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Study Effect of Pads shapes on Temperature Distribution for Disc Brake Contact Surface

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ABSTRACT

This study describes an inertial dynamometer system (test rig) which has been applied to the testing of disc brake pads at different operating conditions. The test rig is equipped with several measuring instruments, and data acquisition systems [DAQ], which are necessary for performing the tests. Two sets of brake pads are tested. This study explains the temperature distribution obtained by experiments on two different shapes of brake discs pads affected by the types of shapes of brake discs pads, disc geometry and operating conditions. The test results also showed that the friction with hatched pad better fade resistance than the others.

Keywords: - disc brake; thermal stress; hatched pads; temperature distribution.

I. INTRODUCTION

During the operation of the brake system, kinetic energy is converted into thermal energy through friction between the brake pad and rotor faces. Excessive thermal loading can result in surface cracking, judder and high wear of the rubbing surfaces. High temperatures can also lead to overheating of the brake fluid, seals and other components. Initially the generated thermal energy is transferred by conduction to the components in contact and next by convection and radiation to environment (Fig.1) as explained in [1, 2, 3]. Brakes absorb the kinetic energy of moving masses by help of friction forces. The dynamic of braking process depends on friction pair materials, loading and temperature, as well as impact of environment [4]. Limpert [5] compared the solid and ventilated rotor thermal performance and concluded that the total convective heat transfer coefficient consisted of approximately one-third cooling from the vanes, and two-thirds from the friction surfaces exposed to the ambient air. Temperature distribution and comparison of simulation results and experimental results in the disc by 2D thermal analysis using axisymmetricmodel is presented in[6]. In [7] showed through experiment that the brake torque variation depends on several factors such as the temperature, the number of revolutions and the disc depends on several factors such as the temperature, thickness variation**.** The analytical modeling and dynamic characteristics of disc brake systems under equal contact loads on both sides of the disc can be found in [8]. New mathematical equations for heat generation between disc brake and pads include on parameters such as the duration of braking, vehicle velocity, geometries and the dimensions of the brake components, materials of the disk brake rotor and the pad and contact pressure distribution are shown in [9]. The factors affecting the interface temperature, including the number of braking applications, sliding speed, braking load and type of friction material are presented in [10]. Thermal analysis of a brake system requires frictional energy dissipation as a heat input. Frictional heat dissipation can be easily determined under the dynamometer laboratory conditions where the brake torque and the rotational speed of the brake disk are know. For vehicle braking the frictional heat dissipation should be determined from the given vehicle and brake system parameters [11]. In [12] determined the transient temperature distributions in a disc brake during a single brake application using Finite difference numerical technique. Hyperbolic heat conduction which includes the effect of the finite heat propagation is gaining importance.

This paper aims to study and compare the temperature distributions caused by mutual sliding of two members of the disc brake pads, and describes an inertial dynamometer system which has been applied to the testing of disc brake assembly at different operating conditions.

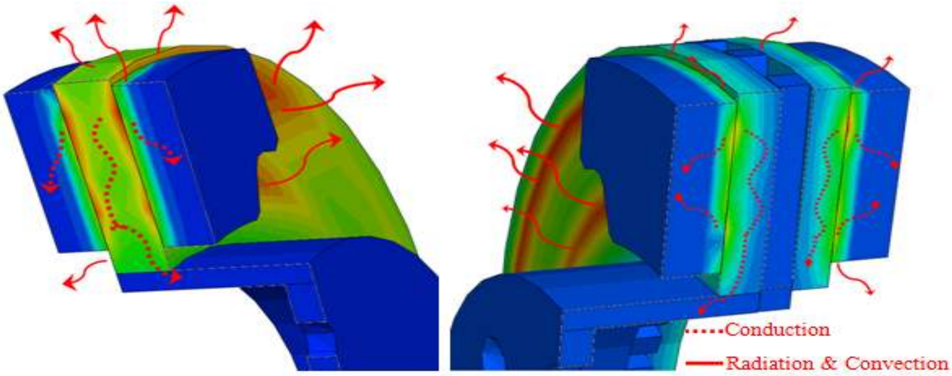


Fig. 1: Heat dissipation inside and outside the discs due to conduction, convection and radiation [3]

II. THEORETICAL ANALYSIS

2.1 Determination of Kinetic Friction Coefficient

It is essential to determine coefficient of friction that is generated between the disc and the pad contact interface. It has been known that coefficient of friction would be changed under different braking operating conditions such as brake-line pressure, disc speed, temperature and other factors.

