Mechanics of Advanced Composite Structures 6 (2019) 159 - 165

Semnan University

Mechanics of Advanced Composite Structures

journal homepage: http://MACS.journals.semnan.ac.ir

The Role of Natural Additives on the Wear and Friction Properties of Nanocomposites for Friction Applications

M. Amirjan [a,*], H. Sakiani [b]

[a] Metallurgy Division, Department of Chemical and Materials Engineering, Niroo Research Institute (NRI), 1468617151, Tehran, Iran
[b] Faculty of Mining and Metallurgy, Amirkabir University of Technology, 15875-4413, Tehran, Iran

PAPER INFO

Paper history:
Received 2018-08-12
Received in revised form 2019-02-12
Accepted 2019-04-25

Keywords:
Friction materials
Banana peel
Bagasse
Brake pad
Asbestos free

ABSTRACT

In the present study, the effect of banana peel and bagasse particle additives on the friction and wear behavior of multi-ingredient friction material nanocomposites have been investigated. In order to develop optimized properties of friction nanocomposite, the type and content of natural additives were changed beside the constant amount of other constituents such as alumina nanoparticle and other functional ingredients. The microstructural investigation and wear test were performed. The results showed as the natural additive content increases, the density of nanocomposite, and the hardness decrease. The highest hardness and friction values and the lowest specific wear rate would be achieved for a composite sample with 5 wt. % of baggase additive.

1. Introduction

The appropriate friction coefficient and wear behavior of friction composite materials make them a good candidate for automotive, aerospace, and industrial brake system applications [1-4]. These materials have several components which determine the final properties of composites. An important ingredient of this composite is a func-tional/friction component which asbestos has been used for several years. It was demonstrated that the use of this component affects human health. So, the enforced regulation restricted its application [5-9]. The utilization of eco-friendly materials, especially, agricultural wastes, instead of asbestos, have been reported in several studies.

The use of palm slag as a friction ingredient was investigated by Ghazali et al. [10]. Their results showed the appropriate mechanical and frictional properties of newly developed composites. In another research, they [11] characterized the friction composite containing $CaCO_3$, palm slag, and dolomite. It was demonstrated that the composites containing palm slag revealed the appropriate wear and thermal stability.

The prepared friction composite samples containing cashew nut shell liquid (CNSL) and whisk-ers of potassium titanate were characterized by Kim et al.[12]. Beside the enhancement of friction coefficient, the noise effect reduced as the potassi-um titanate increased in composite composition.

The study by Ibhadode et al. [13] revealed that the palm kernel shells (PKS) could be considered as the alternative candidate for asbestos. Considering the optimized content of functional constituents in friction composite, Ikpambese et al. [14], utilized the 10 wt. % of palm kernel fibers (PKFs) to obtain a com-

* Corresponding author. Tel.: +98-2188079400; Fax: +982188078296
E-mail address: mamirjan@nri.ac.ir

DOI: 10.22075/MACS.2019.15614.1158

posite with comparable properties with a commercial one. The developed composites con-taining plant flax fiber by Zhenzen fu et al. [15]showed enhanced wear behavior of composite in higher temperature. This can be attributed to duc-tile fracture and char formation at elevated tem-perature.

In the present study, the preparation and investigation of the optimized composition of friction materials with inexpensive natural wastes addi-tives were performed. The banana peels and ba-gasse particle/fibers and alumina nanoparticles were utilized beside other nanocomposite consist-ents (up to 15 ingredients) for production of fric-tion materials. Then, the microstrucre, physical and mechanical properties, wear, and friction be-havior of nanocomposite samples were investigat-ed.

2. Experimental Program

2.1. Preparation

In order to evaluate the effect of composition on the properties of friction materials, the sample with different compositions containing alumina nanoparticles and natural additives (banana peel particles and bagasse particle/fiber (Fig. 1)) beside other constituents were prepared. The composition of samples is given in Table 1.

