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Effect of copper on friction and wear properties of copper based friction materials

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KEYWORDS

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ABSTRACT

The research in Copper based friction materials has been focused on the effect of material composition on its physical, mechanical and tribological characteristics, however the information on the improvement of composition and fabrication process is very limited. This research is embarked to improve the material compositions which composed of copper, iron-oxide and graphite on the Copper based friction materials. Three samples composed of copper, iron-oxide and graphite were fabricated through powder metallurgy process. Among the assessment were porosity, hardness and the tribological test which follow the international standard test procedure. Test results show that the A3 sample with the highest volume of copper percentage produces the highest porosity compared to the other test samples. Sample A3 also produced higher and stable coefficient of friction (COF) at the lowest weight loss. Based on current findings, it can be concluded that the sample A3 which composed of 85% of copper is the best formulation which can replace the available commercial carbon as it produces a higher COF and lowest weight loss.

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1.0 INTRODUCTION

Brake friction material is an important element in the braking system and the most critical components of vehicles braking mechanism are brake pads (Jang, 2013). The competency of the brake depends totally on the quality and proper composition of the brake friction materials, high coefficient of friction and less wear rate (Mortimer et al.; TAUSS, 1958). The composition selection depends on the nature of the application (Kuse et al, 1994). Proper determination of frictional materials and amounts of constituents is based on experience or by experimentation technique in developing a new formulation (Nagesh et al., 2014). The purpose of friction brakes materials is to decelerate a vehicle by changing the kinetic energy of the vehicle to heat energy, by means of friction, and dissipating that heat to the surroundings. Brake materials shall resist to corrosion, lightweight, long life, low noise, stable friction, low wear rate, and acceptable cost versus performance. According to Popescu et al., the required market performance criteria for brake pads materials shall be able to sustain a high and stable COF, in various conditions, including at high temperatures (Popescu et al., 2013). Besides that, friction materials should possess a very good wear resistant material durability in service. In addition, it also should have a good strength at elevated temperatures and high thermal conductivity (Popescu et al., 2013). All these characteristics are important because neglecting it will cause harm and risk to road safety. In order to meet the required friction characteristics, most brake materials are not made out of a single component, but rather are composites of many materials (Blau, 2001).

Friction brakes material is classified based on its composition and can be divided into five types: namely as asbestos, non-asbestos organic, semi-metallic, metallic, and carbon-based friction materials. For metallic friction materials, it can be classified as either copper- or iron-based. The copper or iron-based friction materials are typically fabricated utilizing powder metallurgy (P/M) technique because of its favourable circumstances. P/M is a continually and rapidly evolving technology embracing most metallic and alloys materials, and a wide variety of shapes. P/M process eliminates solidification-induced chemical segregation and structural defects. Powder metallurgy friction materials are powder composites made of metal matrix, friction components and solid lubricants (Lazarev, 1971). Copper-based materials have many advantages compared with iron-based such as better heat conductivity and friction resistance and widely used in aircraft, shipping and high-speed railway brakes.

Combination of numerous ingredients in Cu-based friction materials makes it a complex composite which are necessary for their friction and wear performance. If the wear behaviours and mechanisms of them could be better understood in a wide range, a series of Cu-based P/M friction materials with excellent properties could be prepared by adjusting chemical component (Jaafar et al., 2012). Cu-based materials have numerous advantages as compared with Fe-based, for example, better heat conductivity, and better wear resistance (Xiong et al, 2007). Graphite is commonly used as the lubricant in the Cu-based friction material. It is able to stable the COF at high-temperature condition (Chen et al., 2003). Adding of graphite in Cu-based will form a porrosive structure (Çeliktaş et al., 2012). According to Österle et al., one reason for using copper as pad ingredient is their excellent thermal conductivity (Österle et al., 2010). Thus, the maximum surface temperature can be controlled and the susceptibility of the system to local overheating in the form of hot band or hot spotting is reduced. However, they later suggested additional impacts of copper on brake performance are not clear.

The composition of friction material is an essential factor in achieving satisfactory performance in service. Element types and weight percentage in the composition of brake friction material shall influence the physical, mechanical and tribological properties. Thus, the optimized composition shall improve the hardness, friction and wear properties. In this project, the effect of the composition on the mechanical and tribological properties is performed by increasing one material weight percentage and decreasing the other materials according to the based formulation. The Cu-based friction materials were prepared by using powder metallurgy techniques which include mixing, compacting and sintering. The specimen was subjected to the physical test (density and porosity), mechanical test (hardness), and the tribological test (friction and wear). The optimized copper-based P/M brake friction material was selected based on the best physical, mechanical and the tribology test results.

