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Effect of the particle angularity on friction coefficients and grit embedment of brake material

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KEYWORDS
Hard Particles
Friction Coefficient
Particle Angularity
Grit Embedment
Brake Material

ABSTRACT
Effect of hard particle angularity on frictional coefficients and grit embedment of brake material was investigated. Silicon carbide, silica sand and garnet were used with drag and stop mode test. The spike parameter quadratic fit (SPQ) method was applied to characterize the particles angularity. Results showed that particles angularity exhibited a great influence in modifying the effective contact, wear generation and friction coefficient. Good correlation between pad specimen weight loss and grit embedment was found. Signs of formation and disintegration of contact plateaus correlated well with angularity, suggesting the grit embedment role as wearing mechanism.

1. Introduction

Due to the fact that the brake interface is hidden, covered and buried between the pad and the disc, friction behavior of brake pad material during braking post the most interesting but yet not a fully understood problem [1]. It becomes very challenging to exactly know what really happen to the contact plateaus and material interaction at the brake interface. In addition, the coefficient of friction (CoF) should be relatively high and most importantly stable. The friction coefficient should be stable irrespective of temperature, humidity, age of the pads, degree of wear and corrosion, the presence of dirt and water spraying from the road [2]. Thus, brake frictional materials are designed to provide stable frictional performance over a range of vehicle operating conditions and to exhibit acceptable durability. Despite the fact that brakes operate under a variety of environmental conditions, many laboratory tests for brake materials are conducted under dry conditions and only limited studies included the wet braking conditions [3]. Studies of variety of braking environments, i.e. with the presence of hard particles and contaminants from environment, are limited in the tribological literature.

Operation of brake pad material is often linked to the presence of hard particle derived from the environment. Different sizes and shapes of hard particles can cause increase or decrease in average friction force and momentary peak values of friction force at the braking interface. The open design and position of the disc brake to the environment can result in the disturbance to the tribological characteristics of the friction interface due to operating factors. Factors such as humidity and the presence of hard particles in the air can influence the tribological processes and indirectly affect the braking effectiveness. These difficult to control factors, i.e. hard particles and contaminants, are often present and represent serious tribological problems during braking operation.

In braking, the abrasion at the friction interface is caused by the abrasive and hard particles that are included in the composition of the brake pad. In normal braking (without external particle), the hard and abrasive particles embedded in the pad will involve in the friction process and get released due to pyrolysis of phenolic resin especially at elevated braking temperature. The particles size and shape of hard particles are two important

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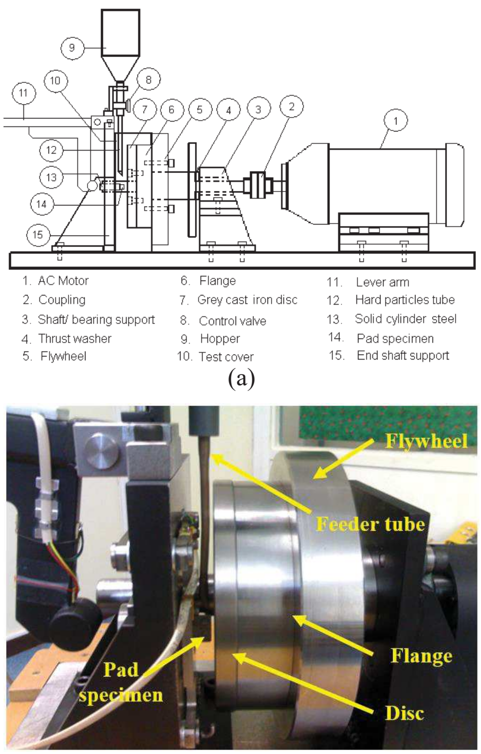
parameters that can affect friction and wear rate in sliding couple [4-5]. Recently, more attention was given to the effects of the particle sizes of the abrasives on friction performance. There have been several studies, e.g. in [6-7] on different particle size effect and their correlation with friction behaviors of braking system. Abrasive particle such as zircon, silicon carbide and alumina with different sizes are used to study the friction wear properties of brake materials. The shape of the particle protrusions also contributes to the severity of wear [8-10].

In this work, the effect of particle angularity on the frictional coefficients and grit embedment of pad material was studied using three different hard particles, i.e. the silica sand, garnet and silicon carbide. Grit embedment analysis on the pad specimen wear was performed using SEM to find possible correlation with particle angularity.



(a)

(b)

Figure 1: a) Schematic diagram and b) picture of the brake test rig developed for the drag tests.