The nanocomposite preparation performed in two main steps, including mixing/blending of in-gredients gradually in a blade mixer and compact-ing the blends in two steps: (1) compaction of mix-ture at room temperature at pressure of 23.4 MPa in a die to form a preform; (2) compaction the pre-form in 30 MPa pressure at 150 ◦C on hot press then curing the compacts in an oven for 2 h at 120 ◦C followed by 150 ◦C for 5 h. For each nanocompo-site composition, three samples with a diameter of 50 mm and thickness of 5 mm were prepared and investigated.

2.2. Characterization

The density of the prepared nanocomposites was measured using Arechmides' method according to ASTM B962 standard[16]. Also, the porosity of the samples was measured according to JIS D4418 standard[17]. In order to investigate the microstruc-ture and phase distribution in nanocomposite sam-ples, the optical microscopy (OM) and scanning electron microscopy (FESEM MIRA3 TESCAN, 15KV) were used. The hardness evaluation of com-posite samples was performed by a Brinell test method using 125 kgf loading, a ball with a 5 mm diameter and loading time of 15 s.

Wear, and friction behavior of nanocomposites were determined by the pin on disk method ac-cord-ing to ASTM G-99-05 standard [18]. For better consistency to real and performance condition, the test procedure was chosen according to SAE j661, JIS D4411, SAE J8660, ISO 286-P67 and ISIRI 586 [19]. So, the applied pressure of 1 MPa, the rota-tional speed of 417 RPM (0.54 m/s linear speed) and a distance of 1000 m were considered. The schematic of the pin on the disk test device and test specimens (30×30 mm) are shown in Figs. 2 and 3, respectively. The wear counter face was made with gray cast iron. The wear rate of samples was calcu-lated as follows:

$$wear\ \ rate = (W_0 / W_1) / S = \Delta W / S = \Delta W / 2\pi NDt \qquad (1)$$

where W_0 is the initial weight of wear sample (g), W_1 is final weight (g), is weight loss (g), S is distance (m), D is disk diameter (m), N is rota-tional speed (RPM), and t is test time (s).

Also, in order to compare the obtained results with those of other researchers and data normalizing, the specific wear rate was calculated as follows:

$$specific\ \ wear\ \ rtate = \Delta V / F.S \qquad (2)$$

where is volume loss of samples, F is ap-plied force, and S is the distance (1000 m). Note that the selected test procedure is close to the mild braking condition [20].

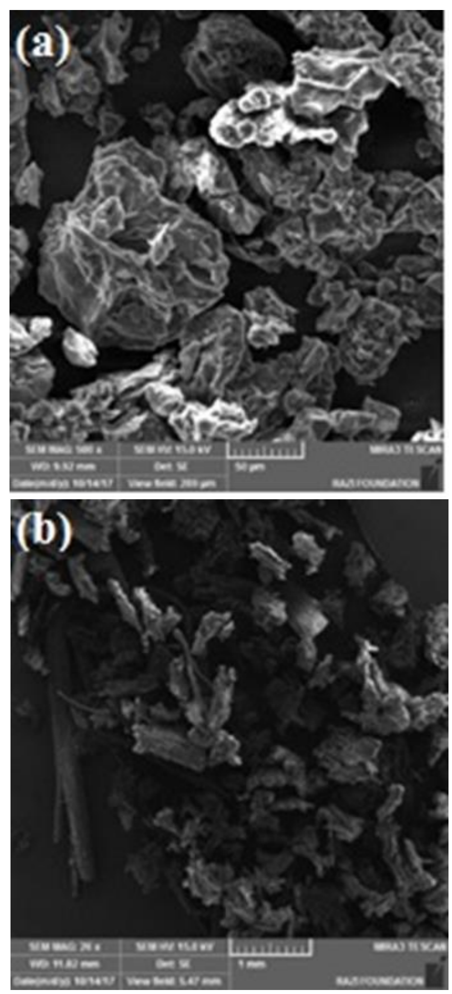

Fig. 1. The morphology of used natural ingredients, (a) banana peels particles; (b) bagasse particle/fibers

