

CHARACTERISTICS OF THE DISC BRAKE COATING

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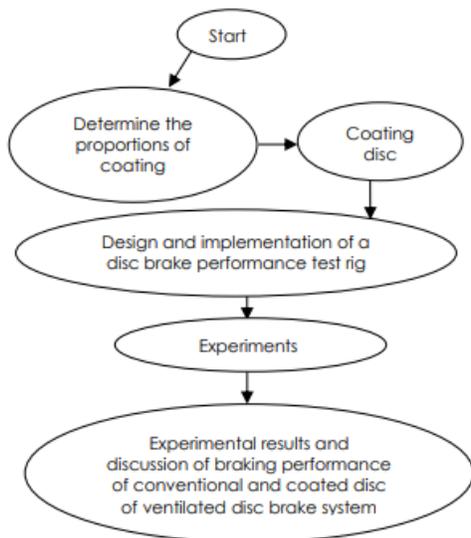
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Graphical abstract



Abstract

The vehicle and passengers' safety depends on the efficiency of the brakes, which work to convert kinetic energy into heat during the braking process through friction. Therefore, it is necessary to obtain a high-performance and stable coefficient of friction under different temperatures and operating conditions. The purpose of this paper is to improve the coefficient of friction and braking force at different operating condition as sliding speed 150, 300, 450 and 600 r.p.m, initial braking temperature 40, 70, 100, 130 °C, final braking temperature, braking time 60 seconds and deferent brake oil pressure 2.5, 5, 7.5, 10 bar for a ventilated disc brake system and used brake disc coating with (AL₂O₃ – 3 vol%) alumina for the coated disc brake sample with a brake pad containing (AL₂O₃ - 0.5 vol%) alumina and comparing it to commercial gray cast iron disc original with a brake pad containing (AL₂O₃ - 0.5 vol%) alumina. The experimental results indicate an improvement in the coefficient of friction and braking force for the coated disc with (AL₂O₃ – 3 vol%) alumina with a brake pad containing (AL₂O₃ - 0.5 vol%) and then, final operating temperature of a coated disc is relatively higher than to the results of the commercial disc without coating.

Keywords: Disc Brake Coating, Brake Friction Materials, Friction Brake, Characteristic Brake, Ventilated Disc Brake

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1.0 INTRODUCTION

The vehicle's brakes depend on friction to convert the vehicle's kinetic energy into thermal energy. Thus, this friction produces a high temperature which the brake parts are exposed, especially the area of the friction surfaces [1]. Therefore, it is necessary to get rid of excess heat, otherwise the temperature of the rotor (disc or drum) may rise. Which affects braking performance negatively [2]. The materials that brakes

are made of must have a set of properties, including resistance to high temperatures and rapid disposal, provide stable friction coefficient at high temperature to avoid brake fade, fast repeatable response [3]. In disc brakes, the friction surfaces are exposed to good ventilation compared to drum brakes, thus the frictional heat is dissipated at a faster in the disc brake system [4]. GCI discs are characterized by several properties, the most important of which are their high melting point and quick release of excess heat.

Therefore, it is the most widely used material in brake discs, The COF increased with increasing the alumina and graphite on the gray iron disc samples, Aluminum alloy is relatively better then compared to GCI and cast steel in terms of price and environmental impact [5,6]. Ceramic materials have received attention due to their unique properties in recent years, such as silicon carbide, alumina, and zirconia [7,8]. Despite the advantages of gray cast iron, it is subject to corrosion and a low coefficient of friction and braking force in some difficult operating conditions. It also causes relatively harmful effects due to the dust resulting from the friction and corrosion process [9]. Many studies have discussed that 55% of automobile emissions result from disc and pad wear resulting from friction during the total brake loading process [10,11]. Several different types of coatings have been explored over the years, to reduce wear and obtain a stable coefficient of friction. There are many techniques, the most important of which are thermal spraying processes, and non-thermal spraying processes, which are the most widely used [12]. Oxide ceramic materials have been applied in many applications that require corrosion resistance and stable friction, such as titanium oxide (TiO_2), aluminum oxide (Al_2O_3) and chromium oxide (Cr_2O_3), which are widely used materials due to their high strength and hardness, good corrosion resistance, and tolerance to high temperatures [13,14,15]. In this study, cobalt was used as a brake disc coating material. A brake dynamometer test was conducted, which ranged from 50 to 400 km/h, to validate the method of preparing the brake disc for a laser coater (LC-disc). The LC disc showed a constant coefficient of friction (COF), ranging between 0.296 and 0.44. The COF decreased as the initial speed increased [16]. The friction disc's maximum temperature during emergency braking is over 700 °C [17, 18]. In this paper, aluminum-based composite coatings reinforced with TiC particles of different mass percentages (20 %, 40 %, 60 %) aluminum alloy by direct laser deposition technology. distribut The 40 %TiC coating shows the most excellent wear resistance [19].

