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RESEARCH

Characteristic Evaluation of Brake Block Material

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ABSTRACT

This paper reports on a comparison of the frictional characteristics of three different samples of brake block materials. Two commercial brake blocks (composite and grey iron/metallic) and a non-commercial composite brake block were extracted to form pins (specimens), and then their frictional properties were evaluated using a pin-on-disc apparatus. The non-commercial composite brake block that was investigated in this work was developed as a substitute for the grey iron brake block. The results revealed that the composite brake blocks had a higher wear resistance and were more stable in terms of their coefficient of friction at various contact pressures and sliding speeds compared to the grey iron brake block. The non-commercial composite brake block that was developed in this research had a coefficient of friction that was close to that of the grey iron brake block, and hence, it can be considered as a substitute for the grey iron brake block.

1. INTRODUCTION

Friction braking is applied to reduce the speed of a train, thereby enabling it to reach a certain lower speed or to halt at a certain stopping distance. The braking action is performed by pressing the brake blocks against wheel treads. Friction causes heat generation and a temperature rise at the contact surface. Drag braking using a grey iron brake block for 5 minutes at a contact pressure of 0.225 MPa and a sliding speed of 100 km/h causes the temperature on the wheel surface to rise until 300 ^{o}C [1].

Grey iron has been traditionally used as a material for brake blocks. Over the last two decades, a polymer composite brake block has been developed to replace the cast iron brake block. The application of composite brake blocks has some advantages in that they reduce noise [2], have a low specific wear [3], and are lightweight. To avoid excessive wear on the wheel tread surface, the wheel material should be harder than the brake block material. According to the Indonesian National Standard, a wheel made from steel containing 0.60 - 0.75 %C, 0.15 - 0.35 %Si, 0.5- 0,9 %Mn, maximum 0.05 %P, and maximum 0,05 %S, and that has been heat treated has a hardness of 255-321 HB [4]. The diameter of the wheel tread is 780 mm, with a roughness of 2.5 μm after braking with a composite brake block [1]. Meanwhile, the dimensions of the brake block are 80 mm in width, 320 mm in length, and 50 mm in thickness.

During braking, the interaction at the interface between the brake material and the wheel thread affects the frictional behaviour. The contact situation at the interface is very complex and dynamic [5]. The real contact area that forms at the interface is very small compared to the area of the friction surface of the brake material [6]. In a composite brake material, the real contact area is formed by the brake material, which consists of hard or mechanically stable ingredients [7]. Due to shear stress on the contact surface, the brake material will loosen the wear debris that can form a friction layer [8]. The composition of the friction layer affects the coefficient of friction and other tribological characteristics [9].

To have a good braking ability, the friction material should have a stable coefficient of friction. Unfortunately, the coefficient of friction of the brake block is strongly affected by the brake load, sliding speed, and sliding distance [3]. Many papers have reported that the value of the coefficient of friction decreases with an increase in the braking pressure [10,11] or with an increase in the sliding speed [12,13]. The variation in the coefficient of friction due to variations in the contact pressure or sliding speed shows the sensitivity of the coefficient of friction. The sensitivity of the coefficient of friction is indicated by the slope of the line of the friction coefficient value as a function of the contact pressure or sliding speed. It is affected by the inclusion of organic fibres [14] and binder materials [15].

In the present work, the frictional characteristics of a commercial composite brake block and a grey iron (metallic) brake block were investigated and compared with those of a non-commercial composite brake block. The non-commercial composite brake block was developed using industrial waste. The waste, comprised of cast iron chips produced in machining processes, was used as metallic filler. The use of metallic waste as an ingredient in composite brake shoes will be able to reduce the production cost. Metallic fillers are used to improve the mechanical properties, thermal conductivity and frictional characteristics of friction brake materials [11]. The iron particles in the composite brake block enhanced the coefficient of friction and wear performance [16], and maintained the coefficient of friction at elevated temperatures [17]. Semi-metallic friction materials have better wear performance than organic friction materials due to their higher thermal conductivity [18]. A pin-on-disc method was used to measure the frictional characteristics of the samples.

