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Estimation of Brake Pad Wear Using Fuzzy Logic in Real Time

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Abstract— Brake pad components are important in two-wheeled vehicles because they concern the driver's and others' safety. Brake lining wear is an unavoidable phenomenon. This is because of the concept of braking, which involves bringing two things into contact with each other such that they press against each other and rub against each other. Brake pads that have not been replaced make the brakes unable to work normally, so the potential for accidents is even greater. One of the factors causing the problem is negligence and ignorance of the condition of the ream linings, which should be time for the change. This paper proposes a tool that can estimate the condition of the brake pads based on the level of wear in real-time using the fuzzy logic method. Fuzzy logic will estimate the degree of wear of brake pads based on speed, brake fluid pressure, and braking duration parameters. The type of brake used in this paper is the type of disk brake used on two-wheeled vehicles. The test is not carried out or applied to two-wheeled vehicles but is applied to brake pad wear test equipment that works like a two-wheeled vehicle. Based on the test results, the fuzzy logic implanted into the Arduino microcontroller can provide information on the estimated condition of the brake pads on LCDs in real time based on fuzzy set datasets obtained through experimental tests. Based on the experimental results, the brake lining wear test was carried out for 30 minutes with a pressure of 10 and 17 psi. The results showed that the thickness of the brake linings decreased by around 21.66% and 26.68%, respectively.

Keywords— Motorcycle, Brake Pad, Wear, Disc Brake, Fuzzy Logic, Arduino

I. Introduction

Brake pads are a component of a motorized vehicle that functions to slow down and stop motorized vehicles, cars, and trucks. When the vehicle travels at high speed, the brake pads play an important role in the driver's safety [1].

In the concept of braking, the thing that can not be avoided is wear and tear. Brake pad wear occurs because two objects are pressing and rubbing against each other. The brake pads' fast and slow wear rate is influenced by several factors, such as speed, pressure, surface hardness, and material hardness [2]. In [3], so that the brake pad components work properly, it is necessary to replace the brake pads when the vehicle has traveled 20,000 km. However, many motorists forget or ignore the time to replace the brake pads, which should be the time to replace the brake pads. Conditions like this can be dangerous for motorized vehicle drivers with two or more wheels because the condition of the brake pads that are worn down causes braking not to work normally, and the chance of an accident is getting bigger.

Studies on brake pads, especially regarding brake pad wear, have been carried out by previous researchers. On [2] has conducted a study of wear level analysis on disc brakes with speed variations. This is done to determine the effect of speed on wear volume, wear coefficient, and brake lining wear rate. The method used is experimental testing using a brake lining wear tester. According to [4] also conducted an experimental study of wear depth and friction coefficient due to Stick-Slip on Reciprocating Wear using pin-on plate type tribometer test equipment. The results of this study indicate that the greater the loading, the greater the wear caused by stick-slip friction. Analysis of the wear rate of disc brakes has also been carried out on the braking system of a Yamaha Vixion 150cc motorbike[5]. This study aimed to determine the durability of the brake material under pressure during operation and to determine the wear of the brake pads on the effect of variations in pressure and braking rotation on the wear rate of motorcycle brake linings [6][7]. The method used to determine the wear rate of the brake pads is to find the difference in the weight of the brake pads before and after braking by considering parameters such as braking pressure, rotation (RPM), and braking time. After obtaining the difference in the weight of the brake pads, a manual calculation is carried out to find the wear rate of the brake linings.

Many researchers have studied the parameters that affect the wear of various materials and observed that the wear rates increased with increasing the sliding speed and normal load. In contrast, some of them have been focused on friction temperature and its relation to wear [8]–[11]. They found that the friction temperature increased with increasing normal load and sliding speed, and the wear volume increased with the friction temperature [12][13].