2. Experimental Procedure

A brake test rig was used to conduct the drag mode sliding tests under controlled braking conditions. A schematic diagram and the picture of the test rig are shown in Figure 1. The microstructure of the pad material is a mixture of shiny metallic constituents of steel fiber, barium sulphate and non-metallic particles of silicon oxide within a polymeric binder of phenolic resin were identified using optical microscopy and EDX. The grey cast iron disc material contains of graphite flakes suggesting a typical cast dendritic microstructure [8].

Hard particles were supply to the gap through the small feeder tube at the rate of 2.5 gm/s. The gap between the disc and pad specimen is about 1.0 mm. The running–in of the pad specimen was done for 5 minutes using a constant braking pressure of 0.6 MPa for surface adaptation of the contact areas. Sieving for different hard particle size range was carried out using the Endecotts sieve test equipment. Hard particles were sieved for 15 min into the size ranges of 50-180 μm. A series of short duration drag tests at four different 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 was used to evaluate the effects of hard particle grit shape on friction stability. Friction stability is usually used to determine 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.

3. Result and Discussion

The SPQ values are related to the angularity of the particle and these can vary between 0 and 1. The more angular the particle is, the closer the SPQ value to 1. In this work, silicon carbide particles have the highest SPQ angularity value of 0.45 compared to 0.27 for silica sand and 0.30 for garnet. SPQ values for silica sand and garnet are close to each other due to their similar geometric shape. Previous study by Stachowiak [9] has reported SPQ value of 0.22 for silica sand, 0.25 for garnet and 0.4 for silicon carbide for grit particle of the size between 250-300 μm. From results obtained, silicon carbide grit particles generated higher CoF values compared to silica sand and garnet especially at high disc sliding speeds. At higher disc sliding speed, it was assumed that silicon carbide particles not only mixed with other wear debris faster, but their angularity resulted in higher micro-cutting process that increase the formation rate of effective contact and the generation of much smaller wear debris. Many loose wear debris of much smaller size, below 10 μm, were observed during the experiment with silicon carbide compared to silica sand and garnet as shown in Figure 2. Larger quantity of small wear debris seems to fill the cavities at the brake pad surface to contribute to the increased of effective contact area before their ejection from the contact. In addition, occurrence of grit fragmentation was recorded during the experiment with silicon carbide and these fragmented grit particles could form additional effective contact to increase the CoF value [10].

More compacted wear debris could form a friction film to reduce the friction force and CoF. In addition, silicon carbide particles resulted in higher pad specimen weight loss and contributed to greater formation of compacted wear debris at the brake surface. Hard braking test was carried out at braking pressure of 1.0 MPa until the disc was completely stopped. Increase in braking pressure resulted in more effective generation of much smaller wear debris. More silicon carbide particles were fully embedded (FE) into the pad surface or into the compacted wear debris. The CoF values for the three grit particle types are shown in Figure 3.

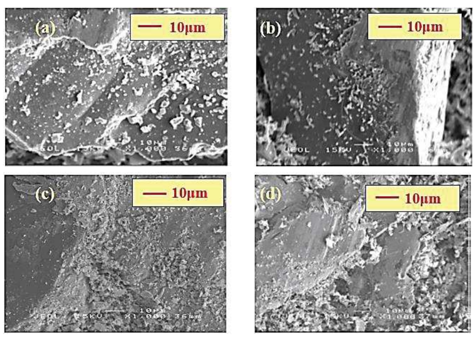


Figure 2: Numerous wear debris of the size below 10 µm observed in tests with silicon carbide (a) and (b) but lesser wear debris with (c) silica sand and (d) garnet

During hard braking test, silicon carbide resulted in lower CoF values compared to the silica sand and garnet especially at higher speeds. Silicon carbide seemed to embed more easily and involved in micro-cutting. Sharp corners of the silicon carbide particle significantly determined the occurrence of full embedment (FE). Refer to Table 1(a) for area percentage of embedment and Table 1(b) for weight loss of the pad specimen. Silica sand and garnet particles generated more wear debris at higher speeds, but many of the wear debris were ejected. Therefore, these wear debris contributed to the higher CoF values. However, at low disc sliding speed, silicon carbide particles were involved more in micro-cutting process and many sharp corners of the silicon carbide were not contributing much to the wear debris when they were involved in FE.

