Polímeros: Ciência e Tecnologia
E-ISSN: 1678-5169
abpol@abpol.org.br
Associação Brasileira de Polímeros
Brasil

Mutlu, Ibrahim; Sugözü, Ilker; Keskin, Ahmet
The effects of porosity in friction performance of brake pad using waste tire dust
Polímeros: Ciência e Tecnologia, vol. 25, núm. 5, 2015, pp. 440-446
Associação Brasileira de Polímeros
São Carlos, Brasil

http://dx.doi.org/10.1590/0104-1428.1860

SCIENTIFIC-TECHNICAL

The effects of porosity in friction performance of brake pad using waste tire dust

Ibrahim Mutlu[1]*, Ilker Sugözü[2] and Ahmet Keskin[3]

[1]Technology Faculty, Afyon Kocatepe University, Afyonkarahisar, Turkey
[2]Tarsus Technology Faculty, Mersin University, Mersin, Turkey
[3]Bolu Vocational School, Abant Izzet Baysal University, Bolu, Turkey
***ibrahimmutlu@aku.edu.tr**

Abstract

This research is focused on the effect of porosity on the friction-wear properties of automotive brake pads. Waste Tire Dust (WTD) was used as a new friction material in brake pads. Newly formulated brake pad materials with five different components have been produced by conventional techniques. In the experimental studies, the change of the friction coefficient, the temperature of the friction surface, the specific wear rate, and the hardness, density and porosity were measured. In addition, the micro-structural characterizations of brake pads are determined using Scanning Electron Microscopy (SEM). The mean coefficient of friction, porosity and specific wear are increased due to a WTD rate increases, on the other hand, hardness and density are decreased. As a result, WTD can be considered as an alternative to revalorize this kind of waste products in the brake pads and the amount of porosity of the brake pad affected the friction coefficient and wear behavior of the pad.

Keywords: *brake pad, composite materials, friction, porosity, waste tire.*

1. Introduction

Automotive friction materials have been formulated for about one century[1]. Nowadays, formulated automotive friction materials are generally multi-component systems that comprise more than 10 components, in order to achieve the desired friction properties[2,3]. A characteristic friction material is a multi-component polymer matrix composite with a formulation often developed empirically[4]. Brake pads used in automotive brakes are generally made of many components. These are classified into four major categories binder, fibers, friction modifiers and fillers all of which are based on the major function they perform apart from controlling friction and wear performance[5]. Brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. Unfortunately, the manufacturing process inevitably produces a wide range of variations in both microstructure and defect population, such as porosity, intermetallic particles, and trapped oxide films, which are all detrimental to the mechanical properties, in particular, the fatigue behavior[6].

In recent years, as other fibers have taken the place of asbestos, the porosity of brake pads has come to be an important constituent of these composite materials. Porosity is involved in the transmission of heat from friction as well as in the sound produced during braking and it helps vent the decomposition gases that sometimes produce a fading effect during a very sudden braking. A spatial characterization of porosity is vital to controlling the structuring of brake pad materials as they are produced[7]. The current trend in the research field is the utilization of industrial or agricultural wastes as a source of raw materials for composite development[8]. This will provide more economical benefit and also environmental preservation. Moreover, many factors should be considered when developing brake materials to fulfill requirements such as, a stable friction coefficient and a lower wear rate at various operating speeds, pressures, temperatures, and environmental conditions in the automotive sectors[9-11].

Tire accumulation is a growing worldwide problem because it is recalcitrant to the environment. Every year about 800 million tires are rejected, and this amount is increasing by 2% each year[12]. Different strategies have been proposed to eliminate rubber wastes including incineration with energy recovery or grinding them down to be used as modifiers for different materials[13]. Sintering of rubber is another possibility of recycling tires. This process requires only the application of heat and pressure to achieve cross-linked rubber with good mechanical properties[14]. No information is available in the literature on the use of Waste Tire Dust (WTD) for the formulation of new brake pad materials. Therefore, brake pad materials have been formulated with the aim of using WTD as a new industrial waste material for automotive friction materials. In the experimental studies, the change of friction coefficient, the amount of wear, density, hardness and porosity were measured. In addition, micro-structural characterizations of braking pads were looked at by using a SEM. The results revealed that WTD can in fact be used for friction materials in the brake lining pad. This study has been undertaken to investigate the effects of porosity on automotive brake pads from 5% to 15% by the weight of waste tire dust. In addition, it was investigated the relationship between wear behavior, porosity and friction characteristics of the pad was investigated.