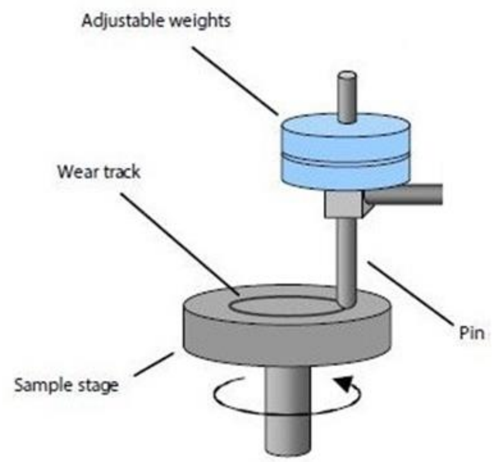

Fig. 2. The schematic of the pin on the disk test device

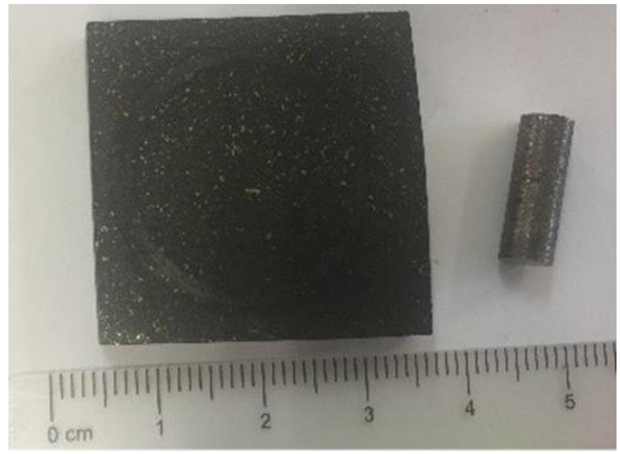

Fig. 3. The nanocomposite wear sample and cast iron pin used for the wear test

Table 1. Composition and designation of the specimens

		Ingredient Contents (%wt.)					
Ingredients	Functionality	BPG0	BP10	BP5	BG10	BG5	BPG5
Rock wool	Fiber	10	10	10	10	10	10
Carbon fiber		3	3	3	3	3	3
Glass fiber		5	5	5	5	5	5
Steel fiber		6	6	6	6	6	6
SiO_2	Friction Modifier	3	3	3	3	3	3
MgO		3	3	3	3	3	3
Graphite		8	8	8	8	8	8
Brass powder	Functional Fillers	8	8	8	8	8	8
Vermiculite		10	10	10	10	10	10
Phenolic Resin	Resine	15	15	15	15	15	15
Calcium carbonate	Inert filler	5	5	5	5	5	5
n-Al_2O_3	Abrasive	4	4	4	4	4	4
Bagasse	Friction/filler	0	0	0	10	5	5
Banana peel		0	10	5	0	0	5
barite	Inert filler	20	10	15	10	15	10

3. Results and Discussion

3.1. Microstructure, Density, and Hardness

Figs. 4 and 5 show the OM and SEM micrograph from the surface and a cross section of samples, respectively. The homogenous distribution of constituent can be seen in microstructure, which verified the appropriate mixing and preparation. The elemental map analysis of BPG0 sample revealed the good distribution of ingredients via microstruc-ture (Fig. 6).

Fig. 7 indicates the density changes of samples. As can be seen, the density of the samples contain-ing both natural wastes (BP and BG), decreased as the additive content increased. As the barite con-tent considered to balance the addition of the natu-ral ingredients to nanocomposite and due to lower densities of natural additives than batite, this issue can be justified. Furthermore, the density values are more dependent on its content than its type; because both natural additives have almost similar density [21-23]. The porosity measurement, ac-cording to oil diffusion test, revealed the negligible porosity in microstructure (less than 0.5 %). This indicates that the friction composite samples of the present work have a higher relative density than those of commercial parts [3, 11, 13, 14].