2. EXPERIMENTAL

In this research, the frictional properties of three different brake block samples were measured and compared. The first sample was a commercial composite brake block (C-CBB), the second one was a commercial metallic brake block (C-MBB), and the third one was a non-commercial composite brake block (P-CBB). The commercial brake blocks studied in this paper were those used in Indonesia, while the P-CBB was the composite brake block that was developed in this work. It used the following formulation: Fe (3%), glass fibre (6%), cashew dust (10%), NBR (5%), graphite (30%), phenolic resin (40%), and barite (6%). The specifications of the ingredients were:

Fe particle: particle size = 60 mesh, density = 7.35 gr/cm^3.

Glass fibre: E-Glass, , diameter = 10 μm, length = 3-5 mm, density = 2.54 gr/cm^3.

NBR powder: Baymode® N XL 38.43, size = 120 μm, density = 1,04 gr/cm^3, from LANXESS Corp.

Cashew dust: powder size = 100 mesh, from PT. Java Tohuku Industries (Indonesia).

Graphite: powder size = 100 mesh, purity = 87%.

Novolac phenolic resin: SUMILITERESIN® PR-217 I, powder size = 106 μm, melting point = 90 ^{o}C, from PT. Indopherin Jaya (Indonesia).

Barite: density = 4.5 gr/cm^3.

In this formulation, the novolac phenolic resin bound all the ingredients together so that the composite brake block was able to withstand mechanical loading. It has heat resistance properties and is widely used as binder in friction material manufacturing. Glass fibre was used as a reinforcement to provide strength to the brake material. Fly ash is categorized as an abrasive that helps to remove undesirable films at the surface of the counterpart. The NBR modified the frictional characteristic.

The mixing of the ingredients was carried out using two stages of processing. In the first stage, the powdery ingredients that were mixed were Fe, cashew dust, NBR, graphite, phenolic resin and barite using a high-speed small-scale blender (Philips HR 2115) for 5 minutes. In the second stage, glass fibres were added to the mixture obtained from the first stage, and this was followed by mixing for 10 minutes. These processes produced 80 grams of the mixture. Since a prototype of the composite brake block required approximately 3000 grams of the mixture, the mixing process was carried out 38 times to obtain the required amount of mixture. The prototype of the composite brake block was manufactured by cold moulding of the mixture under a pressure of 10 MPa. The next step, the preformed brake block was placed in the hot mould and then pressed under a pressure of 10 MPa at 165 °C for 60 minutes. Cold and hot mouldings were performed using a hydraulic press machine. These moulding processes were conducted using custom-made equipments.

The custom-built pin-on-disc tester, as shown Fig. 1, was used to evaluate the frictional properties of the samples. A pin specimen was mounted on a specimen holder that was pressed against the surface of the rotating disc. Two cylinder pins (specimens), with dimensions of 10 mm in diameter and 22 mm in length, were cut from each brake block sample. The frictional characteristics of each specimen were evaluated using the testing parameters shown in Table 1. The experiments on the first and the second test parameters used the same specimen. The measurement of the coefficient of friction and the specific wear for each specimen was repeated twice.

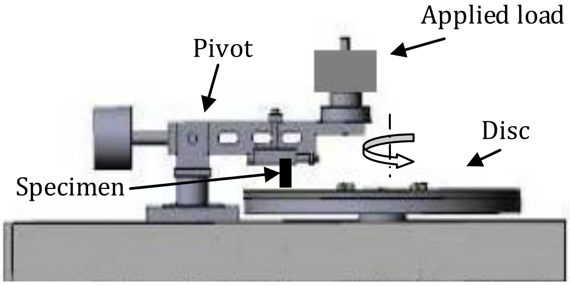


Fig. 1. Test set up of friction testing.

A rotor disc, with a diameter of 450 mm and thickness of 10 mm, was manufactured using DIN X 153 CrMoV 12 steel alloy. Its hardness and roughness were 54 R_C and 0.43 – 1.37 μm, respectively. The friction testing began by rubbing the surface of the specimen on the disc with a contact pressure of 2.5 MPa and sliding speed of 5 m/s until the entire surface of the specimen was worn out. This procedure was performed to obtain a uniform contact between the specimen and the disc before measuring the friction coefficient.

