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Impact of Engine Speed and Time Variations on Temperature and Friction Coefficient of Brake Pads with Remote Monitoring Test Equipments System

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***Abstract* - Failure of the brake system causes many fatalities that lead to accidents; one of the many causes is Brake Fade. Brake fade mostly caused by braking temperature that exceeds the maximum temperature of the brake lining material, resulting in a decrease in the coefficient of friction (braking power). Therefore, this paper was conducted to analyze the effect of braking temperature on the coefficient of friction, thickness reduction, and braking time. The type of brake used is a disc brake with four brands of brake lining including, AHM brand, Indopart brand, OSK brand. The test method carried out in this research is divided into two methods, the first method is braking from a variety of RPM until a steady condition (the state of the engine stops), and the second method is performing braking cycle test where braking is carried out every 500 RPM with a holding time of 1 minute. Measurement of braking temperature using an Infra-red thermometer and thermocouple which becomes a series of RMS-Brake. Measurement of braking time and brake lining thickness before and after the test is also carried out to determine its effect on braking temperature. As the test results, AHM brand fading at a temperature of 305.9˚C with a friction coefficient of 0.09738, Indopart brand fading at a temperature of 191.1˚C with a friction coefficient of 0.1067, OSK brand fading at a temperature of 203.7˚C with a friction coefficient of 0.109057. In addition, there is also the effect of temperature on the reduction of brake lining thickness, where the AHM brand is the least thickness reduction of 0.1 mm to reach 250.4˚C.**

Keywords: Disc brake, temperature, coefficient of friction, fading temperature, brake lining thickness.

I. INTRODUCTION

Brakes are designed to reduce speed or slow down and stop a vehicle. According to experts, brakes are a very important requirement for safe driving and can also stop at any place and in various conditions can function properly and safely. Malfunctioning brakes can lead to accidents because the driver loses control of the vehicle's speed. Due to the importance of the brake function, maintaining the brakes and all related components (brake sub-assembly) must be done regularly [11].

This study will discuss the effect of variations in motor engine speed and braking time on temperature and friction coefficient of brake pads [2]. One of the factors that affect braking ability is temperature, because a brake lining when it reaches its maximum temperature limit will reduce its braking ability due to a decrease in the coefficient of friction or what is commonly called brake fade. In this research, the test was carried out by measuring the temperature of a certain engine speed where braking was carried out to determine the amount of friction coefficient by also knowing the thickness of the brake lining before and after testing [1]. In addition, braking time is also needed to determine the amount of deceleration.

In this research, the motorcycle used as a test object is a 125 CC capacity with production year of 2005 which is statically designed and installed a disc brake lining test tool based on the Remote Monitoring System (RMS) on its working system [9]. From this test, it can be seen the relationship between the amount of temperature and the length of braking so that the friction coefficient of changing the thickness of the lining and the maximum temperature of the brake lining can be known, besides that it can later provide a warning that the brake lining has to be replaced. The information obtained in the form of temperature graph output in real time and can be accessed online. This is expected so that testing and observation can be done remotely so that it seems practical [7].

The results of this paper are generally expected to produce a monitoring system that can not only be applied to motorbikes, but can be applied to cars and even in various large industries such as heavy equipment used in mining. In addition, it can be a guideline for motorcycle users in carrying

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out motorcycle maintenance, especially disk brake maintenance.

II. RESEARCH METHODOLOGY

2.1 Stages of Research

In this research, several stages were carried out, including the design stage of the prototype device, making the prototype device, testing the prototype device, finishing the prototype, installing the prototype sensor on the brake, testing the brake lining, analyzing the temperature data, submitting the data to the arduino web server, and evaluating the website display.

2.2 Prototype Design

At this stage, the design of the testing prototype is carried out using a hand sketch first which is then drawn using Solidwork software so that the visual of the prototype can be seen correctly in its shape and dimensions.

2.3 Prototype-Making Process

At this stage, the 125 cc motorcycle test equipment material is assembled into a tool model by removing the body cover, cutting the unneeded frame, adding a swing arm and welding it, putting one wheel at the back and putting it together with drum brakes and disc brakes, these components are connected by a chain connected to the motor drive engine.

