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RESEARCH

Investigation of Friction Behaviors of Brake Shoe Materials using Metallic Filler

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A B S T R A C T

Some vehicles use brake shoe made from semi-metallic materials. Semi-metallic brake shoes are made from a combination of metallic and non-metallic materials. Metallic particles are added in the formulation of brake shoe material to improve composites characteristics. In this paper, friction behaviors of brake shoe material using metallic filler were investigated. Machining chips of cast iron and copper wire of electric motor used were incorporated in composite as metallic fillers with amount 0, 2, and 4 vol. %. Friction testing was performed to measure coefficient of friction by pressing surface specimen against the surface of rotating disc. The results show that cast iron chip and Cu short wire have effect on increasing coefficient of friction of brake shoe material. They form contact plateau at contact surface. At contact surface, the Cu short wires which have parallel orientation to the sliding contact were susceptible to detach from the matrix.

1. INTRODUCTION

Generally, brake shoes or brake pads which were applied in brake system of vehicles were manufactured using composite materials. Composite brake shoes consist of many ingredients in order to meet various requirements of brake performance. It is well known that properties of constituent materials contribute on composite characteristics. Thus, in manufacturing of composite brake shoe, the selection of ingredients, particle shape, and concentration is important for obtaining characteristics of brake shoe materials as required. There are many alternatives ingredients which can be applied in manufacturing of composite brake shoe. Some vehicles use brake shoe made from organic or completely *non-metallic* materials, and others made from semi-metallic materials. Semi-metallic brake shoes are made from a combination of metallic and non-metallic materials. In general, “low steel” of semi-metallic composite uses 10–40 % of steel fiber reinforcement [1].

Metallic particles are added in the formulation of brake shoe material to provide better properties [2,3]. They are important in composite brake shoe because they enhance the conductivity of composites and have additional functions that are to improve coefficient of friction and wear resistance [4]. Macro-particles of metal may serve as reinforcements in composite and they forms primary contact plateau at contact surface during braking [5,6]. Inclusion of metallic fillers led to an increase in μ (coefficient of friction) and decrease in μ sensitivity towards pressure, speed and temperature [7,8]. Thermal conductivity and performance of composite brake shoe increased with increasing of steel wool amount [9]. As steel fiber, copper that is mixed in composite brake shoe able to enhance thermal conductivity and provide primary contact plateau at composite surface [10]. When gray cast iron was used as a counter disk at low temperatures, the friction materials containing copper or steel fibers showed high speed sensitivity [2]. The steel wool has higher effect than aramid pulp on coefficient of friction [8]. More wear was observed in the bigger powder particles of metal comparing to the smaller ones due to more worn material during the brake action [11].

Metal particles obtained from industrial wastes have potential for using as an ingredient in brake shoe composite and substitute the commercial metal filler [12]. Utilizing metal waste as ingredients in composite brake shoe is able to reduce production cost. To manufacture composite brake shoe using metallic filler from industrials waste that have friction characteristics as specified, information about their effects on friction performance of brake shoe material are required. Only a limited number of literatures reported utilizing metal from industrial waste to use as filler for brake shoe composite. Hence, in this paper, friction properties of brake shoe material using metal waste as filler were investigated. Metal wastes used in this study were machining chips of cast iron and copper wire of electric motor used.

2. EXPERIMENTAL

In this work, cast iron chips were collected from machining workshop in ferro casting industry. They were ball milled and then sieved using 60 mesh size (opening size is 0.25 mm) of screen. The Cu short wires incorporated in composite were produced by cutting Cu wires with length less than 2 mm which were obtained from electric motor used. Diameter of Cu wire was 0.3 mm. The morphology of cast iron chips and Cu short wires are shown in Figs. 1 and 2, respectively. The composition of brake shoe material and its specimen designations are given in Table 1. Procedure of composite specimen preparation has been described in our previous paper [13]. In this experiment, three specimens for each variation of composite formulation were fabricated. A cylinder specimen with 10 mm in diameter and flat end surface obtained from specimen fabrication as shown in Fig. 3 was tested using pin on disc machine (Fig. 4).

