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Investigation of Tribological Properties of Brake Pads by Using Rice Straw and Rice Husk Dust

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Abstract: In the present study, investigation of new materials to replace the asbestos has started to be considered. Brake pads used in automotive industry contain materials composed of more than ten different ingredients. In this study, the use of Rice Straw Dust (RSD) and Rice Husk Dust (RHD) has been investigated for assessing the tribological properties of brake pads. RSD and RHD both have silica in them which gives the pad materials a ceramic like behavior. To obtain RSD and RHD, rice straw and rice husk were grained after they have been dried. Different amounts of RSD and RHD were included in the brake pad mix along with the other regular ingredients. These newly formulated brake pads have been tested under Friction Assessment and Screening Test (FAST). Friction coefficient, wear rate and Scanning Electron Microscope (SEM) for friction surfaces were examined to assess the performance of these samples.

Key words: Brake pad, composite materials, friction, tribology, wear

INTRODUCTION

Frictions materials that have been used in automotive brake pads were formulated almost a century ago. Although, in the early 1920s, asbestos fiber was chosen as a friction material for use in all kinds of vehicles, due to its harmful effects on human health, Non Asbestos Organic (NAO) materials have become main stream nowadays.

A characteristic friction material is a multicomponent polymer matrix composite with a formulation, which is often developed empirically (Filip *et al.*, 2002). The high-energy conditions and complex mechano-chemical interactions on the friction surface during braking make it difficult to predict the chemistry and particle size of newly formed species. Even if the raw materials selected for manufacturing a brake lining are in conformation with the environmental requirements, it is possible that newly formed wear particles will have different chemistry and structure. In contrast to other tribological applications, a relatively high friction coefficient in the range of 0.3-0.7 is normally desirable when using brake lining materials (Roubicek *et al.*, 2008). The friction coefficient should be moderately high, but most significantly must be unchanging during of braking. 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).

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. 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 (Osterle *et al.*, 2001).

Agricultural products are emerging as new and inexpensive materials in the friction material development with commercially viability and environmental acceptability (Bledzki and Gassan, 1999). Among these kinds of materials, lignocellulosic fillers are considered as attractive candidates to be used as fillers of thermoplastic polymers (Cyras *et al.*, 2001). In this way, it is possible to obtain composite materials with properties quite similar to the already known synthetic-filler reinforced plastics with their superior properties such as low cost, low density, enhanced energy recovery, biodegradability and recyclability. However, the high sensitivity to moisture makes their use limited (Bledzki and Gassan, 1999; Garcı´a *et al.*, 2007).

One of the agricultural residues which can be potentially used as fillers of polymeric materials is the rice husk. Rice is the most important food crop grown in the world and planted on an estimated 540 million tons every year. The rice husks are grinded and burned at low temperature. After this process, white ash is gained. The white ash consists of 80% silica. The rice straw on the other hand consists of 30% cellulose, 20% hemicelluloses and lignin, about 10% water and 15% mineral ash. The mineral ash consists mainly of silica (95%), insoluble silicates of aluminum, iron, magnesium and calcium (Seki, 2006). Rice straw and rice husk are known to have low lignin and high silica as shown in Table 1 (Van Soest, 2006). A variety of epoxy-hardener systems with lignin (up to 20%, in some cases) have been shown to improve the adhesive joint shear strength (Wang *et al.*, 1992).

Table 1: Lignin and silica amounts in rice straw and husk (Van Hoest, 2006)

Mixture	Rice straw	Rice husks
SiO_2 (g kg^{-1})	130	230
Lignin (g kg^{-1})	35-70	160

In this study, Rice Straw Dust (RSD) and Rice Husk Dust (RHD) are used to obtain friction material for the brake pads, since, it includes high proportion of silica. Effect of using friction materials obtained from RSD and RHD on friction coefficient and abrasion resistant has been investigated. Different amounts of RSD and RHD were mixed with other regular ingredients in the brake pad. In the experimental studies, the change of friction coefficient and the amount of wear were measured. In addition, micro-structural characterizations of braking pads were looked at by using a Scanning Electron Microscopy (SEM). The results revealed that RSD and RHD can in fact be used for friction materials in the brake lining pad.