This study summarizes the effect of coating the brake disc with aluminium oxide (Al_2O_3 - 3 vol%) for the coated disc with a brake pad containing (Al_2O_3 - 0.5 vol%) alumina and comparing the results to the conventional commercial disc without coating. The experimental results showed the improvement of the coefficient of friction and braking power of the coated disc compared to the conventional commercial disc without coating.

2.0 METHODOLOGY

2.1 Main Components of Test Rig and Description

There are two types of brake dynamometer designs. The first type is used to examine the brake performance at constant speed, and it is called drag-type dynamometer [20,21]. An inertia-type brake dynamometer that has a fly wheel is the second type

[22]. The purpose of brake performance test rig (drag-type) brake dynamometer shown in Figure 1 and its main components shown in Table 1 is to generate kinetic energy that the braking system can overcome and measure the brake power of the uncoated commercial disc and coated disc with (Al_2O_3 - 3 vol%) for the ventilated disc brake system with the brake pad containing (Al_2O_3 - 0.5 vol%).

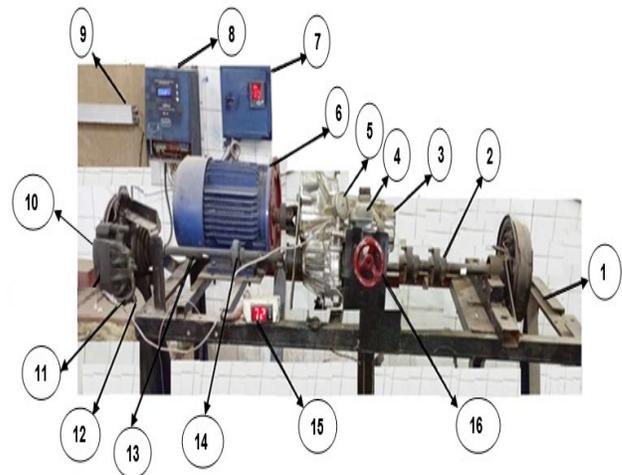


Figure 1 Brake performance test rig

Table 1 Main components of test rig

No.	Component
1	Test rig chassis
2	Coupling
3	Gearbox
4	Master cylinder
5	Pressure gauge
6	A.C motor
7	Power meter
8	Inverter
9	Braking resistor
10	Disc brake system
11	Hydraulic tube
12	Thermocouple
13	Axel
14	Coupling
15	Temperature control unit
16	Scraw push with a handel

A disc brake of Hyundai Excel 2005 model is used in the test rig. This braking system is a ventilated disc brake a Floating type, in Figure 2 shows, the main components of the disc brake system. The floating disc brake system has one wheel cylinder, it contains one hydraulic piston on only one side of a main Caliper, pad holder clips, fixing screws, braking plate and the brake pads.



Figure 2 Disc brake of Hyundai excel 2005 model

In this study, laboratory experiments were carried out on two discs, the first a traditional commercial disc and the other a coated disc. The first disc was without any modifications (without coating), while the second coated disc was coated with ($Al_2O_3 - 3 \text{ vol\%}$). A brake pad containing ($Al_2O_3 - 0.5 \text{ vol\%}$) was used with the regular commercial disc without coating and coated disc brake.

2.1.1 The Normal Force and Kinetic Energy Generation Unit

To generate kinetic energy, there must be a source of movement in the test device. The motor power generation unit in the test rig consists of: Firstly: an electric A.C motor with a maximum power of 7.5 (Kw) at a maximum rotational speed of 2900 r.p.m, which is controlled through, secondly: a variable frequency device of type VFC-18, thirdly: a gearbox Four-speed variable speeds to increase control over the rotational speed of the system. The main factor for generating braking force is the normal force that affects the wheel cylinder piston, by pressing the brake oil to create friction between the pad and the disc brake. In the test rig, the normal force generation unit consists of was used screw push with a handle to control in brake oil pressure and a master cylinder of commercial passenger car of Hyundai Excel 2005 model is used to generate the constant normal force.