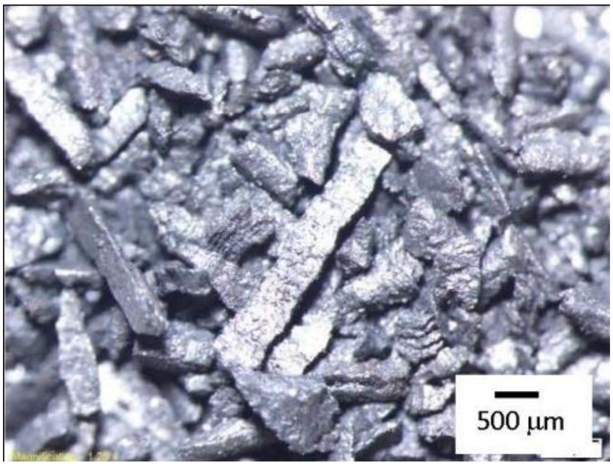

Fig. 1. Microstructure of cast iron chips.

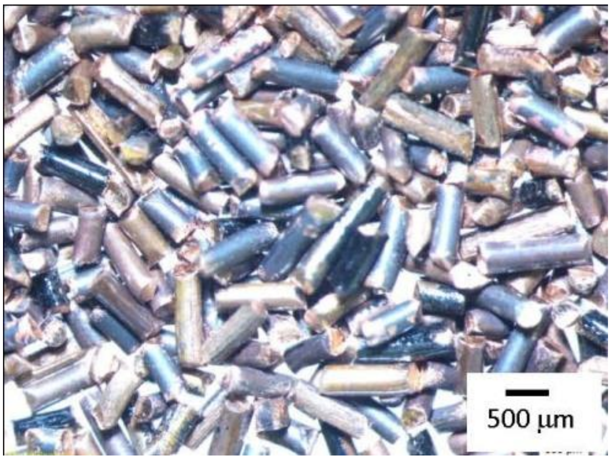

Fig. 2. Microstructure of Cu short wires.

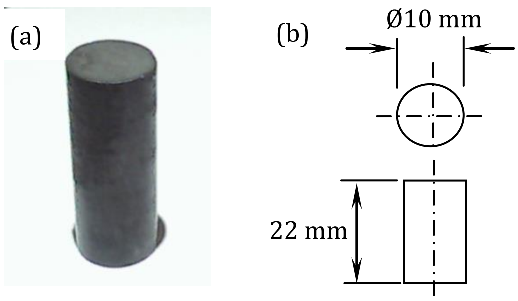

Fig. 3. Composite material: (a) fabricated composite specimen, (b) specimen dimension.

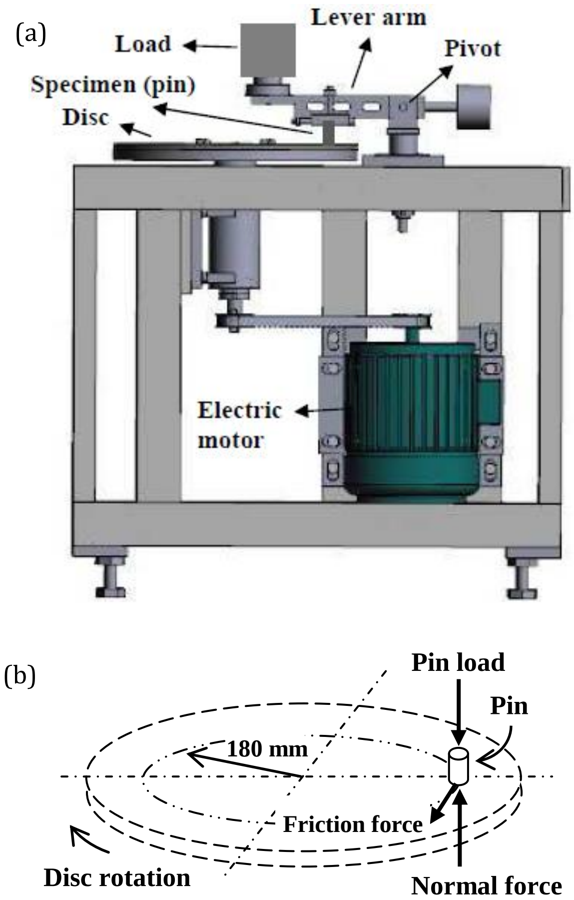

Fig. 4. Test set up of friction testing: (a) schematic of pin on disc machine, (b) Forces acting on contact surface.

