thermal instability (Barber, 1969), iii) wear mechanism (Libsch and Rhee, 1977) and iv) micro cracks (Ho, 1977;

Table 1. Composition of used zeolite.

Weigth	SiO_2	Al_2O_3	Na_2O	MgO	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Others	Total
Percentage (%)	75.84	11.32	0.18	0.71	0.01	3.76	2.12	0.08	0.01	0.93	4.96	100

Table 2. The ingredients of samples (wt%).

Specimens code	Z5	Z10	Z15	Z20	Z25	Z30	Z35
Zeolite	5	10	15	20	25	30	35
Cashew	5	5	5	10	15	20	25
Phenolic resin	20	20	20	20	20	20	20
Al_2O_3	5	5	5	5	5	5	5
Graphite	5	5	5	5	5	5	5
Brass particles	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Cu (size 225-300 µm)	15	15	15	15	15	15	15
Barite	42.5	37.5	32.5	27.5	22.5	17.5	12.5
Total	100	100	100	100	100	100	100

Talib et al., 2001). These phenomena result in the changes of physical properties and microstructure of friction materials with increased braking times and applied loads. The micro structural changes phenomena can be clarified by studying the surface morphology of the wear surface and subsurface (Talib et al., 2003). In the literature, there are a lot of studies about using new material for the brake pads in order to increase braking performance (El-Tayeb and Liew, 2009; Zhang et al., 2010; Dadkar et al., 2009; Mutlu, 2009a; Sugozu and Mutlu, 2009). In this study, investigation of performance of zeolite as a novel material in the brake pads is presented. Zeolite was ground in order to obtain dust. This dust was sifted. Seven kinds of specimens were manufactured with different compositions. The specimens were tested at 7 m/s speed and 0.551 MPa pressure for 30 min in order to obtain the friction coefficient, wear resistance and failure behavior.

MATERIALS AND METHODS

In this study, a new automotive brake friction material was developed by using zeolite as filler materials; and their performance on brake friction characteristics was especially examined. Friction materials investigated were a non-asbestos organic (NAO) type material containing seven different ingredients including zeolite. Zeolites are crystalline, hydrated aluminosilicates of groups and II element as formed naturally or synthesized. Zeolites are formed of AlO_4 and SiO_4 tetrahedra, bonded together via the oxygen atoms and assembled in such a way as to constitute cavities, cages and channels, uniformly penetrating the entire lattice volume (Das et al., 1997). Zeolite was supplied by TEKNOMIN Inc., a mining company in Gördes-Manisa, Turkey. The composition of the zeolite studied in this work is shown in Table 1. The study was carried out for seven different mixtures of the brake pads. The ingredients in the friction material comprise binder resin, friction modifiers and space filler. Friction material specimens were produced by a conventional procedure for a dry formulation following dry-mixing, pre-forming and hot pressing (Mutlu, 2002; Mutlu et al., 2005). The composition of procedure for a dry formulation following dry-mixing, pre-forming the friction materials studied is shown in Table 2. These ingredients were then mixed for 10 min using a commercial blender. The final mixture was loaded into an inch square (small samples) mold for pre-forming under pressing at a pressure of 9.8 MPa. Pre-formed samples were put in hot pressing mold and under pressing at a pressure of 14.7 MPa and 180°C for 15 min. During the hot pressing process, pressure was released several times to release the gases that evolved from the cross linking reaction (polycondensation) of the phenolic resin. Using the friction assessment and screening test (FAST) machine, friction tests were performed for each material.

The friction coefficient characteristics of the pad onto the disc made of pearlitic gray cast iron were investigated with changing the pads. The FAST machine uses a pearlitic gray cast iron disc (diameter of 180 mm) and a brake pad test sample with dimensions of 12.7 × 12.7 × 5.00 mm. Before performing the FAST testing, the surfaces of the test samples and the cast iron discs were ground with 320-grid sandpaper. It is expressed as a mean value of entire braking dependence during the FAST test. The weight of each sample was taken before and after the friction test. Wear rate was calculated as weight loss for per mm^2 of the sample during the tests. Braking tests were carried out under 0.551 MPa pressure, 7 m/s velocity and at temperatures from 50 to 400°C for 1800 s. The temperature and friction coefficient values were saved in a databank. For comparison purposes, the FAST testing was also repeated with samples obtained. For each sample, three friction test procedures were applied and the average of these three tests was recorded. Friction coefficient-temperature-time graphs are obtained to identify the effect of these variables. Friction coefficient of surface material couple needs to be high and stable. Figure 1 shows the disc test equipment used in this study.

RESULTS AND DISCUSSION

Friction performance

The coefficient of friction (µ) varied significantly in the initial stage of testing, since the size of the contact area

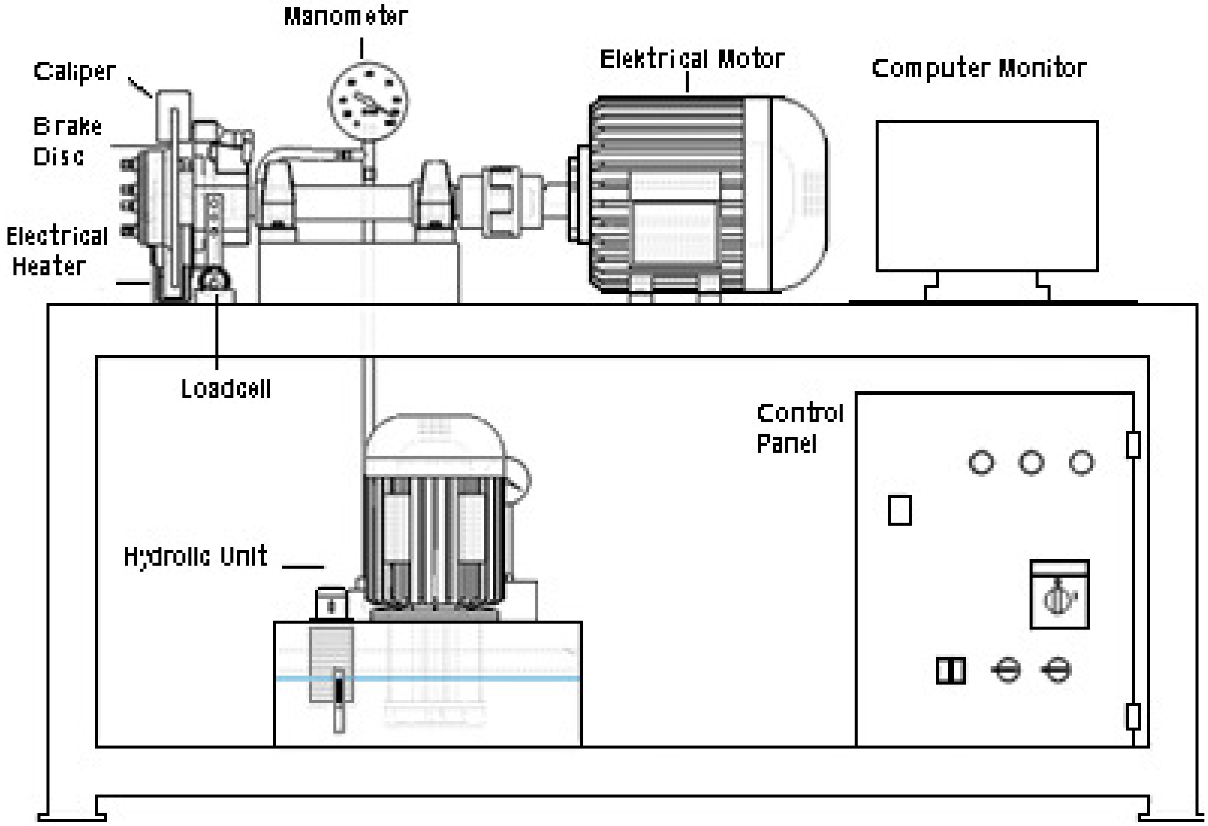

Figure 1. Disc test equipment.