Table 1. Test parameters in friction testing.

Variation of parameter	**Contact pressure (MPa)**	**Sliding speed (m/s)**
Variation of contact pressure	1, 1.75, 2.5	5 (constant)
Variation of sliding speed	1 (constant)	5, 10, 15

The pin-on-disc apparatus was equipped with a load cell and data acquisition system (Advantech USB-4716) to measure the friction force that was generated by the sliding contact between the rotor disc and pin specimen. Data on the friction force were collected during the friction testing for 200 seconds with a capture rate of 1 data/second. The coefficient of friction was obtained by dividing the average of the friction force data by the normal force. Meanwhile, the specific wear was calculated by dividing the loss in wear volume by the normal force and the sliding distance. The friction testing for measuring the specific wear was carried out at a contact pressure of 1 MPa (196 N), sliding speed of 5 m/s, and testing duration of 20 minutes (or a sliding distance of 5950 m). The loss in wear volume was obtained by measuring the thickness of the sample before and after the test. The micro structure and worn surface of the specimens were examined by a scanning electron microscope and metallurgical microscope.

3. RESULTS AND DISCUSSION

3.1 Physical and mechanical properties

Table 2 shows the physical and mechanical properties, and the chemical composition of the brake block samples. The composite C-CBB and P-CBB materials used phenolic resin as a matrix. Both samples were different in terms of their chemical composition due to differences in the material filler and material filler concentration.

Although there were differences in their chemical composition, the physical and mechanical properties of C-CBB were relatively similar to those of P-CBB. C-MBB was a brake block that was made of grey cast iron so it was harder and stronger than C-CBB and P-CBB.

Table 2. Physical and mechanical properties, and chemical composition of brake block samples.

Properties		**C-CBB**	**P-CBB**	**C-MBB**
Density (gr/cm^3)		2.10	2.17	7.10
Hardness (BHN)		22	22	177
Flexural strength (MPa)		23	24	226
Chemical composition (%Wt):	C	44.65	62.24	3.45
	O	28.85	11.09	
	Na	01.02		
	Mg	02.25		
	Al	03.34	0.97	
	Si	08.84	1.83	1.61
	Ca	00.26	0.30	
	Fe	02.52	8.48	Bal.
	S		2.30	
	Ba		12.31	
	Mn			0.43

Figure 2 shows the microstructure of the C-CBB sample, which consisted of many different particles bound by phenolic resin. Referring to the EDS result, it was quite possible that the C-CBB contained $CaCO_3$, CaO, Al_2O_3, MgO, graphite (C), SiO_2, and iron oxide. The elements of C and O were also detected due to the presence of phenolic resin in the composite brake block. The particles of SiO_2, Al_2O_3, and CaO might indicate that C-CBB used the glass fibre for reinforcement. This indication was supported by the microstructure, as shown in Fig. 3. Glass fibre is an industrial material that is produced using SiO_2, Al_2O_3, and CaO as its major constituents.

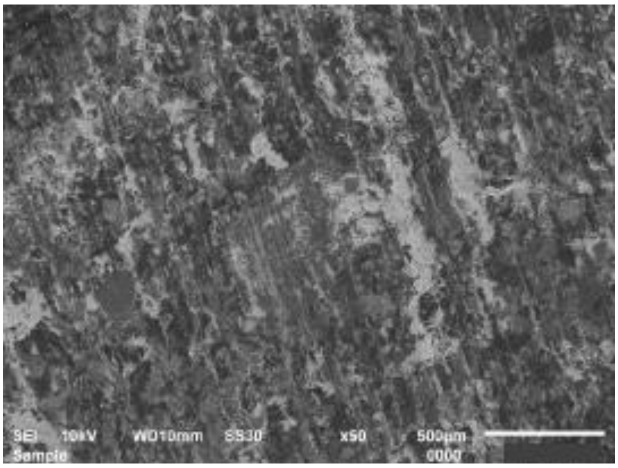


Fig. 2. Microstructure of C-CBB showing general view of surface specimen.

