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EXTERNAL PARTICLE SHAPE ANALYSIS AND ITS EFFECT ON TRIBOLOGICAL PERFORMANCE OF DISC BRAKE

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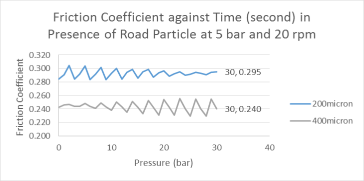
Graphical abstract



Abstract

The open design of disc brake and its location close to the road surface may lead the road particles of various sizes and shapes to enter in between brake pads and disc rotor. This study presents an experimental approach to determine the particle shape effect on friction and wear characteristics of OEM disc brake under different operating condition. Two types of external particles which are road particles and silica sand with two range of size of 200 µm and 400 µm were used. Testing was conducted for variable load and sliding speed. Presence of external particle with various size and shape affect the wear rate, friction coefficient and surface topography of the brake pad. Smaller particle generated more wear. Moreover, the particles which have sharped shape or high angularity resulted in higher weight loss of the pad and contribute to greater formation of compacted wear debris. Wear rate and friction coefficient also increase with contact pressure.

Keywords: Brake pad, external particle, wear, friction

Abstrak

Reka bentuk cakera brek yang terbuka dan terletak berhampiran dengan permukaan jalan menyebabkan zarah jalan dengan pelbagai saiz dan bentuk masuk di antara pad brek dan cakera pemutar. Kajian ini membentangkan pendekatan eksperimen untuk menentukan kesan saiz dan bentuk zarah ke atas geseran dan kehausan sistem brek OEM cakera di bawah keadaan operasi yang berbeza. Dua jenis zarah luaran iaitu zarah jalanan dan pasir silika dengan dua jenis saiz 200 µm dan 400 µm telah digunakan. Ujian diadakan dengan nilai beban dan kelajuan yang berbeza. Kehadiran zarah luar pelbagai saiz dan bentuk memberi kesan kepada kadar haus, pekali geseran permukaan dan topografi pad brek. Saiz kecil zarah akan menjana lebih banyak haus. Selain itu, zarah-zarah yang tajam bentuknya atau kesegian tinggi menyebabkan penurunan berat pad yang lebih dan menyumbang kepada pembentukan zarah serpihan terpadat. Kadar haus dan geseran pekali juga meningkat dengan tekanan permukaan.

Kata kunci: Pad brek, zarah luar, haus, geseran

1.0 INTRODUCTION

Friction and wear on the brake pad is caused by several factors such as design of the brake pad, brake pressure, driving speed, disc rotor surface roughness, loads applied, friction, power acting between the pad and disc and presence of water, dirt and external particle [1-5]. This study focuses on the effect of external particle size and shapes effect on tribological performance of disc brake. The design of disc brake that is too open and located close to the road surface may lead to the road particles to enter in between brake pads and rotor disc [3]. In disc brake system, the main factor that contributes to the wear of brake pad is the friction [6, 7]. Friction coefficient of disc brake system describes how well two objects can move against each other. It can be calculated by dividing force required to slide an object on a surface with the weight of the object. To have good braking performance, we need to have stable high friction coefficient. Friction materials for both brake pad and rotor must be designed to also best suite temperature performance. As the temperature increase, the friction coefficient starts to increase or decrease and cause the brake to wear or fades.

The variety of size and shape of external particle that presence between the surfaces of disc and pad will affect braking capability and also performance of braking system. The external grit particles like silicon carbide and silica sand that have different shapes can cause higher friction and wear to the braking system [4, 5]. Many researchers were reported to investigate the brake surface evolution by statistical and numerical approaches based on simplified structural model [8-10] but most of them neglected surface topography induced by external particles to the initial composition of the pad-disc system. It is a fact that the tribological behaviour of brake system is influenced by the external particles, which can be introduced into the pad/disc contact surfaces, like road grit particles [7], or a water spray onto the interface [5, 11]. Despite of the sensitivity of the brake pad to the environment such as external particles, there exist only a limited number of research articles reporting this issue.

This experiment will help to understand the particle size and shape effect on friction and wear characteristics of OEM disc brake under different operating condition. The testing will be following a standard braking test by applying external particle below 400 micron and under dry sliding condition.

