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Effect of Sliding Speed on the Performance of Coated Ventilated Disc Brake

1Rewida Sami Abdullah, 2 AhmedAbouAlyazid, 3 Ibrahim Ahmed

1Researcher, Automotive and tractor engineering department, faculty of engineering, Helwan University, Egypt

2professor at Automotive and tractor engineering department, faculty of engineering, Helwan University, Egypt

2professor at Automotive and tractor engineering department, faculty of engineering, Helwan University, Egypt

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ABSTRACT:
This research paper is about enhancing tribological behaviour of ventilated disc brake by using (Cr3C2-75 % NiCr25 %) coating on the first disc and (Al2O3-87 % TiO2 13%) coating on the second disc to compare them with the plain disc with no coating to determine if this coating materials improve the coefficient of friction (µ) and brake force (Fb) with variable sliding speed and different initial temperatures after comparison it is concluded that the second disc with (Al2O3-87 % TiO2 13%) coating has the most low coefficient of friction and low final temperature than the first disc with (Cr3C2-75 % NiCr25 %) coating. The plain disc is the highest one.

First, the test rig is designed and constructed to examine the performance of the brake system. Second, two different coating layer is used on two brake discs. After that, some experimental tests are conducted on the three discs at different sliding speeds at constant brake oil pressure and at different initial operating temperatures. Finally, comparisons between three brake discs are performed. Experimental results showed that the brake force (Fb) and the coefficient of friction (µ) of the second disc with (Al2O3-87 % TiO2 13%) coating is lower than the brake force and the coefficient of friction of the first disc with (Al2O3-87 % TiO2 13%) coating and the brake force (Fb) and the coefficient of friction (µ) of the first disc is lower than the brake force and the coefficient of friction of the plain disc with no coating.

KEYWORDS: Coating, Ventilated disc brake, Brake force(Fb), Friction coefficient(µ) , sliding speed , initial temperature.

I. INTRODUCTION

Braking system is the most important system in the vehicle which granite the safety of the passengers. It is the task of braking mechanisms to slow or stop the movements of the vehicles under different operating conditions. The most important components of these mechanisms are the disc and lining pairs. Brake discs are made of graphite cast iron. The friction of the brake pad against a cast iron disc has a great technological importance in the automotive industry. In addition, different physical rules of contact and friction mechanisms are involved in micro scale of braking. Friction motion is required and the coefficient of friction must be stable. The disc and lining pair must maintain its structure without being affected by temperature, humidity and the degree of wear, dirt and water splashes on the road. They also do not vibrate and make noise [1].

The surface properties of the brake disc exposed to high temperatures need to be improved. One of the most commonly used methods to solve the problems arising from friction and wear mechanisms is coating.

NiCrBSi coatings straighten the homogeneity by reducing porosities and improve micro structuralproperties and tribological performance. These coatings

are widely used in large industrial applications wherehigh temperature wear, friction, corrosion and oxidation are required. Wu et al. [2] investigated the microstructure and mechanical properties of 24CrNiMo dust on the brake disc by laser coating.

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During the braking, the kinetic energy of the vehicle is converted into the heat energy through friction. The braking elements are subject to very heavy thermo mechanical conditions under heat, speed and load. Friction properties of the brake disc must be thermally more stable against the heat

energy generated on it in order to maintain stability[3].

In this study, the performance of thecoated brake discs is investigated and as a result, the coated disc showed an improvement compared with the original disc due to the coefficient of friction and brake force.

II. EXPERIMENTATION

2.1 Test rig description:

The brake test rig has two main objectives. The first objective is the ability to measure the generated brake power of the plain disc brake, the first disc with (Cr_3C_2-75 % $NiCr$25 %) coating and the second disc with (Al_2O_3-87 % TiO_2 13%) coating. at all operating parameters. The second objective of the test rig is to generate the required kinetic energy that could be overcome by the braking system. The test rig is designed and constructed to achieve these requirements. Fig.1 shows the main components of the test rig which are disc brake system assembly, components of generation the kinetic energy.