To calculate the applied normal force (F_n) of the disc brake system acting on the brake pad, the brake oil pressure must be measured, and the piston head area known. The following equations explain this:

$$A_s = \frac{\pi}{4} D_s^2 \quad (1)$$

$$P = \frac{F_n}{A_s} \quad (2)$$

$$F_n = P * A_s \quad (3)$$

Where: D_s is the piston diameter of the slave cylinder equals (0.052 m), A_s is the piston area of the slave cylinder equals ($2.12 * 10^{-3} \text{ m}^2$), F_n is the applied force of the disc brake system, in laboratory experiments, oil

pressure values of 2.5, 5, 7.5 and 10 bar were chosen, according to equation (3). These pressure values equal the applied force of 551, 1103, 1654 and 2206 N respectively for the ventilated disc brake system as shown in Figure 3.

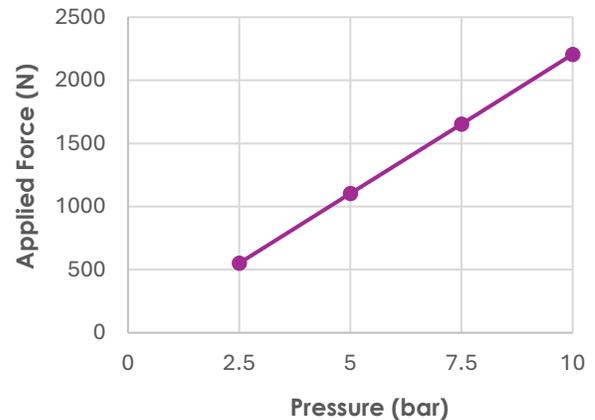


Figure 3 Effect of pressure on applied force of commercial and coated disc with pad contains $Al_2O_3 - 0.5 \text{ vol\%}$

2.1.2 The Temperature and Speed Measurement

The coefficient of friction is affected by the operating temperature and the sliding speed of the rotor disc, which affects braking performance. was used a digital temperature measuring unit was assembled and a J-type thermocouple with a range of 700 °C as shown in Figure 4. An initial operating temperature of 40, 70, 100, and 130 °C was chosen at the beginning of each experiment. Measured the final operating temperature at the end of each experiment for 60 seconds of braking time for the conventional and coated brake disc at each constant pressure during the experiment. The sliding speed of rotor disc was measured at different sliding speeds are 150, 300, 450 and 600 r.p.m during different operating conditions. using a DT6234 digital tachometer with a range of 5 to 10,000 r.p.m. As shown in Figure 5.

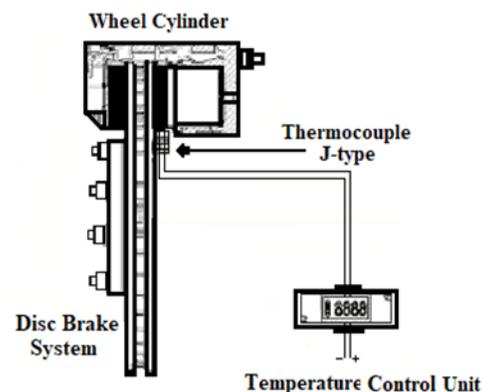


Figure 4 The temperature measurement unit



Figure 5 Digital tachometer model DT6234

2.2 Brake Torque Calculation

Braking torque is very important to evaluate braking performance, and the results of this study depend on several factors, including braking torque, motor power was measured using a Schneider PM 1200 digital power meter with a range from 20 w to 300 kw, see Figure 6.



Figure 6 Digital power meter unit

The rotational speed and braking power of the commercial and coated disc were measured during braking time and the following equations explain how to calculate braking torque as a function of sliding speed of rotor disc and braking power.

$$P_b = P_L - P_{no} \quad (4)$$

Where: P_b is the brake power (watt), P_L is the electric motor power during the braking process (watt), P_{no} is the electric motor power during the operation with no braking load (watt).

$$T_b = \frac{P_b}{\omega} \quad (5)$$

$$\omega = \frac{2\pi n}{60} \quad (6)$$

Where: T_b is the brake torque (N.m), ω is the angular speed of the rotating disc (rad/sec), n is the sliding speed of the rotating disc (r.p.m).

2.3 Friction Coefficient and Brake Force Calculations

The following equations explain how to calculate the coefficient of friction and braking force for a disc brake system with a conventional uncoated disc and coated disc with a brake pad containing (Al_2O_3 - 0.5vol%).

$$T_b = 2 F_b \cdot R_{eff} \quad (7)$$

Where: R_{eff} is the effective radius of the brake pad, equals 0.089 m, r_i is the inner radius of the brake pad(m), r_o is the outer radius of the brake pad (m), F_b is the brake force generated at the contact interface (N).