The composites were fabricated using high volume fraction of graphite (30 %) in order to obtain composite which have low coefficient of friction. Brake shoe materials with low coefficient of friction are suitable to replace cast iron brake shoe for existing train application without requiring brake system modification. This is because cast iron brake shoe has low coefficient of friction when slide across on wheel tread. If the coefficient of friction of brake shoe material used is too high and existing train brake system is not modified, train will undergo wheel locking and skidding during braking due to excessive force braking.

Friction testing was performed by pressing surface specimen against the surface of rotating disc as shown in Fig. 4. The rotor disc of a DIN X 153 CrMoV 12 steel with hardness of 54 RC was used as the mating counterface. Combination of a lever arm and a pivot creates the system lever, so that, the force pressing pin against the disc is proportional to applied load. The pin specimen was inserted in its holder and the load was added to the system lever in order to obtain the selected of the normal force at contact surface. Surface roughnesses of specimens were 1.98-5.04 μm. Before the specimen was subjected to friction testing, the specimen was worn by rubbing it against the disc with contact pressure of 2.5 MPa and sliding speed of 5 m/s until wear on the specimen surface attaining 100 % of area contact, and followed by cleaning of the surface of specimen and disc. After that, the applied load and the motor speed were set as the desired value, and then friction testing was began. The coefficient of friction was not measured directly during performing of friction testing, but, it was obtained by calculation. The coefficient of friction was obtained by dividing the friction force by the normal force. When friction test was being run, the friction force at contact surface was measured using load cell that was mounted on the pin on disc machine. Data of the friction force were collected during 200 second with capture rate of 1 data/second using data acquisition system. Three specimens for each composition were tested, and two times observations of friction testing were performed for each specimen. Friction tests were performed using parameters as shown in Table 2. Contact pressure was calculated by dividing the normal force by the area of cross section of the pin specimen.

Table 1. Composition (in % volume) and specimen designations.

Ingredients	Variation of cast iron chip amount			Variation of Cu short wire amount	
	WM	2 % CI	4 % CI	2 % Cu	4 % Cu
NBR rubber, cashew dust, glass fiber, phenolic resin	57	57	57	57	57
Graphite	30	30	30	30	30
Cast iron chip	0	2	4	0	0
Cu short wire	0	0	0	2	4
Barite	13	11	9	11	9

Table 2. Test parameters using in friction test.

Variation of parameter	Testing parameter
Contact pressure (or normal force)	Contact pressure in MPa (or normal force in N) : 1 (78.5), 1.75 (137.4), 2.5 (196.2), with sliding speed was kept constant at 5 m/s
Sliding speed	Sliding speed (m/s) : 5, 10, 15, with contact pressure was kept constant at 1 MPa (78.5 N)

3. RESULTS AND DISCUSSION

3.1 Effect of cast iron chip

Figure 5 shows an example of average of friction force data that was recorded from friction testing. The corresponding coefficient of friction of this data was obtained by dividing the average of friction force (=17.346 N) by the normal force (=78.5 N), so that it was 0.220. Six data of coefficient of friction for each composition and for each variation of parameter friction testing were obtained by testing on 3 specimens with 2 observations each. Then, the average coefficient of friction and the standard deviation from the six data was plotted in figure to show effect of composition and parameter testing on the coefficient of friction.

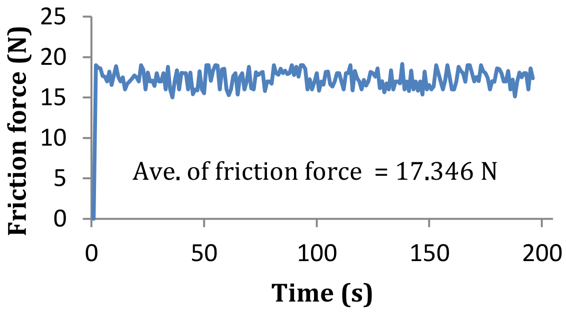

Fig. 5. An example of friction force record showing the average of friction force for WM specimen with testing parameter: contact pressure 1 MPa (or 78.5 N) and sliding speed 5 m/s.