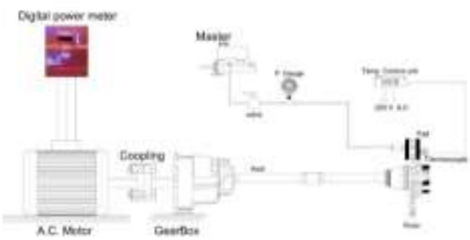

Figure (1) Main components of the test rig

A disc brake of Hyundai Excel passenger car is used in the test rig. This braking system is a floating caliper disc brake. The main components of this system are shown in Fig.1. It consists of floating caliper with its slave cylinder which contains a hydraulic piston of diameter 5.3 cm, rotor disc, two brake pads, wheel bearing, finger and hub. The hydraulic pipe is connected between the master cylinder and the hydraulic piston.

Figure (2) disc brake of Hyundai Excel.

2.2 kinetic energy generation:

An A.C electric motor is used in the test rig, as shown in Fig. (1). The electric motor is three phase type which has maximum power 10 Hp at 1500 r.p.m. In order to do the experiments at various speeds, a gear box with differential unit of a Hyundai Excel passenger car is installed between the electric motor and the brake system. This gear box and its differential unit have reduction ratios of 6.5, 3.9, 2.6, 1.9, 1.5 and a reverse reduction ratio of 6.8.

2.3 Normal force generation

The braking force is depending on two main parameters. The first parameter is the normal force affecting the brake pad. The second parameter is the coefficient of friction between the brake pads and the rotor disc. So, the normal force is considered the main factor of generating the brake force. Hence its effect on the braking process has to be taken into consideration. The generated normal force must have constant values during the tests according to the to the operating conditions. A master cylinder of commercial passenger car model Hyundai Excel is used to generate the constant normal force

2.4 Pressure measurement:

The value of the oil pressure in the brake system is measured by using an oil pressure gauge. The pressure gauge is mounted in the hydraulic line between the master cylinder and the slave cylinder of the brake system. The normal force is calculated as the multiplication of the piston area of the slave cylinder and the magnitude of the oil pressure. Different values of the normal force are determined according to the values of the oil pressure.

Four oil pressure values of 2.5, 5, 7.5, 10 bar are selected during the tests .According to

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equation (3) these values of pressure equal normal forces of 550, 1100, 1650, 2200 N respectively. To insure that the normal force is constant during the tests, a control valve was used to achieve this aim. The valve was mounted into the hydraulic line between the master cylinder and the slave cylinder. This valve is opened to identify the required pressure and it is closed during the test to insure that the pressure is constant as well as constant normal force.

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

$P = \frac{F_{n.c}}{A_s}$ (2)

$F_n = P * A_s$ (3)

Where:

D_s The piston diameter of the slave cylinder equals (0.053 m)

A_s The piston area of the slave cylinder equals ($2.2*10^{-3}$m2)

F_n The normal force which affects the brake pad.

2.5 Brake torque calculation and speed measurement :

In this work the brake power is measured by using digital power meter. The type of the digital power meter is Schneider PM 1200 which has range from 20 watt to 300 k.watt and has an accuracy 1% of reading for power and gives 60 readings per minute. The power meter measured the power of the electric motor during the braking process as the normal force affected the brake pad. The rotational speed of the rotor disc (sliding speed) is also a very significant parameter in the braking process. The sliding speed of the braking system was measured by a digital tachometer which its type is (DT2234) and it has range from 5 to 100000 r.p.m with accuracy of 0.5 %. The first aim of measuring the sliding speed of the braking system was to calculate the angular speed of the rotating disc which was used with brake power to calculate the brake torque. The second aim was to know the behavior of the brake system with different sliding speeds.