For a disc brake commercial and modified system there is a pair of brake pads, thus the total brake torque is:

$$T_b = 2 F_b R_{eff} \quad (8)$$

$$R_{eff} F = \frac{r_i + r_o}{\omega} \quad (9)$$

From equation (8) the brake force of the commercial and modified system can be calculated as follow:

$$F_b = \frac{T_b}{2R_{eff}} \quad (10)$$

Where: F_b is the brake force (N), however, braking force varies depending on the normal force and friction coefficient, which is resulting as following:

$$F_b = \mu * F_n \quad (11)$$

The friction coefficient can be calculated as below:

$$F_b = \mu * P * A_s \quad (12)$$

$$\mu = \frac{F_b}{P A_s} \quad (13)$$

Where: μ is the friction coefficient [22].

3.0 RESULTS AND DISCUSSION

Laboratory experiments focused on studying several factors to evaluate braking performance using a brake pad containing (Al_2O_3 - 0.5 vol%) alumina, a brake disc coated with (Al_2O_3 - 3 vol%) alumina, and a commercial uncoated disc, at sliding speeds of 150, 300, 450, 600 r.p.m and at pressures of 2.5, 5, 7.5 and 10 bar at initial operating temperatures of 40, 70, 100 and 130 °C. For each experiment, the coefficient of friction, brake torque and brake force were

determined during 60 seconds of testing during the various operating conditions mentioned above.

3.1 Effect of Brake Oil Pressure at Sliding Speed 150 R.P.M. On Brake Force

The results shown in Figure 7 and Figure 8 show the increase in the brake force due to the increase in the brake oil pressure at constant sliding speed 150 r.p.m and the results show that the brake force of commercial disc less than brake force of coated disc with alumina (AL₂O₃ -3 vol%) with pad contains (AL₂O₃ -0.5 vol%) alumina at every pressure.

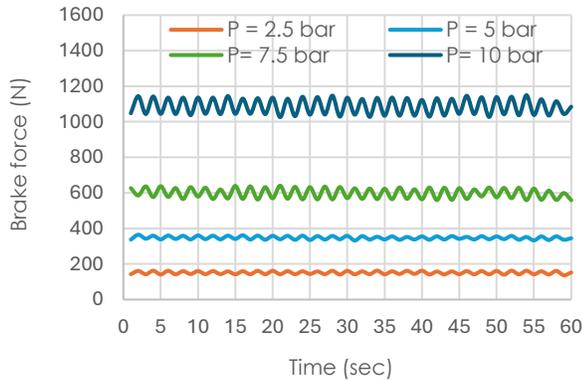


Figure 7 Effect of pressure on the brake force of commercial disc at sliding speed 150 r.p.m

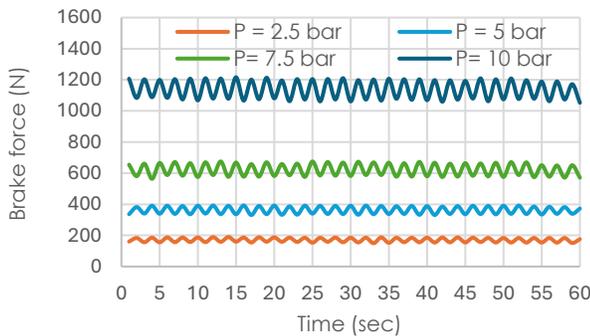


Figure 8 Effect of pressure on the brake force of coated disc at sliding speed 150 r.p.m

In Figure 9 the results illustrated that the brake forces of the uncoated commercial disc brake at initial temperature 40C are 151.118, 347.339, 597.769 and 1086.148 N respectively and the mean brake forces of coated disc brake are 170.642, 362.536, 622.472 and 1137.016 N respectively at brake oil pressure of 2.5, 5, 7.5 and 10 bar respectively. At each constant pressure, the value of the brake force of coated disc increases by 12%, 8.3%, 4.1% and 4.5% respectively depending on the value of the brake force of the uncoated commercial disc brake.

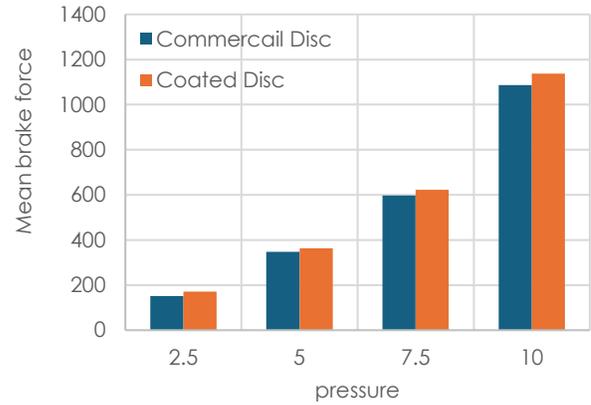


Figure 9 Effect of pressure on the mean brake force of commercial and coated disc brake with pad contain (AL₂O₃ - 0.5 vol%) at sliding speed 150 r.p.m