2. Materials and Methods

2.1 Materials, formulations and specimen preparation

In this study, a new automotive brake friction material was developed by using additive WTD. WTD is obtained from the waste tires of automobile via grinding in Turkey. Five different specimens were produced. These specimens contain WTD, phenolic resin, copper particles, aluminum oxide, graphite, brass particles, cashew and barite. An analytical balance was used to weigh the components. Friction material specimens were produced by a conventional procedure for a dry formulation following dry-mixing, pre-forming and hot pressing. These components were then mixed for 10 minutes using a commercial blender. The final mixture was loaded into an inch square (small specimens) mold for pre-forming under pressing at a pressure of 9.8 MPa. Pre-formed specimens were put in hot pressing mold at a pressure of 14.7 MPa and 180 °C for 15 minutes. During the hot pressing process, pressure was released several times to release the gases that evolved from the cross linking reaction (poly condensation) of the phenolic resin. Detailed conditions for each manufacturing step can be found in the author's other study[15]. The percentages of the phenolic resin, copper particles, aluminum oxide, graphite, brass particles and cashew didn't change in five different specimens. On the other hand, the percentages of the barite and WTD changed inversely proportional to each other. The composition of the friction materials studied in this work is shown in Table 1.

Table 1. The components of specimens (weight %).

Specimens Code	WTD1	WTD2	WTD3	WTD4	WTD5
Phenolic Resin	20	20	20	20	20
Cu Particles	15	15	15	15	15
Al_2O_3	5	5	5	5	5
Graphite	5	5	5	5	5
Brass Particles	2.5	2.5	2.5	2.5	2.5
Cashew	10	10	10	10	10
Barite	37.5	35	32.5	30	27.5
WTD	5	7.5	10	12.5	15
Total	100	100	100	100	100

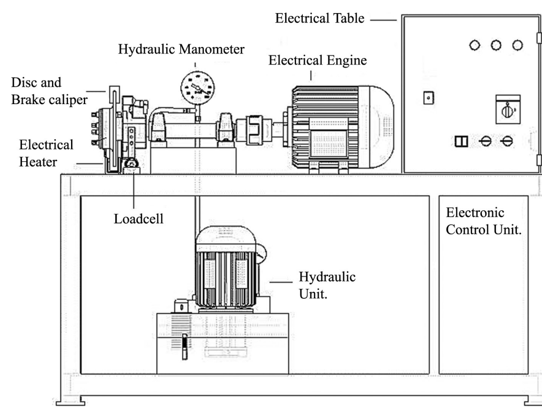

Figure 1. The disc test equipment used in this study.

2.2 Test and analysis

In this study, the performance of WTD on brake friction characteristics was examined. The friction coefficient-temperature-time graphs and the mean coefficient of friction were obtained to identify the friction characteristic. In order to define friction coefficients of automotive brake pad under different temperatures, a test device was used. Figure 1 shows the disc test equipment used in this study.

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 specimen 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 specimens and the cast iron discs were ground with 320-grid sandpaper. The normal load was varied to achieve a constant friction force. Braking tests were carried out under 1.05 MPa pressure, 6 m/s velocity and at temperatures from 50 to 400 °C for 500 seconds. An electrical heater was used in order to achieve a 400 °C friction surface temperature. The temperature and friction coefficient values were stored in a databank. The tests were repeated three times for each specimen. Friction coefficient-temperature-time graphs are obtained to identify the effect of these variables. The friction coefficient of surface of the friction material pairs needs to be high and stable. The friction coefficient was calculated by measuring normal and tangential pressures throughout a 500 second test. It is expressed as a mean value of entire braking dependence during the friction coefficient test. Wear rate was calculated as the specific weight loss of specimens during the tests. Specific wear rate is determined by the mass method following the Turkish Standard (TS 555)[16] and British Standard (BS AU142)[17] and was calculated by the following equation:

$$V = \frac{m_1 - m_2}{L f_m \rho} \quad (1)$$

where, V is specific to wear (mm^3/MJ), m_1 is the mass of brake pad before testing (kg), m_2 is the mass of brake pad after testing (kg), L is the friction distance calculated by using the number of revolution and radius of the disc (m), f_m is the average friction force (N), ρ is the density of brake pad (kg/mm^3).

The friction surfaces of the specimens were characterized using SEM (LEO 1430VP). The specimen surfaces for the SEM observations were always coated with carbon. The density of the specimen was determined by weighing the specimen on a digital scale and measuring their volume by the liquid displacement method. Hardness testing was carried out on a Brinell hardness testing machine using a 62.5 kgf load and 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. Therefore, it was concluded that the braking pads were homogeneous. Porosity was also measured for WTD containing specimens. Porosity is calculated by using the following Equation 2:

$$\Phi = \frac{W_3 - W_1}{W_3 - W_2} \times 100 \quad (2)$$

where, Φ is porosity(%), W_1 is the dry weight of specimens (g), W_2 is the specimens soaked in water for 48 hours in water weight(g), W_3 is the weight of the specimens after waiting 48 hours in water specimens(g).