2.6 Brake force and friction coefficient calculations:

The brake force and friction coefficient are most important parameters indicate the performance of disc brake at high temperatures in this work. By calculating the brake torque the braking force can be calculated as following:

$T_b = F_b . r_{eff}$ (4)

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

$T_b = 2 F_b r_{eff}$ (5)

$r_{eff} = \frac{r_o + r_i}{2}$ (6)

Where :

F_b The brake force generated at the contact interface (N)

r_{eff} The effective radius of the brake pad, equals 0.089 m

r_o The outer radius of the brake pad (m)

r_i The inner radius of the brake pad(m)

From equation (10) the brake force of the conventional and modified system can be calculated as follow:

$F_b = \frac{T_b}{2 r_{eff}}$ (7)

Where:

F_b The brake force (N)

T_b The brake torque (N.m)

However the braking force is dependent upon the normal force and the friction coefficient, which is derived as below:

$F_b = \mu F_n$ (8)

the coefficient of friction can be calculated as follow :

$F_b = \mu P A_s$ (9)

$\mu = \frac{F_b}{P A_s}$ (10)

Where:

μ The friction coefficient.

2.7 Temperature measurement

The effect of the initial operating temperature is considered during this work to investigate its effect on the performance of the plain disc , the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating . A thermocouple of J-type was selected and is fixed in the brake pad to measure the friction temperature at the contact area between the brake disc and the brake pad. The output signal of the thermocouple was sent to the temperature control unit (thermostat). The temperature control unit is adjusted at a certain temperature. As the brake pad temperature reaches to the adjusted temperature of the control unit. Four initial operating temperatures are selected during the tests. These values were 38˚C, 60˚C, 80˚C and 100 ˚C.

III. RESULTS AND DISCUSSION:

The experimental work is carried out to investigate the effect of sliding speed at constant brake oil pressure and at different initial operating temperatures on the brake force and friction coefficient of the plain disc brake , the first disc

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with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating. All experimental tests are conducted in the same conditions 60 seconds of braking. The brake power was measured every second by the digital power meter. The sliding speed, the brake oil pressure and the initial operating temperature were measured during each test for the three brake discs. The brake force and friction coefficient of the three discs were calculated every second and plotted with the brake time during each test.

3.1 Effect of sliding speed at brake oil pressure 5 bar and initial temperature 38˚C:

The effect of sliding speed of the rotating disc on the brake forces of plain disc , the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating at pressure 5 bar and initial temperature 38 ℃ is presented in Fig. (3), Fig. (4) and fig. (5).The results showed that, the brake forces of the three discs fluctuate with no identical trend at each constant sliding speed with the braking time. The fluctuation of the brake force is due to the variation of the friction coefficient with the braking time. Also it can be seen that, the brake forces of the three discs are decreased with increasing the sliding speed. The results presented in Fig. (6) Show the variation of the mean brake force of the three discs at different sliding speeds. From the results, it can be seen that the increase of the sliding speed of the rotating disc cause a decrease of the mean brake force of the three discs. The mean brake forces of the plain disc are 413, 403, 394, 382 N, and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 370, 361, 351 and 330 N and the mean brake forces of the second disc with (Al2O3-87 % TiO2 13%) coating are 348, 338, 322 and 317 at sliding speeds 50, 100, 150, 200 r.p.m respectively.

The results presented in Figure (7) show the variation of the mean friction coefficient of the three discs at pressure 5 bar and initial temperature 50℃ at different sliding speeds 50, 100, 150 and 200 r.p.m. The results indicated that, the increase of the sliding speed of the rotating disc cause a decrease of the mean friction coefficient of the three discs. The increase of sliding speed from 50 r.p.m to 200 r.p.m causes a decrease on the mean friction coefficient from 0.375 to 0.0.349 for the plain disc and from 0.336 to 0.3 for the first disc with (Cr3C2-75 % NiCr25 %) coating and from 0.317 to 0.288 for the second disc with (Al2O3-87 % TiO2 13%) coating . Also the mean friction coefficient of the plain disc is higher than the mean friction coefficient of the first disc and in the first disc it is higher than the second disc at each constant speed.