Figure 10 the presented results show the effect of brake oil pressure on mean friction coefficient of commercial and coated disc at sliding speed of 150 r.p.m at initial temperature 40°C and 130°C. The results show that, with increased oil pressure, the average friction coefficient increases of the commercial and coated disc brake. Also, the results show that the average friction coefficient of coated disc brake is more than the average friction coefficient of the commercial disc brake at each pressure this is due to the indicated that alumina improves friction coefficient. The increase of the oil pressure from 2.5 to 10 bar causes an increase in the mean friction coefficient, from 0.2739 to 0.4923 for commercial disc at initial temperature 40 °C, from 0.266 to 0.486 at initial temperature 130 °C and from 0.3093 to 0.5153 at initial temperature 40 °C, from 0.299 to 0.501 at initial temperature 130 °C for coated disc.

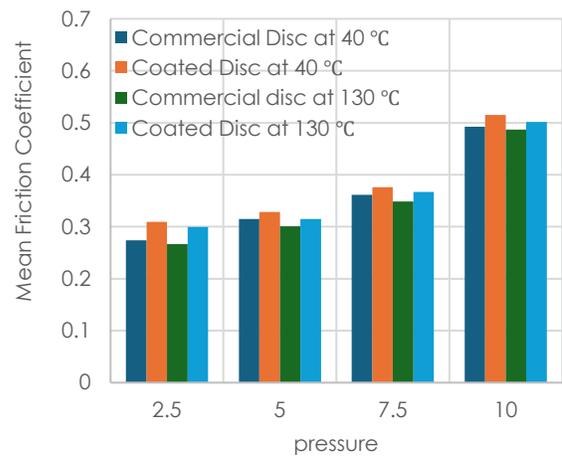


Figure 10 Effect of brake oil pressure on the mean friction coefficient of commercial and coated disc at initial temperature 40, 130°C at sliding speed 150 r.p.m

3.2 Effect of Brake Oil Pressure on Operating Temperature at Sliding Speed 150 R.P.M

Figure 11 shows The effect of brake oil pressure on the final temperature after each experimental at initial temperature 40 and 130 °C of commercial and coated disc brake at sliding speed 150 r.p.m .as well The results shown that, As the brake oil pressure increases, the final temperature of commercial and coated disc increase, likewise, the final temperature of uncoated commercial disc less than the final temperature of coated disc at each pressure. This is due to the decreasing friction coefficient in uncoated commercial disc. The final temperature of the commercial disc is 45,47,53 and 57°C at initial temperature 40°C, and at initial temperature 130°C is 131, 132, 133 and 137°C, and the final temperature for coated disc is 46, 50, 55 and 60°C at initial temperature 40°C and at initial temperature 130°C is 133, 134, 137 and 139°C respectively according to the brake oil pressure of 2.5, 5, 7.5 and 10 bar.

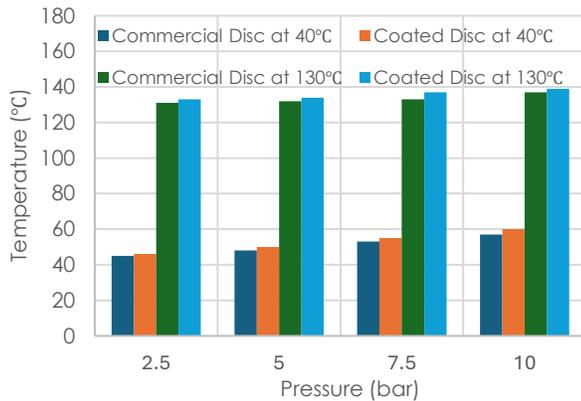


Figure 11 Effect of brake oil pressure on final operating temperature of commercial and coated disc at initial temperature 40°C and 130°C at sliding speed 150 r.p.m

The mentioned temperature values indicate an increase in final temperature values for coated disc by 2.2%, 4%, 3.6% and 5% at initial temperature 40°C and at initial temperature 130°C by 1.5%, 1.4%, 2.9%, and 1.4% according to the value of the final temperature uncoated commercial disc.