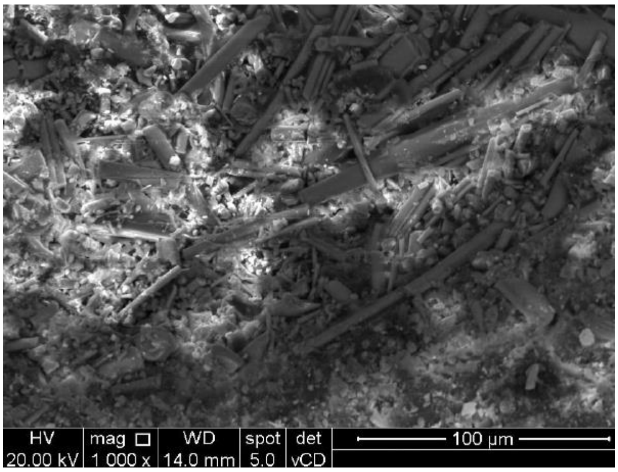


Fig. 3. Microstructure of C-CBB showing glass fibre in specimen.

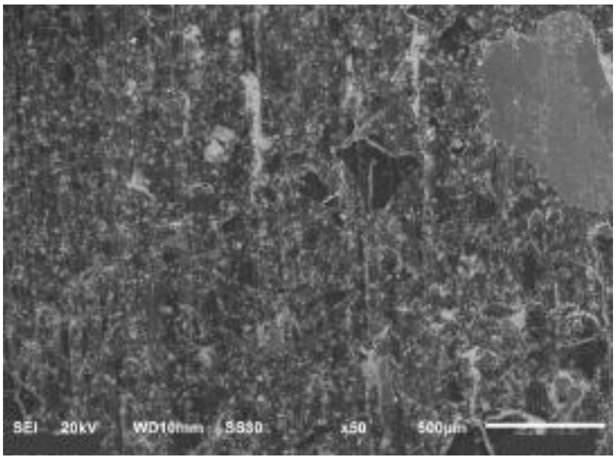


Fig. 4. Microstructure of P-CBB showing general view of surface specimen.

Fig. 5. Microstructure of C-MBB showing ferrite, pearlite and flake graphite phase.

Figure 4 shows the microstructure of P-CBB. The ingredients of P-CBB have already been described in the experimental section. The microstructure of C-MBB revealed that it was mainly comprised of ferrites, a few pearlites, and graphite flakes, as shown in Fig. 5.

3.2 Frictional properties

Figures 6 and 7 show the coefficient of friction of the sample as a function of the contact pressure and sliding speed. The results revealed that the coefficient of friction of C-MBB decreased with an increase in the contact pressure and sliding speed. The decrease in the coefficient of friction with an increase in the sliding speed was attributed to the fact that the hardness of the cast iron at the contact surface decreased with an increase in the sliding speed [19].

In a braking system design, an increase in the coefficient of friction at a low sliding speed or contact pressure should be anticipated to avoid shock braking at the end of the stop. The braking pressure needs to be controlled to compensate for variations in the coefficient of friction in order to obtain smooth braking. Therefore, the brake material must have roughly the same coefficient of friction under various braking conditions. C-CBB and P-CBB had better characteristics than C-MBB because both samples had a lower sensitivity to the coefficient of friction than C-MBB. These characteristics were indicated by the slight change in the coefficient of friction under variations of the contact pressure and sliding speed.

C-CBB had a higher coefficient of friction than C-MBB at all variations of the contact pressure and sliding speed. Meanwhile, P-CBB had a lower coefficient of friction than C-MBB at contact pressures of 1 MPa and 1.75 MPa (for a sliding speed of 5 m/s), and at a sliding speed of 5 m/s (for a contact pressure of 1 MPa). The coefficient of friction of P-CBB was relatively similar to that of C-MBB at a contact pressure of 2.5 MPa (for a sliding speed of 5 m/s), and at sliding speeds of 10 m/s and 15 m/s (for a contact pressure of 1 MPa). If the composite brake blocks are to be used to replace the metallic brake blocks in existing vehicles without requiring modifications to the braking system, then the composite brake blocks should not have a coefficient of friction that is significantly different from that of the metallic brake blocks. When the coefficient of friction of the composite brake blocks is much higher than that of metallic brake blocks, it can cause excessive wear and heat at the surface of the wheels, or wheel skidding on the track.