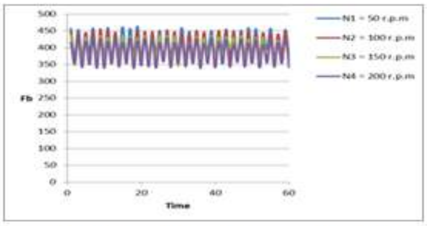

Figure (3)The braking force of the Plain disc with the sliding speed as a function of time at p = 5 bar, T = 38˚ c

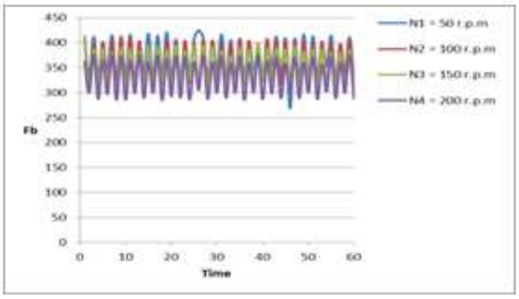

Figure (4) The braking force of first disc with the sliding speed as a function of time at p = 5 bar, T = 38˚ c

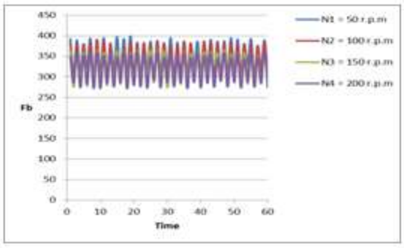

Figure (5) The braking force of second disc with the sliding speed as a function of time at p = 5 bar, T = 38˚ c

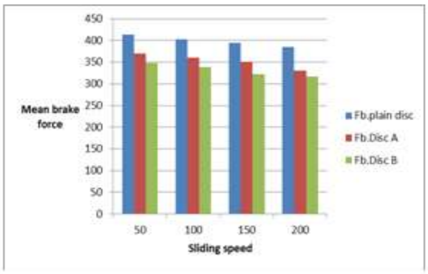

Figure (6) Effect of sliding speed on the mean brake force of plain disc, first disc and second disc at p = 5 bar , T = 38˚ C

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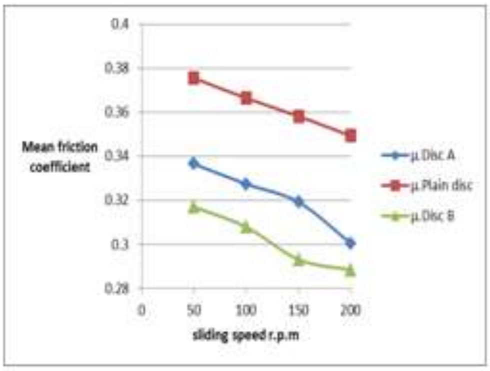

Figure (7) Effect of sliding speed on the mean friction coefficient of plain disc, first disc and second disc at p =5 bar, T=38˚C

3.2 Effect of sliding speed at brake oil pressure 5 bar and initial temperature 60˚C:

Fig.(8),Fig.(9) and Fig.(10) explain the effect of the sliding speed of the rotating disc on the brake forces of the three discs at brake oil pressure 5 bar and initial temperature 60˚C. The experimental results showed that, the increase of sliding speed of the brake disc leads to decrease the brake force of the three discs. Also the brake forces of the three discs fluctuate with no identical trend with the brake time at each constant speed. The fluctuation of the brake force is due to the variation of the friction coefficient with the braking time. The effect of the sliding speed on the mean brake force of the three discs is shown in Fig. (11). From the results, it can be seen that the increase of the sliding speed of the rotating disc cause a decrease of the mean brake force of the three discs. The mean brake forces of the plain disc are 404, 396, 388, 397 N and the mean brake forces of the first disc with (Cr_3C_2-75 % $NiCr$25 %) coating are 361, 342, 334, 325 N and the mean brake forces of the second disc with (Al_2O_3-87 % TiO_2 13%) coating are 339, 331, 316, 309 N at sliding speeds 50, 100, 150 and 200 r.p.m respectively. The mean brake force of the plain disc is higher than the first disc and also the mean brake force of the first disc is higher than the mean brake force of the second disc.

