Effect of brake oil pressure on the performance of coated ventilated disc brake

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Abstract - *This research paper is about enhancing tribological behavior 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 brake oil pressure 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 and 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 are used on two brake discs. After that, some experimental tests are conducted on the three discs at different brake oil pressure at constant sliding speed 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.

Key Words: **Coating, Ventilated disc brake, Brake force *(Fb), Friction coefficient(μ) , brake oil pressure.***

1. INTRODUCTION

Braking systems are undoubtedly the most important component for road safety purposes.

During the braking process, the heat generated by friction between the brake pads and the disc is not quickly dissipated. This mainly depends on geometrical features and manufacturing material. Consequently, numerous negative effects on the entire brake may arise [1].

The brake disc and linings, must meet the requirements of good wear resistance stable coefficient of friction, reduced noise and reduced particle matter emissions. To meet these requirements, the temperature formed by the correct thermal conductivity and friction layer formation conditions are often referred to as key features and is therefore covered by many studies.

The tribological behavior of the brake friction materials is controlled by the properties of the friction layer formed on the lining and disc contact surface. The performance of the system is very sensitive to the contact temperature. The coefficient of friction is relatively high, but most importantly it must be stable. In addition to the safety requirements, there are requirements such as long life and high comfort. The nature of the brake system differs significantly from many other tribological contact cases This tribological contact includes dry sliding contact at high speeds, high contact forces and high temperatures[2].

Ni-based NiCrBSi coatings are widely used in high temperature, corrosion and wear resistance applications. Hardness and wear properties can be improved by adding

Different powder properties into NiCrBSi coating powder. With the addition of WC into NiCrBSi, one of these powders, high micro hardness, high abrasion and corrosion resistance has been achieved which is the reason why it has attracted attention of so many researchers. Nickel in the powder components of 20NiCrBSi- WC12Co exhibits a good adhesion with its excellent wettability, and improves Chrome tribo-mechanical properties. Boron reduces the melting temperature and contributes to the formation of hard phases. Silicon increases the viscosity while lowering the melting temperature [3].

2. EXPERMINTATION

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 (Cr3C2-75 % NiCr25 %) coating and the second disc with (Al2O3-87 % TiO2 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.

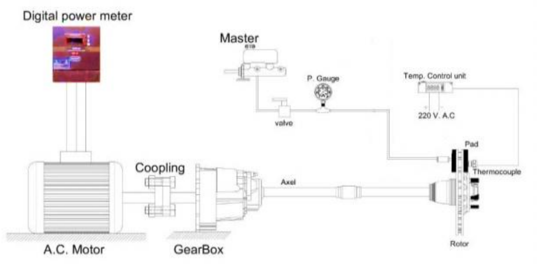

Fig.1 Main components of the test rig

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.

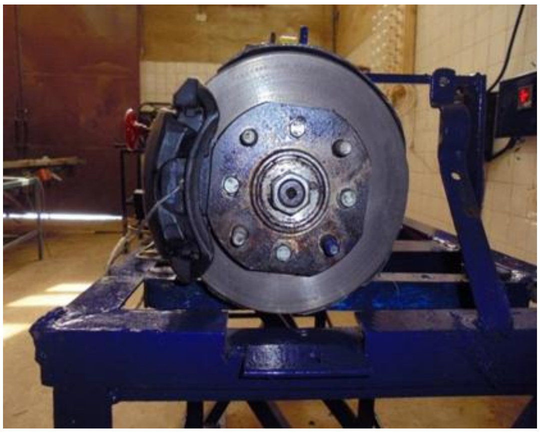

Fig.2 Disc brake of Hyundai Excel.

2.1 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.

2.2 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

2.3 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 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.

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

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

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

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.

2.4 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 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.

2.5 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:

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

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

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

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

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 three discs can be calculated as follow:

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

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:

$$F_b = \mu\, F_n \quad (8)$$

The coefficient of friction can be calculated as follow :

$$F_b = \mu\, P\, A_s \quad (9)$$

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

Where :

μ The friction coefficient.

2.6 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.

