Mekanika: Majalah Ilmiah Mekanika

Frictional Characterization of Gray Cast Iron Train Brake Block Using a Reduced Scale Dynamometer

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The brake block is an important component that serves to slow down and stop the train. The safety of this transportation is very dependent on the reliability of this component. One of the important features of the brake block material is the coefficient of friction. The coefficient of friction of the brake block material should fullfil the requirements. The coefficient of friction of a material is measured using a friction test. Many friction testing methods have been developed to study the characteristics of friction materials. In contrast to previous studies, in this study, the frictional characteristics of gray cast iron brake blocks were evaluated using a reduced scale dynamometer. The friction test is carried out by pressing the brake block specimen to the surface of the rotating wheel. The specimen size of the brake block and carriage wheels is reduced to 1/4 of the original size. The friction test is carried out at a contact pressure of 0.15, 0.20, 0.25, and 0.30 (MPa) and the friction speeds of 3, 6, 9, and 12 (m/s). The results of this study indicate that the coefficient of friction of the gray cast iron brake block decreases with increasing sliding speed and contact pressure.

1 Introduction

Transportation has a very important role in people lives. In its operations, transportation also has safety standards that must be met so that humans are not harmed in its use, such as trains. Trains will not operate safely without a braking system. The braking system is necessary to stop and reduce the speed. For trains to function as a transportation system, a reliable braking system is needed. Reliable braking includes several components that have their respective specifications, functions, and working methods [1].

One of the braking components in a train is the brake block. Rail safety is very dependent on the reliability of this component [1]. The brake block will rub directly against the wheels of the train, then convert the kinetic energy into heat energy through the friction that occurs so that the train can stop. Based on this function, the brake block material must be lower in hardness than a train wheel and have several properties that support its function.

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In general, the material used as material for railway brake blocks in Indonesia is gray cast iron [2]. Its high vibration damping properties, good heat dissipation and wear resistance make grey cast iron used for railroad brake blocks. Gray cast iron has several important properties that are associated with factors that influence wear, such as the type of material subjected to direct contact, geometric parameters (shape, size, and surface hardness), loading, and environmental conditions [3].

In the development of railroad brake blocks, testing of the brake block material capabilities is required. One of the important material capabilities of the brake block is its friction characteristics [2]. A crucial friction characteristic of the brake block material is the coefficient of friction [1]. The coefficient of friction of the train brake block can be measured by means of a friction test. The value of the friction coefficient (μ) of a material is influenced by braking conditions, including contact pressure, sliding speed, and friction distance [4].

Many friction methods have been developed to study the friction characteristics of brake blocks. To date, most of the friction and wear characteristics of brake blocks were tested by the pin-on-disc, block-on-disc, ball-on-disc, or full-scale dynamometer method [4–7]. In this study, the material of gray cast iron brake block was tested for friction using a reduced scale dynamometer. The test is carried out by rubbing the brake block specimen against the wheel surface. The specimen size of the brake block and railroad wheels is reduced by 1⁄4 to its original size.

The frictional characteristics of a material are influenced by braking conditions (friction speed and contact pressure), therefore this study aims to obtain the friction characteristics of gray cast iron brake blocks on the sliding speed and contact pressure. The results of this test are expected to be used as a reference and comparison of composite brake blocks.

2 Experimental Methods

2.1 Microstructure observation

Observation of the microstructure aims to determine the content of the particles in the casting and find out if there are defects in the casting. This observation can show the distribution of the reinforcing material present in the test specimen. This microstructure is carried out without using an etching solution because this observation is only focused on knowing the shape, size, and distribution of graphite. Observation of the microstructure was carried out using an optical microscope.