increased and the friction layer was developed on the surface (Filip et al., 2002; Mutlu, 2009b). The variations of temperature and friction coefficient with test time are given in Figures 2 to 8. As seen from the figures, the friction coefficient shows a little corrugated feature. The friction coefficient for the Z5 and Z15 coded samples increased at the beginning until 100th s and a decrease is observed from 100 to 500th s. Friction coefficient of the Z5 and Z15 samples keeps about a stable friction coefficient from 500 to 1500th s (Figures 2 and 4). In this stage, temperature of friction surface increased up to 250 to 300℃. Such increase can often be attributed to the adhesion of metal chips in the brake pad to the friction surface of the cast iron disc. The observed amount of change in friction coefficient is usually a sign of unstable and aggressive friction. The friction coefficient for Z20 and Z30 coded samples shows a slowly decrease to 400th s (Figures 5 and 7). On the other hand, the friction coefficients for the other three samples (Z10, Z25 and Z35) show a rapidly decrease to 400th s (Figures 3, 6 and 8). In Z10, Z25 and Z35 samples, after μ is first decreased, it maintained at a constant value with slight fluctuations throughout the test. This can be explained as follows: because of heating due to friction, the microstructural changes in the brake pad were finished and thus a constant μ is able to be maintained.

Generally, the friction coefficients of all samples show a small increase after 1500th s. In this period, temperature of friction surface is about 300℃. The increase in μ occurs during the time when metallic materials are trying to brake on disc surface. However, due to friction wear and detachments occur. As a consequence, μ starts to decrease. Later, this behavior repeats with the newly formed friction surface. On the other hand, the decrease in Z10, Z25 and Z35 samples keeps going on with fluctuations as opposed to stability observed in Z20 and Z30 samples. It was found that the friction coefficient decreases with increasing test temperatures (Figures 3, 4 and 6). Generally, friction coefficient decreased between 250 and 325℃ due to the softening of phenolic resin except Z35 coded samples. As a result, fading occurs during the brake action. Furthermore, with the increasing temperatures, the ingredients in the braking pad are affected from each other due to faster diffusion. This phenomenon is called thermal fade (Chugh et al., 2004; Mutlu, 2009c). These results are consistent with the behavior of friction coefficient of all samples except Z30 and Z35. Therefore, if a μ value between 0.30 to 0.35 is desired, Zeolite as filler materials can be used in brake pads with 5 to 25% weights as additive. For higher μ as

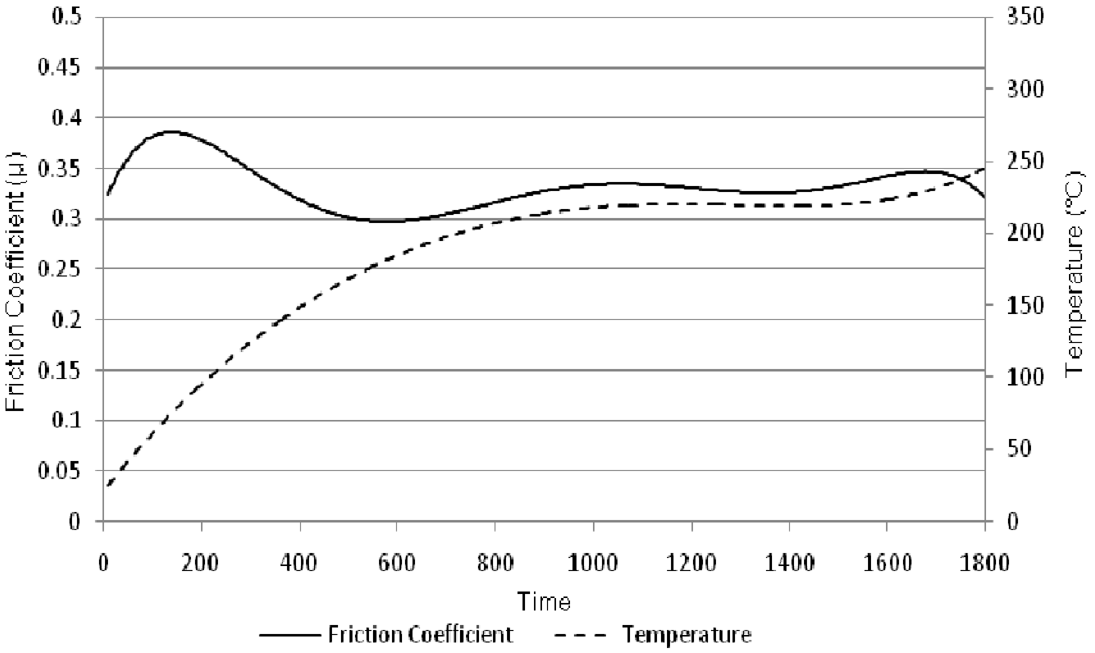

Figure 2. The variation of friction coefficient – temperature vs time of samples Z5.

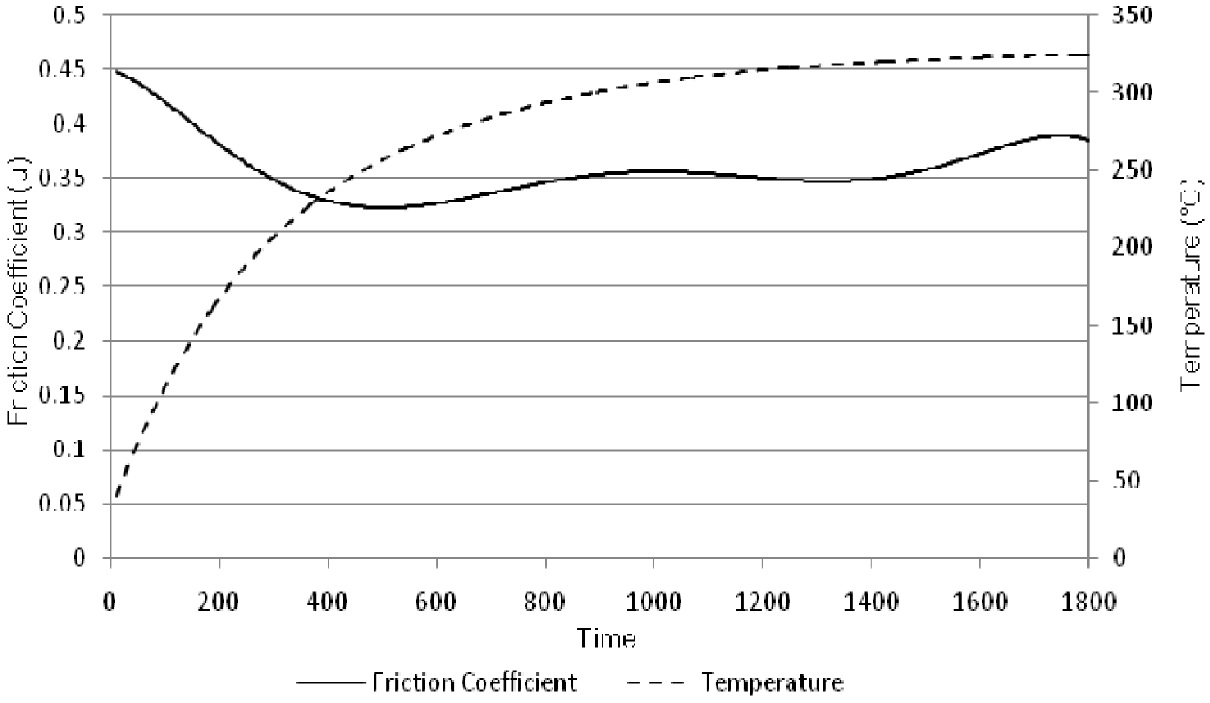

Figure 3. The variation of friction coefficient – temperature vs time of samples Z10.