In research [14], the prediction of brake pad thickness is based on the vehicle's mileage with various road shapes. Then the relationship between the thickness of the brake pads and the vehicle mileage produces an equation which is then analyzed using Microsoft Excel. The results show that the brake pads must be replaced if they have traveled between 30000 – 40000 km. Information about the wear of the brake

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pads has also been done. The method used only detects brake pad wear by recording pad thickness data obtained by retarding the vehicle from 100 to 0 kmph and then the appropriate machine learning algorithm [15]. Studies on the estimation of wear and temperature on pin-disc contacts using artificial neural network methods have also been carried out but the schemes offered are not in real-time [16]. In [17], a neural network prediction of brake pad and disc wear has also been carried out. The friction neural network uses material composition, initial speeds, final speeds, deceleration, and disc sizes to predict brake pads and disc wear. The analysis was performed using the deep learning toolbox in MATLAB and yielded an accuracy of 85% when compared to the dynamometer-based wear measurement.

Several previous studies regarding brake lining wear analysis are still carried out offline. This paper proposes an instrumentation tool that can provide information in the form of estimating the condition of brake lining thickness in real time using fuzzy logic. The parameters used to determine the thickness of the brake pads are pressure, speed, and duration of braking. The type of brake used in this paper is the disc brake type on two-wheeled vehicles. Previously, a search was carried out from various reference sources related to instrumentation that can estimate the thickness of the brake pads in real-time. Still, the reference sources were obtained through manual analysis and experimental test equipment. Estimating the thickness of the brake pads in real-time is a solution to the negligence of motorists to minimize the occurrence of driving accidents.

II. Research Methodology

The design of the proposed brake pad thickness estimation system is not installed on a two-wheeled motorized vehicle but is in the form of an experimental test device in which there is a 1-phase ac motor component connected to a disk brake via a fan belt, a disk brake type component device and an ac motor speed control component.

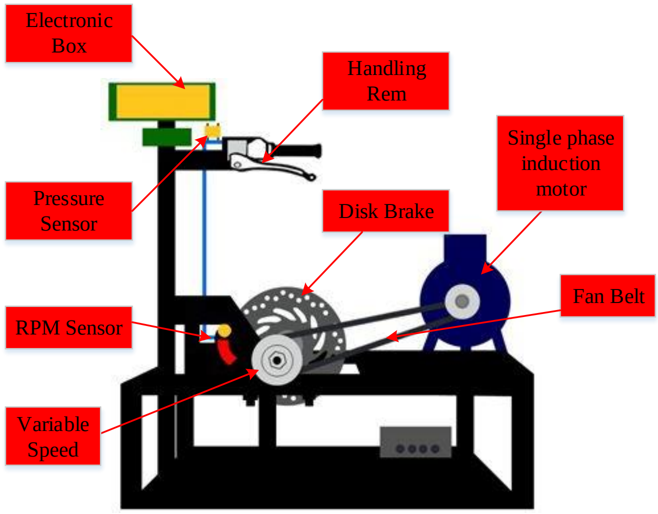

Figure 1. The Development Of A Tool For Estimating The Thickness Of The Brake Lining

Figure 1 shows a one-phase system along with electrical components that may measure the thickness of the brake pads in real-time. The design of the test equipment, as shown in Figure 1, is also a prototype form of a motorized vehicle. So that the built system can estimate the thickness of the brake pads in real-time based on the parameters of pressure, speed, and braking duration, several sensors are used to measure these parameters, namely pressure sensors and speed sensors (see Figures 1 and 2). The pressure sensor is placed in the channel between the handling brake and the caliper. When the handling brake is pressed, the pressure sensor will measure the pressure on the brake fluid.

In comparison, the speed sensor is used to measure the rpm of the disc brake. The duration of incubation uses the timer provided by the microcontroller. The timer starts counting when the pressure sensor detects an emphasis on brake handling. So that the driver can find out information on the condition of the thickness of the brake pads, this system is equipped with a character LCD. The thickness of the brake pads is displayed in percentage units.