2.3.1 Tools and Part

The components which are required in making this RMS-based disc brake lining temperature test tool are as follows.

1. Motorcycle

The motorcycle used as prototype in this research is a motorcycle engine with a capacity of 125cc as can seen in Figure 2.1 below.

Figure 2.1: 125cc Motorcycle Engine

2. Remote Monitoring System (RMS)

In order to assemble Remote Monitoring System – Brake (RMS-Brake) as can seen in Figure 2.2 below, some of part below will be needed.

Figure 2.2: Remote Monitoring System – Brake (RMS-Brake)

a) Microcontroller

Figure 2.3: Arduino-Uno

The microcontroller used is the Arduino-Uno R3 as shown in Figure 2.3 with specifications as found in Table 2.1 Below.

Table 2.1: Arduino Uno Specifications

Microcontroller	ATMega328
Operating Voltage	5V
Input Voltage	7 – 12V
Input Voltage (limit)	6 – 20V
Digital I/O Pin	14(6PWMpin)
Analog Input Pin	6
Direct Current (DC) per Pin I/O	40mA
Direct Current(DC) 3.3V Pin	150mA
Flash Memory	32KBwith boot loader usage about 0,5KB
SRAM	2 KB
EEPROM	1 KB
Timing Speed	16 MHz

b) Thermocouple Sensor K-Type

The temperature sensor which is attached to this test equipment is a K-Type Thermocouple as shown in Figure 2.4. This type of thermocouple has a temperature range of -200°C to +1200°C and extended to 1300°C for short readings.

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Figure 2.4: Thermocouple Sensor K-Type

c) GPRS Shield Module

Figure 2.5: GPRS Shield Module SIM-900

In this research, GPRS Shield Module SIM-900 used in this installation can be seen in the Figure 2.5 above. Also the specification can found in the table 2.2 below.

Table 2.2: GPRS Shield Module SIM-900 specification

Dimension	24 x 24 x 3mm
Weight	3.4g
Input Voltage	3.4 – 4.5V
Operational Temperature	-30^{o}Csampai+80^{o}C
QuadBand850/900/1800/1900MHz	
GPRSmulti-slot10/8class	
GPRS mobile station B class	
Command AT control	
SIM Application Toolkit	
Low power consumption	

d) Thermal Display LCD

Thermo display as shown in Figure 2.6 below is used to facilitate the reading of temperature data from the thermocouple. The features presented in the LCD consist of 20 characters and 4 lines, has 208 stored characters, there is a programmable character generator, equipped with a back light.

Figure 2.6: GPRS Shield Module SIM-900

e) PCB

PCB is used to place electronic components, which are installed and assembled, where one side is coated with copper to solder the legs of the components. In this RMS circuit, a common PCB is used, namely a perforated PCB.

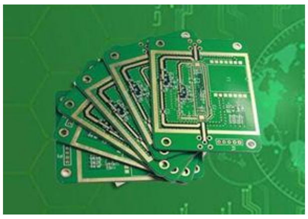

Figure 2.7: PCB

f) Cable

Cables are used to connect between the components that make up the RMS-Brake. The total length of the cable used is ± 1.5 meters. The cable used in this RMS circuit is a type of rainbow cable.

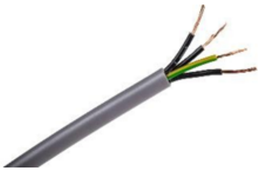

Figure 2.8: Cable

g) Power Supply

Power supply is used to provide power to turn on the RMS-Brake. And in this circuit, a power bank is used to make it more practical to use and portable. The voltage required to turn on the Arduino microcontroller is 5V.

Figure 2.9: Power Supply

h) Solder

Solder used to assemble electronic circuits contained on a pcb board. Solder is an electronic tool that can convert electrical energy into heat energy. In addition, solder also requires tin in order to glue components on the PCB.

Figure 2.10: Solder

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i) Tin Fiber

Tin serves as an adhesive material on the PCB to assemble electronic components. This tin needs to be heated by solder so that it can stick to the PCB.