3. Results and discussion

The experimental work is carried out to investigate the effect of brake oil pressure at constant sliding speed and at different initial operating temperatures on the brake force and friction coefficient of the plain disc brake , the first disc 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 brake oil pressure at sliding speed 100 r.p.m and initial temperature 38˚C:

The effect of brake oil pressure 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 sliding speed 100 r.p.m 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 brake oil pressure 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 increased with increasing the brake oil pressure. The results presented in Fig. (6) Show the variation of the mean brake force of the three discs at different brake oil pressure. From the results, it can be seen that the increase of the brake oil pressure cause an increase of the mean brake force of the three discs. The mean brake forces of the plain disc are 194, 403, 615, 830 N and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 173, 360, 545 and 755 N and the mean brake forces of the second disc with (Al_2O_3-87 % TiO_2 13%) coating are 162, 338, 523, 722 at brake oil pressure 2.5, 5, 7.5, 10 bar respectively.

The results presented in Figure (7) show the variation of the mean friction coefficient of the three discs at sliding speed 100 r.p.m and initial temperature 38°C at different brake oil pressure 2.5, 5, 7.5 and 10 bar. The results indicated that, the increase of the brake oil pressure cause an increase of the mean friction coefficient of the three discs. The increase of brake oil pressure from 2.5 bar to 10 bar causes an increase on the mean friction coefficient from 0.354 to 0.377 for the plain disc and from 0.315 to 0.343 for the first disc with (Cr_3C_2-75 % NiCr25 %) coating and from 0.295 to 0.328 for the second disc with (Al_2O_3-87 % TiO_2 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 brake oil pressure.

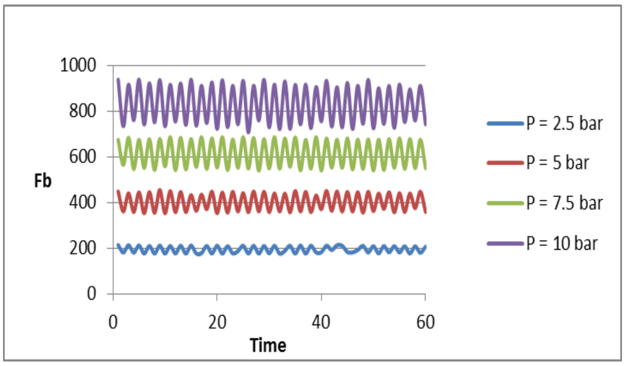

Fig.3 Effect of pressure on the brake force of plain disc at N = 100 r.p.m, T = 38°C

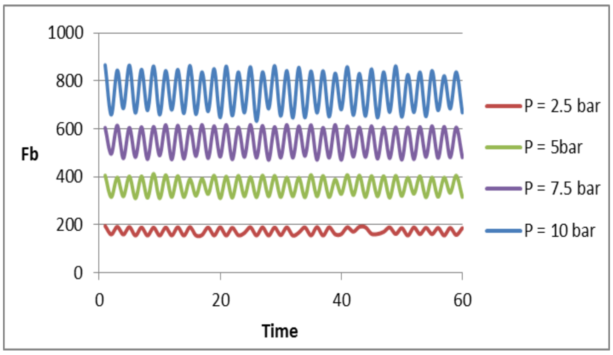

Fig.4 Effect of pressure on the brake force of the first disc at N = 100 r.p.m, T = 38° C

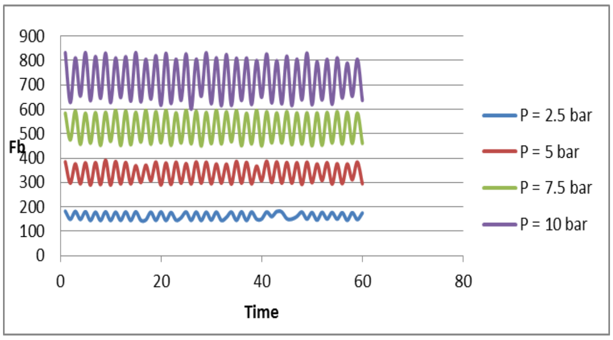

Fig.5 Effect of pressure on the brake force of the second disc at N = 100 r.p.m, T = 38° C