MATERIALS AND METHODS

In this study, a new automotive brake friction material was developed by using RSD and RHD and their performance on brake friction characteristics was specifically examined. Friction materials investigated in this study were Non Asbestos Organic (NAO) type materials containing four different ingredients including RSD and RHD. This study was carried out for 4 different mixtures of 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. Detailed conditions for each manufacturing step can be found in the researchers other study (Mutlu *et al.*, 2007). The composition of the friction materials studied in this research is shown in Table 2.

An analytical balance was used to weigh each of the ingredients which were mixed for 10 min using a commercial blender. The final mixture was loaded into a cylindrical (small samples) or a brake lining (brake lining samples) mold. The mixtures in both mold types were hot pressed at 180°C for 15 min and subsequently post cured. 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. Post-curing was carried out at a constant temperature of 180°C by placing the samples in a preheated furnace (Fisher scientific Isotherm Furnace) for 4 h (Kristkova *et al.*, 2004).

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

Specimens code	RS4	RS20	RH4	RH20
Phenolic resin	20.0	20.0	20.0	20.0
Cu particles	5.0	5.0	5.0	5.0
Al_2O_3	3.0	3.0	3.0	3.0
Graphite	7.0	7.0	7.0	7.0
Brass particles	2.5	2.5	2.5	2.5
Steel fibers	10.0	10.0	10.0	10.0
Cashew	5.0	5.0	5.0	5.0
Barite	43.5	27.5	43.5	27.5
Rice straw dust	4.0	20.0	-	-
Rice husk dust	-	-	4.0	20.0
Total	100.0	100.0	100.0	100.0

Using the Friction Assessment and Screening Test (FAST) machine, friction tests were performed for each material. For each sample, three friction test procedures were applied and the average of these three tests was recorded. For comparison purposes, FAST testing was also repeated with samples obtained. The FAST machine uses a pearlitic gray cast iron disc (diameter of 180 mm, thickness 38 mm) and a brake lining test sample with dimensions of 12.7×12.7×5.00 mm. 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 $v = 7$ m sec^{-1} for 90 min and the temperature was increased from room temperature to around 300°C. Before performing the FAST 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 sec throughout the 90 min test. The weight and thickness of two pads and a disc for each sample were taken before and after the friction test. In order 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. Wear rate was calculated as weight loss for per mm^2 of the sample during the tests.

RESULTS AND DISCUSSION

The coefficient of friction (μ) varied significantly in the initial stage of testing, since the size of the contact area increased and the friction layer was developed on the surface (Filip *et al.*, 2002). The variations of friction coefficient with test time are given in Fig. 1. The characteristic time dependences of μ as detected in FAST for all samples are shown in Fig. 1.

RH4 and RS4 coded samples showed a continuous initial increase in the friction coefficient (μ) between 10th and 20th min of testing in FAST. Such increase can often be attributed to the adhesion of metal chips in the brake lining to the friction surface of the cast iron disc. The observed amount of change in μ of RS4 in Fig. 1

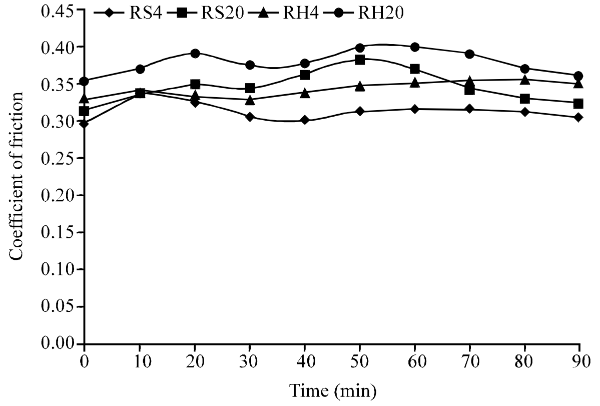

Fig. 1: The change of friction coefficient as a function of time for all samples

slowly decreased after a little increase (i.e., between 10th and 20th min) and then stabilized which is known as the typical friction manner in the literature. Note that this sample has 4% RSD which has 130 g kg^{-1} of SiO_2 and 35-70 g kg^{-1} of Lignin as can be seen from Table 1.

