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The Effect of External Grit Particle Size on Friction Coefficients and Grit Embedment of Brake Friction Material

M.K. Abdul Hamid[a,]*, G.W. Stachowiak[b], S. Syahrullail[a]

[a]*Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia*
[b]*Tribology Laboratory, School of Mechanical and Chemical Engineering, University of Western Australia, Crawley 6009, Western Australia*

Abstract

Changes in friction and contact surfaces characteristics of a brake friction material during drag and stop mode test were investigated using a brake model tribo-tester. Scanning Electron Microscopy (SEM) was utilized to reveal the surface topography characteristics and analyze the external particle size effects on friction coefficients and grit embedment. Silica sand with three different particle sizes of 50-180 μm, 180-355 μm and 355-500 μm was used in this work. At higher disc sliding speed, results showed that small grit particles cause higher friction due to greater frequency of particles mixing and modifying the effective contact compared to bigger particles. Good friction stability was attributed to smaller particles size providing more stable contact by actively involved in building up and reducing the rate of changes of the effective contact area. Through SEM analysis, signs of formation and disintegration of contact plateaus correlated well with particle size and hence, suggesting the significant role of particle size as wearing mechanism. Grit embedment (GE) was greatly dependent on presence of compacted wear debris as most particles were found embedded into compacted wear debris. Total GE of 2.7% was observed for silica sand of 50-180 μm, 4.5% for 180-355 μm and 3.0% for 355-500 μm.

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1. Introduction

The disturbance on the operation of automotive disc brake can be linked to the presence of grit particle derived from the environment [1-4]. The open design and position of the disc brake close to the road surfaces can influence the tribological characteristics of the friction interface due to operating factors. Humidity and the presence of grit particles in the air can be factors that influence the tribological processes and indirectly affect the braking effectiveness. When the brake is applied, the contact between cast iron disc and soft polymer matrix of brake pad produce wear particles. The wear particles move homogeneously through the contact zone until the abrasive particle adheres to the disc surface and get into the contact zone [4]. However, dirt and particle from environment also may contribute to the abrasion process at the brake interface where both modes of abrasive wear, i.e. two and three body, can be present. Few external grit particles tend to embed into the friction material while some particles together with other contaminants may form a lubricating film before eventually they are expelled from the contact [5].The size

* Corresponding author. Tel.: +60 7 5534667; fax: +60 7 5566159
E-mail address: kameil@fkm.utm.my

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and shape of particles are important factors that influence the formation of transfer films on the disc surface and thus, the changes in frictional force and friction coefficient values. According to Anderson [6], friction coefficients for brake materials can be in a range of 0.07 to 0.7, but most vehicles operate within a narrower range of 0.3 to 0.6. It is expected that the friction coefficient not only should be relatively high but also stable. The coefficient of friction should be maintained at a stable level irrespective of temperature, humidity, age of the pads, degree of wear and corrosion, the presence of dirt and water spraying from the road [7, 8]. The particles also affect the wear rate of the friction material to some extent and the critical particle size is often quoted between 75 and 100 µm.

During braking, the effect of two-body abrasion tends to be a dominating mechanism while the effect of three-body abrasion is rather small. The prerequisite for the two to three body abrasion transitions to take place is that the grit particles are sufficiently strong to resist the shearing forces. If the grit particles are crushed then no wear by micro-cutting can take place. Therefore, the abrasion modes and transition between the two and three abrasion modes are important in determining the friction and wear performance of the braking system and they depend on the factors such as particle size, shape, volume percent, and particle-matrix bonding strength [9]. In this work the effect of grit particles from environment, i.e. the silica sand, on the friction coefficient (CoF) of braking system and particle embedment was studied. Three different size ranges of silica sand, i.e. between 50-180 µm, 180-355 µm and 355-500 µm, were used. The experiments were carried out on vertically oriented brake test rig at different sliding speeds and applied pressures in order to compare the changes in friction coefficient, the fluctuation of frictional force and to evaluate the particle grit embedment (GE).