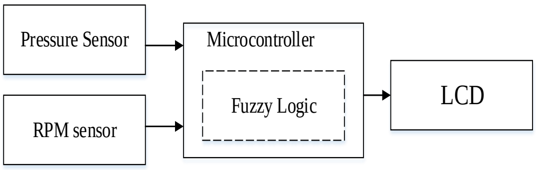

Figure 2. Block diagram of brake lining thickness estimation

As seen in Figure 2, the output signal from the pressure sensor, RPM sensor, and braking duration will be processed by the microcontroller using the fuzzy logic method. Based on these input variables, fuzzy logic will produce output in the form of the estimated weight of the worn brake pads and then convert it into the remaining thickness of the brake pads in percent units (see figure 3). The RPM sensor's output signal is translated into linear speed in units of kilometers per hour so that linear speed data may be obtained. This conversion is done to adjust to the conditions of motorized vehicles.

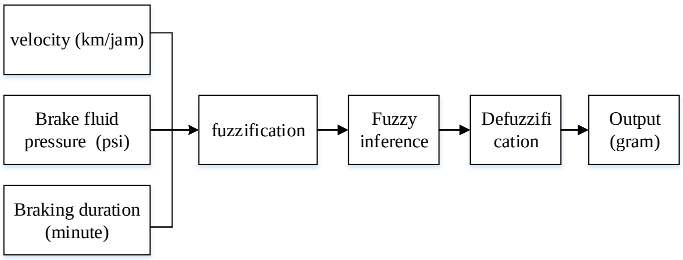

Figure 3. Block Diagram Fuzzy Logic Design

A. *Fuzzification*

As seen in Figure 3, fuzzy logic has three inputs and one output, where each input and output is divided into three membership functions. The membership function of velocity consists of Slow (SL), Medium (M), and Fast (F), as shown in Figure 4. The membership functions for brake fluid pressure and braking duration consist of Small (SM), Medium (M), Big (B) and fast (F), medium (M), and long (L), as shown in

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Figures 5-6 respective. While the membership function output is also divided into three, namely thin (TN), medium (M), and thick (TK), as shown in Figure 7.

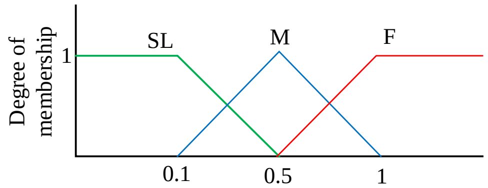

Figure 4. Membership Functions of Velocity

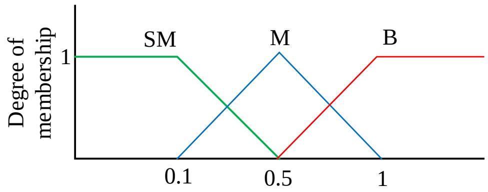

Figure 5. Membership Functions of Brake Fluid Pressure

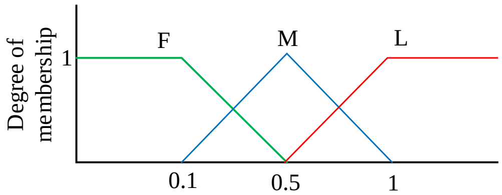

Figure 6. Membership Functions Of Braking Duration

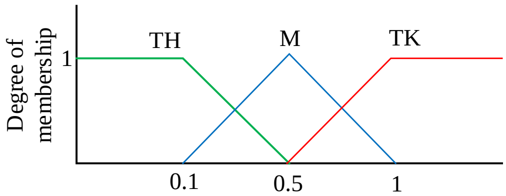

Figure 7. Membership Functions of Brake Pad Wear

B. *Fuzzy Inference*

This section will explain the logical relationship between input and output in fuzzy rules. Experimentation, which is covered in section III, is required to acquire a dataset describing the nature of the relationship between input and output. Table I describes the basic principles that regulate the relationship between input and output.