Braking torque can be calculated as follows:

$$T = F_{friction} r_{eff} \tag{1}$$

Where $F_{friction}$ is the friction force generated at the contact interface and r_{eff} is the effective pad radius. However friction force is dependent upon normal force (F_{normal}) and friction coefficient (μ), which is derived as below:

$$F_{friction} = \mu F_{normal} \tag{2}$$

Normal force (*Fnormal*) can be determined based on brake-line pressure (*p*) applied onto top of the piston, which is given in the following equation:

$$F_{normal} = pA_{piston} \tag{3}$$

Now by substituting equation (3) into equations (2) and then (1), braking torque can be calculated as follows:

$$T = \mu pA_{piston} r_{eff} \tag{4}$$

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

$$T = 2\mu pA_{piston} r_{eff} \tag{5}$$

Since the braking torque output (*T*) can be obtained experimentally, and the cross sectional area of the piston in contact with the braking fluid (A_{piston}), brake-line pressure (*p*) and pad effective radius (r_{eff}) are all known parameters, then coefficient of friction can be calculated. Thus equation (5) now becomes:

$$\eta = \frac{T}{2pA_{piston} r_{eff}} \tag{6}$$

2.2 Brake disc thermal stresses

The brake disc and the pads are exposed to high thermal stresses due to high quantity of energy transformed from mechanical to thermal. Thermal stress σ is defined by the thermal strain generated by temperature variation ΔT inside an object and due to exterior condition of having no possibility to contract or expand [3]. Those stresses can be written as [3]:

$$\sigma = -\frac{E}{1-v}\alpha(\Delta T) \tag{7}$$

Where σ - brake disc thermal expansion coefficient, $\Delta T = T - T_a$, T- local disc temperature (real), T_a – environment temperature, E – Young's modulus, v- Poisson coefficient. The values of α depends on temperature, but in most cases is considered constant. From relation (7), it the dependence of thermal stress with temperature and α coefficient can be observed.

III. EXPERIMENTAL WORK

The experimental work will be presented in three main sections. The first section contains the description of the test rig. The second section the measurement instruments followed used in different tests and data acquisition components [DAQ]. The third section comprises the different tests conducted on brake pads. The details of each section is given below.

3.1 Test Rig

The test rig was designed and constructed to allows testing different types of pads and rotors at different operation conditions. Fig. 2 shows a general layout of the test rig. The test rig consists of engine; spark ignition, four stroke, and 4-cylinders in line 1. The engine equipped with clutch, manual gear box 2, flexible joint 3, and drive shaft supported with four bearing on frame to drive flywheel and disc brake as shown in Fig. 3. The rig uses actual brake system units and components to simulate the vehicle brake system. Brake pedal equipped with electric motor and control unit to control pedal travel.

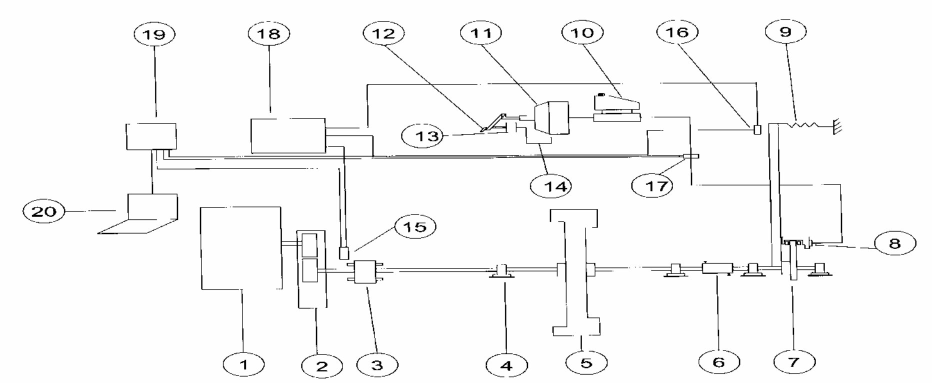
3.2 Measuring Instruments

The test rig is equipped with several measuring instruments, which are necessary for performing the tests. The measuring instruments are shown in Fig. 4 include, pressure transducer, displacement sensor (position sensor), speed sensors and non-contact infrared thermometer. All the transducer and sensors are interfaced with a connector block through shielded cables. The connector block is connected to a DAQ board, (connect with computer by USB cable) that collects the data during experimental test runs.