Figure 2.11: Tin Fiber

2.4 Prototype Testing

Prototype testing started by opening the gas rotation and then braking it fully to make sure the prototype is functioning properly or not.

2.5 Prototype Finishing

Finishing is done by spraying paint on certain parts of the prototype, this is done to prevent corrosion of the test equipment and add to the aesthetics of the prototype.

2.6 Brake Test

Perform the braking tests with prototype that has been assembled following the flow chart in the figure 2.12 below.

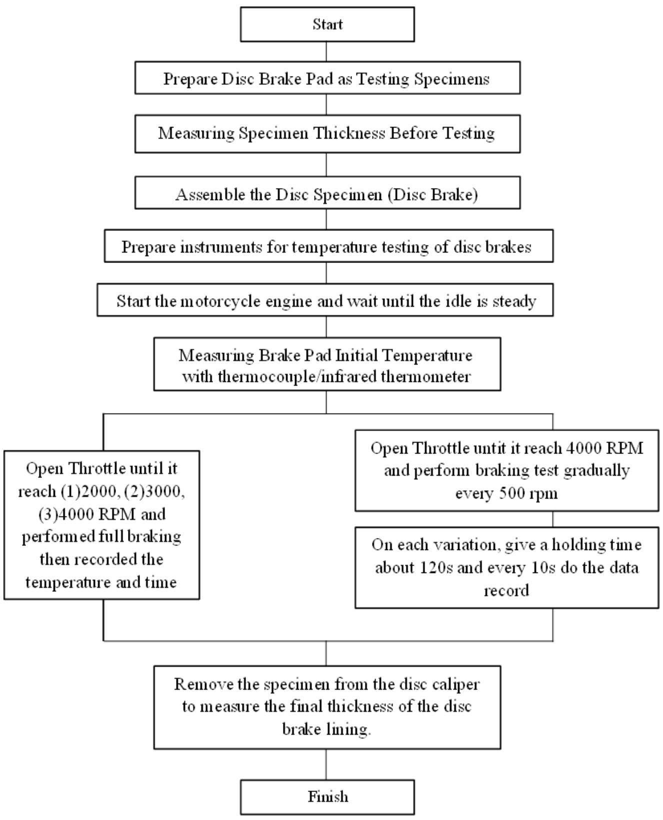

Figure 2.12: Testing Procedure Flowchart

2.7 Collecting Data

When there is a change in temperature, the thermocouple connected to the Arduino will read the phenomenon in real time and forward it to the display and the web. There are some testing parts for collecting data in this research, it can be determined on the list below.

2.7.1 RMS Brake

RMS-Brake which can be seen in Figure 2.13 below is used to process the data read by the thermocouple and later send the results displayed on the website in the form of numerical output of measurement results.

Figure 2.13: RMS-Brake Installation

2.7.2 Infrared Thermometer

Infrared thermometer is a tool used to measure temperature with a temperature range of -50°C - 550°C. Temperature measurement with this infrared thermometer tool measures the temperature contained in the diameter of the two points produced by this tool, and can also adjust the emissivity value depending on the material we are testing.

Figure 2.14: Infrared Thermometer

2.7.3 Thermocouple K-Type

Thermocouple is assembled with Arduino microcontroller to measure temperature. In this test, type K thermocouple is used which has a temperature range of -200 °C - 1200 °C and can be extended to 1300 °C.

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2.7.4 Vernier Caliper

Vernier caliper is a tool used to measure the initial and final thickness of the brake lining test specimen. The vernier caliper itself has an accuracy of 0.05 mm.

Figure 2.15: Vernier Caliper

2.7.5 Tachometer

Tachometer is an instrument used to determine the amount of motorcycle engine rotation (test equipment). The tachometer has an accuracy of about 500 RPM, so it is in accordance with the test procedure which requires a decrease in engine speed every 500 RPM.

2.7.6 Stopwatch

A stopwatch is used for time measurement during braking. The braking time is calculated from the first time pressing the brake lever until the wheel rotation condition stops. In addition, this stopwatch is also needed to measure the temperature recording time every 10 seconds.