TABLE I
FUZZY RULES

IF			THEN
Velocity	**Brake fluid Pressure**	**Braking Duration**	**Brake pad Wear Weight**
SL		F	TH
	SM	M	TH
		L	TH
		F	TH
	M	M	TH
		L	M
		F	TH
	B	M	M
		L	M
M		F	TH
	SM	M	M
		L	TK
		F	M
	M	M	M
		L	M
		F	M
	B	M	M
		L	TK
F		F	M
	SM	M	TK
		L	TK
		F	M
	M	M	TK
		L	TK
		F	TK
	B	M	TK
		L	TK

III. RESULT AND DISCUSSION

Figure 8 shows the results of the mechanical manufacture used to test the wear of the brake pads. The components used and their functions are adjusted, as shown in Figure 1.

Figure 8. Brake Lining Thickness Experimental Test Tool

A. *The Testing of RPM Sensor*

The sensor used is an inductive proximity sensor. This sensor is used to determine the rotation of the disc brake (see figure 9), which is then converted into linear speed with units of km/hour. Table II shows the results of comparing speed measurements between proximity sensors and speed meter measuring devices.

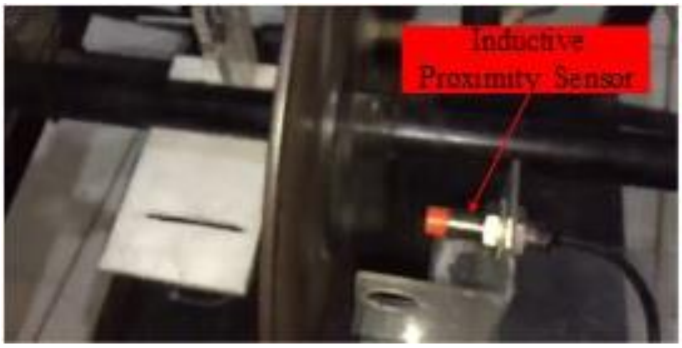

Figure 9. Instalasi And Location Of The Inductive Proximity Sensor

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TABLE II
TESTING OF RPM SENSOR RESULT

Proximity sensor (km/hour)	Speed meter (km/hour)
56	51
55	53
50	51
87	90
89	90
65	65
66	65
63	65
96	98
94	98

B. The Testing of Pressure Sensor

The pressure sensor used is the G1/4 sensor. This sensor measures brake fluid pressure handling when the brakes are pressed. The test was carried out by pressing the handling brake with different pressures. Then the results were compared with an oil pressure analog meter, as shown in Figure 10. Table III shows the results of a comparison of sensor measurements with an oil pressure measuring instrument carried out with ten trials with an error of 1 %.

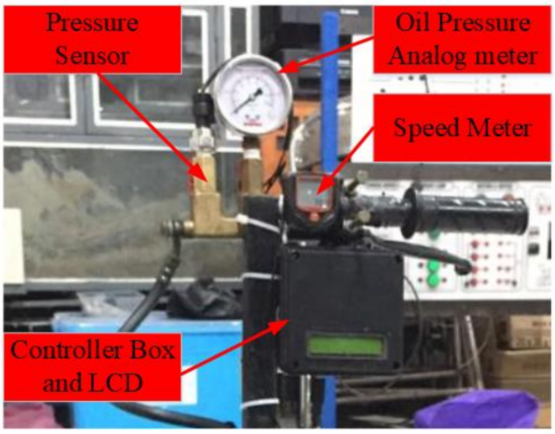

Figure 10. Installation And Location of The Pressure Sensor

TABLE III
TESTING PRESSURE SENSOR RESULT

G1/4 pressure sensor (psi)	oil pressure meter (psi)
10.4	10
14.88	15
20.43	20
24.85	25
18.45	19
18.67	19
18.54	19
14.78	15
14.56	15
14.51	15

C. Brake Pad Wear Test

Brake lining wear testing was carried out to know differences in brake pad wear under different conditions of pressure, speed, and duration of braking. Before testing the wear of the brake linings, it is necessary to test the weight of the brake linings, which are still new and the thickness of the brake linings is already thin. It aims to determine the thickness of the brake pads in conditions of 100% and 0%. The weight test, as shown in Figure 11, is carried out by weighing five types of brake pads with the same brand and then taking the average weight value.