Fig. (12) Illustrate the effect of the sliding speed of the rotating disc on the mean friction coefficient of the three discs at brake oil pressure of 5 bar and initial temperature of 60˚C. The results indicated that, the increase of the sliding speed of the rotating disc cause a decrease of the mean friction coefficient of the three discs. The increase of sliding speed from 50 r.p.m to 200 r.p.m causes a decrease on the mean friction coefficient from 0.367 to 0.344 for the plain disc and from 0.328 to 0.295 for the first disc with (Cr_3C_2-75 % $NiCr$25 %) coating and from 0.308 to 0.281for the second disc with (Al_2O_3-87 % TiO_2 13%) coating . Furthermore, the mean friction coefficient of plain disc is higher than the mean friction coefficient of the first disc and the mean friction coefficient of the first disc is also higher than the mean friction coefficient of the second disc at each constant speed.

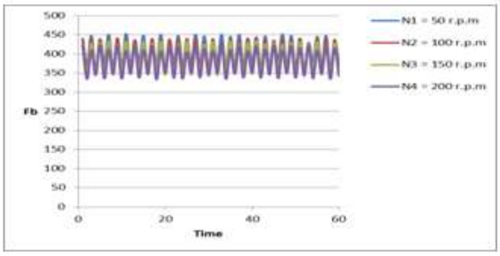

Figure (8) The braking force of the Plain disc with the sliding speed as a function of time at p = 5 bar, T = 60˚ c

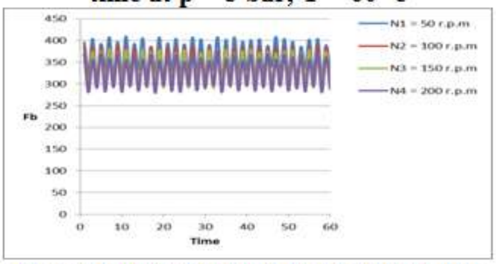

Figure (9)The braking force of first disc with the sliding speed as a function of time at p = 5 bar, T = 60˚ c

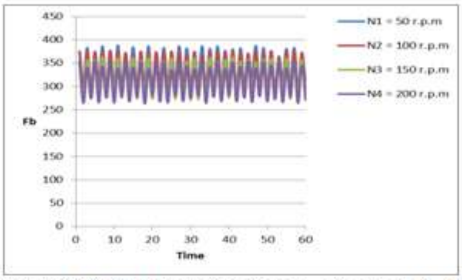

Figure (10)The braking force of second disc with the sliding speed as a function of time at p = 5 bar, T = 60˚ c

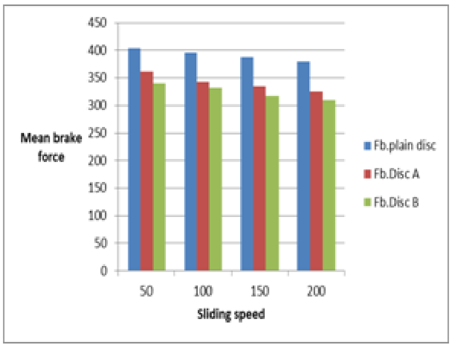

Figure (11) Effect of sliding speed on the mean brake force of plain disc, first disc and second disc at p = 5 bar , T = 60˚c

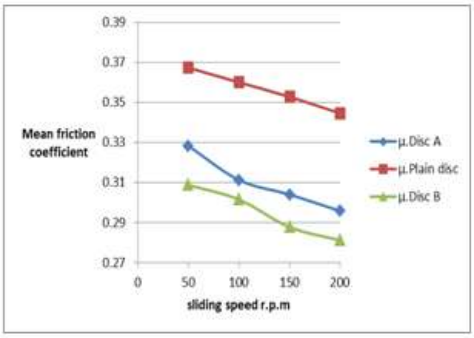

Figure (12) Effect of sliding speed on the mean friction coefficient of plain disc, first disc and second disc at p =5 bar, T=60˚C