2.0 EXPERIMENTAL

In a brake dynamometer, there are two main parts consisting of an electric motor and a hydraulic system. Kinetic energy is produced when the electric motor turns the rotor disc and then converts to heat energy which is generated at the pad and disc interface of the brake system assembly. Dynamometer is normally used to test the ability of engine to move or hold the rpm of the rotor as variable braking force and variable load applied on the engine. Type of test rig that is used in this experiment is a drag-type brake dynamometer. The rotational speed of the shaft is driven by Sumitomo type drive motor that is connected to adapter acting like a hub in real vehicle. Maximum output power and torque that can be achieved by using this DC motor are 11 kW and 413 Nm. The brake tests were carried out using brake dynamometer, as shown in Figure 1.

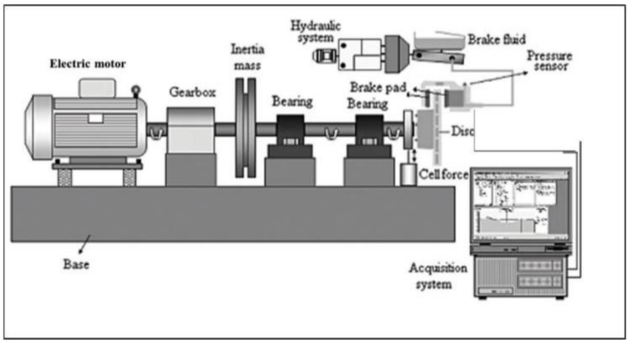


Figure 1 Schematic diagram of brake dynamometer

The dynamometer produces a brake pressure up to 2.0 MPa. Experimental data, such as disc speed, applied pressure, pad temperature and friction force were measured and recorded using data acquisition system of 16 channels Dewetron Fast Fourier Transform (FFT) analyser. The external particles were supplied using two feeder tubes which are attached to the hopper placed on the top and leading side of the brake pad. They were shielded by a transparent cover for particle orientation and distribution in the brake pad/disc gap at both piston and finger sides. The brake test procedure is partly employed from the SAE J2521 standard due to limitations of the dynamometer.

In this study, the weight of the brake pad was measured by using electronic balance before and after the test. The electronic balance that was used in this experiment has 0.1 mg resolution and maximum capacity that can be tested on it is 1200 g. Wear rate of the brake pad can be expressed as

Wear rate, w (kg/s) = (weight loss) / (sliding time)
Where:
Weight loss = initial pad weight – final pad weight
Sliding time = 60 minutes

Then, surface topography study of the brake pad was done by using Scanning Electron Microscope (SEM). From this, the size, shape, elements composition, wear mechanism, mode of abrasion, etc were determined.

3.0 RESULTS AND DISCUSSION

3.1 Wear Rate

Wear rate of the brake pad increases as the applied pressure increases. The deformed and flattened surface asperities of the brake pad will increase the friction coefficient with the pressure applied [1]. The contact between the pad and disc surface also increases as the applied pressure increases. Hence, more wear particles were generated from the contacted surface between the brake pad and disc. Wear of pad also increases with increasing sliding speed. When comparing the wear rate of the brake pad between the external particle sizes, it was found that the bigger the size of the particle, the higher the wear rate (Figure 2). The wear rate of the brake pad should decrease if the size of the particle increases. The wear rate of the composite decreases as the size of the particle becomes coarser [2].

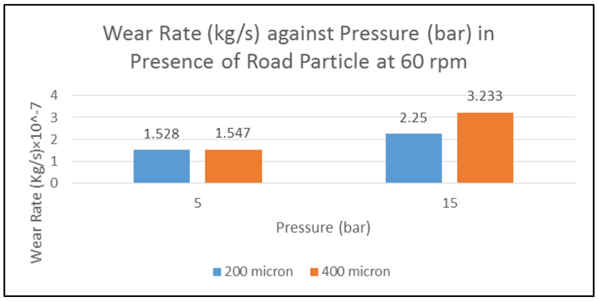


Figure 2 Wear rate for different particle size

There are other factors that can affect the wear rate of the brake pad which are the humidity and temperature. Wear rate of brake pad in presence of 400µm particle is higher than 200µm due to high temperature during test with 400µm particle. Increase in temperature can weaken the materials in contact and it may lead to thermal stress and increase wear [2].