Figure 11. Weighing brake pads

Table IV shows the results of testing the weight of the brake pads under 100% conditions for five types of brake linings in the same brand. The test results found that the average weight of the brake pads, which were still in 100% condition, was 50,257 grams. At the same time, the results of testing the brake pads at 0% conditions are shown in Table II. Testing the brake linings at 0% is carried out by weighing the weight of the brake pads that are already in thin condition or unsuitable for use. This test was carried out by taking samples of 5 types of canvas in the same brand. The results show that the average value of the brake pads in 0% conditions is 40.8602 grams. Based on the canvas weight test results in 100% and 0% conditions, the difference is 9.3968 grams. The difference in these values will be used as a reference in converting the condition of the thickness of the canvas to percent units.

TABLE IV
BRAKE CLOTH WEIGHT IN 100% CONDITION

Brake pad type	Wight (gram)
1	50.785
2	51.829
3	49.245
4	50.213
5	49.214

TABLE V
BRAKE CLOTH WEIGHT IN CONDITION 0%

Brake pad type	Weight (gram)
1	40.829
2	41.253
3	41.221
4	40.245
5	40.753

The next brake wear test is to look for the wear weight of the brake pads under different pressure, speed and braking duration conditions. In addition, the results of this test will be used as a dataset to determine the membership value of each fuzzy set. The scheme for taking the brake lining wear weight dataset is divided into three parts: constant speed (v) settings at values of 50, 75, and 95 km/hour. Then each speed is tested at pressure (P) or breaking fluid pressure with a value of 10,

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15, and 25 psi. In this particular test, braking has performed a length of every three minutes to determine the degree to which the brake linings have worn down. Following this, the test linings are weighed to ascertain the brake linings' final weight. Next, the brake pad wear degree is calculated by calculating the difference between the final weight and the initial weight of the brake pads. Table VI-VIII results from the heavy wear test of brake pads at speeds of 50, 75, and 95 km/h with pressures of 10, 15, and 25 psi, respectively.

TABLE VI
BRAKE PAD WEAR WEIGHT TESTING
WHEN V = 50 KM/HOUR

Braking Duration (minute)	**Brake Pad Wear Weight *P* = 10 psi (gr)**	**Brake Pad Wear Weight *P* = 15 psi (gr)**	**Brake Pad Wear Weight *P* = 25 psi (gr)**
3	0.041	0.078	0.086
6	0.045	0.091	0.1
9	0.049	0.099	0.104
12	0.053	0.104	0.11
15	0.056	0.109	0.116
18	0.059	0.111	0.121
21	0.061	0.114	0.126
24	0.064	0.116	0.13
27	0.067	0.118	0.136
30	0.069	0.121	0.141

TABLE VII
BRAKE PAD WEAR WEIGHT TESTING
TIME V = 75 KM/HOUR

Braking duration (minute)	**Brake Pad Wear Weight *P* = 10 psi (gr)**	**Brake Pad Wear Weight *P* = 15 psi (gr)**	**Brake Pad Wear Weight *P* = 25 psi (gr)**
3	0.088	0.097	0.102
6	0.102	0.114	0.123
9	0.111	0.127	0.14
12	0.12	0.138	0.156
15	0.129	0.152	0.171
18	0.137	0.165	0.185
21	0.145	0.174	0.199
24	0.153	0.183	0.214
27	0.162	0.191	0.228
30	0.171	0.199	0.241

TABLE VIII
BRAKE PAD WEAR WEIGHT TESTING
TIME V = 95 KM/HOUR

Braking duration (minute)	**Brake Pad Wear Weight *P* = 10 psi (gr)**	**Brake Pad Wear Weight *P* = 15 psi (gr)**	**Brake Pad Wear Weight *P* = 25 psi (gr)**
3	0.131	0.142	0.49
6	0.159	0.183	0.541
9	0.187	0.22	0.585
12	0.218	0.262	0.637
15	0.245	0.303	0.675
18	0.263	0.334	0.712
21	0.282	0.366	0.755
24	0.297	0.392	0.799
27	0.313	0.416	0.851
30	0.327	0.444	0.886