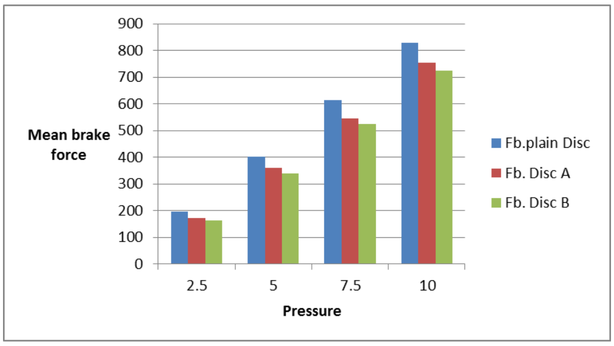

Fig.6 Effect of pressure on the mean brake force of plain disc & first disc & second disc at N = 100, T = 38°C

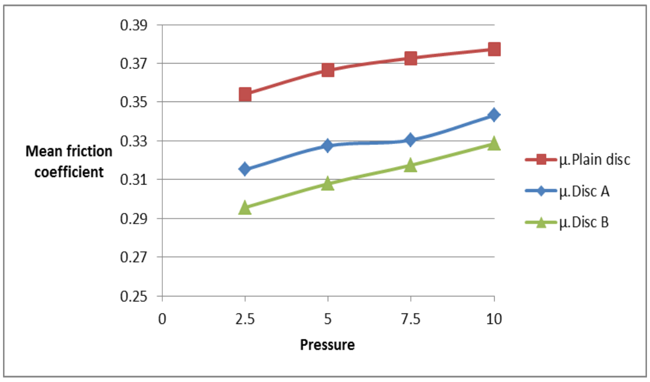

Fig.7 Effect of pressure on the mean friction coefficient of plain disc & first disc & second disc at N = 100, T = 38° C

3.2 Effect of brake oil pressure at sliding speed 100 r.p.m and initial temperature 60°C:

Figures (8),(9) and (10) explain the effect of the brake oil pressure of the three discs at sliding speed 100 r.p.m and initial temperature 60°C. The experimental results showed that, the increase of the brake oil pressure of the brake disc leads to increase 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 brake oil pressure. The fluctuation of the brake force is due to the variation of the friction coefficient with the braking time. The effect of the brake oil pressure on the mean brake force of the three discs is shown in Figure (11). From the results, it can be seen that the increase of the brake oil pressure cause a increase of the mean brake force of the three discs. The mean brake forces of the plain disc are 139, 396, 606, 816 N and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 114, 342, 536, 735 N and the mean brake forces of the second disc with (Al2O3-87 % TiO2 13%) coating are 104, 331, 504, 692 N at brake oil pressure 2.5, 5, 7.5 and 10 bar 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.

Figure (12) Illustrate the effect of the brake oil pressure on the mean friction coefficient of the three discs at sliding speed 100 r.p.m and initial temperature of 60˚C. The results indicated that, the increase of the brake oil pressure cause an increase of the mean friction coefficient of the three discs. The increase of brake oil pressure from 2.5 bar to 10 bar causes an increase on the mean friction coefficient from 0.352 to 0.37 for the plain disc and from 0.309 to 0.334 for the first disc with (Cr3C2-75 % NiCr25 %) coating and from 0.289 to 0.314 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 brake oil pressure.

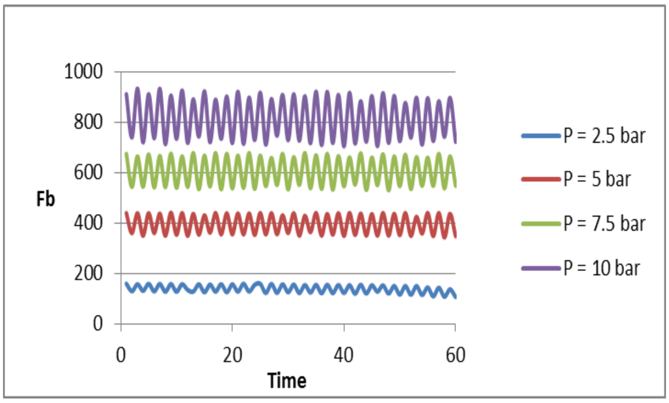

Fig.8 Effect of pressure on the brake force of plain disc at N = 100 r.p.m, T = 60˚C