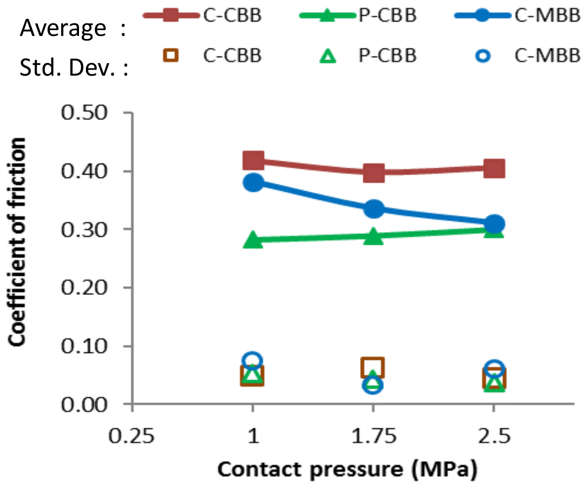


Fig. 6. Average and standard deviation of the coefficient of friction of samples as a function of contact pressure (for sliding speed constant at 5 m/s).

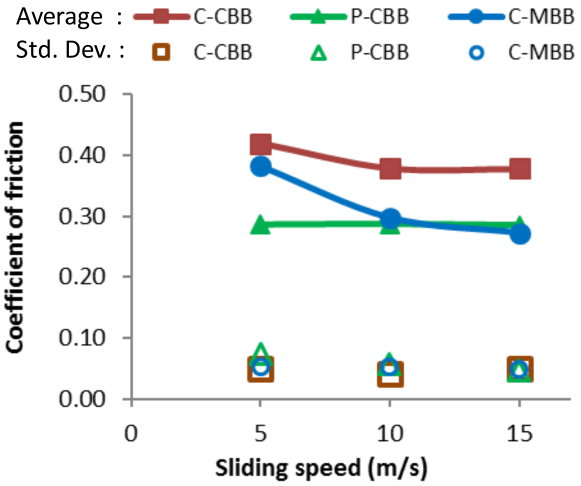


Fig. 7. Average and standard deviation of the coefficient of friction of samples as a function of sliding speed (for contact pressure constant at 1 MPa).

Figures 8 and 9 revealed that the rise in temperature on the disc surface increased with increasing contact pressure and sliding speed, respectively. The rise in temperature during the friction testing on C-MBB was lower than that of C-CBB and P-CBB, especially at a high contact pressure and sliding speed. This phenomenon was attributed to the fact that the thermal conductivity of C-MBB (grey cast iron) was higher than that of C-CBB and P-CBB. Therefore, the heat dissipation from the contact surface to the specimen and to the specimen holder on C-MBB was higher than for C-CBB and P-CBB. Meanwhile, the rise in temperature during the friction testing on P-CBB was slightly lower than that of C-CBB. This indicated that the thermal conductivity of P-CBB was higher than that of C-CBB.

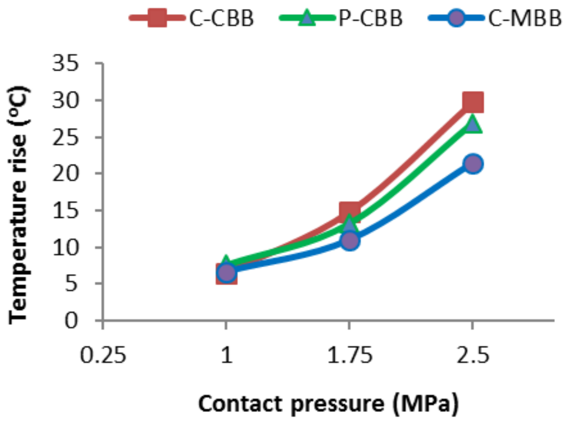


Fig. 8. Temperature rise of disc surface as a function of contact pressure (for sliding speed constant at 5 m/s).