Figure 6 shows effect of cast iron chip on average and standard deviation of coefficient of friction as a function of contact pressure and sliding speed. The results indicate that cast iron chip has effect on increasing of coefficient of friction of brake shoe composite. This behavior is attributed to the fact that cast iron chip forms contact zone with disc surface [14,15] as shown in Fig. 7. The result of elemental analysis using EDS indicated that this contact zone was formed by iron particle as shown in Fig. 8. At contact zone, cast iron chips as like as steel fiber sustain normal and friction load, and undergo plastic deformation [10,14,16]. During friction sliding, cast iron chip contributes on increasing of coefficient of friction through metallic adhesion with disc surface [2,16,17]. Shear stress at sliding contact of cast iron chip in brake shoe composite is able to generate wear debris of iron and iron oxide also, and then to form friction layer [17-20]. Iron oxides in the friction layer also are caused by wear mechanism of the steel disc [21].

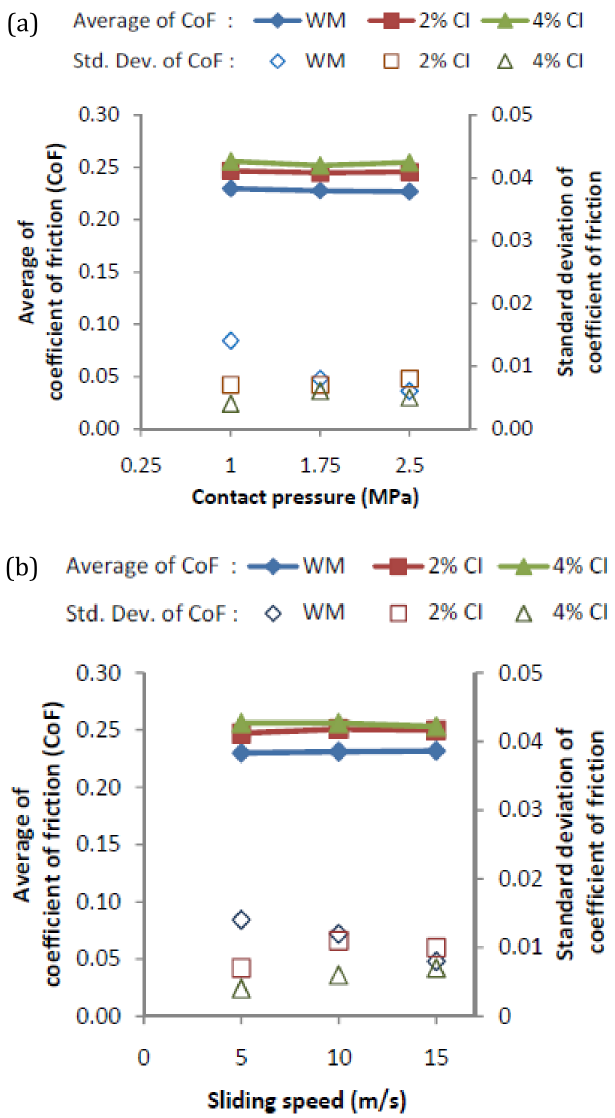

Fig. 6. Effect of cast iron chip amount on coefficient of friction as a function of: (a) contact pressure, (b) sliding speed.

Figure 6 also shows that coefficient of friction of all specimens relatively stable as a function of contact pressure and sliding speed. A different results in previous reports showed that coefficient of friction increases [22] or decreases [13,23] with increasing of contact pressure and coefficient of friction increases [22] or decreases [2,24] with increasing of sliding speed.