values, Z10 samples can be recommended. Furthermore, if stability is desired in μ, Z5 coded sample is suggested as better material for brake pads when compared to others. Some middle vibrations and noise were observed during testing in the FAST.

Characteristics of friction surfaces

Apparently, the friction layers formed by the wear particles generated during friction. The chemistry and structure of a friction layer depend on bulk materials

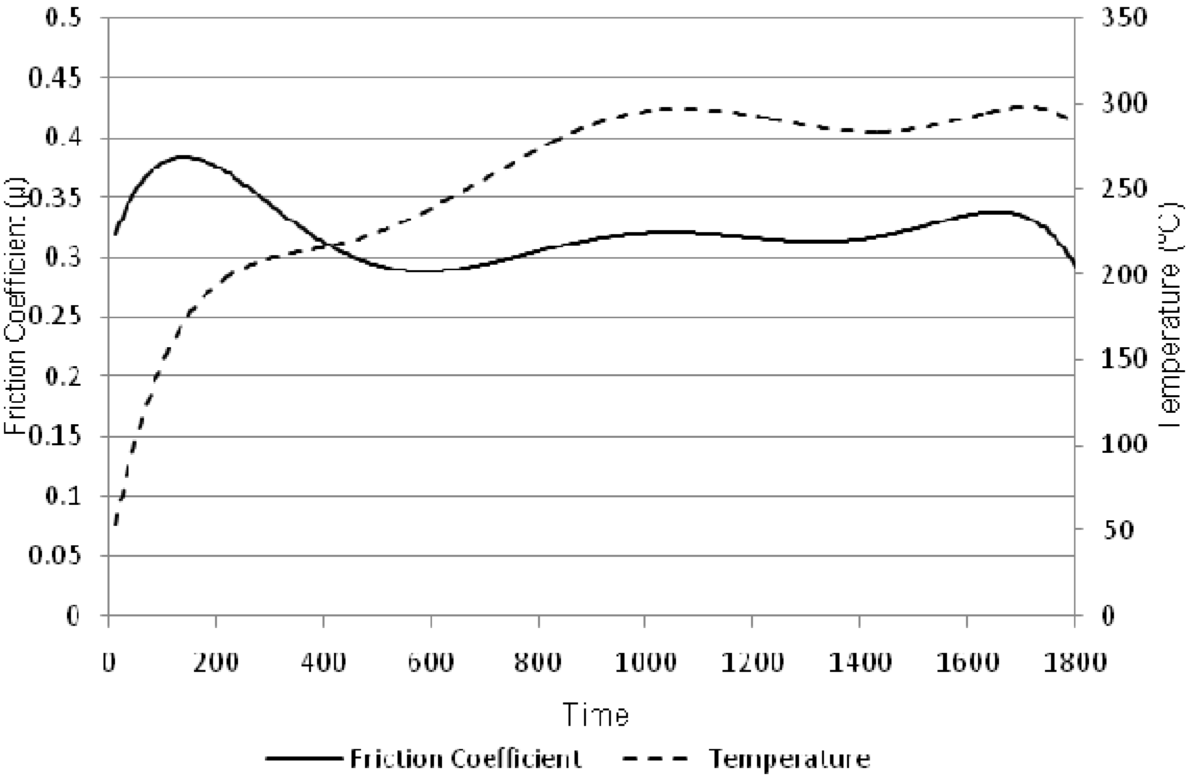

Figure 4. The variation of friction coefficient – temperature vs time of samples Z15.

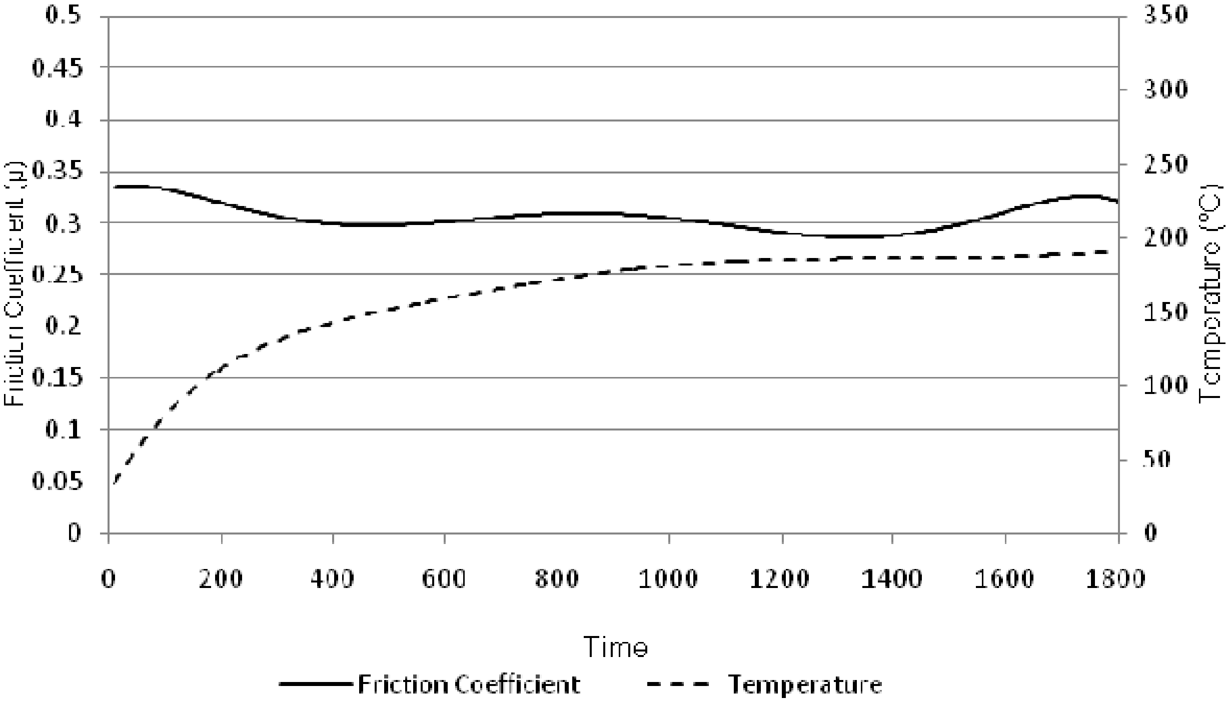

Figure 5. The variation of friction coefficient – temperature vs time of samples Z20.