3.3 Experiments

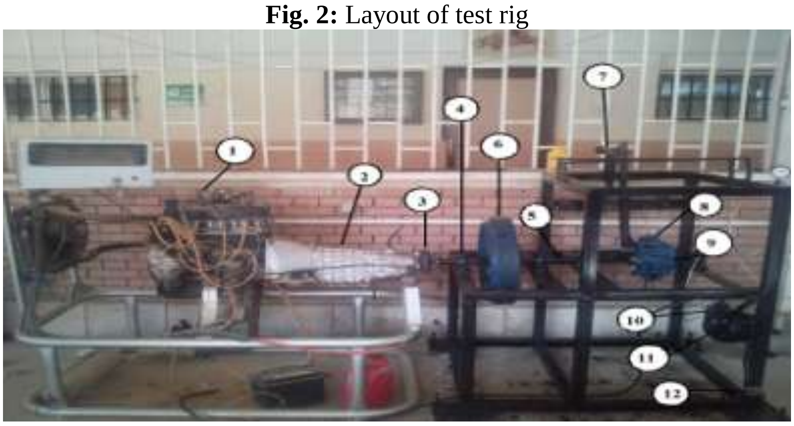
The experimental research was carried out in the laboratory on disc brake dynamometer Fig. 3, in a short time repeating braking regime. Two different shapes of pads were tested on disc brake dynamometer. Fig 5 shows two types of pads.

During the experiment the disc brake surface temperature, brake pressure, rotor velocity and braking time were measured.



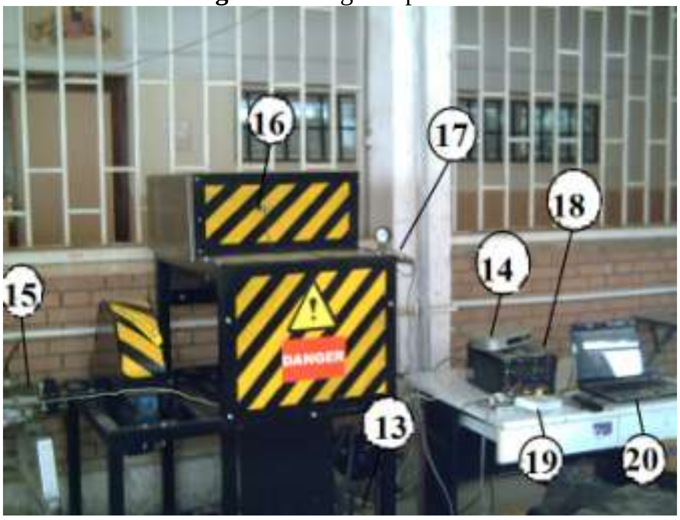
1- Engine 2- Manual gearbox 3- Flexible joint 4-Bearing 5-Flywheel
6-Coupling 7-Vented disc 8- Caliper 9-Spring 10- Brake master
11-Brake servo 12- Brake pedal 13- Brake pedal motor
14- Brake pedal motor control 15- RPM sensor 16-Displacement sensor
17-Pressure sensor 18-DCsupply 19- DAQ board
20- CPU

Fig. 2: Layout of test rig



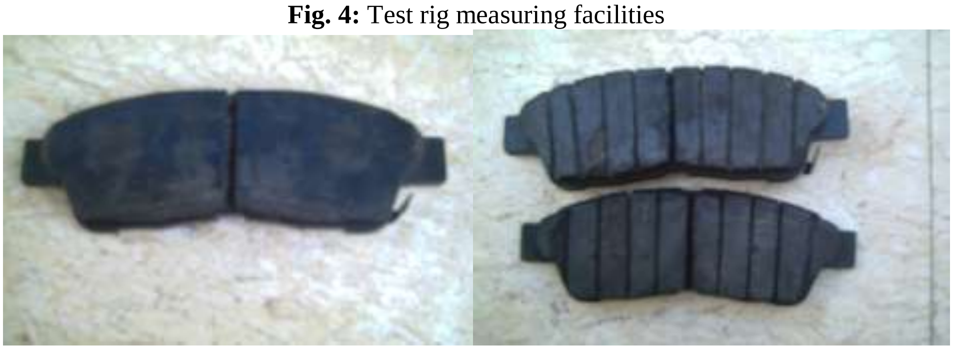
1- Engine 2- Manual gearbox 3- Flexible joint 4-Bearing 5-Flywheel
6-Coupling 7-Vented disc 8- Caliper 9-Spring 10- Brake master
11-Brake servo 12- Brake pedal