3.3 Effect of sliding speed at brake oil pressure 5 bar and initial temperature 80˚C:

Fig.(13),Fig.(14) and Fig.(15) explain the effect of the sliding speed of the rotating disc on the brake forces of the three discs at brake oil pressure 5 bar and initial temperature 80˚C. The experimental results showed that, the increase of sliding speed of the brake disc leads to decrease the brake force of the three discs. Also the brake forces of the three discs fluctuate with no identical trend with the brake time at each constant speed. The fluctuation of the brake force is due to the variation of the friction coefficient with the braking time. The effect of the sliding speed on the mean brake force of the three discs is shown in Fig. (16). From the results, it can be seen that the increase of the sliding speed of the rotating disc cause a decrease of the mean brake force of the three discs. The mean brake forces of the plain disc are 303, 295, 286, 277 N and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 287, 279, 275, 266 N and the mean brake forces of the second disc with (Al2O3-87 % TiO2 13%) coating are 282, 274, 264, 226 N at sliding speeds 50, 100, 150 and 200 r.p.m respectively. The mean brake force of the plain disc is higher than the first disc and also the mean brake force of the first disc is higher than the mean brake force of the second disc.

Fig. (17) Illustrate the effect of the sliding speed of the rotating disc on the mean friction coefficient of the three discs at brake oil pressure of 5 bar and initial temperature of 80˚C. The results indicated that, the increase of the sliding speed of the rotating disc cause a decrease of the mean friction coefficient of the three discs. The increase of sliding speed from 50 r.p.m to 200 r.p.m causes a decrease on the mean friction coefficient from 0.276 to 0.251 for the plain disc and from 0.261 to 0.242 for the first disc with (Cr3C2-75 % NiCr25 %) coating and from 0.256 to 0.234 for the second disc with (Al2O3-87 % TiO2 13%) coating . Furthermore, the mean friction coefficient of plain disc is higher than the mean friction coefficient of the first disc and the mean friction coefficient of the first disc is also higher than the mean friction coefficient of the second disc at each constant speed.

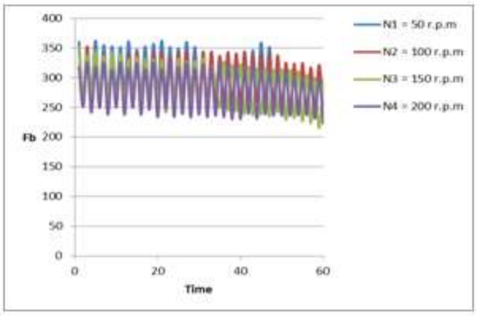

Figure (13) The braking force of the Plain disc with the sliding speed as a function of time at p = 5 bar, T = 80˚ c

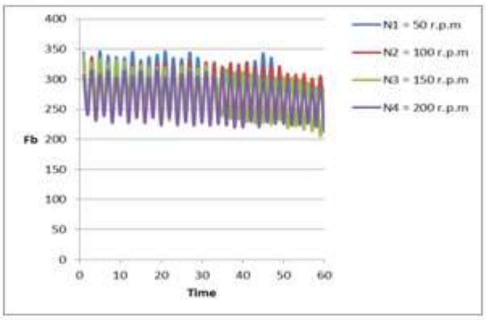

Figure (14) The braking force of the first disc with the sliding speed as a function of time at p = 5 bar, T = 80˚ c

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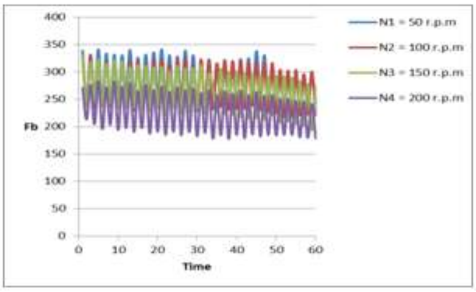

Figure (15) The braking force of the second disc with the sliding speed as a function of time at p = 5 bar, T = 80˚ c

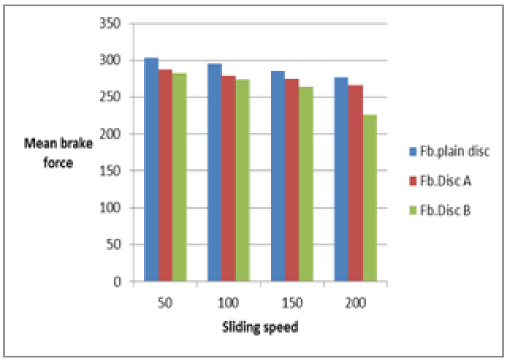

Figure (16) Effect of sliding speed on the mean brake force of plain disc, first disc and second disc at p = 5 bar , T = 80˚c