2.7.7 Disc Brake Specimen

In this study, a disc brake was used as a test specimen as shown in Figure 2.16.

Figure 2.16: Testing Disc Brake

The variations of disc brake lining brands used are brand A, brand B, and brand C which can be seen in Figure 2.17.

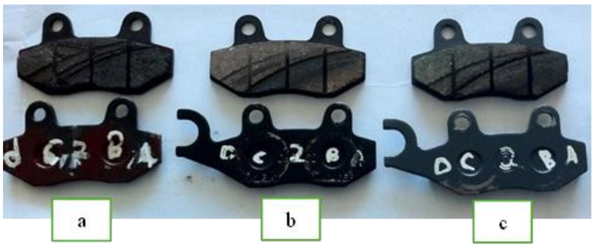

Figure 2.17: Testing Disc Brake Disc brake pads (a) OEM, (b) OSK brand, (c) Indopart brand

The disc brake pad test specimen is divided into 4 measuring points according to the part of the disc brake pad that is limited by the gap as shown in Figure 2.18.

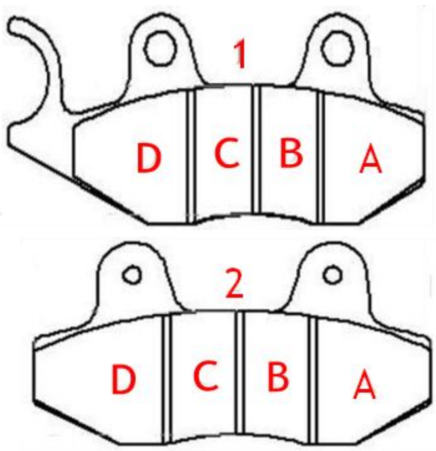

Figure 2.18: Disc brake lining measuring point position

2.8 Data Transmition

The method of Arduino sending temperature data to the web is by using a GPRS modem connected to the Arduino, then the data is forwarded to the Arduino Web Server, and forwarded back by hosting to the website.

III. RESULTS AND DISCUSSION

3.1 Test Results with RPM Variations until Steady

The results obtained from this experiment are the effect of temperature increase in each braking, and also the effect on RPM variations (2000 RPM, 3000 RPM, and 4000 RPM). This experiment was carried out from various variations of RPM until steady conditions, and was carried out 10 times repeatedly in a short time. The following are the results of tests carried out on several brands including, Indopart Brand, OSK Brand, and OEM brake linings.

From the experiments carried out, it was found that the effect of temperature increase was quite significant in each

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braking, but there was a fairly rapid decrease in temperature as well. This can be due to the fact that disc brakes have a good enough braking force so that the temperature at each braking is quite high, but disc brakes are also considered capable of releasing heat from braking quite quickly, because braking occurs in open spaces, unlike drum brakes. In addition, disc disks that are made to have holes are also designed to be able to release heat quickly.

3.1.1 RPM Variations for Indopart Brand

The change of temperature for Indopart brand disc brakes can be seen in Figure 3.1, Figure 3.2, and Figure 3.3. Where for engine speed 2000 RPM obtained a maximum temperature of 62.8˚C, while for engine speed 3000 RPM obtained a maximum temperature of 91.8˚C, and for engine speed 4000 RPM obtained a maximum temperature of 93.9˚C. From the description above, the higher the engine speed, the greater the temperature change during braking.