The design and development of brake pad formulations is a well-known problem which attributes to the coefficient of friction, fade, recovery and wear over a wide range of working conditions such as speed, braking force, braking duration, temperature and environment. From time to time, technology will evolve and develop. Nowadays there are many new advances in automotive technology such as high-speed train was invented. Therefore, the design of the brake pad formulation also has to keep changes with the technological pace and development. Asbestos has been used for many years, however it has been banned in many countries due to its carcinogenic material. Consequently, several alternatives materials have been introduced and increasingly used. iron and carbon have used as additional materials which effected the Cu-based composition due to different friction and wear characteristics. However, the recent study has been focused only on the effect of material and its characteristic on brake friction but not really into the composition of friction material formulation improvements. Therefore, this research will be directly focused on improving the formulation of copper-based powder metallurgy specifically on the physical (porosity), mechanical (hardness), and the tribological properties (friction and wear).

2.0 EXPERIMENTAL PROCEDURES

In this study, the research work has going through several processes which included the materials selection, materials composition, sample preparation and characterization of the fabricated samples. The composition of friction materials was designed by changing one factor at a time to determine the volume percentage for each formulation. The sample was fabricated by using powder metallurgy process which include mixing of the powder, preforming, cold compaction and sintering process. Each sample was subjected to physical, mechanical and tribological tests for the characterization purpose.

2.1 Sample Preparation

Friction material has been classified according to its composition and categorized into asbestos or organic friction materials, non-asbestos organic friction materials, metallic friction materials, semi- metallic friction materials and carbon-based friction. In this study, metallic friction materials were selected and applied as brake pad compositions. A copper-based friction material containing high concentration of copper relative to iron and carbon was developed in this study. Carbon, copper and iron oxide materials were obtained from the local supplier company in Selangor, Malaysia.

Three samples were weighed according to different volume percentages (vol. %) of ingredients as presented in Table 1 and were prepared through powder metallurgy process. All these 3 samples were compared with commercial available powder metallurgy friction materials. The ingredients were mixed for 30 minutes in a turbula mixer model Glen Mills Turbula T2F with a rotating speed of 50 rpm. The weight ratio of 30:1 was set between the tungsten carbide ball to the ingredients weight

Table 1: Sample composition.

Ingredients	Carbon (vol. %)	Copper (vol. %)	Iron oxide (vol. %)	Total (100%)
A1	7	65	28	100
A2	5	75	20	100
A3	3	85	12	100
Commercial	2	75	23	100

The mixed powders were compacted to a size of 25 mm x 25 mm x 5 mm at a pressure of 625 MPa (18 ton) using an automatic hydraulic press (Carver, USA). The compacted samples were sintered in a tube furnace at temperature of 960^{o}C under nitrogen based (95%N2, 5%H2) in a tube furnace.

2.2 Testing and Analysis

Each developed sample was subjected to hardness, porosity and friction test in accordance with the international standard procedures. Table 2 listed the instruments and standard test methods used to measure the physical (porosity), mechanical (hardness) and tribological (COF and weight loss) properties of the test samples.

Table 2: Equipment and standard method used for testing.

Testing	Instrument	Standard Test Method
Shore hardness test	Durometer hardness tester scale D	ASTM D2240
Porosity	Tech-Lab Digital Heating Calculator	JIS 4418
Friction and wear	CSM Pin-on-Disc Tribometer machine	ASTM G 99

2.2.1 Shore Hardness Test

The data for microhardness of the samples was obtained according to American Standard Test Method ASTM D2240 using Durometer hardness tester scale D. The hardness value was determined by the penetration of the Durometer indenter into the sample. Measurements were taken by indenting at five locations in each specimen. The maximum, mean and minimum values of shore hardness (Scale D) were determined from the five readings on each specimen.

2.2.2 Porosity Test

Porosity is defined as the percentage of the volume of the absorbed oil relative to the volume of the test piece. The porosity of the samples was measured using Tech-Lab Digital Heating Calculator. The test was conducted in accordance with Japanese Industrial Standard JIS 4418. The sample size for porosity test have a dimensions of 25 x 25 x 5 mm. Each test was calculated individually and rounded to two significant figures in accordance with MS ISO 31-0. The porosity was calculated by using Equation (1);

$$P = \frac{m_2 - m_1}{\rho} \times \frac{1}{V} \times 100 \quad (1)$$

Where,
P is the porosity (%);
m_1 is the mass of test piece (g);
m_2 is the mass of test piece after absorbing oil (g);
ρ is the density of test oil g/cm3; and
V is the volume of test piece (cm3).