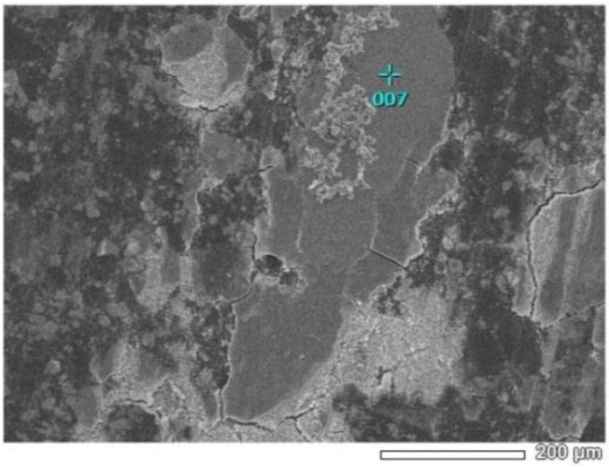

Fig. 7. Worn surface showing contact plateau of iron particle.

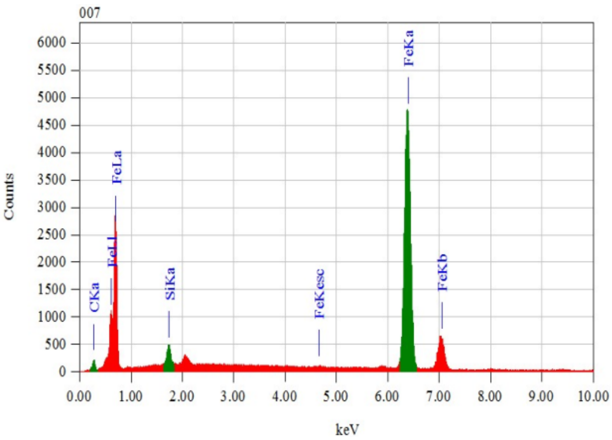

Fig. 8. The result of elemental analysis using EDS at contact plateau showing iron particle.

In this work, the volume fraction of cast iron chip has insignificant effect on changing of coefficient of friction as a function of contact pressure and sliding speed as shown in Fig. 6. It is indicated by a similar trend of the changing of coefficient of friction of WM, 2 % CI, and 4 % CI specimen for variation of contact pressure and sliding speed. Other report showed that inclusion of metallic filler tends to a decrease in the pressure sensitivity [7]. The possible reason of those different behaviours is the high volume fraction (30 %) of graphite used in the present work. During friction test performed, graphite in composite produces wear debris and forms friction layer in contact zone [14,25,26] that acts as solid lubricant between disc and composite surface [15]. Friction layer that contains high volume fraction of graphite effect on preventing adhesion and micro-welding of metallic constituents [25].

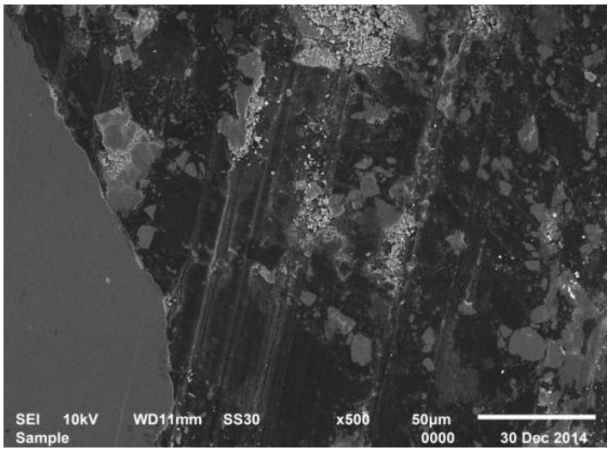

Fig. 9. SEM micrograph of 4 % CI specimen showing grooved appearance.

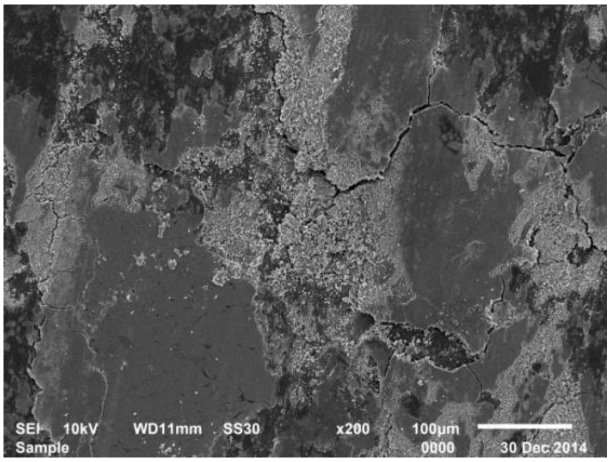

Fig. 10. SEM micrograph of 4 % CI specimen showing deposit of wear debris around the primary plateau.