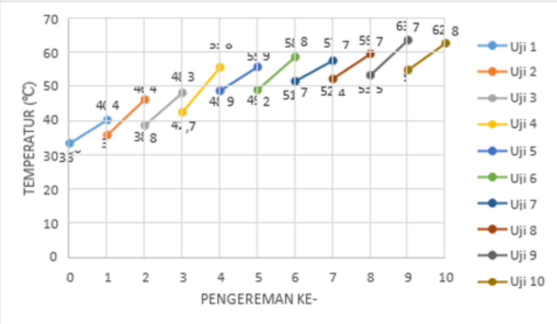

Figure 3.1: Indopart brand 2000-Steady RPM variation chart

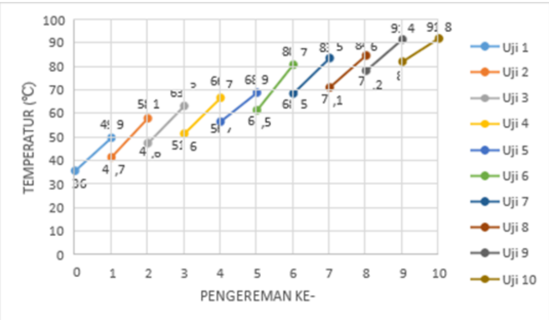

Figure 3.2: Indopart brand 3000-Steady RPM variation chart

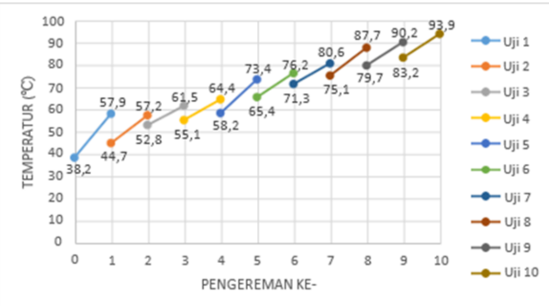

Figure 3.3: Indopart brand 4000-Steady RPM variation chart

3.1.2 RPM Variations for OSK Brand

Temperature changes for OSK brand disc brakes can be seen in Figure 3.4, Figure 3.5, and Figure 3.6. Where for engine speed 2000 RPM obtained a maximum temperature of 72.9˚C, while for engine speed 3000 RPM obtained a maximum temperature of 84.2˚C, and for engine speed 4000 RPM obtained a maximum temperature of 100.6˚C. From the description above, the higher the engine speed, the greater the temperature change during braking.

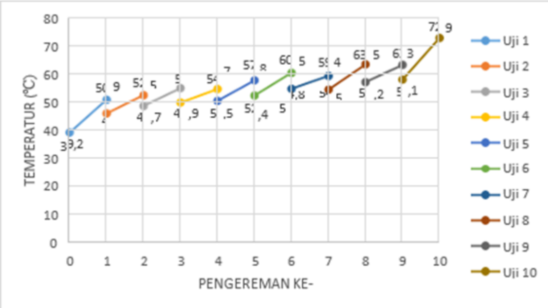

Figure 3.4: OSK brand 2000-Steady RPM variation chart

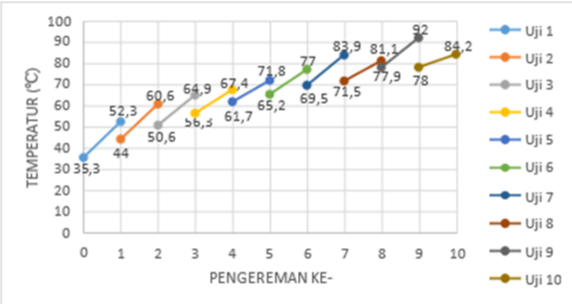

Figure 3.5: OSK brand 3000-Steady RPM variation chart

Figure 3.6: OSK brand 4000-Steady RPM variation chart

3.1.3 RPM Variations for OEM Brand

Temperature changes for OEM brake linings can be seen in Figure 3.7, Figure 3.8, and Figure 3.9. Where for engine speed 2000 RPM obtained a maximum temperature of 41.7˚C, while for engine speed 3000 RPM obtained a maximum temperature of 48.3˚C, and for engine speed 4000 RPM obtained a maximum temperature of 59.2˚C. From the

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description above, the higher the engine speed, the greater the temperature change during braking.