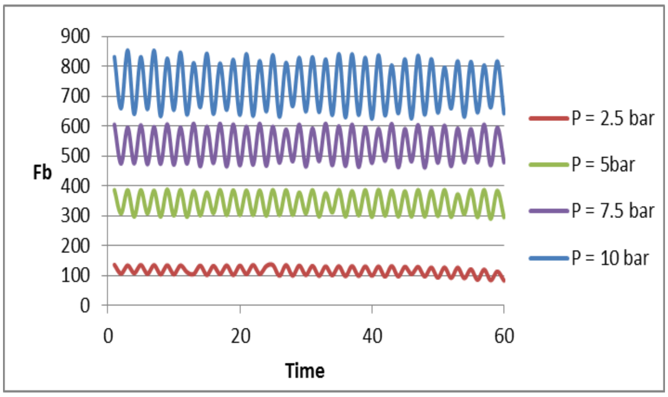

Fig.9 Effect of pressure on the brake force of first disc at N = 100 r.p.m, T = 60˚ C

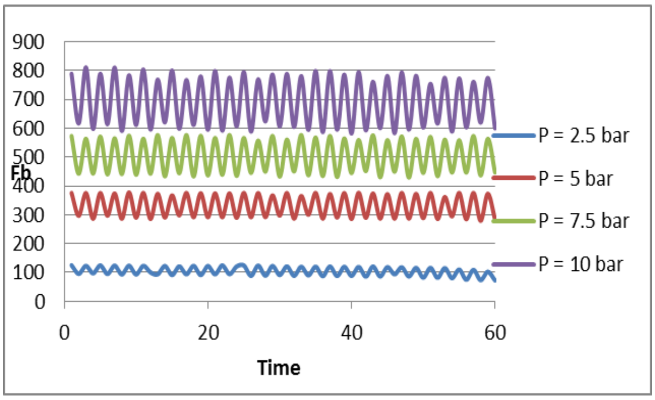

Fig.10 Effect of pressure on the brake force of second disc at N = 100 r.p.m, T = 60˚ C

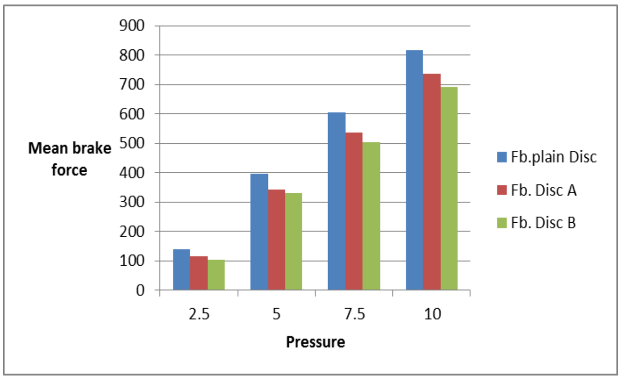

Fig.11 Effect of pressure on the mean brake force of plain disc &first disc & second disc at N = 100r.p.m, T = 60˚C

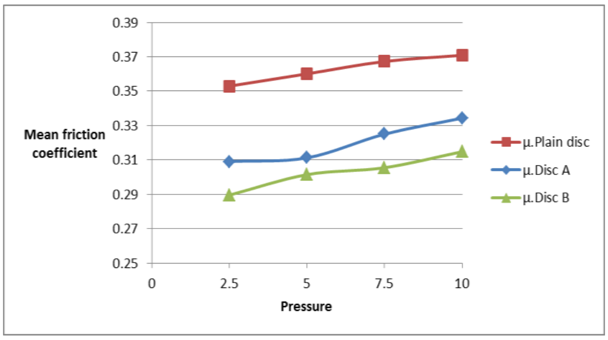

Fig.12 Effect of pressure on the mean friction coefficient of plain disc &first disc &second disc at N = 100 r.p.m, T = 60˚ C

3.3 Effect of brake oil pressure at sliding speed 100 r.p.m and initial temperature 80˚C

Figures (13),(14) and (15) explain the effect of the brake oil pressure on the brake forces of the three discs at sliding speed 100 r.p.m and initial temperature 80˚C. The experimental results showed that, the increase of brake oil pressure of the brake discs leads to increase 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 Figure (16) from the results, it can be seen that the increase of the brake oil pressure cause an increase of the mean brake force of the three discs. The mean brake forces of the plain disc are 139, 295, 459, 627 N and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 133, 279, 438, 605 N and the mean brake forces of the second disc with (Al2O3-87 % TiO2 13%) coating are 128, 274, 432, 589 N at brake oil pressure 2.5, 5, 7.5 and 10 bar 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.