(lining and disc), testing conditions and environment. The role of the friction layer may vary depending on its

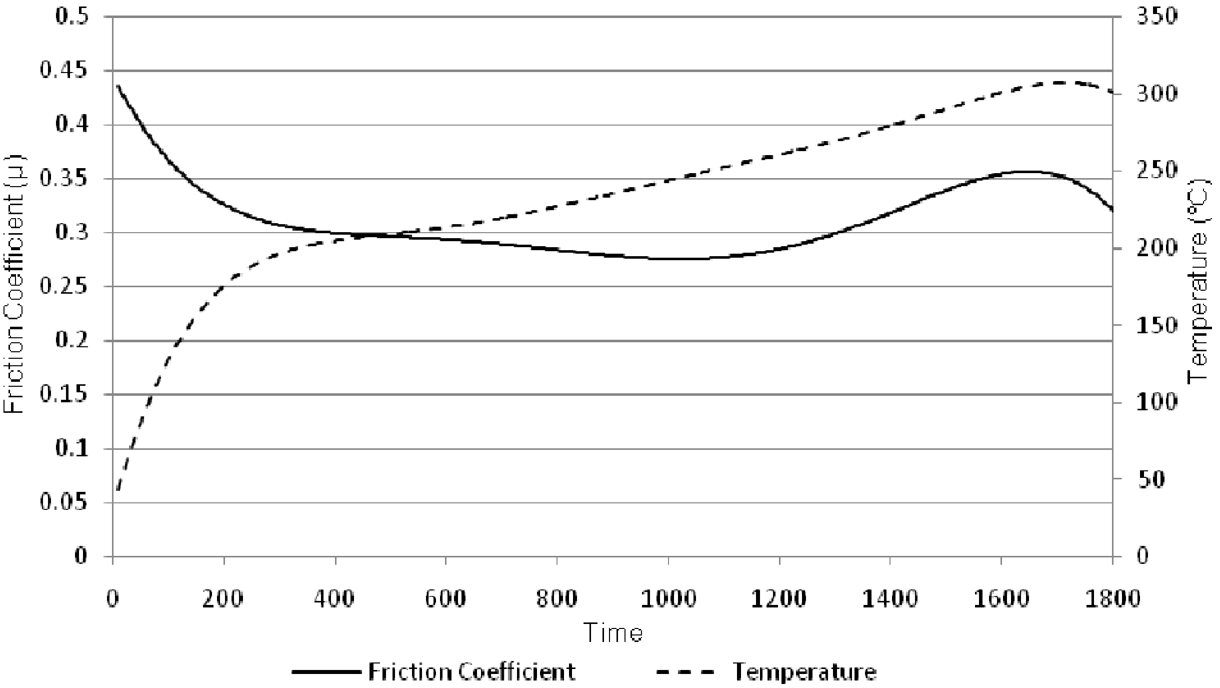

Figure 6. The variation of friction coefficient – temperature vs time of samples Z25.

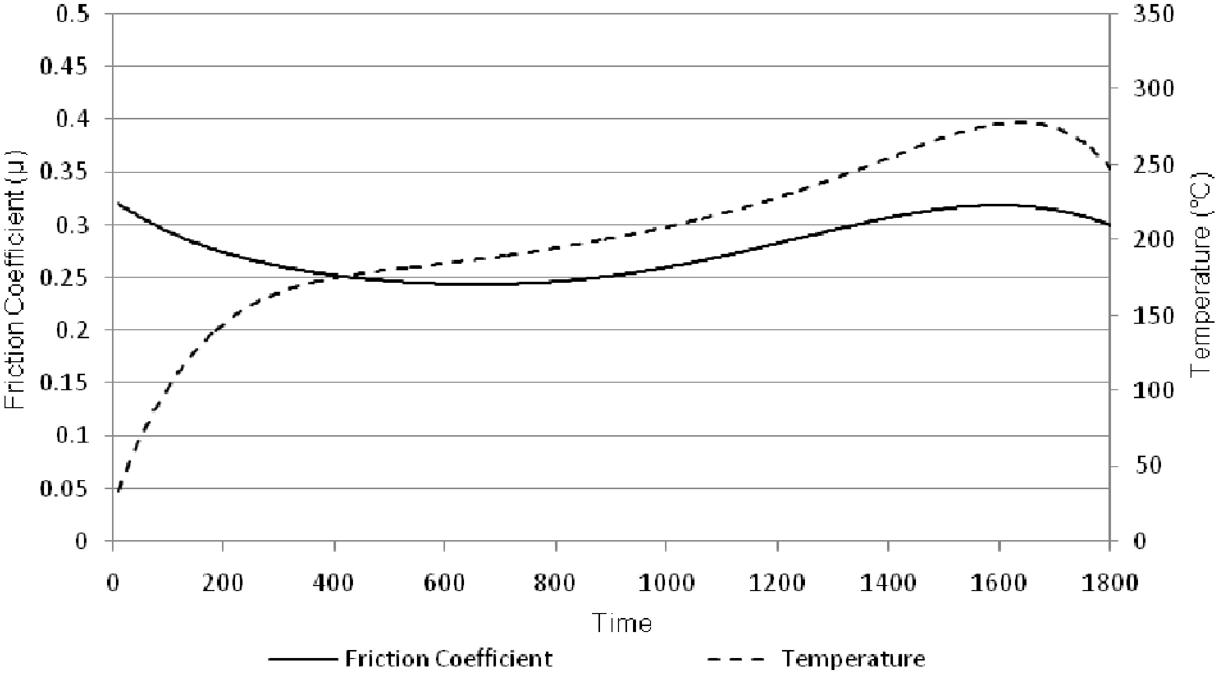

Figure 7. The variation of friction coefficient – temperature vs time of samples Z30.

characteristics (Eriksson et al., 1999; Hee and Filip, 2005). The SEM micrographs of the braking pad surfaces after the braking test are illustrated in Figures 9 to 15. The friction surfaces of the samples were characterized using scanning electron microscopy (SEM, LEO 1430 VP). The sample surfaces for the SEM observations were always coated with carbon. There are micro-voids on the surface of almost all samples. Micro-voids consist of falling of the metallic particles during the friction. It is seen from Figures 9 and 11 that larger micro-voids