3.3 Effect of Sliding Speed on Brake Force of Rotating Commercial and Coated Disc

In Figure 12 and Figure 13 the results show the variation of the mean brake force of the commercial and coated disc brake at different sliding speeds. The results show that the increase in the sliding speed of the rotating disc causes a decrease in the mean brake force of commercial and coated disc. This is due to a decrease in the friction coefficient. From the results, it can be concluded that the friction coefficient decreases with increasing sliding speed, due to several reasons as follows: Lubricating oxides form at elevated temperatures, and if the surface

frictionally melts, the molten liquid can lubricate the asperity contacts. The mean brake forces of commercial disc are 151, 141, 130 and 123 N at brake oil pressure 2.5 bar , 347, 332, 325 and 287 N at 5 bar, 597, 570, 557 and 544 N at 7.5 bar, 1086, 1061, 1028 and 999 N at brake oil pressure 10 bar and the mean brake forces for coated disc are 170, 160, 153, 142 N at brake oil pressure 2.5 bar and 362, 351, 340 and 314 N at 5 bar, 622, 591, 579 and 568 N at 7.5 bar, 1137, 1103, 1086 and 999 at 10 bar at sliding speeds of 150, 300, 450 and 600 r.p.m respectively, Also, the results in Figure 12 and Figure 13 show that, at each constant speed, the value of the mean brake force of coated disc increase approximately by 11.1%, 11.8%, 9.8% and 11.2% at brake oil pressure 2.5 bar and increase at 5 bar by 4.1%, 5.4%, 4.4 and 8.5% and increase at 7.5 bar by 4%, 3.5%, 3.7% and 4.2% and increase at 10 bar by 4.4%, 3.8%, 5.3% and 7.6% respectively according the value of mean brake force of commercial disc brake. This is due to the alumina enhances friction coefficient and brake force.

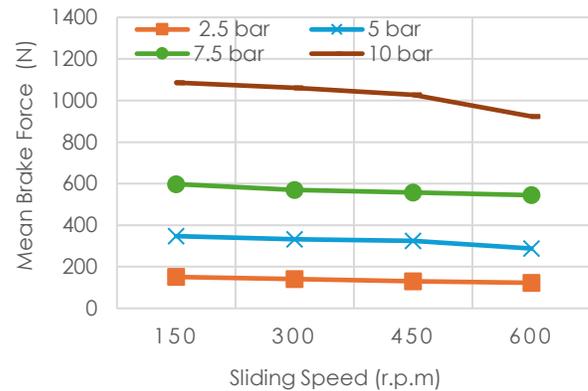


Figure 12 Variation of mean brake force of commercial disc as a function of different sliding speeds at pressure from 2.5 bar to 10 bar

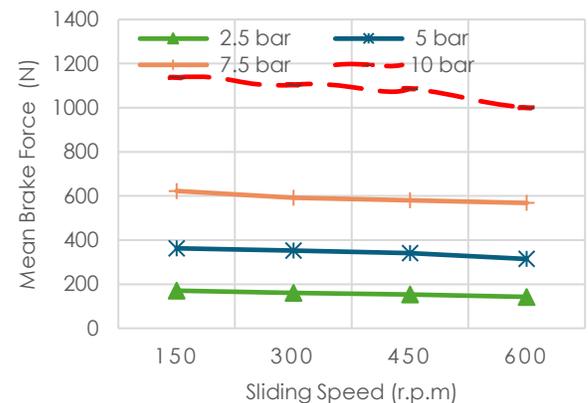


Figure 13 Variation of mean brake force of coated disc as a function of different sliding speeds at pressure from 2.5 to 10 bar

3.4 Effect of Sliding Speed of Rotating Commercial and Coated Disc on Operating Temperature at Different Brake Oil Pressure

The results in Figure 14 and Figure 15 presented the effects of sliding speed of rotating commercial and coated disc on final temperature at pressure of 2.5 bar, the results explain that, with the increase of the sliding speed of the rotating commercial and coated this leads to an increase of final temperature of commercial and coated disc. The final temperature of commercial disc at initial temperature 40°C are 45, 60, 67, 71°C and the final temperature of coated disc are 46, 62, 68, 74°C and at initial temperature 70°C for commercial disc are 72, 74, 75, 77°C and for coated disc are 75, 77, 78, 79°C and at initial temperature 100°C for commercial disc are 101, 102, 103, 105°C and for coated disc are 103, 104, 105, 107°C and for commercial disc are at initial temperature 130°C are 131, 132, 130 and 135°C and for coated disc are 133, 134, 136 and 138°C at sliding speeds of 150, 300, 450 and 600 r.p.m respectively. As well, the results show that, at each constant speed, the value of final temperature of coated disc increased approximately by 2.1%, 3.2%, 1.4% and 4.5% respectively at initial temperature 40°C and at initial temperature 70°C increase approximately by 4%, 3.8%, 3.8% and 2.5% respectively and at initial temperature 100°C increase approximately by 1.9%, 1.9%, 1%, and 1.8% and at initial temperature 130°C increase approximately by 1.5%, 1.4%, 1.4% and 2.1% according to the value of the final temperature of uncoated commercial disc, This is because increased friction coefficient of coated disc at different operating temperature according to value of final temperatures of uncoated commercial disc.