D. Testing of Performance Fuzzy Logic

It is important to put the newly developed fuzzy logic through a series of tests in which the parameters of pressure, velocity, and brake duration are arbitrarily combined. The performance of the fuzzy logic may be evaluated. The design fuzzy rules and datasets obtained in the previous test will be translated into a computational language and then embedded into the microcontroller. In addition, the value of the initial weight of the brake pads is also entered into the microcontroller so that it can estimate the final weight of the brake pads after wear and tear. The estimation results will be displayed in percent form on the LCD in real-time with a sampling time every 5 minutes.

The test scheme was carried out by giving a speed setting of around 50 km/hour. The tests were divided into two parts to make a comparison of the estimated results of the brake pads. The first part of the test was conducted when the pressure was approximately 10 to 17 psi, and each of the two parts of the test lasted for 30 minutes. The results of these tests can be found in Tables IX, and X. A comparison of the amount of wear on the brake pads when the pressure is around 10 and 17 psi may be seen in Figure 12. This shows that at the same speed, the wear rate of the brake pads is greater when the brake fluid pressure is greater.

TABLE IX
BRAKE CLASS WEAR ESTIMATION TEST
WHEN THE PRESSURE IS ABOUT 10 PSI

Velocity (km/hour)	**Pressure (psi)**	**Duration (minute)**	**Brake Pad Wear Estimation (%)**
58.85	10.8	5	4.67
50.82	10.4	15	8.19
52.43	10.2	20	12.48
50.67	10.6	25	15.92
56.42	11.4	30	21.66

TABLE X
BRAKE CLASS WEAR ESTIMATION TEST
WHEN THE PRESSURE IS ABOUT 17 PSI

Velocity (km/hour	**Pressure (psi)**	**Duration (minute)**	**Brake Pad Wear Estimation (%)**
50.28	17.64	5	4.82
51.24	17.43	15	10.11

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Velocity (km/hour	Pressure (psi)	Duration (minute)	Brake Pad Wear Estimation (%)
50.67	17.86	20	15.14
54.23	17.54	25	21.3
51.45	17.9	30	26.68

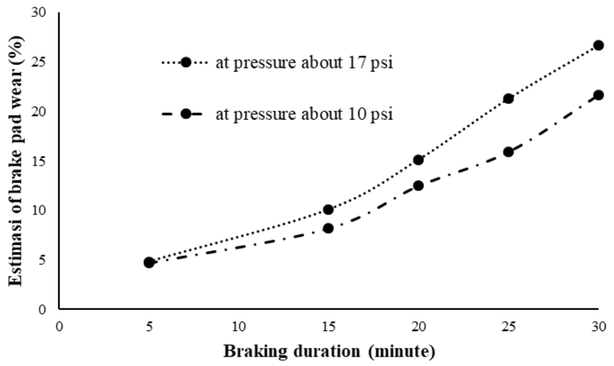

Figure 12. Brake Lining Wear Comparison

IV. Conclusion

Estimation of brake lining wear based on a microcontroller using fuzzy logic has been made. Based on the test results, fuzzy logic can provide an estimated value of the percentage of brake pad wear according to the dataset. Even though fuzzy logic has three inputs, the Arduino microcontroller can execute it quickly. The greater the brake fluid pressure or velocity, the faster the wear rate. Estimating brake pad wear and braking duration has an almost linear relationship. When the braking duration is 30 minutes, and the pressure is 10 psi, the brake pads have decreased by around 21.66%.