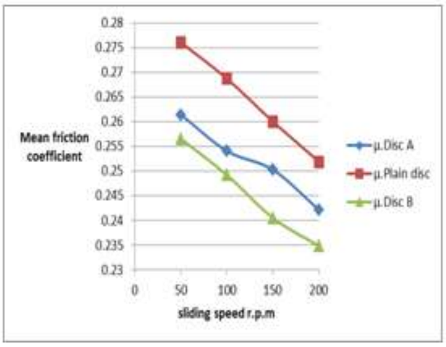

Figure (17) Effect of sliding speed on the mean friction coefficient of plain disc, first disc and second disc at p =5 bar, T=80˚C

3.4 Effect of sliding speed at brake oil pressure 5 bar and initial temperature 100˚C:

Fig.(18),Fig.(19) and Fig.(20) explain the effect of the sliding speed of the rotating disc on the brake forces of the three discs at brake oil pressure 5 bar and initial temperature 100˚C. The experimental results showed that, the increase of sliding speed of the brake disc leads to decrease the brake force of the three discs. Also the brake forces of the three discs fluctuate with no identical trend with the brake time at each constant speed. The fluctuation of the brake force is due to the variation of the friction coefficient with the braking time. The effect of the sliding speed on the mean brake force of the three discs is shown in Fig. (21). From the results, it can be seen that the increase of the sliding speed of the rotating disc cause a decrease of the mean brake force of the three discs. The mean brake forces of the plain disc are 260, 252, 245, 237 N and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 255, 246, 241, 231 N and the mean brake forces of the second disc with (Al2O3-87 % TiO2 13%) coating are 249, 244, 239, 226 N at sliding speeds 50, 100, 150 and 200 r.p.m respectively. The mean brake force of the plain disc is higher than the first disc and also the mean brake force of the first disc is higher than the mean brake force of the second disc.

Fig. (22) Illustrate the effect of the sliding speed of the rotating disc on the mean friction coefficient of the three discs at brake oil pressure of 5 bar and initial temperature of 100˚C. The results indicated that, the increase of the sliding speed of the rotating disc cause a decrease of the mean friction coefficient of the three discs. The increase of sliding speed from 50 r.p.m to 200 r.p.m causes a decrease on the mean friction coefficient from 0.236 to 0.215 for the plain disc and from 0.231 to 0.21 for the first disc with (Cr3C2-75 % NiCr25 %) coating and from 0.227 to 0.205 for the second disc with (Al2O3-87 % TiO2 13%) coating . Furthermore, the mean friction coefficient of plain disc is higher than the mean friction coefficient of the first disc and the mean friction coefficient of the first disc is also higher than the mean friction coefficient of the second disc at each constant speed.

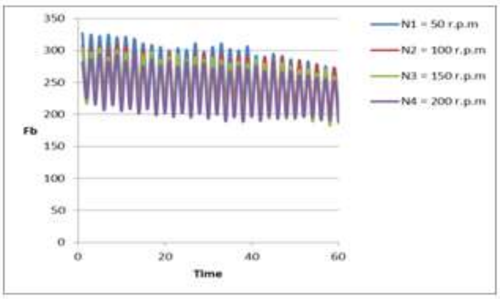

Figure (18)The braking force of the plain disc with the sliding speed as a function of time at p = 5 bar, T = 100˚ c

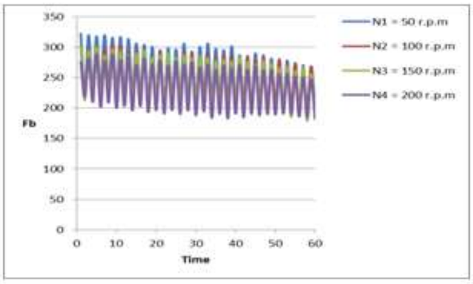

Figure (19)The braking force of first disc with the sliding speed as a function of time at p = 5 bar, T = 100° c