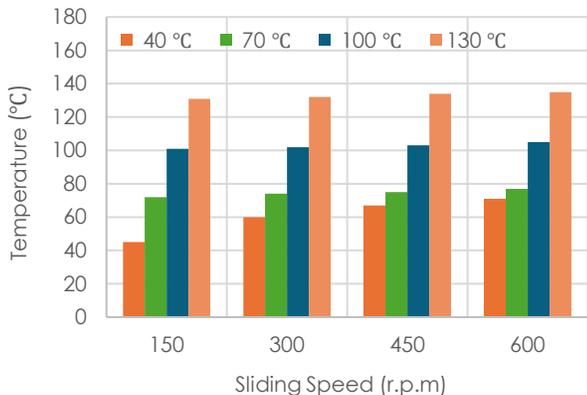


Figure 14 Effect of sliding speed on the final temperature of commercial disc at brake oil pressure 2.5 bar

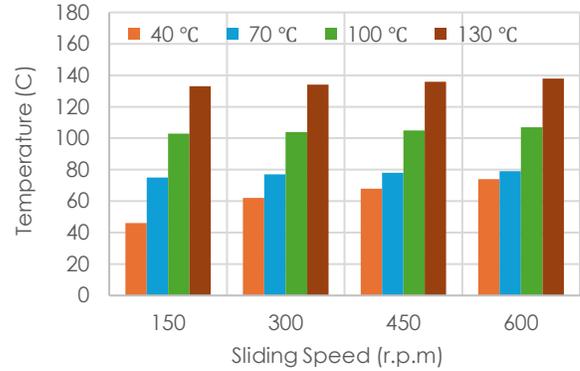


Figure 15 Effect of sliding speed on the final temperature of coated disc at brake oil pressure 2.5 bar

3.5 Effect of Brake Oil Pressure on Brake Torque at Different Sliding Speed

The results in Figure 16 and Figure 17 showed, at initial temperature 40°C effects of brake oil pressure on brake torque of commercial and coated disc brake at sliding speed 150, 300, 450 and 600 r.p.m respectively at pressure 2.5 bar. The results explain that the mean brake torque of commercial disc are 26.45, 24.73, 22.88 and 21.53 N.m at brake oil pressure 2.5 bar and the mean brake torque of coated disc are 29.87, 28.03, 26.85 and 24.22 N.m at sliding speeds of 150, 300, 450 and 600 r.p.m respectively, Also the results shown that, the coated disc have a higher mean brake torque than the mean brake torque of commercial disc. with increasing the sliding speed from 150 to 600 r.p.m causes a decrease on mean brake torque from 26.45 to 21.53 N.m at initial temperature 40 °C for commercial disc and decrease from 29.87 to 24.22 N.m at initial temperature 40°C for coated disc. At each constant speed, the value of the mean brake torque of coated disc increases approximately by 10.3%, 14.2%, 15.3% and 12.5% at brake oil pressure 2.5 bar respectively according to the value of mean brake torque of commercial disc this is due to enhancement of friction coefficient and brake power.

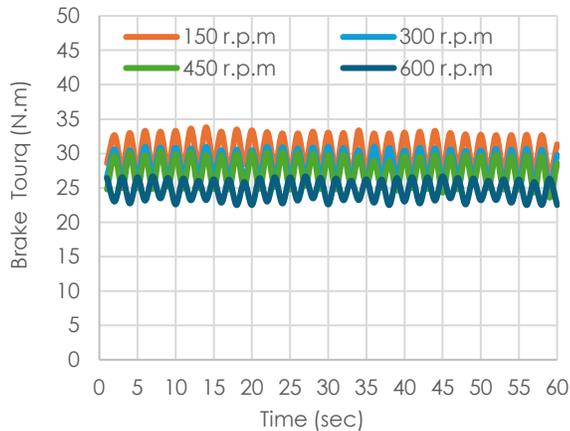


Figure 16 Effect of sliding speed on brake tourq of commercial disc at brake oil pressure 2.5 bar

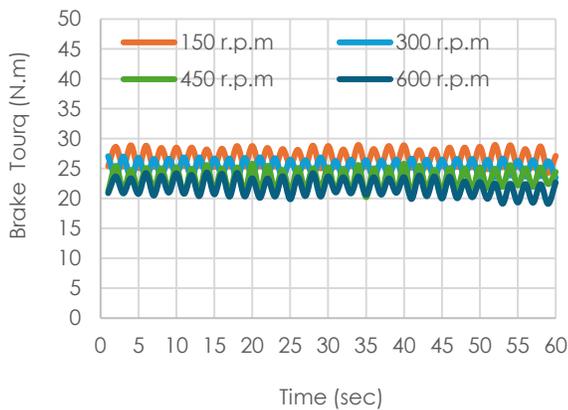


Figure 17 Effect of sliding speed on brake tourq of coated disc at brake oil pressure 2.5 bar