Figures 9 and 10 shows SEM micrograph of rubbing surface of 4 % CI specimen. The grooved appearance is found on rubbing surface that indicates friction direction as shown in Fig. 9. This phenomenon is attributed to the fact that the asperities on disc surface penetrate into the softer surface of specimen and there is relative motion on contact surface. This mechanism is called ploughing. There are two mechanism of ploughing that is ploughing by surface asperities and ploughing by third body [27]. Figure 10 shows primary contact plateau that was formed by cast iron chip. This primary plateau is surrounded by deposit of wear debris. Due to combination of contact pressure and friction heat, wear debris that pile up around the primary plateau is able to form new plateau and it is called secondary plateau [6].

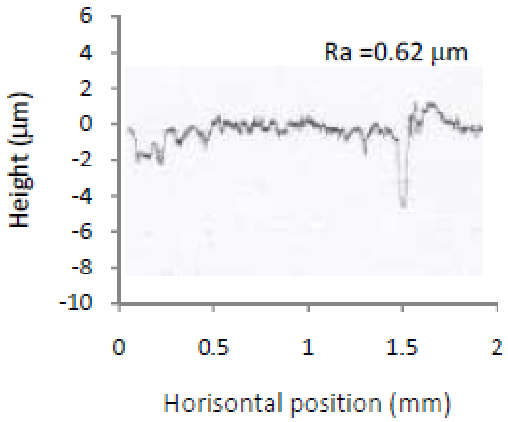

Fig. 11. Rubbing surface profile of 4 % CI specimen.

Figure 11 shows rubbing surface profile of 4 % CI specimen parallel to sliding direction with Ra value of 0.62 µm. Meanwhile, the higher Ra value of 1.48 was obtained when wear profile of rubbing surface was measured perpendicular to sliding direction. It was caused by the grooved appearance as shown in Fig. 9.

3.2 Effect of Cu short wire

Figure 12 shows effect of Cu short wire on average and standard deviation of coefficient of friction as a function of contact pressure and sliding speed. Figure 12 shows that addition with 2 % Cu has insignificant effect on increasing of coefficient of friction of brake shoe composite for all variations of contact pressure and sliding speed. It is indicated by not much appreciable difference value of coefficient of friction between WM and 2 % Cu specimen. Meanwhile, addition with 4 % Cu to composite has significant effect on increasing of coefficient of friction. Kumar and Bijwe [28] also reported that Cu had effect on increasing coefficient of friction and its effect was affected by its amount. Similar to iron particle, copper particle in composite brake shoe is able to form primary contact plateau at composite surface [10] as shown in Fig. 13. The result of elemental analysis using EDS indicated that this contact zone was formed by Cu particle as shown in Fig. 14. Although copper is soft hardness ingredient, the contact surfaces of the copper are strengthened by severe plastic deformation due to friction sliding with counter disc [10,29].

In general, Fig. 12 shows that coefficient of friction of all variation of volume fraction of Cu specimens insignificantly change as a function of contact pressure and sliding speed. It is indicated by not much appreciable difference trend of changing of coefficient of friction for variation of volume fraction of Cu as a function of contact pressure and sliding speed. A different results in previous reports showed that coefficient of friction changes with increasing of contact pressure and sliding speed [13,22-24]. The possible reason of this different phenomenon was affected by high volume fraction (30 %) of graphite used in the present work as already described.