3. Results and Discussion

3.1 Friction performance

The coefficient of friction (μ) varied significantly in the initial stage of testing. This can be attributed to the fact that the size of the contact area increased and the friction layer developed on the surface. The variations of μ with its respective test time are depicted in Figure 2. As seen in the figure, the friction coefficients show different features depending on the content.

It is seen in this figure that μ initially increased in all specimens, then slowly decreased. There is an increase in μ between 0th-100th second which degrades slightly after the 100th second where μ kept almost constant in WTD1, WTD4 and WTD5 coded specimens. Such an 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 the friction coefficient is usually a sign of unstable and aggressive friction. Some vibration and noise were observed approximately until the 100th second of testing. This vibration was typically observed at the beginning of the test before the development of the stable friction layer. After the 100th second this degradation somewhat slowed with slight fluctuations. Till the 450th second, as a result of friction, a temperature of 300-350 °C is achieved on the friction surface. WTD2 and WTD3 coded specimens show a fluctuation in μ from the 100th second to the 400th second. It shows a rapid decrease and a rapid increase in μ.

The increase in μ occurs when metallic materials inside brake pads rub against cast iron brake disc surface. However, due to friction wear detachments occur. As a consequence, μ starts to decrease. Later, this behavior repeats with the newly formed friction surface. This situation is fluctuating, and undesirable. These specimens include 7.5% and 10% WTD, and μ is decreased from 0.47 to 0.40 in a short time. A rapid increase or decrease in μ has led to a rapid increase in temperature on the surface of friction. On the other hand, the μ for the WTD1, WTD4, and WTD5 specimens increase