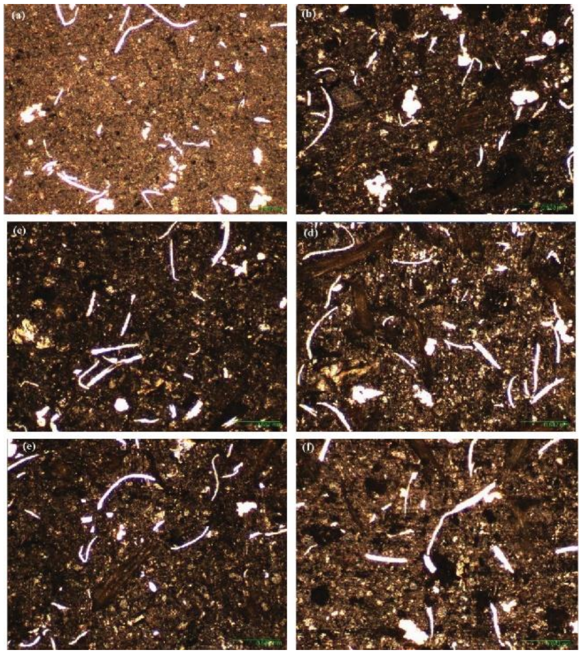

Fig. 4. Optical micrographes from composite surface, (a) BPG0, (b) BP10, (c) BP5, (d) BG10, (e) BG5, (f) BPG5

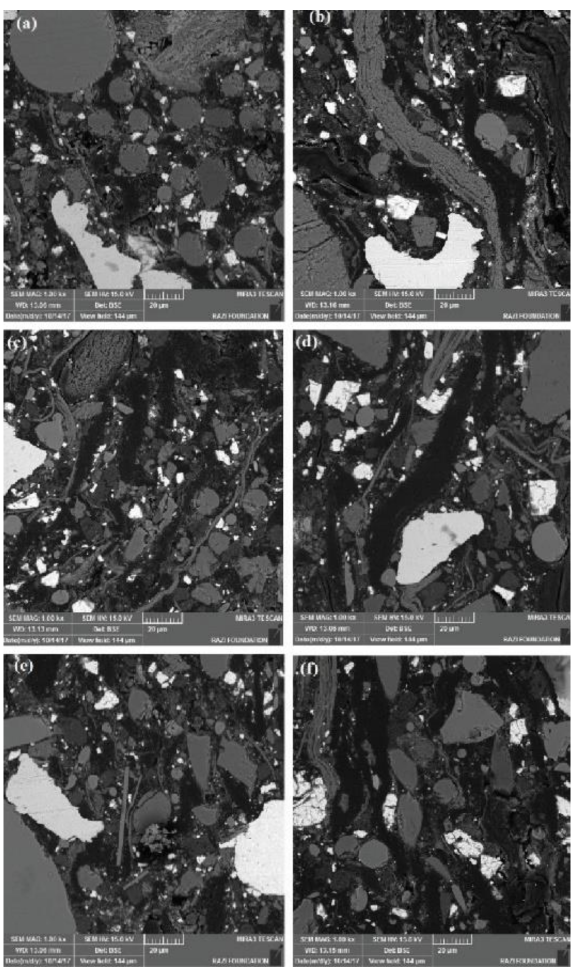

Fig. 5. Scanning electron microscopy micrographes from nanocomposite cross sections, (a) BPG0, (b) BP10, (c) BP5, (d) BG10, (e) BG5, (f) BPG5