While μ of RH4 slowly decreased between 10th and 20th min as in case of RS4, later it increased more than that of RS4 and finally stabilized at the value of 0.35. This sample has 4% RHD which has 230 g kg^{-1} of SiO_2 and 160 g kg^{-1} of Lignin as can be seen from Table 1. It is important to observe that the difference between the two used samples (RS4 and RH4) became apparent after 40th min. This can be explained as follows: Since the temperatures become higher (i.e., 350-400°C) after 40th min, it is conjectured that the micro-structural changes on the brake pad were completed and thus μ does not change at all.

The same experiments were conducted by changing the RSD and RHD rates to 20%, respectively. RS20 and RH20 shows similar behavior until 40th min as observed in the case of RS4 and RH4. However, since the RS and RH rates were higher (i.e., 20%), the increase in μ is higher until 55th min as shown in Fig. 1. After the 55th min, with the effect of high temperature and unforeseen changes in the brake pad material, the binder material lost its bounding capability and thus a slow decrease in μ is observed. This decrease is more significant in RS20 than RH20 since the rate of lignin and silica were lower in RS20. As a result of such fading in μ, it finally stayed around 0.33-0.36. As can be shown from the Table 3, the μ achieved in all samples are 0.315 and 0.381, respectively which are considered to be very good when compared to friction coefficients achieved in current brake pads (Blau, 2001).

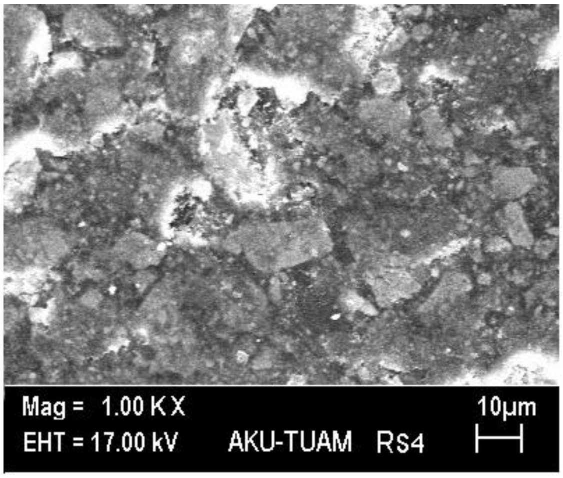

Fig. 2: SEM micrographs of brake pad sample for RS4

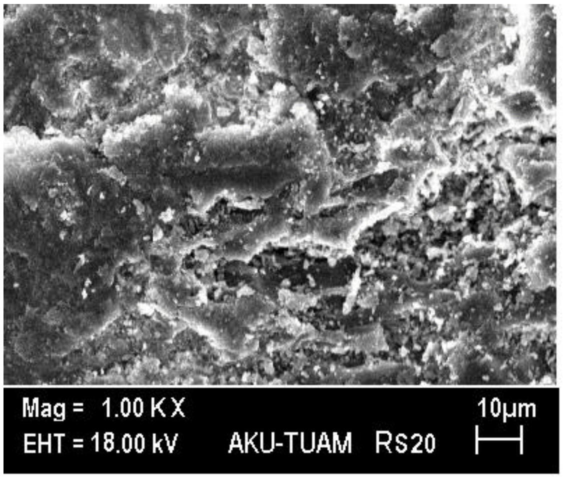

Fig. 3: SEM micrographs of brake pad sample for RS20

As can be seen from Fig. 2-5, the silica particles are homogenously distributed in the body (white points). 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 bigger size. The bigger sized micro-voids are due to falling 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 stayed as effective in friction surface. All matters were homogeneously distributed in the matrix and therefore, very few micro voids were observed in the structure.