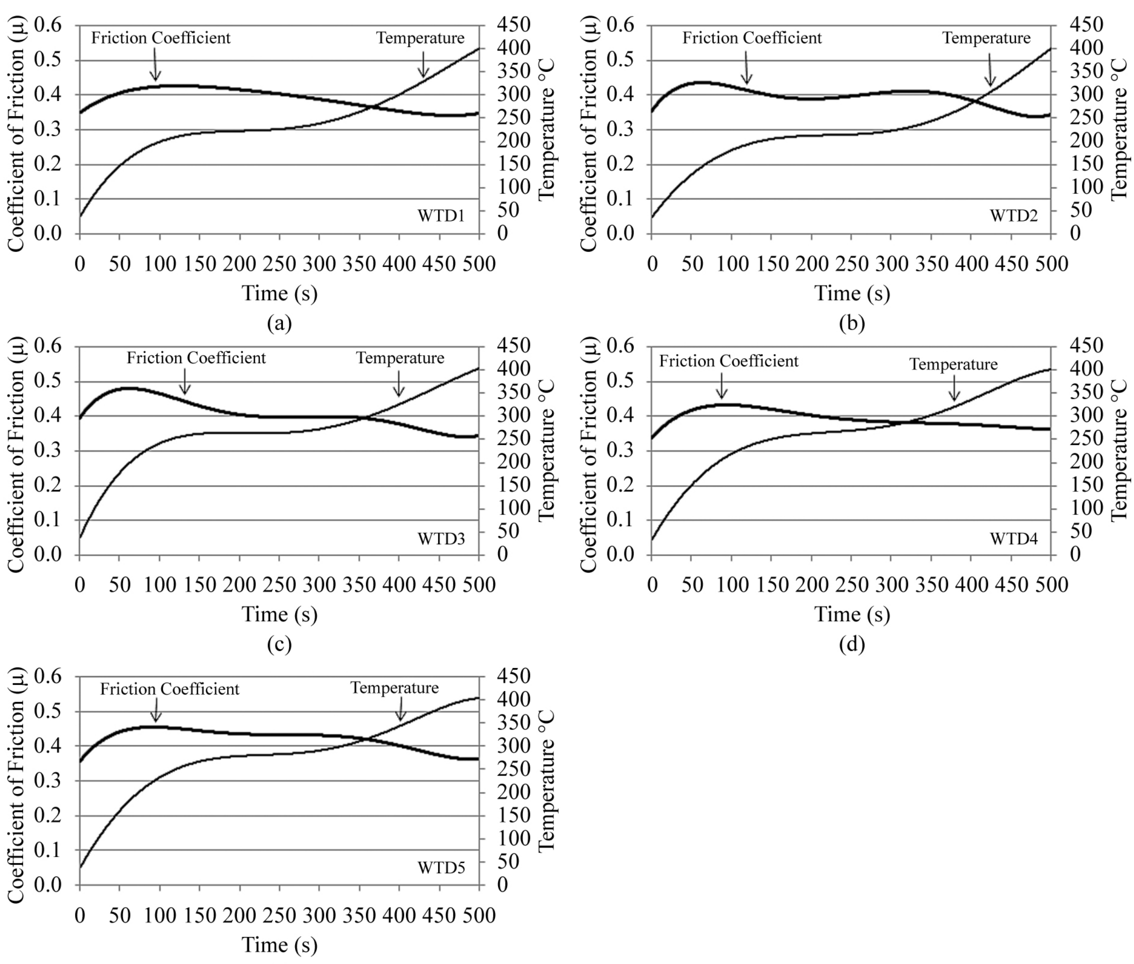

Figure 2. The change of friction coefficient as a function of time for specimens.

at the beginning of test and a small decrease is observed after 100-150 seconds.

It is seen from this figure that the friction coefficient gradually increases in all specimens up to 150 °C. It shows a variable behavior between the temperatures of 150 °C and 350 °C. It is found that μ decreases with increasing testing temperature. Generally, μ decreases between 350 °C and 400 °C due to softening of phenolic resin. As a result, fading occurs during the brake action. Furthermore, with the increasing temperatures, the components in the braking pad affected each other due to the faster diffusion. This phenomenon is called thermal fade[18,19]. The friction behavior of specimens coded WTD1, WTD4 and WTD5 are consistent with each other. Therefore, if a higher μ is desired, WTD can be used 5, 12.5, and 15% as an additive. WTD1, WTD4 and WTD5 coded specimens can be suggested as better material for brake pads than the others. In addition, a more stabilized μ is obtained with these specimens.

In WTD1, WTD4 and WTD5 coded specimens, after μ first increases, it maintains a constant value with slight fluctuations. This can be explained as follows: Because of heating due to friction, the micro-structural changes in the brake pad are finished and thus a constant μ is able to be maintained. μ of WTD1 specimen has risen slowly, but μ of other specimens has risen quickly. These results are consistent with the behavior of friction coefficient of all of specimens. These specimens have almost a similar average μ value between 0.39 and 0.44. Therefore, if a μ value between 0.40 and 0.45 is desired, WTD can be used in brake pads with 12.5 and 15% weight as additive. For higher μ values, adjusting the rate of WTD can be recommended. Furthermore, if stability is desired in μ, WTD5 coded specimen is suggested as better material for brake pads when compared to others (Table 2).

3.2 Character of friction surfaces

SEM micrographs of braking pads using WTD after the braking test for frictional surface including the information about the friction layer are shown in Figure 3. These figures show the worn surfaces of all specimens tested at sliding speed of 6 m/s. It is seen from these figures that a homogeneous microstructure is observed in the frictional surfaces. 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 by an inspection of the specimen surface after the friction test. Systematic analysis of the surface of the 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.

As seen from the micrographs, some particles in the rubbed surfaces of pads are detached from the body and created macro-voids in addition to the micro-voids as shown in Figure 3, WTD3, WTD4, and WTD5. In pads, particle–matrix detaching and cracking are observed due to softening and charring of matrix resin as can be seen in Figure 3, WTD3 and WTD4. It is also clear from Figure 3 that the component are homogeneously distributed in the matrix and, therefore, very few micro voids are observed in the structure. It is known that[20] if the metal-component coherent surface is larger, friction and wear will increase. It is also observed that Al_2O_3 particles are distributed in a quite homogeneous manner and therefore they can possibly remain effective on the friction surface. The worn metallic particles imply that they actively participated in friction during braking test. The macro voids are formed as a result of falling of the metallic particles during the friction process. In addition, micro voids were observed on the surface (Figure 3, WTD3 and WTD4). Figure 3 shows the wear debris of all specimens. The abrasive effect of the detached particles further increases wear rate (Figure 3, WTD3, WTD4 and WTD5)[21,22].

Similarly, WTD is well spread out over the braking pad and hence larger micro-voids occur in the specimens, having a higher rate of WTD particles as seen in Figure 3, WTD4 and WTD5. The micrographs reveal that the higher the rate of WTD content, the coarser the particles of the resulting wear debris are, indicating severe wear (Figure 3, WTD3, WTD4 and WTD5). Typical wear debris consists of sheared-deformed polymer matrix containing small detached participles; the wear powder of the metallic counterpart. The particles can either be lost from the contact zone immediately after being detached from the composite surface, or remain there for a while as transferred and back-transferred layers[22].