2.2 Hardness testing

Hardness testing aims to determine the hardness of a material. Hardness testing in research refers to the ASTM E10 standard. Hardness testing is carried out at 3 points for each specimen. Indenter steel ball 2.5 mm diameter, load 187.5 kg and loading time 30 seconds. The Brinell hardness testing scheme is shown in Figure 1 and the hardness test specimen is shown in Figure 2.

$$BHN = \frac{P}{\left[\frac{\pi D}{2}\right]\left[D - \sqrt{D^2 - d^2}\right.} \tag{1}$$

where,
BHN = Brinell hardness number (kg/mm2)
P = Load used (kg)
D = Indenter diameter (mm)
d = Indentation diameter (mm)

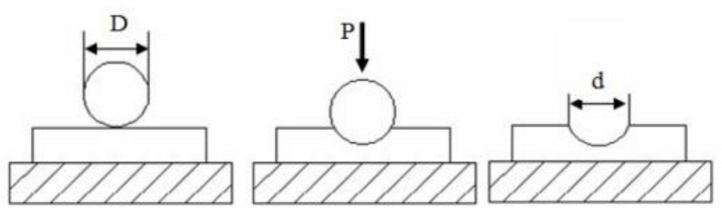

Figure 1. Schematic of the Brinell hardness test

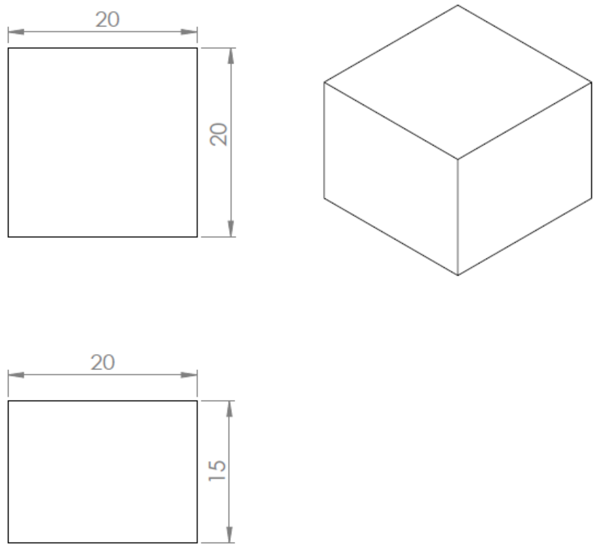

Figure 2. The hardness test specimen

2.3 Friction testing

Friction testing was carried out using a reduced scale brake dynamometer as shown in Figure 3. This dynamometer is divided into several main parts, namely the wheel rotating mechanism, the specimen pressing section, the friction force sensor section, and the wheel temperature. This friction coefficient test was carried out on a wheel that rotates at a constant speed and then the brake block specimen was given a pressing force using a pneumatic system.

The material tested was a gray cast iron brake block with dimension of 320 mm x 80 mm x 50 mm. The brake block material is cut into test specimens with a size of 80 mm x 20 mm x 13 mm or reduced to ¼ the original size. The wheel rotating mechanism used is a 3-phase electric motor. The wheel speed can be adjusted using an inverter and can be adjusted based on the desired sliding speed. The specimen pressing mechanism used a pneumatic system so that the magnitude of the pressing force can be varied easily. The load cell was used as a friction sensor which was placed perpendicular to the compressive force. The wheel temperature during the friction test was measured using an infrared thermometer. The value of the friction coefficient of testing was calculated using Equation 2.

$$\mu = \frac{F\_friction}{N} \tag{2}$$

where,

μ	= Coefficient of friction
F_friction	= Average friction (N)
N	= Specimen loading force (N)