Figure (17) Illustrate the effect of brake oil pressure on the mean friction coefficient of the three discs at sliding speed 100 r.p.m and initial temperature of 80°C. The results indicated that, the increase of the brake oil pressure cause an increase of the mean friction coefficient of the three discs. The increase of brake oil pressure from 2.5 bar to 10 bar causes an increase on the mean friction coefficient from 0.252 to 0.285 for the plain disc and from 0.243 to 0.275 for the first disc with (Cr3C2-75 % NiCr25 %) coating and from 0.233 to 0.268 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 brake oil pressure.

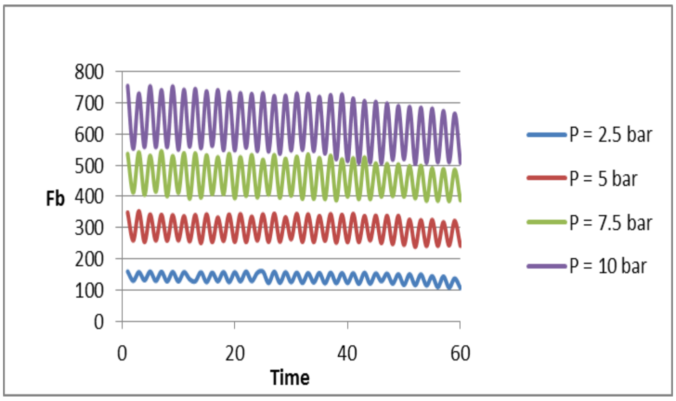

Fig.13 Effect of pressure on the brake force of plain disc at N = 100 r.p.m, T = 80˚C

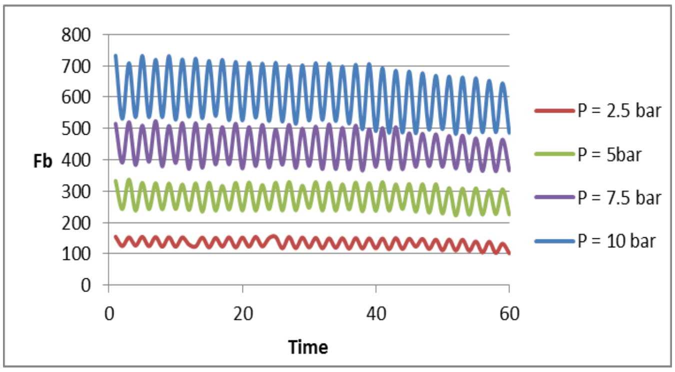

Fig.14 Effect of pressure on the brake force of first disc at N = 100 r.p.m, T = 80˚ C

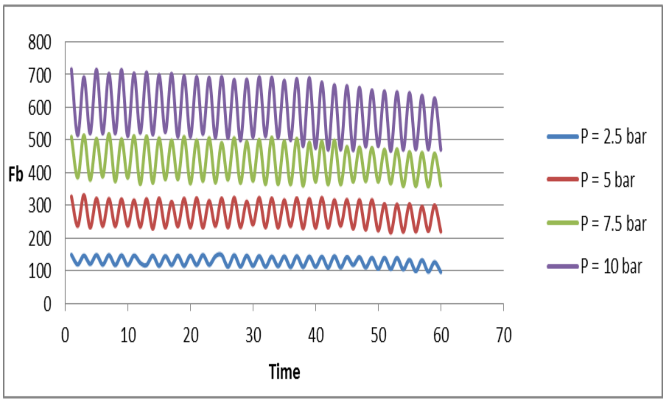

Fig.15 Effect of pressure on the brake force of second disc at N = 100 r.p.m, T = 80˚ C

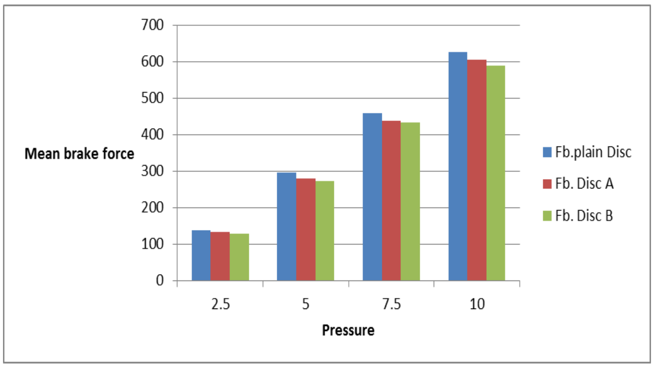

Fig.16 Effect of pressure on the mean brake force of plain disc &first disc & second disc at N = 100 r.p.m , T = 80˚C