References

[1] N. Publikasi, J. Teknik, M. Fakultas, and U. M. Surakarta, "Pengaruh gaya kompaksi pada pembuatan kampas rem dengan resin serbuk sebagai pengikat," 2014.
[2] A. Keausan *et al.*, "ANALISA KEAUSAN KAMPAS REM PADA DISC BRAKE DENGAN VARIASI KECEPATAN," *Momentum*, vol. 13, no. 2, pp. 78–83, 2017.
[3] Kupang.tribunnews.com, "Idealnya Ganti Kampas dan Cairan Rem Setelah Jarak Tempuh Ini," 2019. .
[4] R. Raja and B. Siregar, "Studi Eksperimental Kedalaman Aus dan Koefisien Gesek Akibat Stick-Slip pada Reciprocating Wear," vol. 6, no. 2, pp. 268–271, 2017.
[5] R. A. M. Napitupulu, C. S. P. Manurung, and C. Sembiring, "Laju Keausan dan Kekerasan Kampas Rem Pada Sistem Pengereman Sepeda Motor," vol. 4, no. 1, pp. 10–19, 2022.
[6] A. Intang, "Studi Pengaruh Tekanan Pengereman Dan Kecepatan Putar Roda Terhadap Parameter Pengereman Pada Rem Cakram Dengan Berbasis Variasi Kanvas," *Tek. Mesin Untirta*, vol. II, no. JurusanTeknik Mesin. Fakultas Teknik, Universitas Tamansiswa Palembang, pp. 9–19, 2016.
[7] S. Sumiyanto, A. Abdunnaser, and A. N. Fajri, "Analisa Pengujian Gesek, Aus Dan Lentur Pada Kampas Rem Tromol Sepeda Motor," *Bina Tek.*, vol. 15, no. 1, p. 49, 2019.
[8] P. Tao, Y. Yang, X. Chen, and Y. He, "Effect of Load on Surface Friction and Wear Behavior in ZrCuNiAl Bulk Amorphous Alloy," *Mater. Focus*, vol. 4, no. 2, pp. 150–153, 2015.
[9] A. Riyadh, A. Haftirman., and A.-D. Y. Khairel Rafezi., "Effect of Load and Sliding Speed on Wear and Friction of Aluminum– Silicon Casting Alloy," *Int. J. Sci. Res. Publ.*, vol. 2, no. 3, pp. 3–6, 2012.
[10] M. Ramesh, T. Karthikeyan, R. Arun, and C. Kumaari, "Effects of Applied Pressure on the Wear Behavior of Brake Lining Sliding Against Ferrous and Nonferrous Disc," *Int. J. Adv. Mech. Eng.*, vol. 4, no. 3, pp. 285–290, 2014.
[11] M. A. Chowdhury and D. M. Nuruzzaman, "Experimental investigation on friction and wear properties of different steel materials," *Tribol. Ind.*, vol. 35, no. 1, pp. 42–50, 2013.
[12] Y. Wang, X. D. Li, and Z. C. Feng, "The relationship between the product of load and sliding speed with friction temperature and sliding wear of a 52100 steel," *Scr. Metall. Mater.*, vol. 33, no. 7, pp. 1163–1168, 1995.
[13] A. Gåård, N. Hallbäck, P. Krakhmalev, and J. Bergström, "Temperature effects on adhesive wear in dry sliding contacts," *Wear*, vol. 268, no. 7–8, pp. 968–975, 2010.
[14] M. Gailis and D. Berjoza, "On prediction of motor vehicle brake pad wearout," *Eng. Rural Dev.*, vol. 11, no. January 2012, pp. 349–354, 2012.
[15] C. C. Harlapur, "Brake pad wear detection using machine learning," *Int. J. Adv. Res. Ideas Innov. Technol.*, vol. 5, no. 2, pp. 498–501, 2019.
[16] A. K. F. Hassan and S. Mohammed, "Artificial Neural Network Model for Estimation of Wear and Temperature in Pin-disc Contact," *Univers. J. Mech. Eng.*, vol. 4, no. 2, pp. 39–49, 2016.
[17] K. Choudhuri and A. Shekhar, "Predicting Brake Pad Wear Using Machine Learning," pp. 2–5, 2020.

DOI : http://dx.doi.org/10.25139/inform.v8i1.5760