Figure 3.7: OEM brand 2000-Steady RPM variation chart

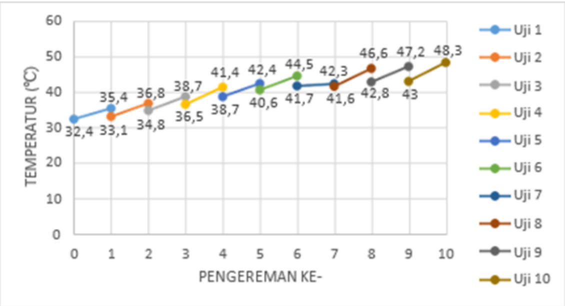

Figure 3.8: OEM brand 3000-Steady RPM variation chart

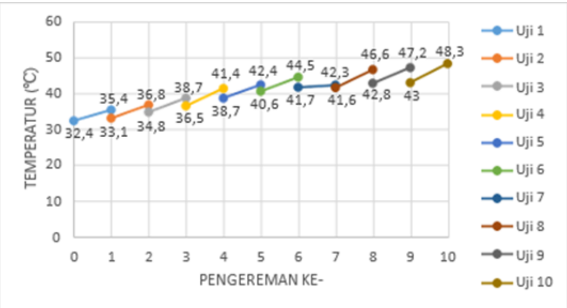

Figure 3.9: OEM Brand 4000-Steady RPM Variation Chart

3.2 Braking Cycle Test Results

The results obtained from this test are the maximum temperature (fading temperature) that can be achieved from each brake lining, and the holding of engine speed when reaching the maximum point. This test was carried out starting from engine speed of 4000 RPM which was then braked at 500 RPM to hold braking for 1 minute. So after 1 minute, braking is again carried out at 500 RPM and so on until it reaches the maximum temperature (fading). The following are the results of tests carried out on several brands including, Indopart Brands, OSK Brands, and OEM brake linings.

3.2.1 Braking Cycle for Indopart Brand

The change in temperature against engine speed with braking for Indopart brand disc brakes can be seen in Figure 3.10. Where the maximum temperature (fading) of 191.1˚C is reached, with the engine rotation holding at 2500 RPM. In this condition the brake lining is no longer able to stop the rotation of the wheel or is often called a lose-driving control.

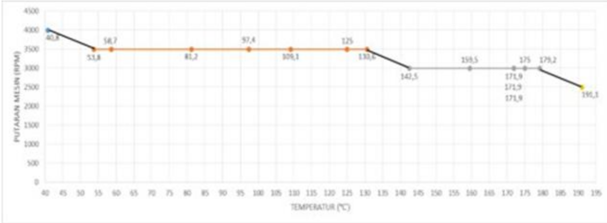

Figure 3.10: Indopart Brand Braking Cycle Chart

3.2.2 Braking Cycle for OSK Brand

The temperature change with respect to engine speed with braking for OSK brand disc brakes can be seen in Figure 3.11. Where the maximum temperature (fading) of 203.7˚C is reached, with the engine holding at 2500 RPM. In this condition the brake lining is no longer able to stop the rotation of the wheel or is often called a lose-driving control.

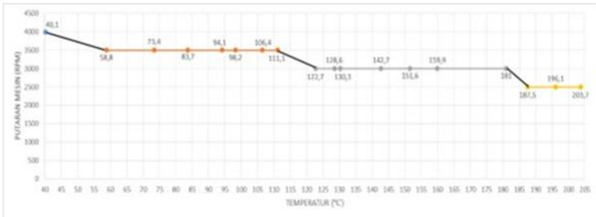

Figure 3.11: OSK Brand Braking Cycle Chart

3.2.3 Braking Cycle for OEM Brand

The temperature change with respect to engine speed holding with braking for OEM brake linings can be seen in Figure 3.12. Where a maximum temperature (fading) of 132˚C is reached, with engine rotation holding at 2500 RPM. In this condition the brake lining is no longer able to stop the rotation of the wheel or is often called a lose-driving control.