2. Test rig and testing procedure

Special test rig to simulate real braking operation was developed for the purpose of this study, i.e. to conduct the drag and stop mode friction tests under controlled braking conditions. The schematic diagram with the photo of test rig is shown in Fig. 1. A series of short duration drag and stop mode tests at sliding speeds of 4 m/s, 8 m/s, 10 m/s and 12 m/s at constant pressure of 0.6 MPa, 0.8 MPa and 1.0 MPa were used to evaluate the grit particles size effects on the change of friction coefficient and particle embedment. Each particle size was tested at three repeated short braking periods. In drag mode test, the total braking time was 120 seconds with the applied load of 0.6 MPa and 0.8 MPa. Stop mode test was carried out at pad contact pressure of 1.0 MPa until the disc stop completely. Change of CoF values is related to the consistency of friction force at sliding interface and is also known as the friction stability. The term friction stability describes the consistency of friction force at different speeds and applied pressure. Therefore it can be used as brake stability indicator since to have good friction stability means to maintain the same level of friction force at different braking condition. For grit particle embedment analysis, evaluation of the grit particle embedment was conducted using SEM and optical microscopy in order to find correlations with different sliding speeds, applied pressures and particle grit sizes.

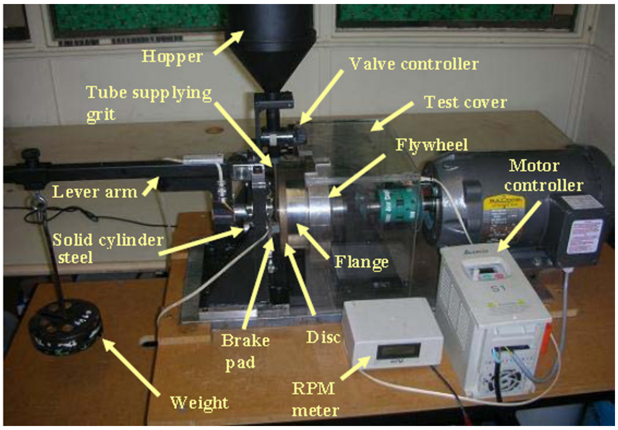


Fig. 1. The brake test rig used for the drag and stop mode tests.

3. Results and Discussion

CoF values for different particle sizes tested at various speed are shown in Figure 2. The results showed that the presence of grit particles from environment can influence the friction response significantly. Once the particles enter the gap, the value and amplitude of friction coefficient tend to change with the speed and load applied. CoF values were higher with smaller particle of 50-180 µm where they were assumed to fill up the pad cavities and increased the effective contact. However, CoF values for grit particle of 180-355 µm and 355-500 µm were lower because the bigger particles were assumed to create small interface gap and reduce the effective contact.

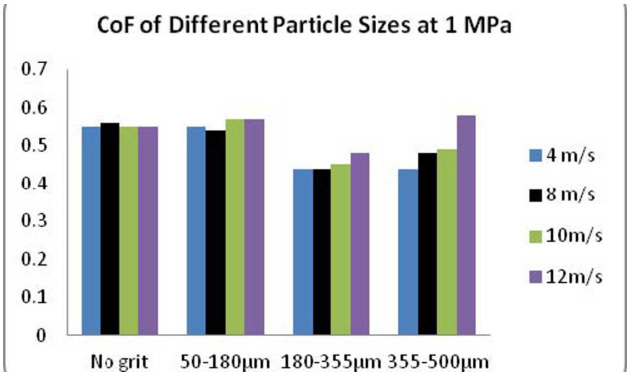
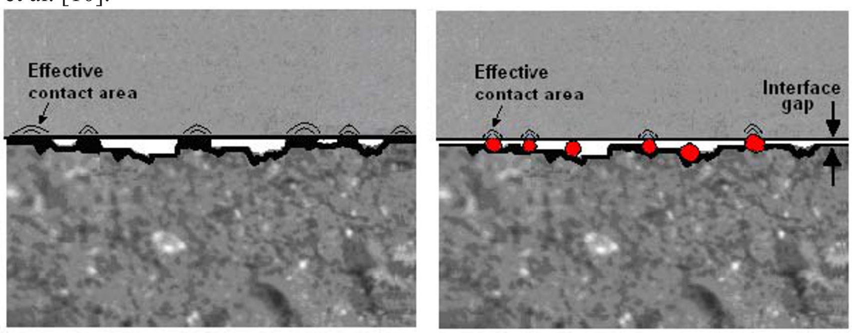


Fig. 2. The CoF values comparison with increasing grit particle sizes at four different speeds

At low speed, the larger particle size groups tend to lower the CoF values. The presence of grit particles is assumed to reduce the effective contact area as they themselves become the main contact plateau when they enter the sliding contact as schematically illustrated in Fig. 3. At medium sliding speeds of 8 and 10 m/s, presence of grit particle has similar effect but with small increase of CoF compared to no grit case. However, the CoF values increased at maximum sliding speed of 12 m/s for bigger particle size of 355-500 µm because they were assumed to roll and mix faster with other wear debris to quickly expand the effective contact area and help to accelerate the mixing process.