As can be seen from Figure 3, WTD1 and WTD2, the friction layer is not continuous. A thick friction layer is developed on the surface after testing. Such a layer is developed predominantly in scratches which were filled with friction debris. The "uncovered areas" were dominantly associated with the presence of graphite on the surface. Graphite is characterized by its lubricating properties, and a low adherence of the friction layer can result. It can be clearly seen that friction layers have been formed in the specimens. Larger "uncovered" areas were observed during the testing. An image analysis of the friction surface revealed that the uncovered areas did not correspond to the content of graphite in the bulk (Figure 3, WTD3 and WTD5). On the other hand, the amount of surface covered by deformed

Table 2. Typical characteristics of the brake pad used in this study.

Specimen code	Mean coefficient of friction	Standard deviation	Specific wear (g/mm^2)	Hardness (HRB)	Density (g/cm^3)	Porosity (%)
WTD1	0.40764	0.08024	0.21×10^{-6}	25.3	2.170	6.578947
WTD2	0.39601	0.06676	0.22×10^{-6}	26.8	1.678	9.333333
WTD3	0.42259	0.066897	0.24×10^{-6}	26.5	1.704	15.28571
WTD4	0.42899	0.06754	0.26×10^{-6}	21.5	1.739	17.66667
WTD5	0.44123	0.06926	0.31×10^{-6}	20.9	1.709	18.3