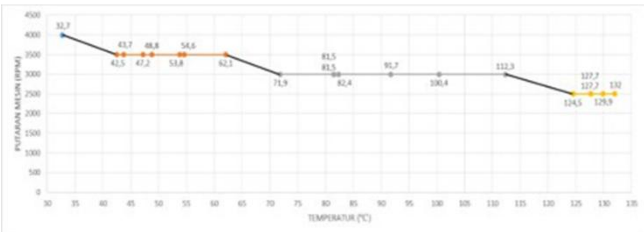

Figure 3.12: OEM Brand Braking Cycle Chart

3.3 Correlation of Coefficient of Friction to Temperature

From the braking cycle test, the coefficient of friction of each braking temperature is obtained. Each brand of brake lining has a different coefficient of friction at the beginning of

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the test, but when the brake lining reaches the maximum temperature point (fading) the coefficient of friction value almost has the same value (± 0.1). The overall coefficient of friction decreases at the beginning of braking, but will increase again or what is considered the optimum coefficient of friction at a certain temperature depending on each brand of brake lining. If it has passed the optimum temperature of the braking, the coefficient of friction of the brake lining will continue to decrease until the lowest coefficient of friction or is considered fading. The following is a graph of the coefficient of friction values for several brands including, Indopart Brand, OSK Brand, and the OEM brake lining.

3.3.1 Coefficient of Friction for Indopart Brand

Changes in the coefficient of friction that occur for Indopart brand disc brake linings can be seen in Figure 3.13. Where at the beginning of the test the coefficient of friction is 0.33912 with a temperature of 40.8˚C, and reaches an optimum point at a value of 0.28878 with a temperature of 97.4˚C, while at the maximum point (fading) only has a value of 0.1067 with a temperature of 191.1˚C.

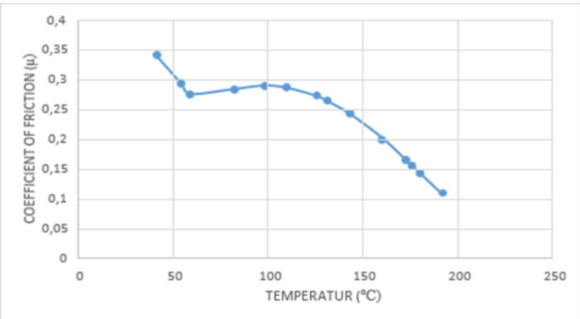

Figure 3.13: Indopart Brand Friction Coefficient Graph

3.3.2 Coefficient of Friction for OSK Brand

Changes in the value of the coefficient of friction that occur for OSK brand disc brake linings can be seen in Figure 4.23. Where at the beginning of the test the coefficient of friction is 0.305691 with a temperature of 40.1˚C, and reaches an optimum point at a value of 0.289089 with a temperature of 94.1˚C, while at the maximum point (fading) only has a value of 0.109057 with a temperature of 203.7˚C.

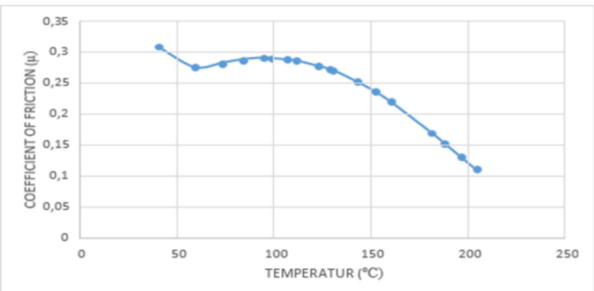

Figure 3.14: OSK Brand Friction Coefficient Graph

3.3.3 Coefficient of Friction for OEM Brand

The change in friction coefficient value that occurs for OEM brake linings can be seen in Figure 3.15. Where at the beginning of the test the coefficient of friction is 0.301829 with a temperature of 32.7˚C, and reaches an optimum point at a value of 0.289895 with a temperature of 62.1˚C, while at the maximum point (fading) only has a value of 0.100952 with a temperature of 132˚C.

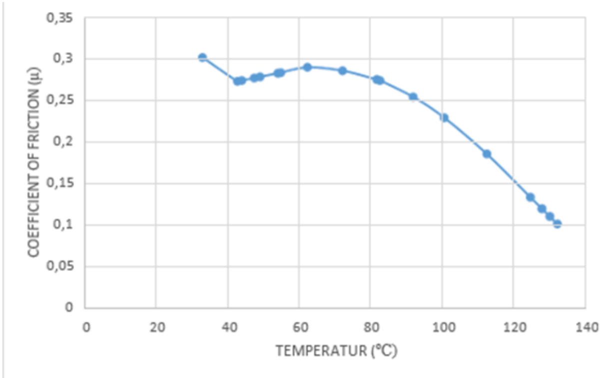

Figure 3.15: OEM Brand Friction Coefficient Graph

3.4 Comparison of Maximum Temperature (Fading) and Coefficient of Friction

From the results of the maximum temperature (fading) and coefficient of friction contained in section 3.1 and section 3.2 above, a comparison table can be made of the four brands of brake lining to determine which brake lining is the best and lowest based on the maximum temperature (fading) and coefficient of friction. The comparison of the four brands of brake lining can be seen in Table 3.1.