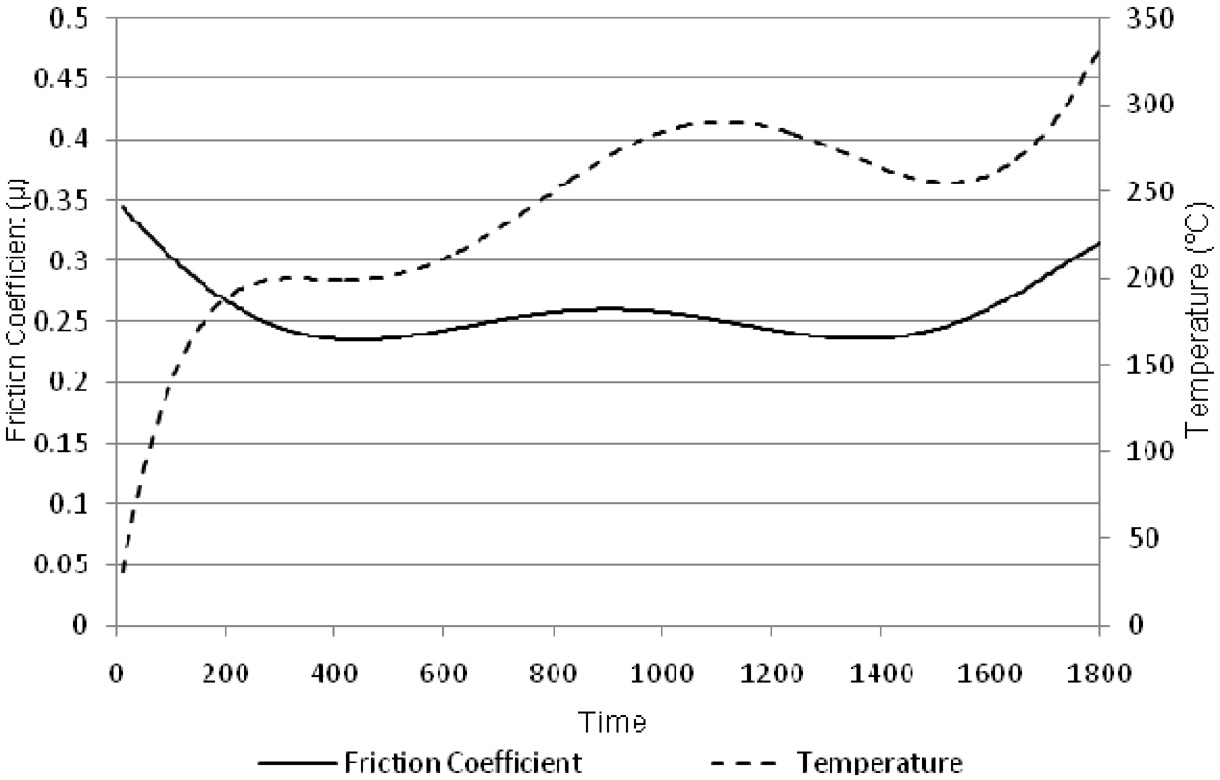

Figure 8. The variation of friction coefficient – temperature vs time of samples Z35.

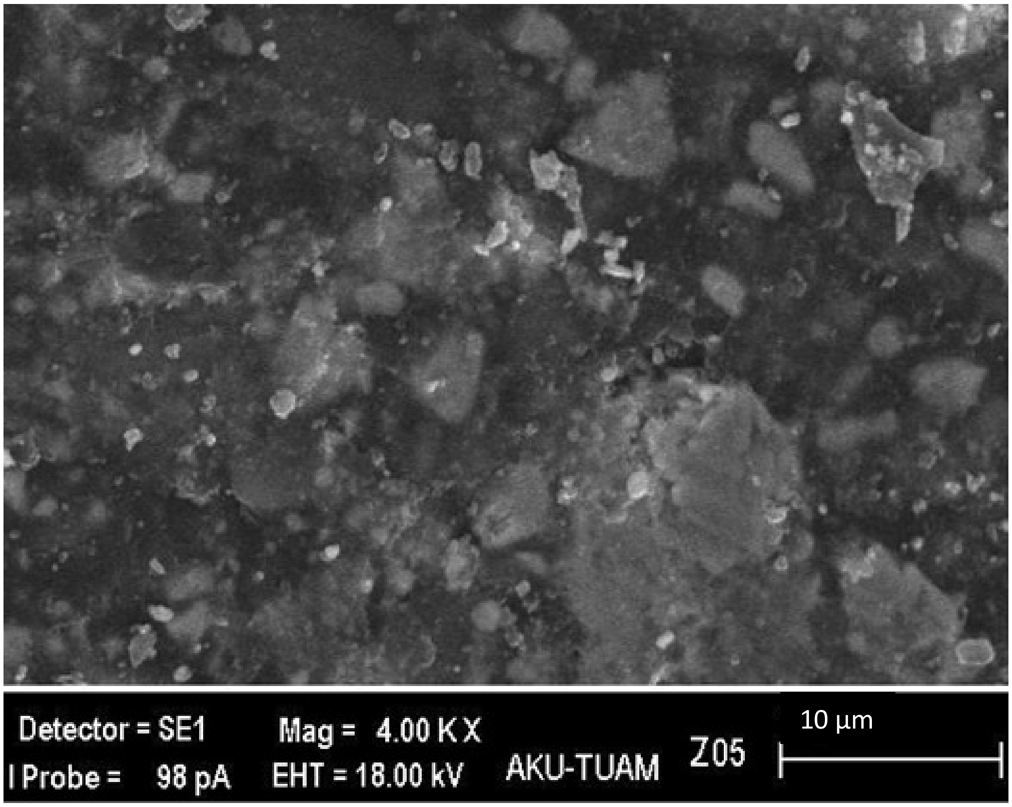

Figure 9. SEM micrographs of brake pad specimens (Z5 coded).

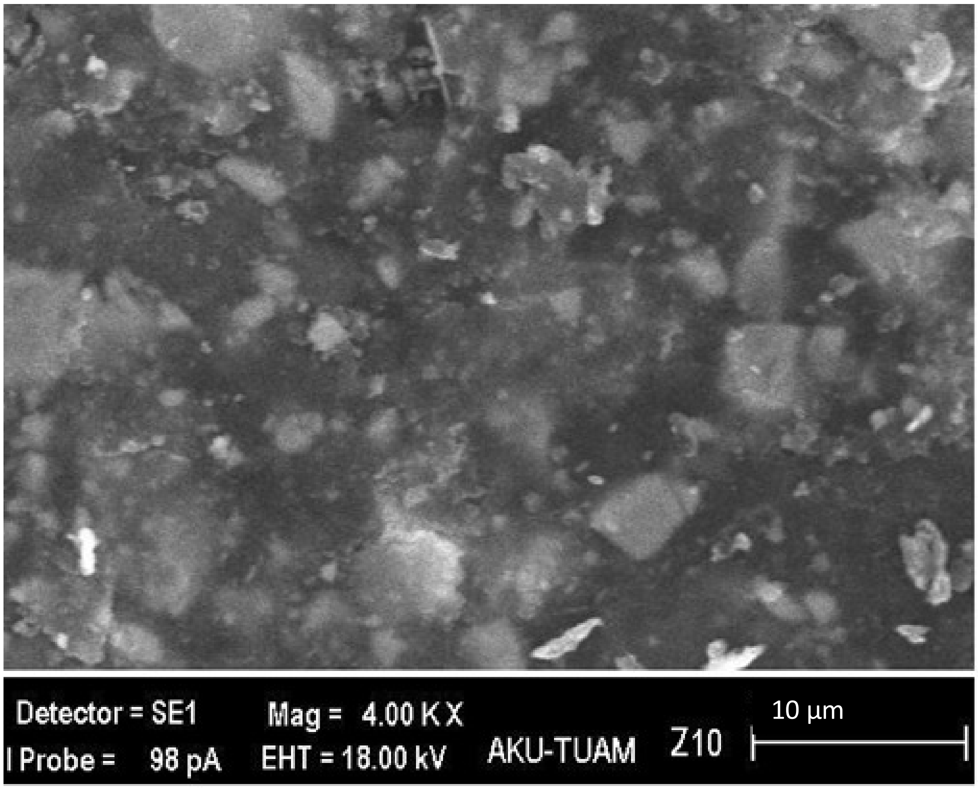

Figure 10. SEM micrographs of brake pad specimens (Z10 coded).