2.2.3 Friction and Wear Test

Friction and wear test of the friction material was performed on CSM Pin-on-Disc Tribometer machine. The tests were carried out at a room temperature by applying a load of 10 N for a sliding distance 1 km with a rotating speed of 0.035 m/s. The machine used an Alumina ball with 6 mm diameter as the static partner. The static ball was used to slide at a radius of 6 mm on the samples. All the test samples were tested on same load and speed. The weight of ball and sample were measured before and after test accomplished to determine the weight loss for wear rate calculation. The test was conducted in accordance with American Standard Test Method ASTM G 99. The wear rate shall be calculated by using Eq. (2).

$$Wear\ rate\ \left(\frac{g}{s}\right) = \frac{weight(g)}{distance\ (cm)} \times speed\ \left(\frac{cm}{s}\right) \tag{2}$$

3.0 RESULTS AND DISCUSSION

3.1 Material Properties

The results for shore hardness test and porosity is presented in Table 3. The results show that sample A3 which possesses the highest volume percentage of copper produces the highest porosity compared to other test samples. It was also observed that the shore hardness of all test samples is slightly lower than commercial available sample as shown in Table 3. The highest value of hardness for sample A2 is taught due to highest composition of metallic materials (copper and iron powders) in the formulation. Too hard indicates that the material is brittle while too soft indicates that material is porous, low density and higher wear rate.

Table 3: Test Results.

Sample	Hardness (Shore D)	Porosity (%)
Commercial	86.2	26.1
A1	81.1	27.3
A2	82.7	29.3
A3	82.1	35.3

Figure 1 shows the relation between the porosity properties with vol.% of copper in the composition. It is shown that all the test samples have higher porosity than the commercial sample. Sample A3 that has the lowest carbon content produced the highest porosity among the samples. The low carbon content in A3 sample has reduces the fill between the particles and creates more pores. Based on these results, it can be concluded that porosity shall increase by increasing the volume percentage of carbon content.

Porosity has significant influence on the materials ability to withstand wear and to reduce noise. Besides that, it is essential to absorb the heat in brake pad friction materials for the effectiveness of the brake system. Porosity also affects resilience (able to return to normal shape after stretching) and compressibility which both of it can also affect brake effectiveness. However, porosity is needed in certain amount in brake pads as to reduce influence of water and oil on the friction coefficient.

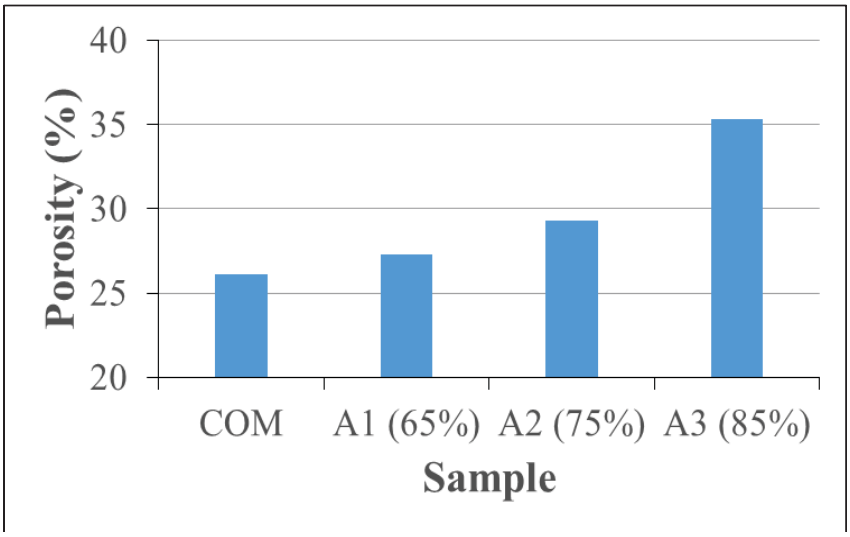

Figure 1: Effect of copper on porosity behaviours.