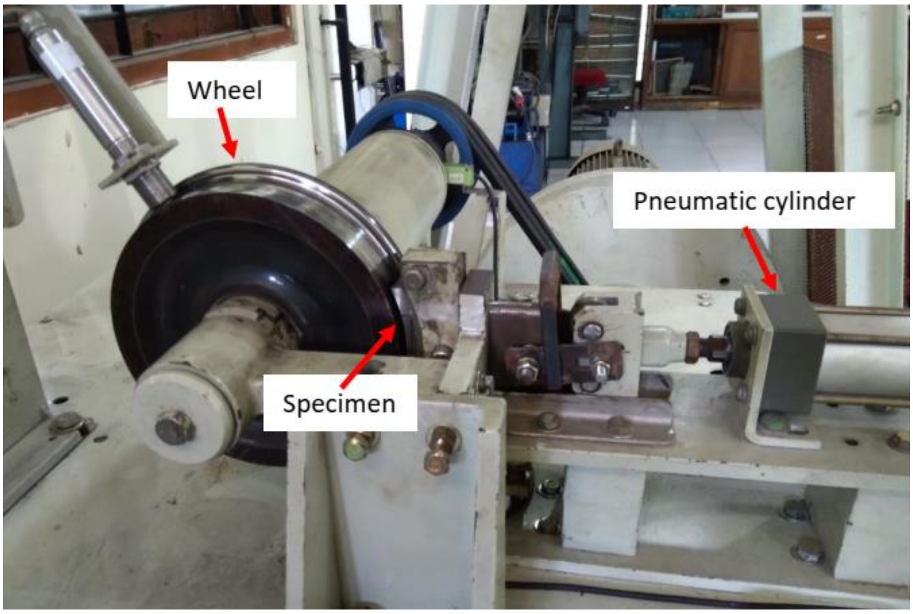

Figure 3. A reduced scale brake dynamometer used in this research

3. Result and Discussion

3.1 Microstructure

Observation of the microstructure of the brake block material was carried out to obtain information about the shape, size, and distribution of graphite in grey cast iron material. The results of the research on the microstructure testing of grey cast iron are shown in Figure 4. The microstructure shows the visible dark-colored and evenly distributed graphite flakes. The microstructure shows that the test specimens have a long and medium-sized distribution of graphite. The graphite size of the specimens has an average length of 40-70 µm and an average width of 5 µm. Graphite greatly affects the hardness level of the cast iron material. The more graphite matrices that are formed, the softer the material is [8]. Figure 4 also shows that no other content is seen in the test specimens other than graphite. This is because the microstructure was taken without going through the etching process first so that the matrix composing the test specimen was not visible.

Carbon and silicon affect the formation of graphite in cast iron. The carbon in cast iron combines with iron in the form of carbides or exists in the free state as graphite. The process of graphitization occurs when the bond between carbon and iron in cementite is released into free carbon. This process will be easier if the carbon content in cast iron is above 2% and it is also due to the presence of silicon (Si). This silicon causes cementite to become unstable so it tends to become graphite.

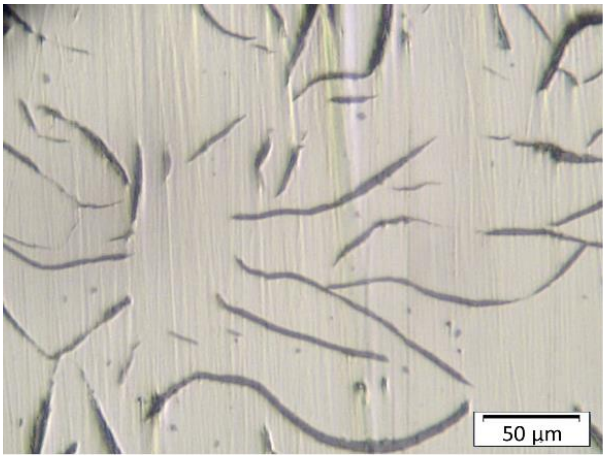

Figure 4. Microstructure of gray cast iron brake block

3.2 Hardness

Hardness testing is useful for knowing the resistance of a material to the pressure of other materials. This test uses the Brinell method using a steel ball indenter with a diameter of 2.5 mm and a load of 187.5 kg in a loading time of 30 seconds. This hardness test is carried out at 3 points of emphasis for each specimen. Hardness testing results are shown in Table 1.