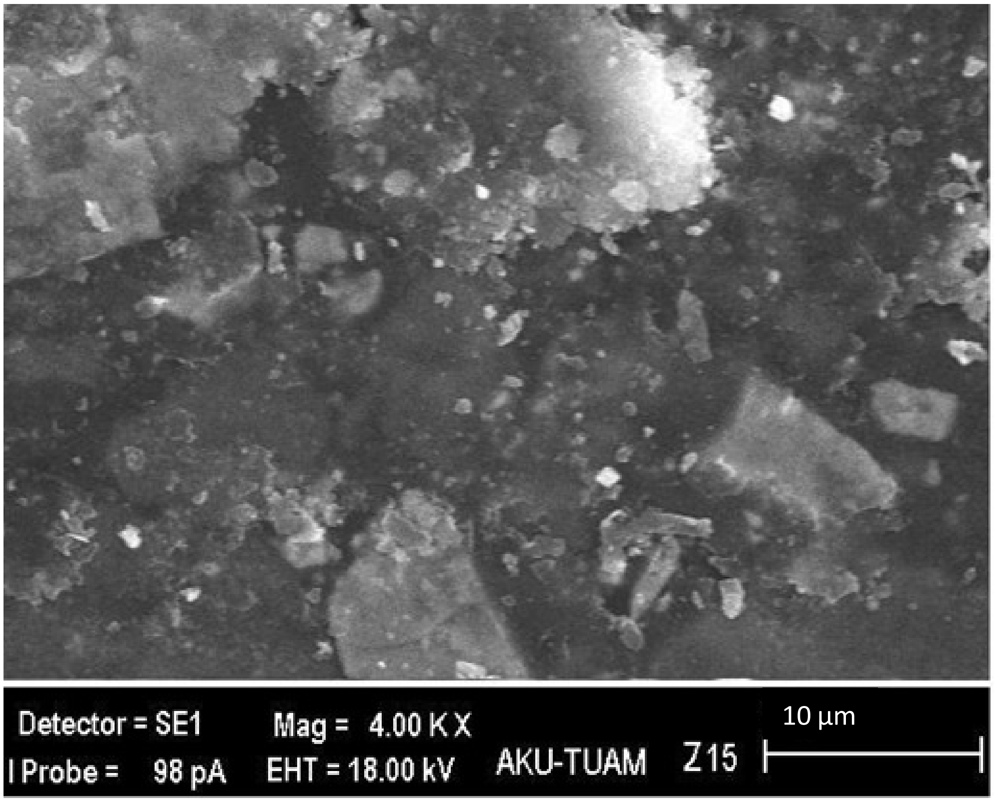

Figure 11. SEM micrographs of brake pad specimens (Z15 coded).

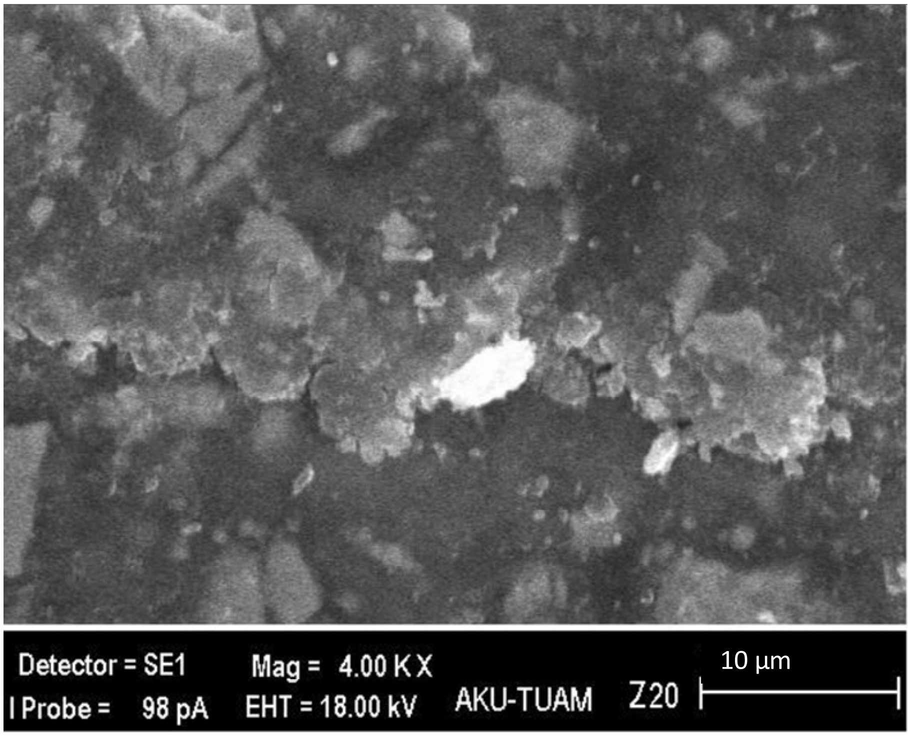

Figure 12. SEM micrographs of brake pad specimens (Z20 coded).

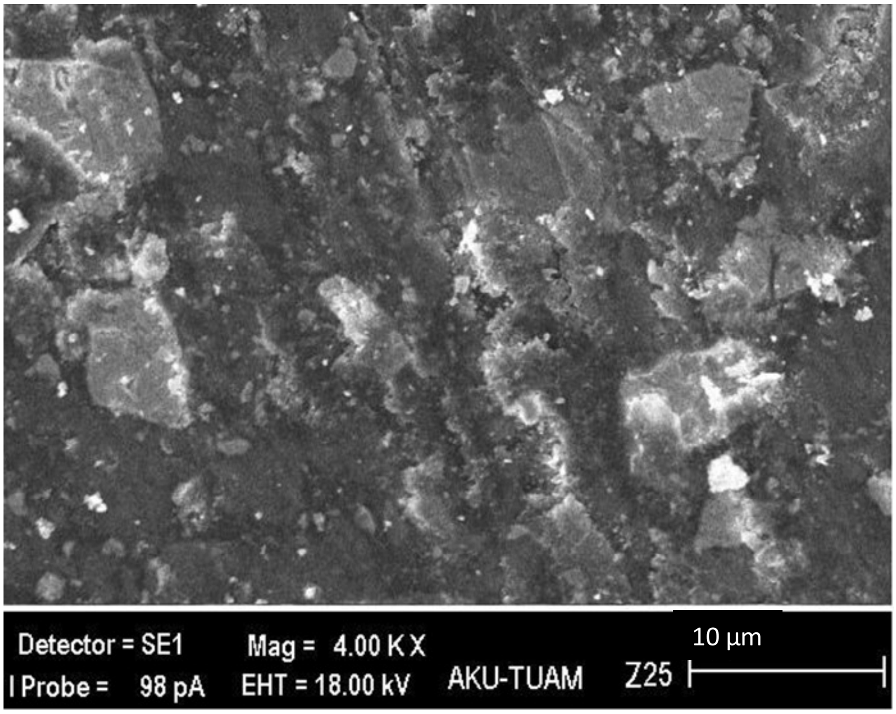

Figure 13. SEM micrographs of brake pad specimens (Z25 coded).

occurred in the samples due to detaching metallic particles. As seen, some particles are detached from the body causing micro-voids. The micro-voids on the surface of the samples can be classified as smaller and