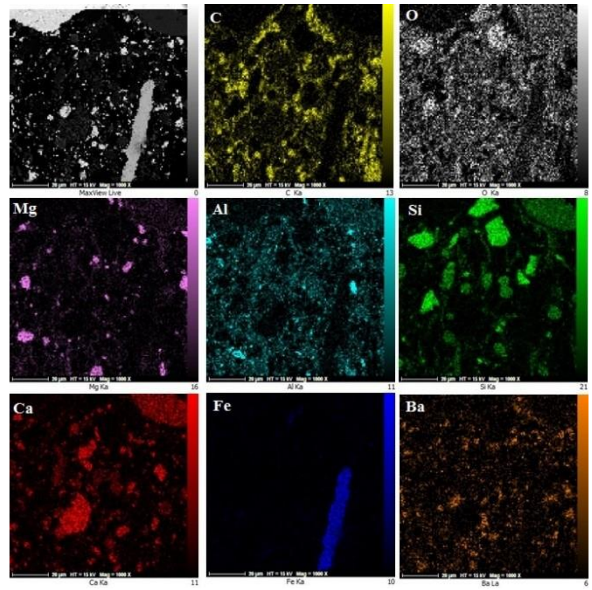

Fig. 6. Elemental map analysis of BPG0 sample

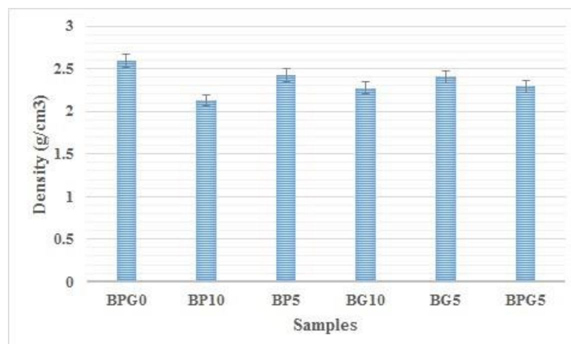

Fig. 7. Density changes' trends for nanocomposite samples

The results of the hardness measurement are shown in Fig. 8. As can be seen, in a given type of natural additives (BP/BG), as the additive contents increase, the hardness decreases. Moreover, in a given content of additive, the hardness value of BG containing nanocomposite is more than BP one. Consequently, the hardness loss of nanocomposite without natural additive is lower than the sample using BG additive.

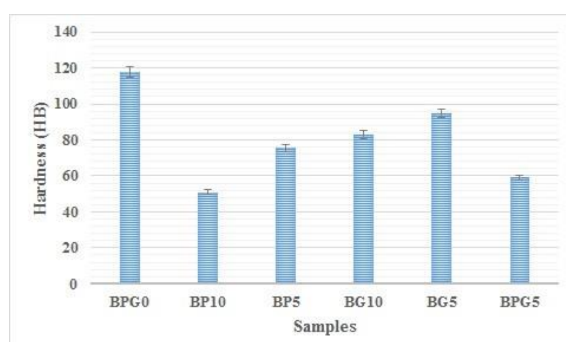

Fig. 8. Hardness of investigating nanocomposies

3.2. Wear and Friction

Table 2 gives the results of the wear test of nanocomposite samples. The comparison of wear rate feauture of nanocomposite samples is shown in Fig. 6.

In order to investigate the wear behavior, it should make the comparison in two aspects: (1) the additive content; (2) the effect of additive type. The BP5 and BG5 samples had a 14% lower wear rate than that of BPG0 (without natural additives); on the other hand, the sample containing 10 wt. % of natural wastes showed different conditions. The BG10 composite sample had about 14% higher wear rate than that of the sample without natural addi-tive. The BPG5 and BP10 samples revealed a 40% and 600% higher wear rate than the reference sample, respectively.

The wear rate comparison of BG5 and BG10 samples depicted that the increase of bagasse con-tent leads to loss of wear properties. On the other hand, the comparison of BP5 and BP10 samples showed the severe loss of wear properties as the BP content increases. In a research conducted by Aigbodion et al.[3], the samples with 30% phenolic resin and 70% bagasse fiber were investigated in which, as the fiber/particle size decreases from 710 μm to 100 μm, the hardness changes from 80 to 100 HB and the density decreases from 1.44 g/cm^3 to 1.37 g/cm^3. Furthermore, the wear rate increased [3]. All samples containing natural wastes (except BP10), had the lower specific wear rate than the reference sample (without additive) which is the evidence of high performance and life of theses samples [24]. The specific wear rate of BG5 and BP5 samples compared with Sangnark and Noomhorm's research [22] revealed that according to the fric-tion coefficient, the performance would be ac-ceptable.