Average CoF values tend to increase with speed for all the cases with presence of grit particles. At lower speeds, presence of the grit particles did not seem to significantly affect the CoF values presumably due to their less active role in the generation of wear debris. However, more wear debris was generated at higher speed resulting in rapid growth of the effective contact areas due to grit particles rapidly mixing with other wear debris. In other words, the results showed that at higher sliding speeds, generation of wear debris was increased and the mixing process was accelerated. In fact, a few embedded grit particles formed primary contact plateaus themselves in the first instance and assisted in the generation of wear debris and secondary contact plateaus. Fig. 4 graphically shows the grit particles acting as the primary and the wear debris as the secondary contact plateaus at brake pad interface. These results on the formation of the secondary plateaus composed of compacted wear debris are also supported by the work of Eriksson et al. [10].



(a) (b)

Fig. 3. Changes of effective contact areas at lower speed (a) without grit particle and (b) with grit particle.

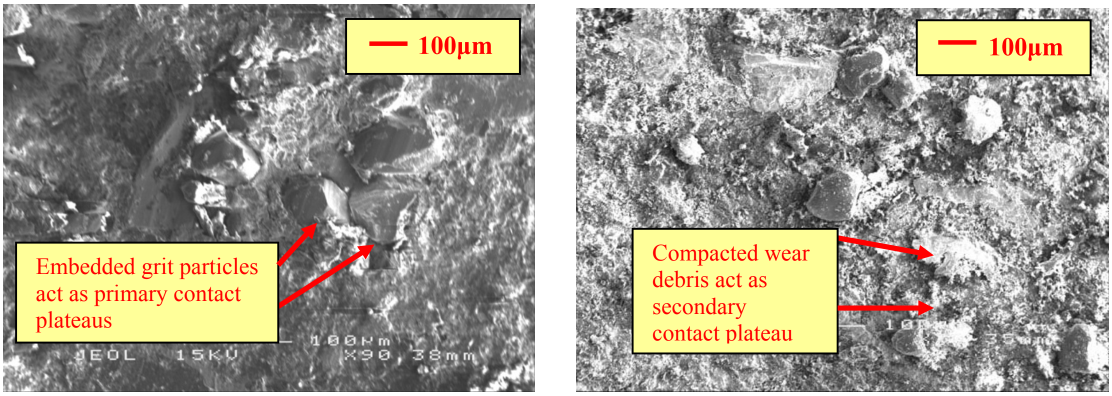


Fig. 4. SEM images of grit particles act as primary contact with wear debris as secondary plateaus at brake pad interface.

When investigating the effect of grit particle size on the particle embedment, it was observed that larger particle size of 355-500 µm tend to cover total of 3.0% of the pad area compared to 4.5% for particle size of 180-355 µm and 2.7% with particles of 50-180 µm. In drag test, no fully embedded particle was found during SEM examination for larger particles but partially embedded grits were observed in all the size ranges. Few smaller particles were fully embedded into the cavities on the pad as shown in Figure 5 for stop mode test and some were embedded next to the compacted wear debris. Difference in level of grit embedment may also due to difference in grit angularity. Smaller particles are more angular but the angularity effect on the grit embedment would need to be thoroughly investigated.

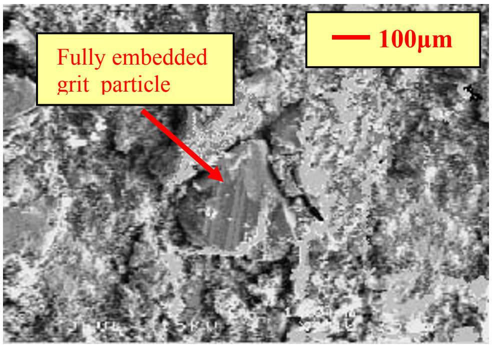


Fig. 5. Fully embedded grit particle next to compacted wear debris at contact pressure of 1.0 MPa

3. Conclusion

From this study, the experimental results showed that the external grit particles have significant effect on CoF values especially with the bigger particle which reduces the sensitivity of the CoF at lower speeds. Higher CoF values and more stable contact were recorded with small particles which actively involved in building up and increasing the rate of changes of the effective contact area. Also average CoF values tend to increase with speed for all the cases with presence of grit particles due to faster mixing of grit particle with other contaminants and GE was greatly dependent on presence of compacted wear debris. Lastly, the sliding speed and applied pressure significantly influence the percentage and level of particle grit embedment.

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