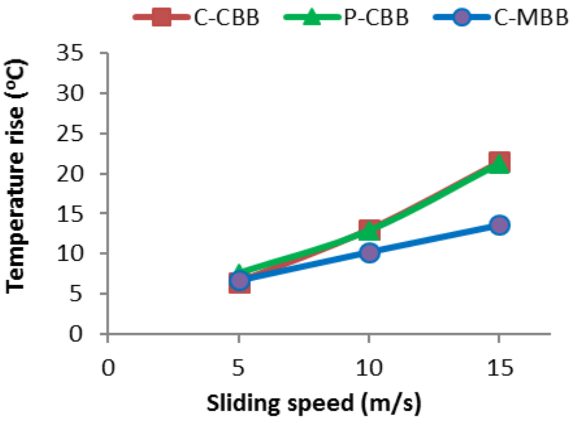


Fig. 9. Temperature rise of disc surface as a function of sliding speed (for contact pressure constant at 1 MPa).

Table 3. Specific wear of specimens.

Material	Specific wear (mm^3/Nm)
C-CBB	3.17×10^{-6}
P-CBB	2.35×10^{-6}
C-MBB	425×10^{-6}

A comparison of the specific wear of the samples is shown in Table 3. There was not much of an appreciable difference between the specific wear of C-CBB and that of P-CBB. The specific wear of C-MBB was much higher (about 100 times) than the specific wear of C-CBB and P-CBB. This result indicated that the composite brake blocks had a much longer life than the grey iron brake block. The high specific wear of the grey iron was reported in a previous paper. The specific wear of grey cast iron was 250 x 10^{-6} mm^3/Nm at a contact pressure of 0.16 MPa and a friction velocity of 3 m/s [20]. This phenomenon was attributed to the fact that the soft phase, i.e. ferrite in the C-MBB microstructure, tended to form an adhesion on the counterface [21]. Furthermore, the presence of graphite flakes in the microstructure of the grey cast iron caused a fracture in the ferrite phase, thereby generating wear debris [20]. Meanwhile, the composite specimens (C-CBB and P-CBB) had a low specific wear because they contained graphite as a solid lubricant that promoted the stabilization of the coefficient of friction and the minimization of wear through the friction layers [22].

Figure 10 shows the worn surface of C-CBB. The contact plateaus were of various sizes, as shown by the big arrow for the big plateau and the small arrow for the small one. The real areas of contact between the specimen and the disc occurred within these contact plateaus, and they were a small portion of the apparent area of the contact plateaus [6]. The contact plateaus were at a higher surface level than the surroundings. They were formed by the hard ingredients in the composite brake block, as shown Fig. 11a. This plateau was formed by glass fibres. It was indicated by its composition, which consisted of SiO_2, Al_2O_3, and CaO, as shown in Fig. 11b. The surroundings of the contact plateaus, that were major portions of the contact surface, were at a lower level than the contact plateaus, as shown by the stars in Fig. 10.