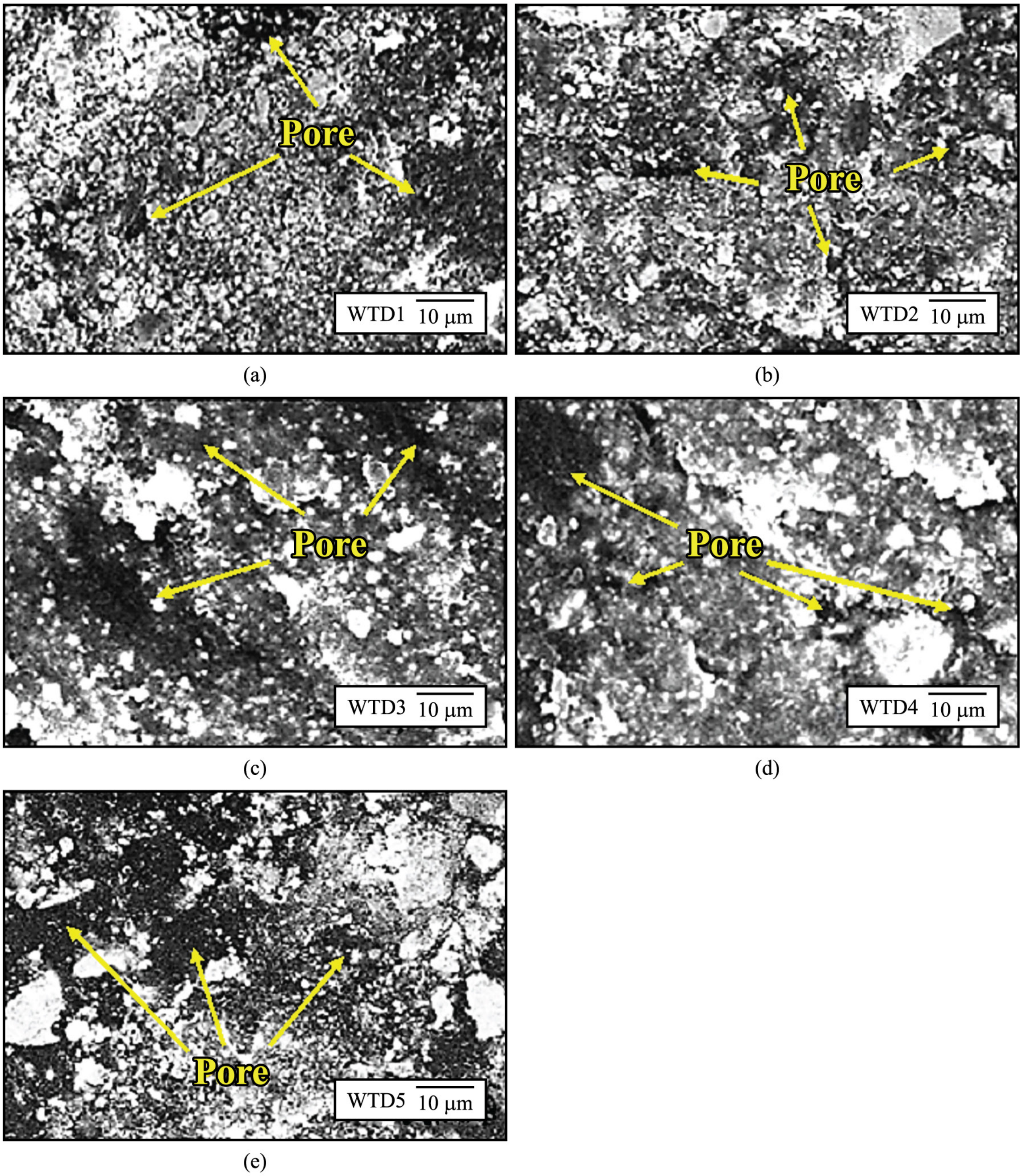

Figure 3. SEM micrographs of brake pad specimens.

metallic particles increases with increased temperature, as apparent in Figure 3, WTD3 and WTD4. This tendency is clearly related to the ability of metallic particles to be easily smeared over the surface with increased temperature. The friction layer adheres well to deform metallic particles.

An active friction surface layer developed in all specimens due to a homogenous distribution of components (Figure 3). While macro-voids exist in WTD4 and WTD5 specimens, these specimen components' WTD rate 12.5 and 15% demonstrate a homogenous distribution (Figure 3, WTD4 and WTD5). In WTD3, WTD4 and WTD5 specimens, since the components actively participate when there is in friction, some particles detach from the bulk and thus macro-voids are observed. On the other hand, micro-voids are observed in WTD1, WTD2 and WTD3 specimens due to the homogenous distribution of components (Figure 3).

3.3 Density, hardness and porosity of brake pad materials

Table 2 presents the density, hardness, porosity, the mean coefficient of friction, the standard deviation of coefficient of friction and specific wear of the specimen during the tests for 500 seconds. A density measurement test was carried out on a laboratory scale to examine the density of the material.

Density depends upon the components in the pad material. A metallic element has a higher density than an organic element. Friction elements often exist as a combination of various elements. The results shown in Table 2 are the average density of three readings for each formulation. It is seen from Table 2 that WTD1 coded specimen has the highest density with the value of 2.170 g/cm^3. It includes 37.5% barite, which is a heavy dust material used as a filled friction material. The higher the barite rate, the higher the density is.

The mass of the specimens was measured before and after the friction test, and wear rates were calculated as a mean value of the weight reduction in the three specimens. As can be seen from Table 2, the mean coefficients of friction and the standard deviation of these specimens are very close to each other. The μ achieved in specimens WTD3, WTD4 and WTD5 are approximately 0.42-0.44 and higher, which are considered to be very good when compared to coefficients of friction achieved in current brake pads. The mean coefficients of friction are higher in addition; the standard deviation is higher in the WTD4 and WTD5 specimens. In addition, the standard deviation is higher in the specimen where the mean coefficient of friction is average in the WTD1 specimen. Finally, less wear is observed on the specimens where the additive WTD material rate is WTD1 or WTD2, compared to the other specimens. But its mean coefficient of friction is lower than one of WTD3, WTD4 and WTD5. Therefore, the WTD material positively contributes to the mean coefficient of friction in brake pads and positively contributes to the wear resistance in brake pads. The detected roughness is very similar for all testing conditions regardless of the testing temperature and pressure applied. This indicates that chemical changes on the surface, rather than varying roughness, is responsible for performance changes.

The highest hardness is observed in WTD2 coded specimen. It has 7.5% WTD. Based on previous experiments, a WTD rate between 5-10% has a positive effect on hardness whereas a WTD rate greater than 12.5% has negative effect on hardness. 12.5% and 15% WTD rate specimens have the lowest hardness and the highest specific wear. Table 2 shows the variation in specific wear rates with increasing WTD rate for all specimens investigated. The specific wear rate is increased with increasing WTD rate as expected.

Table 2 shows the porosity test results for all formulations of brake pad materials. Porosity, a gross measure of the pore structure, gives the fraction of the total volume that is void[23]. Porosity has an important role in automotive brake pad materials since the function of porosity is to absorb energy and heat. This is a very important for the effectiveness of the brake system. Brake pads should have a certain amount of porosity to minimize the effect of water and oil on the friction coefficient. Increasing porosity by more than 10% could reduce the brake noise[11,24]. It was generally observed in our study that the specimens with high porosity tend to exhibit high friction coefficient (Table 2). The shape of the pore is highly variable, as can be recognized by observation of the micrographs. SEM allows for the observation of the surface pore structure. From the porosity results as shown in Table 2, it can be seen that two brake pad formulations, 5 and 7.5% of WTD specimens, show a lower percentage of porosity compared to other specimens. WTD1 has a porosity of 6.58%. On increasing WTD is found to have increased porosity of about 17.67% to 18.3%.