Table 3.1: Comparison of Maximum Temperature (Fading) and Coefficient of Friction

No	Brake Classification	Brand	Fading Temperature (˚C)	Friction Coefficient (µ)
1	Disc Brake	Indopart	191,1	0,1067
2	Disc Brake	OSK	203,7	0,109057
3	Disc Brake	OEM	132	0,100952

From Table 3.1 above, it can be seen that the brake lining with the OSK brand has the highest fading temperature of 203.7˚C and a friction coefficient value of 0.109057, followed by the Indopart brand brake lining with a fading temperature of 191.1˚C and a friction coefficient value of 0.1067, and finally the OEM brake lining with a fading temperature of 132˚C and a friction coefficient value of 0.100952.

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3.5 Temperature Correlation to Thickness Reduction

From the braking cycle test, it can be seen the effect of temperature on the reduction of brake lining thickness of each brand of brake lining tested. Using a vernier caliper with an accuracy of 0.05 mm, the thickness of the brake lining was measured before and after the test to determine the amount of brake lining thickness reduction during the test. Braking temperature is calculated from the difference between the final temperature (fading) and the initial temperature during the test.

Figure 3.16 shows the effect of the amount of thickness reduction on the braking temperature of the four brands of brake lining. The Indopart brand brake lining is the best, because it only experiences a thickness reduction of 0.3 mm with a braking temperature that can reach 120˚C. While the lowest is the built- in brake lining which experiences a thickness reduction of 0.4 mm with only being able to reach a braking temperature of 89.5 ˚C.

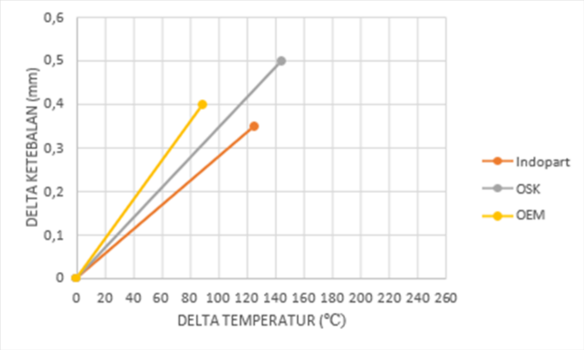

Figure 3.16: Comparison Chart of Thickness Reduction against Temperature

IV. CONCLUSION

Based on the research that has been done, there are several conclusions, namely the RMS work system can be considered quite effective and practical, because we can take measurements with sensors that are programmed by the Arduino microcontroller and connected with a GPRS modem to be sent to the Arduino web server. From this Arduino web server, we only need hosting and a domain that we create to display measurement graphs on the website. The three brands that became the test objects had different fading temperatures and friction coefficient values where the OSK brand became the object with the highest fading temperature at 203.7˚C and a friction coefficient value of 0.109057, while the OEM brand had the lowest fading temperature with a value of 132˚C and a friction coefficient value of 0.100952. From the test, it can be seen the effect of temperature on the reduction of brake lining thickness, where the brake lining brand that experienced the least reduction was the OSK brand which only experienced a thickness reduction of 0.3 mm with a braking temperature that could reach 203.7˚C. The effect of temperature on braking time from each variation of engine speed with the lowest value is the OEM brand because it has the shortest braking time of 1.596 seconds with a temperature increase of 3.84˚C at 2000 RPM; 1.832 seconds with a temperature increase of 2.56˚C at 3000 RPM; and 2.28 seconds with a temperature increase of 5.32˚C.

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