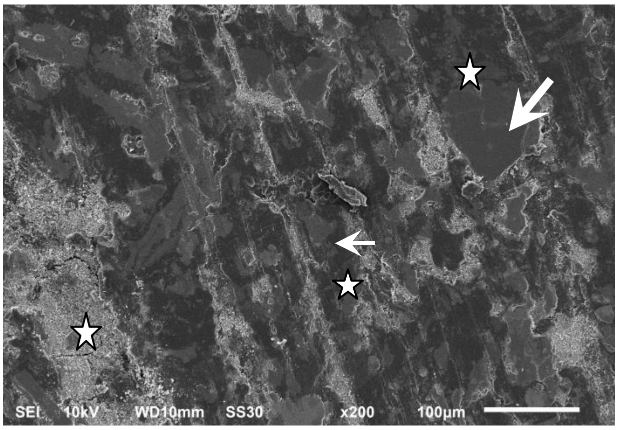
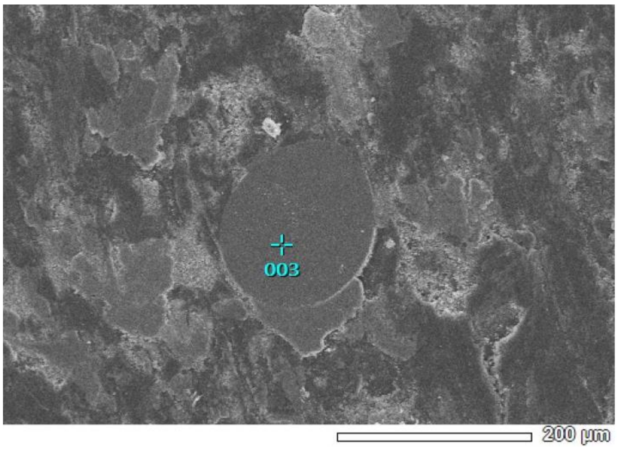
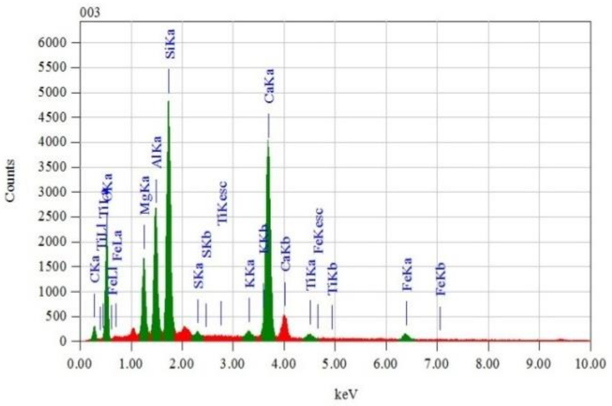


Fig. 10. Worn surface of C-CBB showing contact plateau.



(a)



(b)

Fig. 11. Worn surface of C-CBB showing: (a) contact plateau that was formed by glass fibre, (b) elemental analysis result from EDS.

The rubbing surface of P-CBB is presented on Fig. 12. A contact plateau was formed by the iron particles, as shown by the arrow. The contact between the iron particles and the disc surface induced plastic deformation, and strain hardening at this contact plateau generated iron and iron oxide wear debris, and contributed to friction due to adhesion [23]. The iron particles also had an effect on the increasing thermal conductivity of the polymer composite [24]. In reference to the previous explanation, the contact plateau that was formed by the iron particles affected the frictional behaviour of the composite brake block.

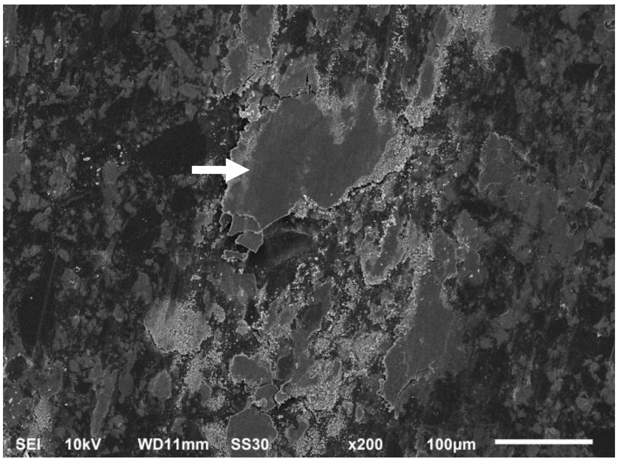
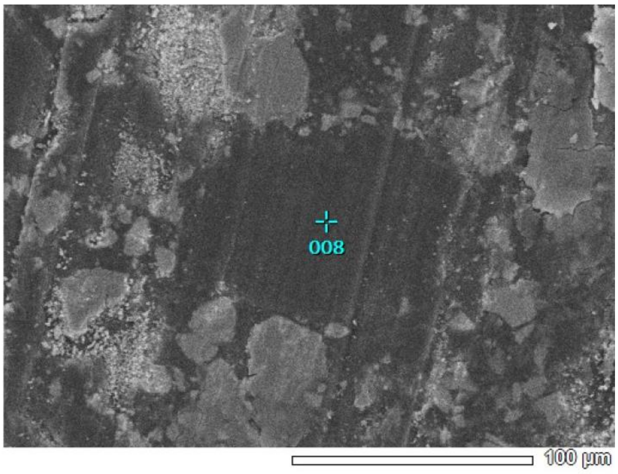
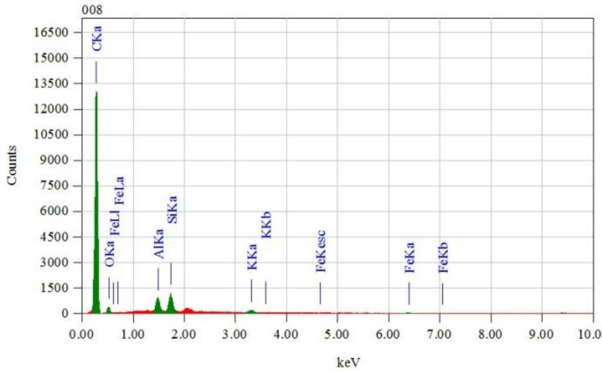