Table 1. Hardness of gray cast iron brake block

Specimen Code	Position of indentation	d_average (mm)	Hardness (BHN)
A	1	1.14	173.7
	2	1.14	173.7
	3	1.12	180.3
B	1	1.1	187.3
	2	1.11	183.8
	3	1.11	183.8
	Average	**1.12**	**180.43**

Based on the research results, it is found that the average value of the Brinell hardness (BHN) for gray cast iron is 180.43 BHN. This value shows that the test material is still in the safe category and meets the hardness value standardized by PT KAI for metallic brake blocks, namely 175 to 197 BHN [9]. Table 1 also shows that the friction caused on the train wheels during braking will not cause damage. The hardness value of this test is different at each point. This is very common because the position of the test point on the test specimen is random.

3.3 Coefficient of friction

Friction test aims to determine the effect of sliding speed and contact pressure on the coefficient of friction of the gray cast iron brake block material. The data observed in this test is the relationship between the friction speed and contact pressure on the friction coefficient. Figure 5 shows a graph of the relationship between the friction coefficient and the sliding speed at a constant contact pressure of 0.15 and 0.30 MPa. The coefficient of friction of the specimen at constant contact pressure of 0.15 MPa with variations in the sliding speed of 3 m/s, 6 m/s, 9 m/s, and 12 m/s are 0.43, 0.38, 0.37, and 0.36, respectively. The coefficient of friction of the specimen at constant contact pressure of 0.3 MPa with variations in the sliding speed of 3 m/s, 6 m/s, 9 m/s, and 12 m/s are 0.38, 0.32, 0.28, and 0.27, respectively.

Figure 5 shows that the highest coefficient is at the friction speed of 3 m/s. This phenomenon is very common with brake blocks. This is because as the friction speed increases, the surface temperature will increase. A very significant increase in temperature during the braking process will result in a decrease in the coefficient of friction which is called the brake fade [10–12]. The material on the surface of the brake block will soften and reduce its shear strength [13]. The decrease in shear strength on the specimen surface will result in a decrease in the friction coefficient [1].

Figure 5 shows that testing at a pressure of 0.30 MPa has a very drastic decrease in the coefficient compared to testing at a contact pressure of 0.15 MPa. This is because at higher pressure, the heat caused by friction is much higher than the heat transferred to the environment [14]. Increasing the contact pressure on the brake block can reduce the friction coefficient because it increases the temperature of the friction parts [15]. The high temperature change on the friction surface causes the material surface to weaken and the shear stress on the surface decreases.

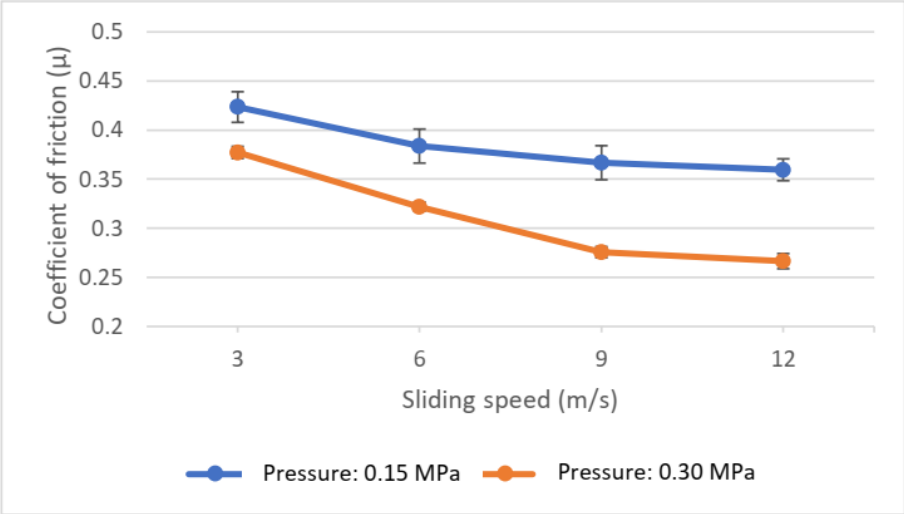

Figure 5. The relationship between the coefficient of friction and the sliding speed at a contact pressure of 0.15 MPa and 0.30 MPa

The relationship between the coefficient of friction against contact pressure at a sliding speed of 3 m/s and a speed of 12 m/s can be seen in Figure 6. The coefficient of friction of gray cast iron brake block at constant sliding speed of 3 m/s with variations in the contact pressure of 0.15 MPa, 0.2 MPa, 0.25 MPa, and 0.3 MPa are 0.42, 0.40, 0.39, and 0.38, respectively. Meanwhile, the coefficient of friction of gray cast iron brake block at constant sliding speed of 12 m/s with variations in the contact pressure of 0.15 MPa, 0.2 MPa, 0.25 MPa, and 0.3 MPa are 0.36, 0.31, 0.29, and 0.27, respectively.