From the experimental results, it was found that higher SPQ value significantly affects the percentage area of grit embedment (GE). In drag mode test, silicon carbide recorded almost double the embedment of garnet and triple that of silica sand at low disc sliding speeds. At higher speeds, the embedment of silicon carbide was observed to be at least double of the garnet and silica sand. However, at lower disc sliding speeds, it appeared that the presence of compacted wear debris helped to provide softer platform at the brake pad surface for the particle GE. At higher disc sliding speeds, presence of smaller amount of the compacted wear debris was compensated by the grit particle angularity resulting in a smaller percentage of grit embedment.

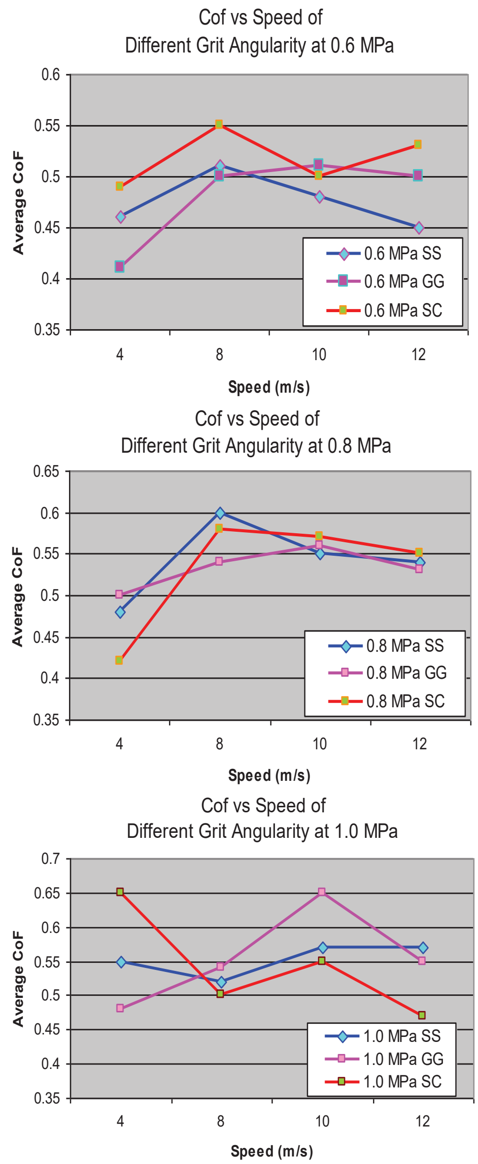


Figure 3: CoF values for the three grit particle types during drag mode and hard braking test

The percentage of silica sand embedment was found to be the lowest of the three grits tested with a maximum embedment of 0.32 %. Garnet and silicon carbide produced a maximum embedment of 0.36 % and 1.16 %. This was expected as higher SPQ values of garnet and silicon carbide contributed to the higher percentage of GE. Particle grit embedment also was found to increase with medium disc sliding speed but was reduced at maximum speeds for most of the cases.

Table 1: (a) Percentage of grit particle embedment and (b) pad weight loss during hard braking test with silica sand, garnet and silicon carbide of 50-180 µm at 1.0 MPa.

Sliding Speed (m/s)	Embedment (% Area) Silica Sand	Embedment (% Area) Garnet	Embedment (% Area) Silicon Carbide
4	0.35	0.10	0.48
8	0.45	0.56	1.04
10	0.68	0.75	1.24
12	0.45	0.42	0.8

(a)

Sliding Speed (m/s)	Weight Loss (g) Silica Sand	Weight Loss (g) Garnet	Weight Loss (g) Silicon Carbide
4	0.0249	0.0177	0.0345
8	0.024	0.0386	0.0237
10	0.0256	0.0357	0.0213
12	0.02	0.0225	0.0095

(b)

4. Conclusion

The particle grit angularity effect on frictional coefficient and grit embedment of brake pad material was investigated. Three different grit particle i.e. silica sand, garnet and silicon carbide of 50 - 180 µm were used. The change of friction coefficient and the grit embedment were measured and analyzed. Experimental results showed that:

- In drag mode test, silicon carbide grit particles generate higher CoF values compared to silica sand and garnet especially at high disc sliding speeds
- During hard braking test, silicon carbide resulted in lower CoF values compared to the other two grit particles especially at higher speeds.
- Medium SPQ value particle (i.e. garnet) was found to produce more weight loss than high SPQ value grit particle (i.e. silicon carbide) at medium speed.
- Higher SPQ values of garnet and silicon carbide contributed to the higher percentage area of grid embedment.

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