4. Conclusions

In this study, WTD was added to the composite and specimens were successfully obtained by a conventional manufacturing method. The effect of the WTD content on the friction and wear behavior of brake pad automotive was experimentally analyzed. The results of friction test showed that WTD can substantially improve properties of friction materials. The performance of such materials may be enhanced by improving the adhesion between both co-components. WTD may be improved by choosing an adequate compatibilizing agent. The use of a low cost compatibilizing agent will be the subject of future studies.

From the friction and wear tests, the following conclusions were reached. The coefficient of friction was found to decrease with an increasing friction surface temperature up to 300 °C. Also the standard deviation was very small, which means that the material has a stable friction characteristic. The standard deviation was in the acceptable range for all specimens. The specific wearing rate of friction materials with WTD relatively increased but these increases are in the acceptable range for all specimens. Some micro-voids and micro-cracks were observed on the worn surface. No direct proportionality between mean coefficients of friction and the standard deviation and wear resistance could be found due to the complexity of composite structure.

The highest friction coefficient was obtained with the specimen having 15% WTD rate. The smaller value was obtained with specimen having 5%, 7.5% WTD rate. The specimens with 7.5%, 10% and 12.5% WTD rate had more stable friction coefficient than other specimens. While the specimens with 10-15% WTD rate had higher friction coefficients, their wear rate was considerably higher than that of others specimens. The 5% WTD rate had higher density and lower porosity compared to other specimens. Porosity of WTD in brake pads was high which is an important factor for friction material. Thus WTD added brake pad composites can be considered as potential candidate. Bulk density and hardness is reduced by adding WTD. As a result of the experiments the structural 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.

Acknowledgements

This research is funded by the Scientific & Technological Research Council of TURKEY (TÜBİTAK) (Grant Reference No: 106M006). The authors wish to acknowledge the TÜBİTAK and our partner organizations for their support.

References

1. Lu, Y. (2006). A combinatorial approach for automotive friction materials: effects of ingredients on friction performance.

Composites Science and Technology, *66*(3-4), 591-598. http://dx.doi.org/10.1016/j.compscitech.2005.05.032.