The investigation of friction coefficient changes of samples in 1000 m distance during wear test for all samples is shown, the friction coefficient ob-tained steady-state condition after 200 m and re-mained constant after it. Table 2 gives the average values of friction coefficient samples.

The BPG0 sample (without additive) having the highest hardness value among the investigating samples, has a friction coefficient of 0.2. This can be due to surface mirroring effect of nanocompo-site, which leads to low friction between brake and disk. The BG5, BP5, and BPG5 samples having the friction coefficient higher than 0.3 have an ac-ceptable condition for light vehicles (0.3-0.4) [20]. Further investigation showed that there is not a direct relation between hardness and wear re-sistance. The study by Mutlu et al. [25]confirmed this issue and corresponded it to nanocomposite structure complexity.

4. Conclusions

In the present study, low-price natural waste materials, including banana peel and bagasse particle/fiber with abrasive nanaoparticles were used beside other constituents for preparation of fric-tion nanaocomposite materials. Then, the micro-structure, wear, and friction behavior was investi-gated and optimized composition selected. The re-sults showed:

- The density of friction nanocomposite sam-ples with natural wastes was ranged from 2.133-2.409 g/cm^3, which had lower values than the samples without natural additives, and the density decreased as the natural addi-tive increased.
- The sample microstructure revealed the homogenous distribution of ingredient in the composite matrix.
- The hardness of the sample with natural additives was ranged from 48-94 HB. The BG5 sample (with 5 wt. % of bagassee additive) showed the highest hardness value.
- The results of pin on disk test about specific wear rate were as follows: BP5/BG5<BG10<BPG5<BPG0<BP10
- The lowest specific wear rate for BP5 and BG5 samples was 2.5*10-8 cm^3/N.m. In all cases, the wear rate of samples with natural addi-tives compared to the samples without addi-tives revealed the lower values, which demon-strates the higher performance of brakes.

Table 2. Wear features of composite samples

Specimens Codes	Wear rate (g/m)	Specific Wear Rate (cm^3/N.m)	Average Friction Coefficient (μ)
BPG0	1.4E-06	5.02E-08	0.21
BP10	9.7E-06	2.50E-08	0.25
BP5	1.2E-06	2.50E-08	0.34
BG10	1.6E-06	3.48E-08	0.21
BG5	1.2E-06	2.50E-08	0.36
BPG5	2E-06	4.35E-08	0.31

Nomenclature

W_0	Initial weight sample (g)
W_1	final weight of wear sam (g)
ΔW	weight loss (g)
S	distance (m)
D	disk diameter (m)
N	rotational speed (RPM)
t	test time (s)
ΔV	volume loss of samples
F	applied force
μ	Friction Coefficient

Acknowledgements

Financial support of the Iran National Science Foundation (INSF- No. 94811636) is gratefully acknowledged.

References

[1] Aranganathan N, Bijwe J. Development of copper-free eco-friendly brake-friction material using novel ingredients. *Wear* 2016; 352-353: 79-91.

[2] Rongping Y, Martynková SG, Yafei L. Performance and evaluation of nonasbestos organic brake friction composites with SiC particles as an abrasive. *J Composite Materials* 2011; 45(15): 1585-93.

[3] Aigbodion V, Akadike U, Hassan S, Asuke F, Agunsoye J. Development of asbestos-free brake pad using bagasse. *Tribology in Industry* 2010; 32(1): 12-7.

[4] Ganguly A, George R. Asbestos free friction composition for brake linings. *Bulletin of Materials Sci* 2008; 31(1): 19-22.

[5] Garg BD, Cadle SH, Mulawa PA, Groblicki PJ, Laroo C, Parr GA. Brake Wear Particulate Matter Emissions. *Environ Sci & Techno* 2000; 34(21): 4463-9.

[6] Cho KH, Cho MH, Kim SJ, Jang H. Tribological Properties of Potassium Titanate in the Brake Friction Material; Morphological Effects. *Tribology Letters* 2008; 32(1): 59-66.