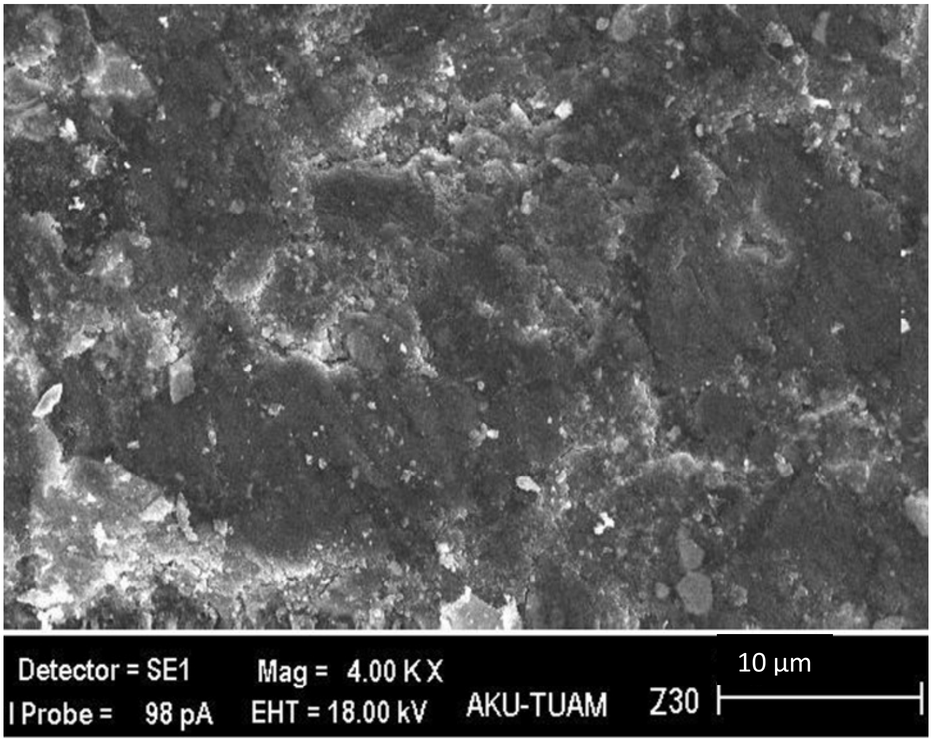

Figure 14. SEM micrographs of brake pad specimens (Z30 coded).

bigger size. The bigger sized micro-voids are due to pitting of the metallic particles during the friction. The worn metallic particles imply that they actively participated in friction during braking test. It is known that if the metal-component coherent surface is bigger; friction and wear will be increased. In addition to micro-voids, there are some micro cracks on the surface. Therefore they remained as effective in friction surface. It is known that if the metal-component coherent surface is bigger, friction and wear will be increased. It is also observed that Al_2O_3 particles are distributed in homogeneous and therefore they stayed as affective in friction surface. In the current work, several characteristic features can be observed on the friction surface of linings. It is seen as white points from Figures 9 and 15 (Mutlu et al., 2007). Also the dark areas can be seen in Figures 9 and 11. Less intimate contact on the trailing edge facilitates the access of air and uneven wear related to a higher oxidation (burn-off) of phenolic resin. This is due to distribution of the friction force over the lining surface (Hee and Filip, 2005).

When the pads heated up during braking, the resin tended to expand and at very high temperatures; and the resin turns into glassy carbon. Carbonized resins weaken the matrix and accelerate pad wear (Figures 9, 10 and 13) (Fischer, 1996; Hee and Filip, 2005). The glassy phase lost support and was torn off from the surface by shear force (Straffelini, 2000). Figures 13 and 14 (SEM) show a thick friction layer developed on the surface of pads. In this particular case, the friction layer covering the friction surface diminishes the abrasive effect of the glassy phase by eliminating the sharp edge of the glass and smoothing the friction surface. Hard glassy particles typically act as an abrasive element, and scratch off the cast iron disc counter face and the material adhering to it (Hee and Filip, 2005). Apparently, the carbonaceous matrix was formed of graphite, coke and degraded phenolic resin. The ingredient having the plastic deformation capability has taken a flake like feature after the friction experiment (Figures 12 and 14). All matters were homogeneously distributed in the matrix and therefore, very few micro voids were observed in the structure (Figures 12, 14 and 15). The friction process is characterized by the development of friction debris. Such debris adheres to the friction surface and forms a friction layer easily visible from an inspection of the sample surface after testing in the FAST (Figures 9 and 11). Systematic analysis of the surface of composite materials indicated that the friction process dominantly occurred on the friction layer, which eventually covered the top of the bulk. The presence of a well-developed friction layer on the friction surface as well as its morphology is easily visible. A detailed view of the friction surface including the information about the friction layer is shown in Figures 9 to 15.

Diffusion is occurred in the Cu particles located in the friction layer. Brighter areas marked as Cu in Figures 11, 13, 14 and 15 represent the regions where the Cu is

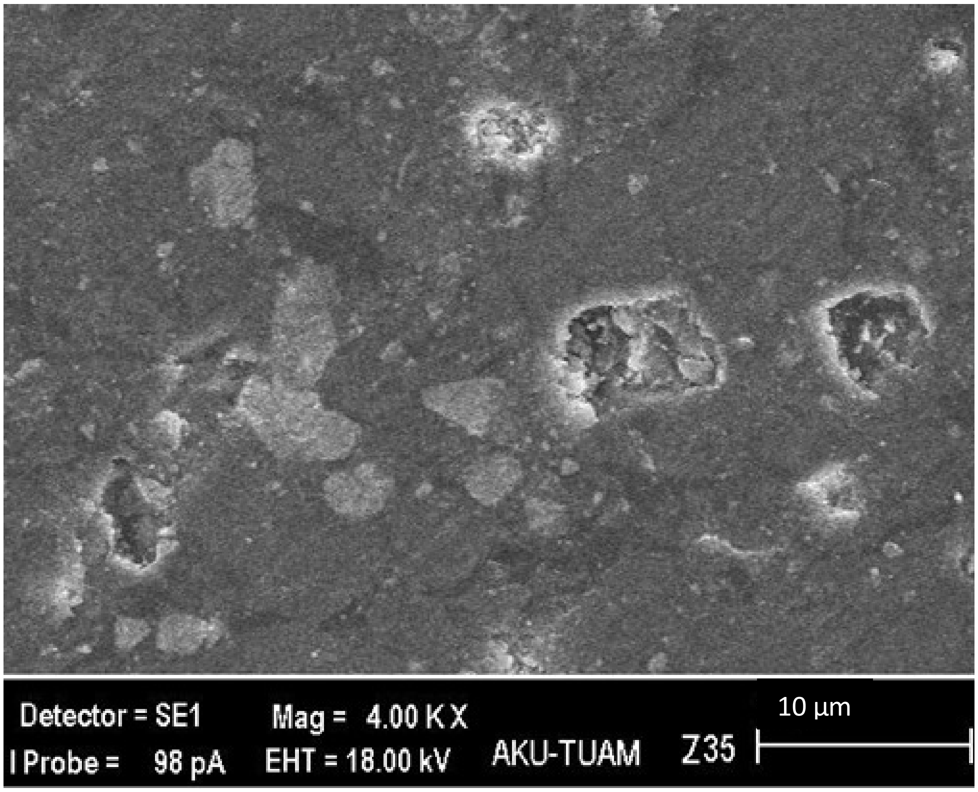

Figure 15. SEM micrographs of brake pad specimens (Z35 coded).