The wear rate for the brake pad in presence of road particle is higher than silica sand for most of the experiments (Figure 3). According to the thesis by Muhammad Arsyad [6], in the study on the external grit particle effect on brake noise of disc braking system shows that the road particle promote high wear rate toward brake pad due to high hardness of the particle. Although the particle of road particle also made of silica sand, the combination between other particle make it harder compare to particle of silica sand only. Higher hardness of the external particle make it hard to embed into the brake pad and will quicker the wear rate on brake pad and disc.

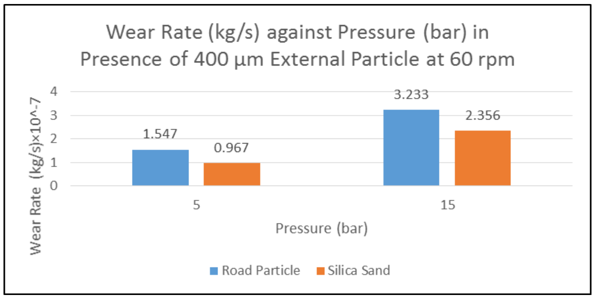


Figure 3 Wear rate for different particle type

Moreover, the particles which have sharped shape or high angularity resulted in higher weight loss of the pad and contribute to greater formation of compacted wear debris. This is due to angular corners of the particles that involve in abrading the surface of pad and disc [7]. From the graph (Figure 3) wear rate also increases as the applied pressure increases. Increase in braking pressure resulted in more effective generation of smaller wear debris [6, 7]. Moreover, wear rate of the pad increase with increasing speed. High speed will have higher sliding distance covered in one minute, hence more wear debris can be generated [4].

3.2 Surface Topography Analysis

The surface topography of the brake pad changed as the applied pressure changed for both in presence of road particle and silica sand. The clearer image in figure 4 and 5 showed that the formation of contact plateaus produced from the compacted debris was influenced by the abrasion process. On top of that, the sliding direction can be seen clearly on the plateau due to increase in pressure that produced shallow line on the pad surface. The plateau can be seen as shiny spots with dark background with the naked eye. Higher the contact pressure will also promote bigger size of plateau on the surface friction of the brake pad form either primary or secondary plateau.

The formation of two and third body abrasion are due to hard particle that function as two body abrasion and third body from the compacted wear debris [7]. The surface of the pads that exhibited craters and grooves can be used to determine whether the pad experienced two body or three body abrasion and described the mixing process at the brake interface [12]. The surface topography of the brake pad that was tested with road particles produce more grooves compare to silica sand. The surface that contains lot of grooves compare to craters is considered dominated by two body abrasion and while surface that contain lot of craters than grooves is considered to be dominated by three body abrasion.

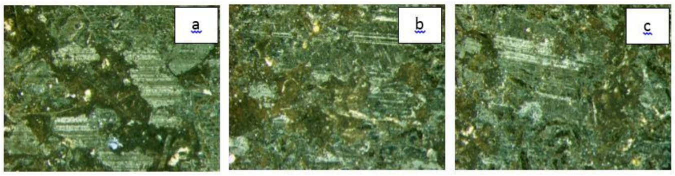


Figure 4 Surface topography at 15 bar and 60 rpm in presence of silica sand (a) left, (b) middle, (c) right of pad

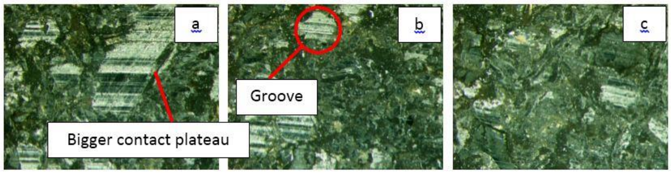


Figure 5 Surface topography at 15 bar and 60 rpm in presence of road particle (a) left, (b) middle, (c) right of pad

From the SEM images in figure 6, the experiment with road particle produced more wear debris of smaller size compare with silica sand. Larger quantity of small wear debris fills the cavities at the surface of the pad and will contribute to increase in effective contact area.