2. Gurunath, P. V., & Bijwe, J. (2007). Friction and wear studies on brake-pad materials based on newly developed resin. *Wear*, *263*(7-12), 1212-1219. http://dx.doi.org/10.1016/j.wear.2006.12.050.
3. Bernard, S. S., & Jayakumari, L. S. (2014). Effect of the properties of natural resin binder in a high friction composite material. *Polímeros: Ciência e Tecnologia*, *24*(2), 149-152. http://dx.doi.org/10.4322/polimeros.2014.038.
4. Roubicek, V., Raclavska, H., Juchelkova, D., & Filip, P. (2008). Wear and environmental aspects of composite materials for automotive braking industry. *Wear*, *265*(1-2), 167-175. http://dx.doi.org/10.1016/j.wear.2007.09.006.
5. Kumar, M., & Bijwe, J. (2011). Composite friction materials based on metallic fillers: sensitivity of μ to operating variables. *Tribology International*, *44*(2), 106-113. http://dx.doi.org/10.1016/j.triboint.2010.09.013.
6. Yi, J. Z., Gao, Y. X., Lee, P. D., Flower, H. M., & Lindley, T. C. (2003). Scatter in fatigue life due to effects of porosity in cast A356-T6 aluminum-silicon alloys. *Metallurgical and Materials Transactions A, Physical Metallurgy and Materials Science*, *34*(9), 1879-1890. http://dx.doi.org/10.1007/s11661-003-0153-6.
7. Rouge, N., Dubois, C., Vermillet, C., & Chambaudet, A. (1995). Characterization of the open porosity of brake pads. I. Development of 2-D porosity image analysis techniques. *Science and Engineering of Composite Materials*, *4*(4), 205-214. http://dx.doi.org/10.1515/SECM.1995.4.4.205.
8. Leman, Z., Sapuan, S. M., Saifol, A. M., Maleque, M. A., & Ahmad, M. M. (2008). Moisture absorption behavior of sugar palm fiber reinforced epoxy composites. *Materials & Design*, *29*(8), 1666-1670. http://dx.doi.org/10.1016/j.matdes.2007.11.004.
9. Wannik, W. B., Ayob, A. F., Syahrullail, S., Masjuki, H. H., & Ahmad, M. F. (2012). The effect of boron friction modifier on the performance of brake pads. *International Journal of Mechanical and Materials Engineering*, *7*(1), 31-35. Retrieved in 29 March 2015, from http://umexpert.um.edu.my/file/publication/00003184_92279.pdf
10. Adebisi, A. A., Maleque, M. A., & Shah, Q. H. (2011). Surface temperature distribution in a composite brake rotor. *International Journal of Mechanical and Materials Engineering*, *6*(3), 356-361. Retrieved in 29 March 2015, from http://ejum.fsktm.um.edu.my/article/1146.pdf
11. Maleque, M. A., Atiqah, A., Talib, R. J., & Zahurin, H. (2012). New natural fibre reinforced aluminium composite for automotive brake pad. *International Journal of Mechanical and Materials Engineering*, *7*(2), 166-170. Retrieved in 29 March 2015, from http://irep.iium.edu.my/26045/
12. Van Beukering, P. J. H., & Janssen, M. A. (2001). Trade and recycling of used tyres in Western and Eastern Europe. *Resources, Conservation and Recycling*, *33*(4), 235-265. http://dx.doi.org/10.1016/S0921-3449(01)00082-9.
13. García, D., López, J., Balart, R., Ruseckaite, R. A., & Stefani, P. M. (2007). Composites based on sintering rice husk-waste tire rubber mixtures. *Materials & Design*, *28*(7), 2234-2238. http://dx.doi.org/10.1016/j.matdes.2006.06.001.
14. Fang, Y., Zhan, M., & Wang, Y. (2001). The status of recycling of waste rubber. *Materials & Design*, *22*(2), 123-127. http://dx.doi.org/10.1016/S0261-3069(00)00052-2.
15. Mutlu, I., Oner, C., & Findik, F. (2007). Boric acid effect in phenolic composites on tribological properties in brake linings. *Materials & Design*, *28*(2), 480-487. http://dx.doi.org/10.1016/j.matdes.2005.09.002.
16. The Turkish Standards Institution. (1992). *TS 555: highway vehicles, brake systems, brake pads for frictional brake*. Ankara: TSE. Retrieved in 29 March 2015, from https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx
17. FreeSTD Standards Worldwide. (1968). *BS AU 142-1968: methods of test for brake linings materials*. Retrieved in 29 March 2015, from http://www.freestd.us/soft/260917.htm
18. Chugh, Y. P., Filip, P., Mohanty, S., & Hee, K.-W. (2004). *A collaborative program for development of frictional materials using industrial wastes*. In *Proceedings of the International Conference on Engineering Education and Research "Progress Through Partnership*" (pp. 609-621). Ostrava: VSB-TUO. Retrieved in 29 March 2015, from http://www.ineer.org/events/iceer2004/proceedings/papers/0609.pdf
19. Mutlu, I. (2009). Investigation of using cedar pine cone dust and boric acid in brake pads. *Journal of Applied Sciences*, *9*(2), 382-386. http://dx.doi.org/10.3923/jas.2009.382.386.
20. Hee, K. W., & Filip, P. (2005). Performance of ceramic enhanced phenolic matrix brake lining materials for automotive brake linings. *Wear*, *259*(7-12), 1088-1096. http://dx.doi.org/10.1016/j.wear.2005.02.083.
21. Tanaka, K., Ueda, S., & Noguchi, N. (1973). Fundamental studies on the brake friction of resin-based friction materials. *Wear*, *23*(3), 349-365. http://dx.doi.org/10.1016/0043-1648(73)90022-7.
22. Ozturk, B., Arslan, F., & Ozturk, S. (2007). Hot wear properties of ceramic and basalt fiber reinforced hybrid friction materials. *Tribology International*, *40*(1), 37-48. http://dx.doi.org/10.1016/j.triboint.2006.01.027.
23. Yi, H.-C. (2004). *The investigation of capillary wick structure fabricated by sintering method* (Master's Dissertation). Tatung University, Taiwan. Retrieved in 29 March 2015, from http://ethesys.lib.ttu.edu.tw/ETD-db/ETD-search/view_etd?URN=etd-0805104-170550
24. Jaafar, T. R., Selamat, M. S., & Kasiran, R. (2012). Selection of best formulation for semi-metallic brake friction materials development. *Powder Metallurgy*, 1-30. Retrieved in 29 March 2015, from www.intechopen.com/download/pdf/28435

Received: Aug. 07, 2014
Revised: Apr. 03, 2015
Accepted: May 25, 2015