Figure 6 shows the effect of contact pressure on the friction coefficient of brake block. The coefficient of friction decreases as the contact pressure increases. This is because the micro-convex-apices (uneven surfaces) are easy to squeeze and add the actual contact area [2]. The increase in contact area causes the temperature on the surface of the brake block to increase and results in a decrease in the coefficient of friction. The decrease in friction coefficient that occurs due to braking operating conditions is called brake fade [10,11]. Brake fade can cause reduced braking power, effective braking, and even brakes to stop working or fail [12].

Figure 6 shows the results of the test with a speed of 12 m/s experienced a very drastic decrease in the coefficient compared to testing at a speed of 3 m/s. This is because, at a higher speed, the heat caused by friction is much higher than the heat transferred to the environment [14]. Increasing the speed of the brake block can reduce the coefficient of friction because it increases the temperature of the friction parts [15]. The high temperature change on the friction surface causes the material surface to weaken and the shear stress on the surface decreases.

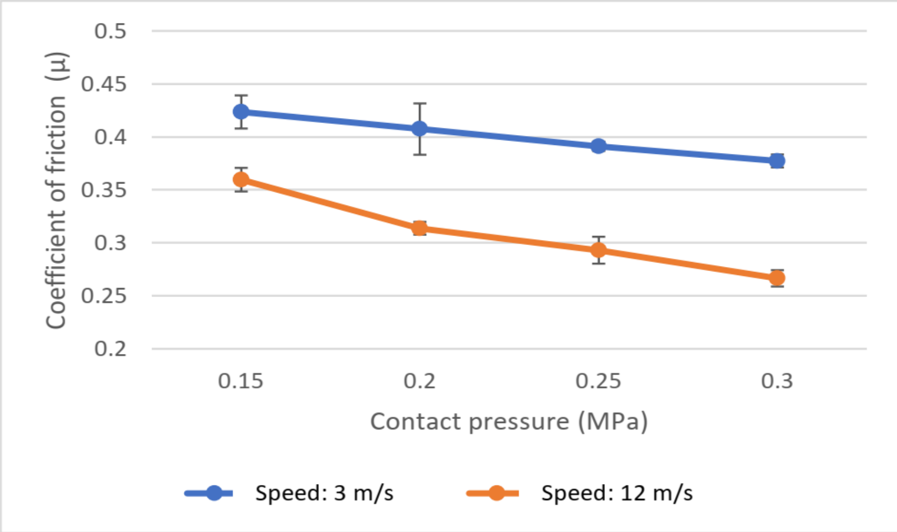

Figure 6. The relationship between the coefficient of friction and contact pressure at a constant sliding speed of 3 m/s and 12 m/s

Surface temperature observations were made at different contact pressures and friction rates. Observations were made on variations in contact pressure with variations in friction speed. The graph of the relationship between temperature and variations in contact pressure with a speed of 3 m/s and a speed of 12 m/s can be seen in Figure 7.

Based on the results of observations on the graph of the relationship between temperature and friction speed of 3 m/s, the average temperature value for 0.15 MPa pressure is 27.17 ℃, then the average temperature value for pressure 0.20 MPa is 28, 11 ℃, then for the average temperature value for 0.25 MPa pressure is 28.21 ℃, and the temperature average value for 0.30 is 28.23 ℃. Based on the results of observations on the graph of the relationship between temperature and friction speed of 12 m/s, the average temperature value for 0.15 MPa pressure is 29.99 ℃, then the average temperature value for pressure 0.20 MPa is 30, 23 ℃, then for the average temperature value for 0.25 MPa pressure is 31.17 ℃, and the average temperature value for 0.30 is 31.93 ℃.