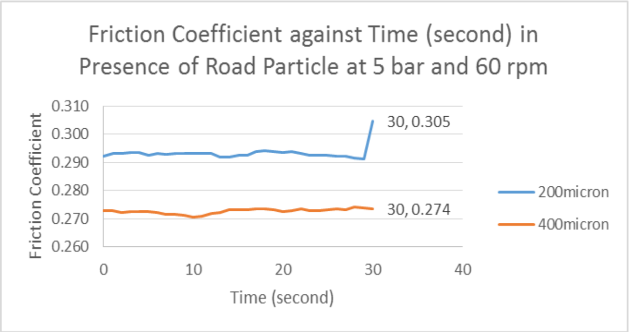


Figure 6 Surface topography under SEM at 15 bar and 60 rpm in presence of road particle

3.3 Friction Coefficient Analysis

Higher CoF value for small particles is due to mixing and changing of effective contact areas [9]. Smaller particles may fill the cavities on the surface of brake pad and resulted in rapid growth of effective contact area [3]. The particles also might provide reinforcement to the brake pad or disc that generate secondary contact plateau at sliding interface.

As we compare the graph for different sliding speed, the pattern of the graph at low sliding speed which is at 20 rpm fluctuated more compare to 60 rpm (Figure 7 and 8). We can see that the friction coefficient value at 60 rpm show a fluctuating pattern with low amplitude. This is due to smaller grit particle size that affects the oscillation amplitude at higher speed by providing more stable contact. The CoF values also increase with the increasing applied pressure. The deformed and flattened surface asperities of the brake pad will increase the friction coefficient with the pressure applied [13, 14].

From the result obtained, road particle seems to have higher CoF than silica sand at high contact pressure and sliding speed (Figure 9). The particle with high angularity or sharped shape mix with other wear debris faster resulted in rapid increase of effective contact and generation of smaller debris [2, 7]. Higher number of smaller debris seems to fill the cavities on the surface of the brake pad that will contribute to increase the effective contact area between the pad and disc.

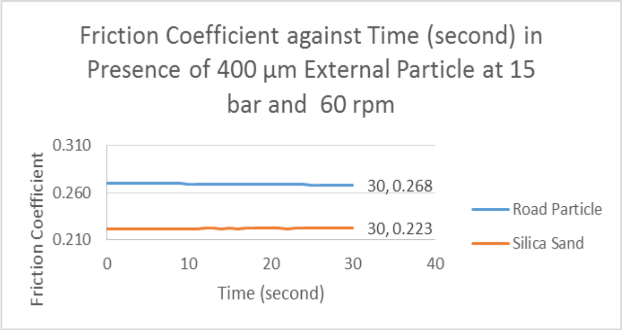


Figure 7 CoF at 20rpm for different particle size

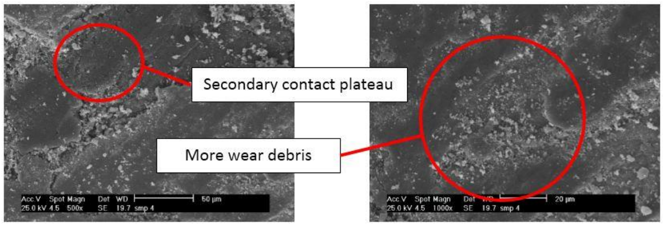


Figure 8 CoF at 60rpm for different particle size

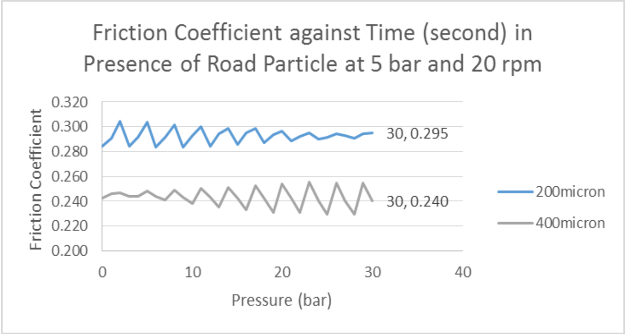


Figure 9 CoF at 60rpm for different particle shape

4.0 CONCLUSION

The following conclusions can be summarized from the experimental work done:

a) Wear rate for the brake pad increase with increasing size of the external particle. On top of that wear rate also increases as the contact pressure, sliding speed and temperature increase.