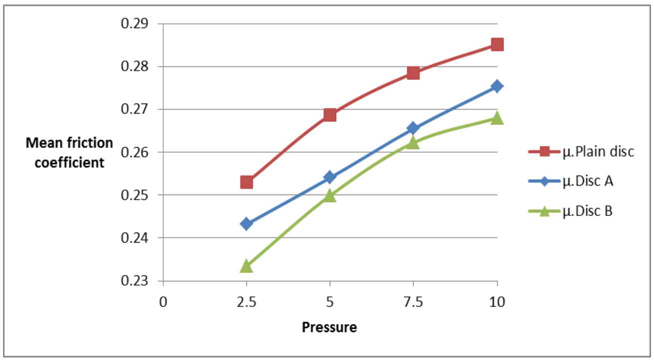

Fig.17 Effect of pressure on the mean friction coefficient of plain disc &first disc &second disc at N = 100, T = 80˚ C

3.4 Effect of brake oil pressure at sliding speed 100 r.p.m and initial temperature 100˚C

Figure (18),(19) and (20) explain the effect of the brake oil pressure on the brake forces of the three discs at sliding speed 100 r.p.m and initial temperature 100˚C. The experimental results showed that, the increase of brake oil pressure leads to increase 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 brake oil pressure on the mean brake force of the three discs is shown in Figure (21).From the results, it can be seen that the increase of the brake oil pressure cause an increase of the mean brake force of the three discs. The mean brake forces of the plain disc are 120, 252, 392, 536 N and the mean brake forces of the first disc with (Cr3C2-75 % NiCr25 %) coating are 117, 246, 384, 533 N and the mean brake forces of the second disc with (Al2O3-87 % TiO2 13%) coating are 114, 244, 376, 520 N at brake oil pressure 2.5, 5, 7.5 and 10 bar 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 at each constant brake oil pressure.

Figure (22) Illustrate the effect of the brake oil pressure on the mean friction coefficient of the three discs at sliding speed 100 r.p.m and initial temperature of 100˚C. The results indicated that, the increase of the sliding speed of the rotating disc cause an increase of the mean friction coefficient of the three discs. The increase of brake oil pressure from 2.5 bar to 10 bar causes an increase on the mean friction coefficient from 0.218 to 0.243 for the plain disc and from 0.213 to 0.242 for the first disc with (Cr3C2-75 % NiCr25 %) coating and from 0.208 to 0.236 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 brake oil pressure.

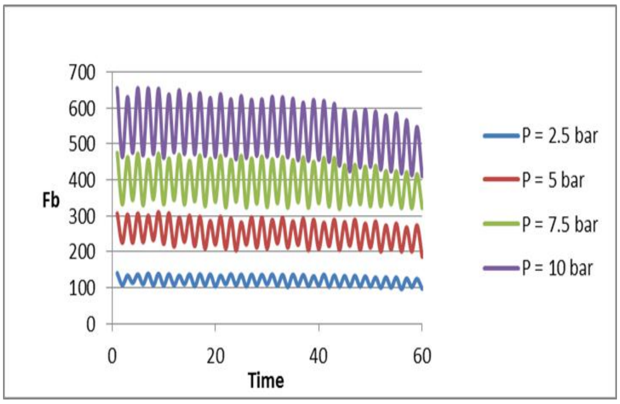

Fig.18 Effect of pressure on the brake force of plain disc at N = 100 r.p.m, T = 100˚C

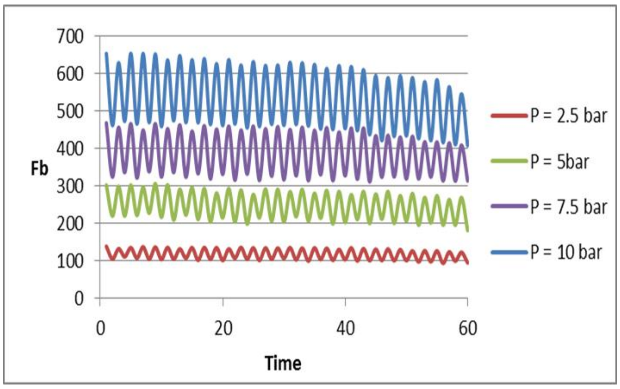

Fig.19 Effect of pressure on the brake force of first disc at N = 100 r.p.m, T = 100˚ C