[7] Roubicek V, Raclavska H, Juchelkova D, Filip P. Wear and environmental aspects of composite materials for automotive braking industry. *Wear* 2008; 265(1-2): 167-75.

[8] Kukutschová J, Roubíček V, Malachová K, Pavlíčková Z, Holuša R, Kubačková J, et al. Wear mechanism in automotive brake materials, wear debris and its potential environmental impact. *Wear* 2009; 267(5-8): 807-17.

[9] Kukutschová J, Roubíček V, Mašláň M, Jančík D, Slovák V, Malachová K, et al. Wear performance and wear debris of semimetallic automotive brake materials. *Wear* 2010; 268(1-2): 86-93.

[10] Ghazali C, Kamarudin H, Shamsul JB, Abdullah MMA, Rafiza AR. Mechanical Properties and Wear Behavior of Brake Pads Produced from Palm Slag. *Adv Mater Res* 2011; 341-342: 26-30.

[11] Ghazali C, Kamarudin H, Jamaludin SB, Abdullah MMA. Comparative Study on Thermal, Compressive, and Wear Properties of Palm Slag Brake Pad Composite with other Fillers. *Adv Mater Res* 2011; 328-330: 1636-41.

[12] Kim YC, Cho MH, Kim SJ, Jang H. The effect of phenolic resin, potassium titanate, and CNSL on the tribological properties of brake friction materials. *Wear* 2008; 264(3-4): 204-10.

[13] Ibhadode AOA, Dagwa IM. Development of asbestos-free friction lining material from palm kernel shell. *J Braz Soc Mech Sci & Eng* 2008; 30(2).

[14] Ikpambese KK, Gundu DT, Tuleun LT. Evaluation of palm kernel fibers (PKFs) for production of asbestos-free automotive brake pads. *J King Saud Univ- Engin Sci* 2016; 28(1): 110-8.

[15] Fu Z, Suo B, Yun R, Lu Y, Wang H, Qi S, et al. Development of eco-friendly brake friction composites containing flax fibers. *J Reinf Plast Comp* 2012; 31(10): 681-9.

[16] American Society for Testing and Materials. Committee B09 on Metal Powders and Metal Powders Products. Standard Test Methods for Density of Compacted or Sintered Powder Metal-lurgy (PM) Products Using Archimedes' Princi-ple: ASTM International; 2009.

[17] Japanese Industrial Standard. Test Procedure of Porosity for Brake lining and Pads of Automo-biles. JIS D4418: Japanese standard Association.

[18] American Society for Testing and Materials. Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus. ASTM G99-05: ASTM International.

[19] Iran National Standard. Brake pad properties and its tests. ISIRI 586.

[20] Österle W, Dörfel I, Prietzel C, Rooch H, Cristol-Bulthé AL, Degallaix G, et al. A comprehensive microscopic study of third body formation at the interface between a brake pad and brake disc during the final stage of a pin-on-disc test. *Wear* 2009; 267(5-8): 781-8.

[21] De Gisi S, Lofrano G, Grassi M, Notarnicola M. Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: A review. *Sustainable Materials and Technologies* 2016; 9: 10-40.

[22] Sangnark A, Noomhorm A. Effect of particle sizes on functional properties of dietary fibre

prepared from sugarcane bagasse. *Food Chemistry* 2003; 80(2): 221-9.
[23] Rasul M, Rudolph V, Carsky M. Physical properties of bagasse. *Fuel* 1999; 78(8): 905-10.
[24] Ikpambese K, Gundu D, Tuleun L. Evaluation of palm kernel fibers (PKFs) for production of asbestos-free automotive brake pads. *J King Saud Univ Engin Sci* 2016; 28(1): 110-8.
[25] Algan İKA. The Effect of Metal Fibers and Borax Powders to Wear and Friction Perfor-mance on the Organic Based Brake Pads. *J Powder Metallurgy and Mining* 2016; 5: 142.