b) The sharped particle shape or high angularity resulted in higher weight loss of the pad and contribute to greater formation of compacted wear debris.

c) Formation of contact plateau can be seen clearly on the pad surface along with sliding direction on the plateau surface due to increase in pressure which produce shallow line on plateau.

d) Higher CoF value obtained for small particle. Higher sliding speed increase CoF and higher speed also produce fluctuating pattern with low amplitude. The CoF values also increase with the increasing of applied pressure.

e) Particles which have sharped shape or high angularity have higher CoF at high contact pressure. At low sliding speed, the particles with sharped shape are less significant on CoF.

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References

[1] Mat Lazim, A. R., Abdul Hamid, M. K., Jamaluddin, M., Abu Bakar, A. R. 2012. The Effect of Road Grit Particles on Brake Pad Surface Topography under Squealing Condition. SAE Technical Paper. doi:10.4271/2012-01-1821.

[2] Mat Lazim, A. R., Abu Bakar, A. R., Abdul Hamid, M. K., Kchaou, M., Elleuch, R. 2013. The Effect of Road Grit Particles on Tribological and Vibrational Aspects of Commercial Brake Pads. Europe's Braking Conference & Exhibition EUROBRAKE 2013, Dresden (Germany).

[3] Nasaruddin, M. A., Abdul Hamid, M. K., Mat Lazim, A. R., Abu Bakar, A. R. 2013. Effects of External Hard Particles on Brake Noise of Disc Braking System. Applied Mechanics and Materials. 388: 213-216.

[4] Mat Lazim, A. R., Abu Bakar, A. R., Abdul Hamid, M. K., Asri, I. M. 2014. Influence of Silica sand Particles on Disc Brake Squeal Noise. Applied Mechanics and Materials, Vol. 471, 81-85.

[5] Abdul Mokti, M. F. F., Abdul Hamid, M. K., Abu Bakar, A. R. 2016. Humidity and Water Effect on Wear Characteristics of Disc Braking System. *Applied Mechanics and Materials*. 819: 612-617.

[6] Muhammad Arsyad, A. R. 2013. The Road Particle Effect on Squeal Noise of Disc Braking System. FYP Thesis. Universiti Teknologi Malaysia.

[7] Abdul Hamid, M. K. 2010. Study of the Grit Particle Size and Shape Effects on the Frictional Characteristics of the Automotive Braking System. Ph.D. Thesis. The University of Western Australia.

[8] Wang, D. W., Mo, J. L., Ouyang, H., Chen, G. X., Zhu, M. H., Zhou, Z. R. 2014. Experimental And Numerical Studies Of Friction-Induced Vibration And Noise And The Effects Of Groove-Textured Surfaces. Mechanical Systems and Signal Processing. 46: 191-208.

[9] Mo, J. L., Wang, Z. G. Chen, G. X. Shao, T. M. Zhu, M. H. Zhou, Z. R. 2013. The Effect Of Groove-Textured Surface On Friction And Wear And Friction-Induced Vibration And Noise. *Wear*. 301: 671-681.

[10] Hetzler, H., Seemann, W. 2008. Friction Induced Flutter Instability-On Modelling And Simulation Of Brake-Squeal. *Proceedings in Applied Mathematics and Mechanics.* 8(1): 10369-10370.

[11] El-Tayeb, N. S. M., Liew, K. W. 2008. Effect Of Water Spray On Friction And Wear Behaviour Of Non-Commercial And Commercial Brake Pad Materials. *Journal of Materials Processing Technology*. 208(1-3): 135-144.

[12] Syaifullah, S. 2012. Study of Brake Wear Particle Generation during Dry and Wet Braking. Undergraduate Thesis, UTM Skudai.

[13] Jared F. 2013. Tribological Investigation on Automotive Disc Brakes. *MANE – 6960 Friction Wear and Lubrication*. 3-10.

[14] Mat Lazim, A. R., Kchaou, M., Abdul Hamid, M. K., Abu Bakar, A. R. 2016. Squealing Characteristics Of Worn Brake Pads Due To Silica Sand Embedment Into Their Friction Layers. *Wear.* 358-359: 123-136.

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