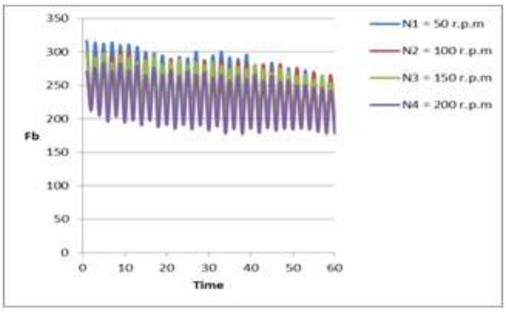

Figure (20)The braking force of the second disc with the sliding speed as a function of time at p = 5 bar, T = 100° c

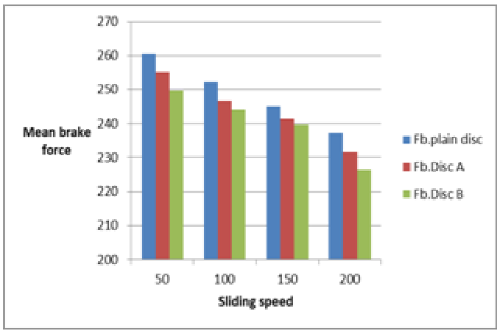

Figure (21) Effect of sliding speed on the mean brake force of plain disc, first disc and second disc at p = 5 bar, T = 100°c

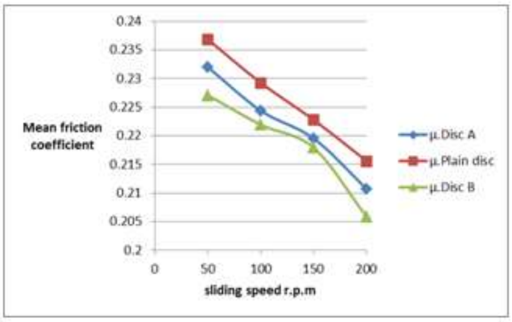

Figure (22) Effect of sliding speed on the mean friction coefficient of plain disc, first disc and second disc at p =5 bar, T=100°C

IV. CONCLUSION

After monitoring the results of our experimental work we can say thatthe main conclusions from the present study can be summarized in the following points:

1- The brake force of the plain disc, the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating varies and fluctuates with no identical trend with the brake time. This is due to the variation of the friction coefficient with the brake time.

2- The increase of the sliding speed decreases the mean brake force of the plain disc, the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating.

3- The increase of the sliding speed from 50 r.p.m to 200 r.p.m at initial temperature 38℃ and brake oil pressure 5 bar decreases the mean brake force of the plain disc, the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating . Also the increase of the sliding speed from 50 r.p.m to 200 r.p.m at initial temperature 60℃ and brake oil pressure 5 bar decreases the mean brake force of the plain disc, the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating and so on at initial temperature 80℃ and 100 ℃.

4- The increase of the sliding speed at constant pressure 5 bar and at different initial operating temperature 38, 60, 80, 100℃decreases the mean friction coefficient of the plain disc, the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating. But at each speed the mean friction coefficient of the plain disc was greater than the mean friction coefficient of the first disc with (Cr3C2-75 % NiCr25 %) coating and the mean friction coefficient of the first disc with (Cr3C2-75 % NiCr25 %) coatingis greater than the second disc with (Al2O3-87 % TiO2 13%) coating.

5- At sliding speeds 50, 100, 150, 200 r.p.m and at brake oil pressure 5 bar the mean brake force of the plain disc with no coating was greater than the mean brake force of the first disc with (Cr3C2-75 % NiCr25 %)at the initial operating temperatures 38, 60, 80, and 100℃ and also the mean brake force of the first disc with(Cr3C2-75 % NiCr25 %) coating was greater than the mean brake force of the second discwith (Al2O3-87 % TiO2 13%) coating at the initial operating temperatures 38, 60, 80, and 100℃.

6- The increase of the initial operating temperature from 38 ˚C to 100 ˚C decreases the mean brake force of the plain disc, the first disc with (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 13%) coating.

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