The photos of RS4 and RH4 samples are blurred when compared to the photos of RS20 and RH20. This can be attributed to the fact that the barite rate is higher in

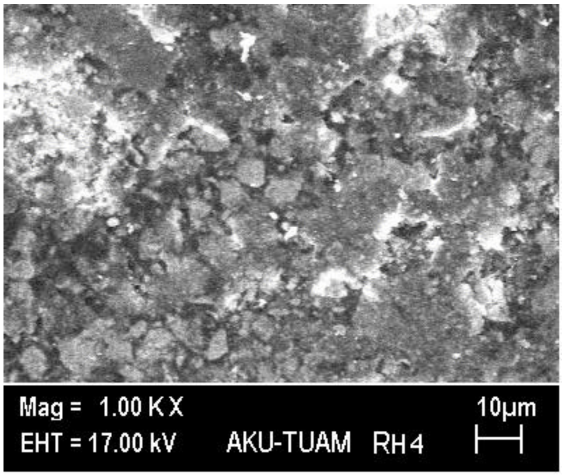

Fig. 4: SEM micrographs of brake pad sample for RH4

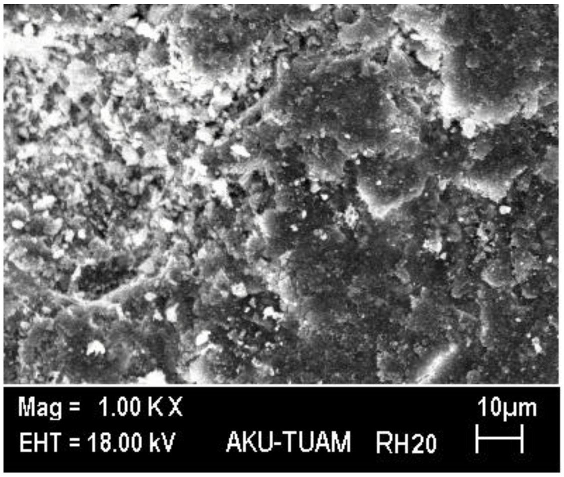

Fig. 5: SEM micrographs of brake pad sample for RH20

Table 3: Typical characteristics of the brake pad used in this study

Sample code	Mean of friction coefficients	SD	Wear rate $(g\ mm^{-2})$
RS4	0.315	0.0106	0.853×10^{-3}
RS20	0.347	0.0168	1.214×10^{-3}
RH4	0.341	0.0099	0.964×10^{-3}
RH20	0.381	0.0120	1.041×10^{-3}

RS20 and RH20 (Fig. 2, 4). Note that in only Fig. 5, the ingredient having the plastic deformation capability has taken a flake like feature after the friction experiment. Overall, it is observed that the used ingredients for the brake pad created a fine structure.

Table 3 presented the mean of friction coefficient, standard deviation of friction coefficient and wear per mm^2 of the sample during the tests. As can be seen from the Table 3, RHD provided better results in terms of friction coefficient when compared to RSD. This observation is also valid for the standard deviation. However, as far as the wear rate is considered, RS4 has a little better wear rate than RH4 which can be ignored. In general 20% rate causes more wear rate than that of 4%. These because; there are more organic material in the mix with 20% of RHD and RSD which causes increased wear rates. As a conclusion, RH20 with 20% of RHD use gives the best result in terms of friction coefficient and standard deviation.

CONCLUSIONS

In this study the following conclusions were drawn:

- RSD and RHD can be effectively used in brake pad formulations when properly combined with other additives
- The experimental results have shown that the friction layer, with the use of RHD significantly improved the overall performance. Simultaneous faded reduction and stabilized friction coefficient
- Wear rates were slightly increased with 20% of RSD and RHD. Some micro voids and micro cracks are observed on the worn surface
- The best mean friction coefficient was achieved with RH20 samples. Furthermore, the standard deviation is in the acceptable range for all specimens
- Friction surface and chemistry strongly affect the frictional performance on the friction layer. The structure of such friction layer differs from the bulk material formulation and also depends on the environment and applied testing condition

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