Fig. 12. Worn surface of P-CBB showing contact plateau that was formed by iron particle

Figure 13a reveals the graphite particles on the worn surface of P-CBB, while Fig. 13b reveals the elemental analysis. As the graphite particles in the composite are soft, they are susceptible to fracture or ploughing by the hard particles or asperities on the surface of the counterpart. The disintegration of the graphite particles generated wear debris to form a friction layer that played a key role as a solid lubricant at the sliding contact surface. Graphite decreased the friction and increased the friction stability of the composite brake material. It also reduced the aggressiveness on the metal surface of the counterpart [25].



(a)



(b)

Fig. 13. Worn surface of P-CBB showing: (a) graphite particle, (b) elemental analysis result from EDS.

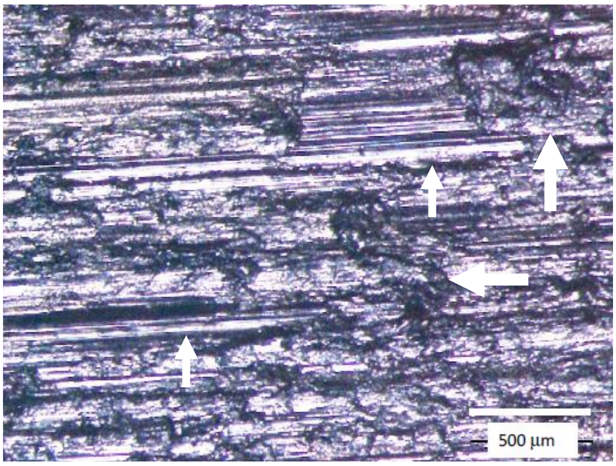


Fig. 14. Worn surface of C-MBB showing grooved appearance.

A grooved appearance on the rubbing surface of C-MBB is shown by the small arrows in Fig. 14. It indicated that abrasive wear occurred on the contact surface. The sliding motion of the disc asperity penetrated into the C-MBB surface to produce grooves that were able to generate wear particles. The sliding contact between the specimen pin and disc also generated heat that increased the temperature on the specimen pin. The hardness of the cast iron pin decreased with an increase in temperature, such that this condition reduced the shear strength and enhanced the wear rate of the specimen [19]. The big arrow in Fig. 14 shows the void on the worn surface of C-MBB. That void was attributed to the fact that friction on the contact surface might have produced large wear particle due to the failure of the matrix phase between the graphite flakes and the contact surface [20].

4. CONCLUSIONS

Three different brake block materials were evaluated using the friction test in a pin-on-disc method. However, that method could not represent the real braking conditions in a train brake system but could only be used to compare the frictional characteristics among the brake block samples. The results indicated that the composite brake blocks had a more stable coefficient of friction and higher wear resistance than the metallic (grey iron) brake block. The low sensitivity of the friction coefficient of the composite brake block towards the contact pressure and sliding speed would produce smooth braking, especially at the end of the stop. The coefficient of friction of P-CBB was close to the coefficient of friction of C-MBB, so P-CBB can be considered as a substitute for metallic brake blocks without the need for any modifications to the braking system.

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