Table 3. Typical characteristics of the brake pad with rice straw used in this study.

Sample code	Mean of friction coefficients	Standard deviation	Density (g/cm^3)	Specific wear rate (g/mm^2)
Z5	0.332	0.028	1.568	2.26×10^{-06}
Z10	0.358	0.038	1.746	1.66×10^{-06}
Z15	0.322	0.032	1.424	2.94×10^{-06}
Z20	0.306	0.039	1.550	2.45×10^{-06}
Z25	0.311	0.068	1.135	2.92×10^{-06}
Z30	0.277	0.044	1.339	1.89×10^{-06}
Z35	0.258	0.039	1.147	1.41×10^{-06}

interacted in the friction layer (Mutlu et al., 2009). Table 3 gives the friction coefficient, standard deviation of friction coefficient, density and specific wear rate of the tested samples. As can be seen from Table 3, the friction coefficients are in appropriate category according to TS 555 (1992) and BS AU142 (1962). Also the standard deviation is very small, which means that the material has a stable friction characteristic. The highest friction coefficient is obtained for the sample having Z10 content. The lowest friction coefficient is obtained for the sample having Z35 content. Finally, less wear is observed with the samples where additive zeolite material rate is 10 and 35% compared to zeolite rates (Table 3). But Z35 coded specimen's mean coefficient of friction is lower than Z10. For the sample Z10, having the highest friction coefficient, the specific wear rate is considerably lower.

Conclusion

In the present study, the effect of zeolite content on the friction and wear behavior of brake pad used in automotive industry is experimentally analyzed. As a result of experiments, structure and chemical composition of the friction layer generated on the friction surface significantly differed from the bulk. It is apparent that no simple relationship exists between composition of the friction layer and bulk material formulation. The sample with 5% zeolite rate have more stable friction coefficient than other samples during the FAST testing. The highest friction coefficient is obtained for 10% zeolite containing sample. The lower value is obtained for 30 and 35% zeolite. While the sample with 10% zeolite rate provided higher friction coefficients, its wear ratio and standard deviations were considerably lower. The standard deviation value for the brake material is also important as it indicates the stability of the braking during brake action. In the study, the standard deviation is in the acceptable range for all specimens. Some micro voids and micro cracks are observed on the worn surface. As a result, addition of 10% (wt) zeolite is recommended for constant frictional coefficient of brake pads, lower wear rate and higher coefficient of friction. It can be concluded that zeolite is compatible with other constituents in brake pad formulation. So it can be used efficiently in brake pad formulation.

REFERENCES

Barber JR (1969). Proc. Roy. Soc. A, 312: 381-394.

British Standards Specification: BS AU 142 - (1968).

Chugh YP, Filip P, Mohanty S, Hee K-W (2004). A collaborative program for development of frictional materials using ındustrial wastes, Int. Conf. on Eng. Edu. and Res. "Progress Through Partnership", VSB-TUO, Ostrava, pp. 609-621.

Dadkar N, Tomar BS, Satapathy BK (2009). Evaluation of flyash-filled and aramid fibre reinforced hybrid polymer matrix composites (PMC) for friction braking applications. Mater. Design, 30: 4369–4376.

Das RK, Bhattacharya S, Ghosh BB, DuttaGupta M (1997). Development and performance studies on ion-exchanged X- zeolites as catalysts for SI engine emission control. SAE paper number: 971652.

El-Tayeb NSM, Liew KW (2009). On the dry and wet sliding performance of potentially new frictional brake pad materials for automotive industry. Wear 266(1-2): 275-287.

Eriksson M, Bergman F, Jacobson S (1999). Surface characterization of brake pads after running under silent and squealing conditions. Wear, 232: 163-167.

Filip P, Weiss Z, Rafaja D (2002). On friction layer formation in polymer matrix composite materials for brake applications. Wear 252:189-198.

Fischer A (1996). Well-founded selection of materials for improved wear resistance. Wear, 194: 238–245.

Hee KW, Filip P (2005). Performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings. Wear, 259: 1088–1096.

Ho TL (1977). In: Proceedings of the International Conference on Wear of Materials 1977, St. Louis, MO, pp. 70-76.

Jacko MG (1977). In: Proceedings of the International Conference on Wear of Materials 1977, St. Louis, MO, pp. 541-546.

Libsch TA, Rhee SK (1977). In: Proceedings of the International Conference on Wear of Materials 1977, St. Louis, MO. pp. 549-555.

Mutlu I (2002). Investigation of some ceramic additive automotive brake pads. PhD dissertation, University of Sakarya, Sakarya, Turkey.

Mutlu I (2009a). Investigation of tribological properties of brake pads by using rice straw and rice husk dust. J. Appl. Sci., 9(2): 377-381.

Mutlu I (2009b). Investigation of boron products used in brake pads, J. Theor. Appl. Mech., Sofia, 39(1): 3-14.

Mutlu I (2009c). Investigation of using cedar pine cone dust and boric acid in brake pads, J. Appl. Sci., 9(2): 382-386.

Mutlu I, Eldogan O, Findik F (2005). Production of ceramic additive automotive brake lining and investigation of its braking characterisation. Ind. Lubr. Tribol., 57(2): 84-92.

Mutlu I, Oner C, Findik F (2007). Boric acid effect in phenolic composites on tribological properties in brake linings. Mater. Design, 28: 480-487.

Mutlu I, Sugozu I, Oner C (2009). Investıgation of friction behavior of boric acid and black pine cone dust added brake pads. 5th Int. Adv. Technol. Symp. (IATS'09), Karabuk, Turkey.

Newman LB (1978). Friction materials-recent advances, Noyes Data Corporation, Park Ridge, NJ.

Österle W, Griepentrog M, Gross T, Urban I (2001). Chemical and microstructural changes induced by friction and wear of brakes. Wear 251: 1469–1476.

Pasto AE, Braski DN, Watkins TR, Porter WD, Lara-Curzio E, McSpadden SB(1999). Characterization techniques for composites and other advanced materials Compos. Part B., 30: 631-646.

Severin D, Musiol F (1995). Konstruktion, 47: 59.

Straffelini G (2000). Experimental observations of subsurface damage and oxidation wear in Al-based metal-matrix composites Wear 245: 216–222.

Sugozu I, Mutlu I (2009). Investigation of the effect of waste tire rubber on friction behaviour in automotive brake linings. J. Theor. Appl. Mech., Sofia, 39: 3: 101–114.

Talib RJ, Muchtar A, Azhari CH (2001). in: Proceedings of the 10th Scientific Conference Electron Microscopy Conference, Malaysia, Kuala Lumpur, pp. 181-184.

Talib RJ, Muchtar A, Azhari CH (2003). Microstructural characteristics on the surface and subsurface of semi metallic automotive friction materials during braking process. J. Mater. Process. Technol., 140: 694-699.

TS 555 (Turkish Standard) (1992). Highway vehicles, brake systems, brake pads for frictional brake, TSE, Ankara.

Zhang SY, Li YY, Qu SG, Chen WP (2010). Friction and wear behaviour of brake pads dry sliding against semi-ınterpenetrating network ceramics/Al-alloy composites. Tribol. Lett., 38: 135–146.