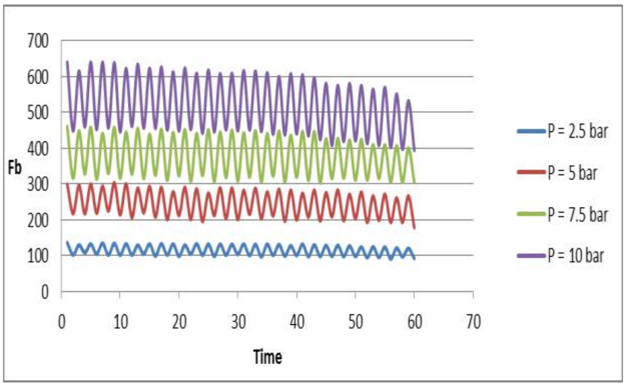

Fig.20 Effect of pressure on the brake force of second disc at N = 100 r.p.m, T = 100˚ C

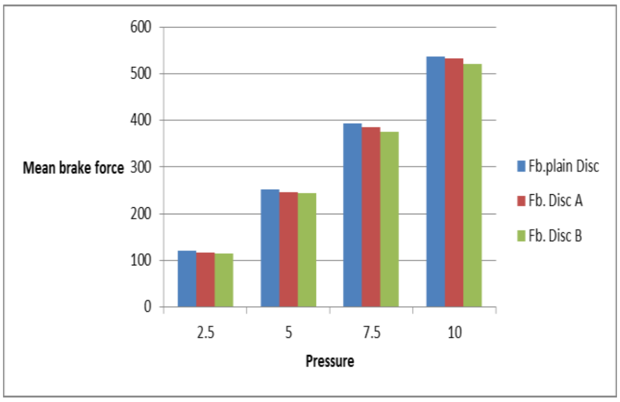

Fig.21 Effect of pressure on the mean brake force of plain disc &first disc &disc second at N =100 r.p.m , T = 100˚C

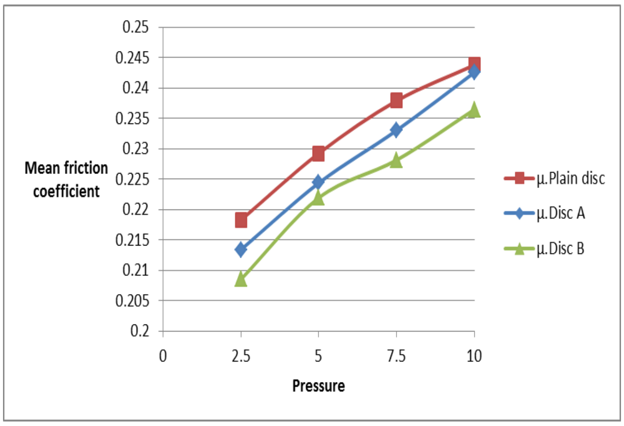

Fig.22 Effect of pressure on the mean friction coefficient of plain disc &first disc &second disc at N=100 r.p.m , T = 100˚C

4. CONCLUSIONS

After monitoring the results of our experimental work we can say that the 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 brake oil pressure increases 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 brake oil pressure from 2.5 bar to 10 bar at initial temperature 38°C and sliding speed 100 r.p.m increases 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 brake oil pressure from 2.5 bar to 10 bar at initial temperature 60°C and sliding speed 100 r.p.m increases 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°C and 100 °C.

4- The increase of the brake oil pressure at constant sliding speed 100 r.p.m and at different initial operating temperature 38, 60, 80, 100°C increases 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 brake oil pressure 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 %) coating is greater than the second disc with (Al2O3-87 % TiO2 13%) coating .

5- At brake oil pressure 2.5, 5, 7.5, 10 bar and at sliding speed 100 r.p.m 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°C 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 disc with (Al2O3-87 % TiO2 13%) coating at the initial operating temperatures 38, 60, 80, and 100°C.

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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