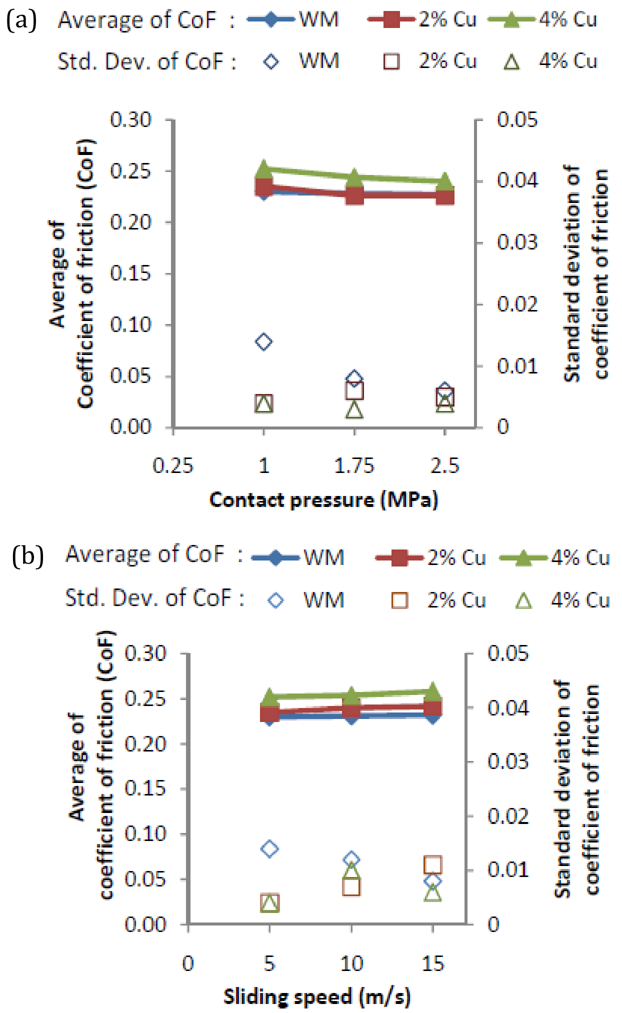

Fig. 12. Effect of Cu short wire amount on coefficient of friction as a function of: (a) contact pressure, (b) sliding speed.

Figure 15 shows SEM micrograph of rubbing surface of 4 % Cu specimen. The void is found on rubbing surface due to loosening of Cu particle during friction testing as shown Fig. 15a. This phenomenon was attributed to the fact that this

Cu short wire orientation was parallel to the sliding contact. During friction testing, the matrix and the Cu particle undergone wear process, and the Cu particle was susceptible to detach from the matrix after wear depth of composite surface attaining about half of the Cu particle diameter [30]. The loosening of the Cu particle also was affected by bonding strength between the Cu particle and the matrix. In this research, the Cu short wire was not strongly held by the matrix. Shear stress at composite surface during friction testing was higher than bonding strength between the Cu short wire and phenolic resin so that the Cu short wire torn out from the matrix. Our previous research [31] also showed that Cu short wire had insignificant effect on strengthening of flexural strength of brake shoe composite due to weak bonding between the Cu short wire and the matrix.

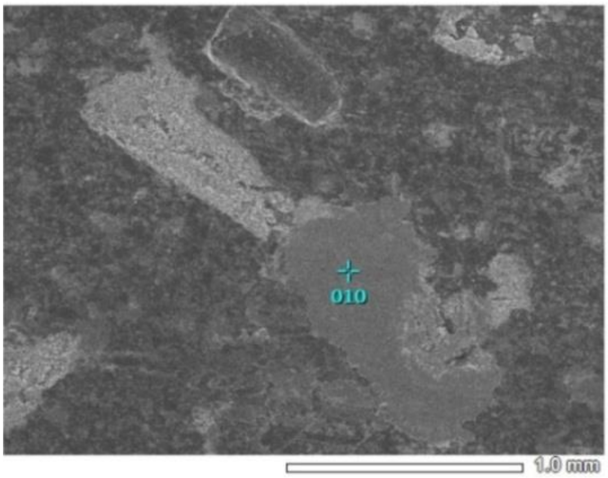

Fig. 13. Worn surface showing contact plateau of Cu particle.