4.0 CONCLUSIONS

The results of this study showed that, the friction coefficient of commercial and coated disc decreases with increasing brake time at a sliding speed of 150 rpm and 600 r.p.m, which leads to decreases in brake tourq, especially with increasing operating temperatures. The mean brake forces of uncoated commercial disc at initial temperature 40C are 151.118, 347.339, 597.769 and 1086.148 N respectively at brake oil pressure of 2.5, 5, 7.5 and 10 bar respectively, as for the mean brake forces of coated disc brake with coating alumina (Al_2O_3 -3 vol%) with pad contain (Al_2O_3 -0.5 vol%) are 170.642, 362.536, 622.472 and 1137.016 N respectively at brake oil pressure of 2.5, 5, 7.5 and 10 bar respectively and at each constant pressure, the value of the mean brake force of coated disc brake increases by 12%, 8.3%, 4.1% and 4.5% respectively depending on the value of mean brake force of uncoated commercial disc. The results also showed that, the increase of the oil pressure from 2.5 to 10 bar causes an increase in the

mean friction coefficient, from 0.2739 to 0.4923 for commercial disc with pad contains (Al_2O_3 -0.5 vol%) at initial temperature 40 °C, from 0.266 to 0.486 at initial temperature 130 °C and from 0.3093 to 0.5153 at initial temperature 40 °C, from 0.299 to 0.501 at initial temperature 130 °C for coated disc with pad contains (Al_2O_3 - 0.5 vol%) and the final temperature of the commercial disc with pad contains (Al_2O_3 -0.5 vol%) is 45,47,53 and 57°C at initial temperature 40°C, and at initial temperature 130°C is 131, 132, 133 and 137°C, and the final temperature for coated disc (Al_2O_3 - 3 vol%) with pad contains (Al_2O_3 - 0.5 vol%) is 46, 50, 55 and 60°C at initial temperature 40°C and at initial temperature 130°C is 133, 134, 137 and 139°C respectively according to the brake oil pressure of 2.5, 5, 7.5 and 10 bar. As was evident from the results as well the mean brake forces for commercial disc are 347, 332, 325 and 287 N and mean brake forces for coated disc with pad (Al_2O_3 - 0.5 vol%) are 362, 351, 340 and 314 N at brake oil pressure 5 bar. The mean brake force of coated disc with pad contained (Al_2O_3 - 0.5 vol%) increased approximately by 11.1%, 11.8%, 9.8% and 11.2% at brake oil pressure 2.5 bar and increase at 5 bar by 4.1%, 5.4%, 4.4 and 8.5% and increase at 7.5 bar by 4%, 3.5%, 3.7% and 4.2% and increase at 10 bar by 4.4%, 3.8%, 5.3% and 7.6% respectively according to the value of mean brake force of commercial disc brake. This is because to the alumina enhances friction coefficient and brake force. At each constant speed, the value of final temperature of coated disc with pad contains (Al_2O_3 -0.5 vol%) increase approximately by 2.1%, 3.2%, 1.4% and 4.5% respectively at initial temperature 40°C and at initial temperature 70°C increase approximately by 4%, 3.8%, 3.8% and 2.5% respectively and at initial temperature 100°C increase approximately by 1.9%, 1.9%, 1%, and 1.8% and at initial temperature 130°C increase approximately by 1.5%, 1.4%, 1.4% and 2.1% according to the value of the final temperature of uncoated commercial disc with pad containing (Al_2O_3 - 0.5 vol%), this is because increase friction coefficient of coated disc at different operating temperature according to value of final temperature of uncoated commercial disc. Also, the coated disc has a higher mean brake tourq than the mean brake tourq commercial disc without coated. with increasing the sliding speed from 150 to 600 r.p.m causes a decrease in mean brake torque from 26.45 to 21.53 N.m at initial temperature 40 °C for commercial disc and decrease from 29.87 to 24.22 N.m at initial temperature 40°C for coated disc. At each constant speed, the value of the mean brake tourq of coated disc increase approximately by 10.3%, 14.2%, 15.3% and 12.5% at brake oil pressure 2.5 bar respectively according to the value of mean brake tourq of commercial disc this is due to enhancement of friction coefficient and brake power.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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