3.2 Coefficient of Friction

The results of coefficient of friction (COF) for all the test samples over the sliding distance are shown in Figure 2. It can be seen from the graph that all the test samples have higher COF than sample using commercial carbon. This shows that activated carbon can be used to replace the commercial carbon. It was noticed that sample A3 with highest copper powder composition produces the highest and stable COF compared to other. Sample A1 also produced similar COF behaviour (with A3 sample) in the early stage of sliding. This is because A1 sample composed lower copper but had higher iron powder in the formulation compared to the other test samples. According to the Society of Automotive Engineer standard SAE J661, the sample A3 with minimum COF of 0.216 has already meet the minimum requirement of COF. Brake pad should have a COF not more than 0.5 for brake friction material. If COF is more than 0.5, it will result the moving vehicle to dive during deceleration process which will not be comfortable experience to the driver as well as the passenger.

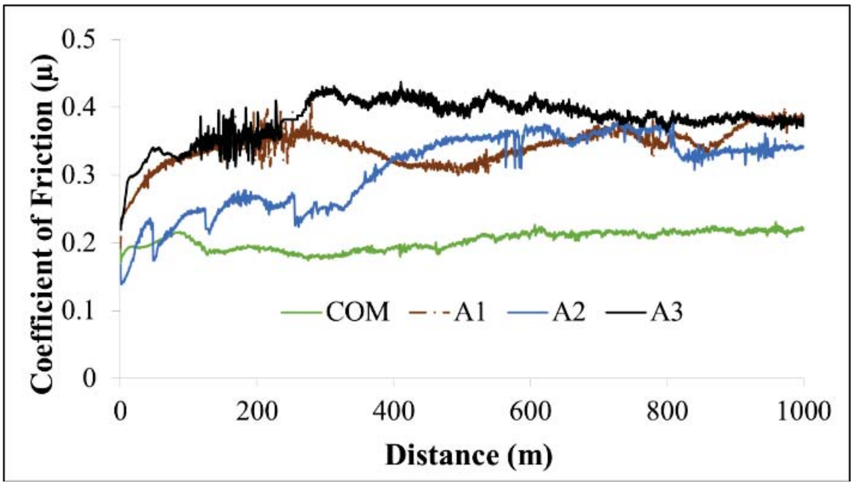

Figure 2: Effect of Carbon on COF behaviours.

3.3 Weight Loss

The lowest weight loss was observed for sample A3 which composed of higher vol. percentage of copper in the composition as shown in Figure 3. Higher copper vol. % in the composition shall increase the thermal conductivity of the sample, thus reduce the surface temperature during braking process. The low wear rate present in this formulation potentially extend the brake pad operating life. This is supported by the findings that the rapid weight loss occurs above the temperature of 260°C was due to oxidative decomposition (Beg & Pickering, 2008). Thus, it can be concluded that sample A3 which composed of 85% vol. percentage of copper is the optimum percentage to be used in the formulation. In addition, test sample A3 also has the lowest amount of activated carbon and higher amount of copper and iron in the sample. Sample A2 it is not suitable for brake friction material due to higher weight loss.

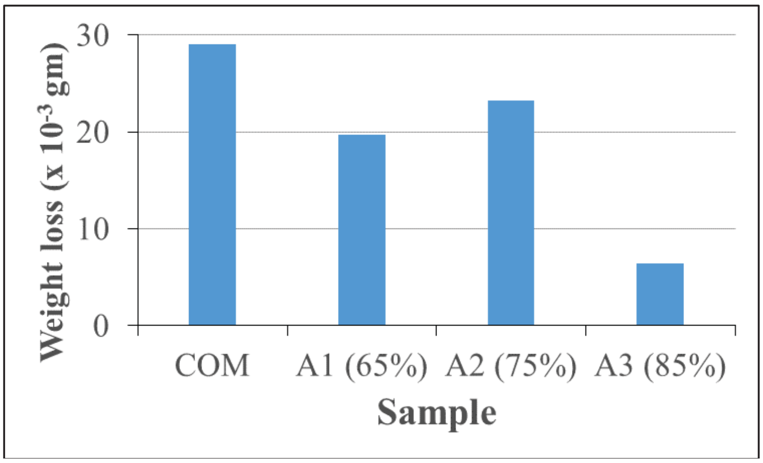

Figure 3: Weight loss characteristics of different vol. % of carbon in the formulation.

4.0 CONCLUSION

In the present study, three formulations of Cu-based friction materials have been tested and evaluated to investigate the effect of copper on physical, mechanical, and the tribological properties. During brake application, friction and wear occurs at the same time. The higher the friction coefficient is; the better performance brake will be produced. The test results show that porosity and hardness properties for copper-based friction materials were found to be better at composition of 3% graphite, 85% copper and 12% Iron oxide. The results demonstrate that this composition designated as sample A3 relatively have stable COF as well as the lowest weight loss.

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