The results of the contact temperature observation showed that the lowest surface temperature was at a pressure of 0.15 MPa which was 27.17 ℃ at a speed of 3 m/s and the highest surface temperature was at a pressure of 0.30 MPa which was 29.99 ℃ at a speed of 12 m/s. The surface temperature increases with the addition of contact pressure. The surface temperature also increases with the addition of the friction speed. The surface temperature for all tests was above 27 ℃. This is because the micro-convex-apices (uneven surfaces) are completely compressed and add to the actual contact area [1]. A larger contact area will generate a greater amount of heat than a smaller contact area. Part of the heat is dissipated into the environment and some of the heat is distributed between the brake block and the wheels, which leads to an increase in the contact surface temperature. The increase in temperature at the contact surface then affects the decrease in the friction strength of the specimen so that there is a decrease in the friction coefficient [1].

High interface temperature will reduce the shear strength and friction forces between the brake pads and the disc [13]. Increasing the speed causes the kinetic energy of the system to increase and an increase in interface temperature of the brake lining which reduce the strength of the surface material so that the coefficient of friction decreases. Therefore, the value of the friction coefficient at a speed of 3 m/s and a pressure of 0.15 MPa is the highest. This is because at a speed of 3 m/s and a pressure of 0.15 MPa there has not been a significant increase in temperature.

Friction tests on composite brake blocks using a reduced scale dynamometer with the same test parameters as this study resulted in a lower coefficient of friction compared to gray cast iron brake blocks. Composite brake block has the lowest friction coefficient of 0.232 and the highest friction coefficient of

0.317, while the gray cast iron brake block has the lowest friction coefficient of 0.27 and the highest friction coefficient of 0.42 [1].

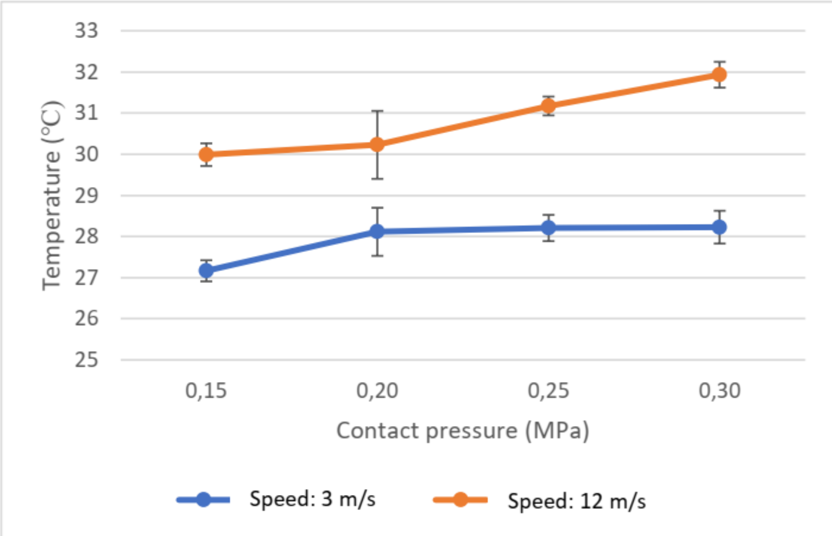

Figure 7. Temperature of contact surface as various of contact pressure at a constant sliding speed of 3 m/s and 12 m/s

4. Conclusion

The friction characteristics of the gray cast iron brake block are affected by the sliding speed and contact pressure. The friction coefficient of the brake block decreases with increasing sliding speed and contact pressure. The highest friction coefficient of the brake block of 0.42 is obtained at a sliding speed of 3 m/s and a contact pressure of 0.15 MPa. Meanwhile, the lowest friction coefficient of the brake block of 0.27 is obtained at a sliding speed of 12 m/s and a contact pressure of 0.3 MPa.

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