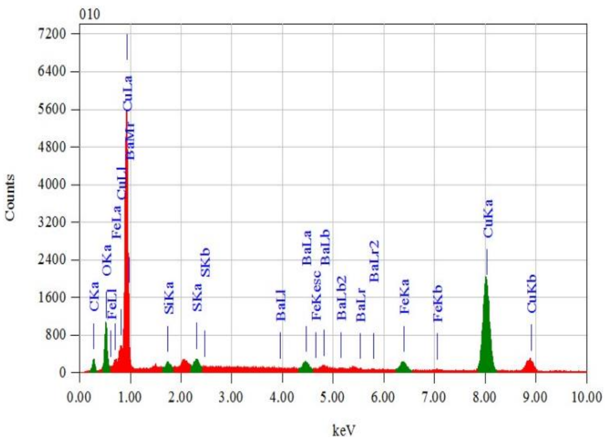

Fig. 14. The result of elemental analysis using EDS at contact plateau showing Cu particle.

Figure 15b shows the existence of void due to material removal on composite surface. This void may be caused by wear through three-body abrasion [14]. The formation of the void also is attributed to the fact that some parts of composite can be loose from the composite surface if strength of the binder bonds in composite surface is lower than the adhesive strength in the contact [32].

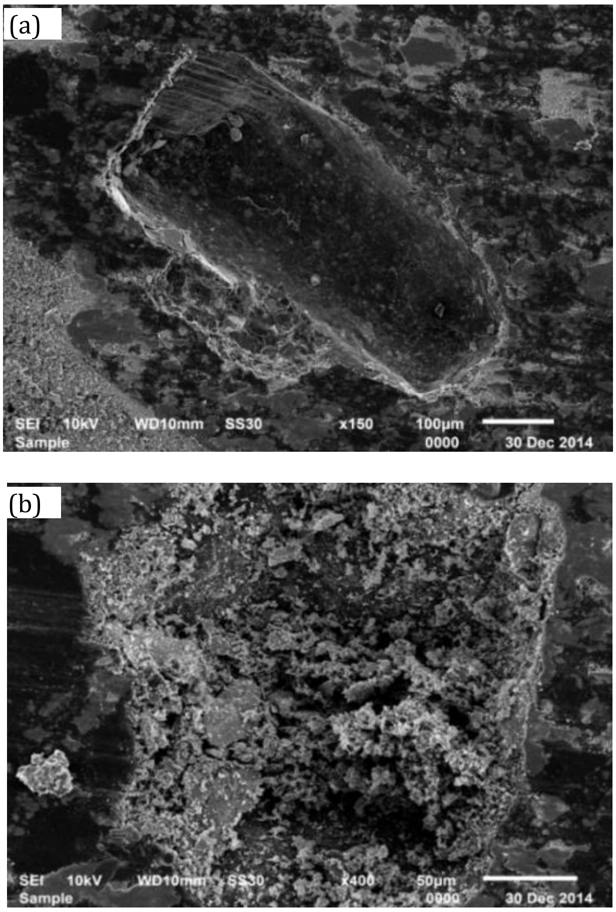

Fig. 15. SEM micrograph of 4 % Cu specimen showing: (a) void due to loosening of Cu particle, (b) void due to composite removal.

In this work, the effect of cast iron chip and Cu short wire on coefficient of friction has been studied. However, those metallic filler effect on friction characteristics of brake shoe material have not been completely evaluated. As common sense, cast iron chip and Cu short wire affect brake shoe material properties due to their contribution on thermal conductivity and hardness of brake shoe material. Therefore, further studies still have been required to fully understand effect of the metallic filler on friction characteristics. In a future, the studies will be carried out to investigate: effect of metallic filler on conductivity thermal, variation of coefficient of friction as a function of disc temperature, and aggressiveness of metallic filler on disc wear.

5. CONCLUSIONS

Cast iron chip and Cu short wire have effect on increasing coefficient of friction of brake shoe material. They have insignificant effect on sensitivity of coefficient of friction to contact pressure and sliding speed due to high volume fraction of graphite in composite.

Cast iron chip and Cu short wire form contact plateau at contact surface.

At contact surface, the Cu short wires which have parallel orientation to the sliding contact were susceptible to detach from the matrix.

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