Fig. 3: Test rig components



13- Brake pedal motor 14- Brake pedal motor control 15- RPM sensor
16-Displacement sensor 17-Pressure sensor 19- DAQ board 20- CPU

Fig. 4: Test rig measuring facilities



(a) Flat pad used in test (b) hatched pad used in test

Fig. 5: Shape of pads tested

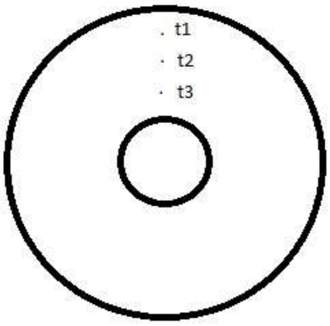


fig. 6: Location of disc brake surface temperature measured

IV. RESULTS AND DISCUSSION

The evolutions of the temperature distribution on a disc brake contact surface during braking for experimental as shown in Figs7 to 11 for both cases under different operating condition.

4.1 Effect of brake pedal travel

Figures from 7 to 8 show the experimental results of the relation between the disc speeds against the measured temperature distribution on a disc brake contact surface in two cases.

Case I: Flat pads used in test

Case II: hatched pads used in test

Fig. 7 represents the temperature distribution on a disc brake contact surface in two cases of pads at slow rate of pedal travel. Fig. 8 shows the effect of fast rate (sudden) of pedal travel.

The detailed analysis of the results revealed that the temperature distribution on a disc brake is greatly affected by the type of brake pad shape, especially when using hatched pad. The temperature increases with the beginning of the process of braking when Flat pad used in test.

The brake disc and the pads are exposed to high thermal stresses due to high quantity of energy transformed from mechanical to thermal.

Thermal stress σ is defined by the thermal strain generated by temperature variation ΔT inside an object and due to exterior condition of having no possibility to contract or expand [3].

Braking performance of a vehicle can be significantly affected by the temperature rise in the brake components. High temperatures during braking may cause brake fade, premature wear, and brake fluid vaporization, bearing failure, thermal cracks and thermally-excited vibration. Therefore, it is important to predict the temperature rise of a given brake system and assess its thermal performance in the early design stage.

The coefficient of friction would be changed under different braking operating conditions such as brake-line pressure, disc speed, temperature and other factors

The coefficient of friction of the brake friction material will drop after prolonged use of the brakes. This is commonly known as brake fade [13].

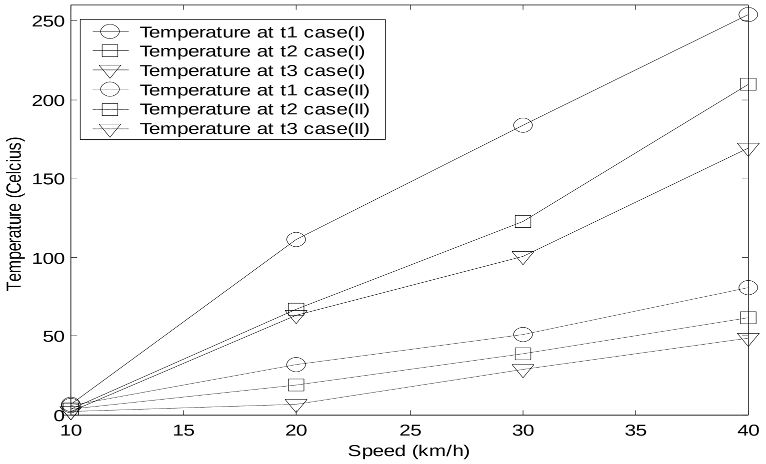


Fig. 7: Temperature Distribution at Slow Rate of Brake Pedal Travel on Disc Brake [Case I & Case II)

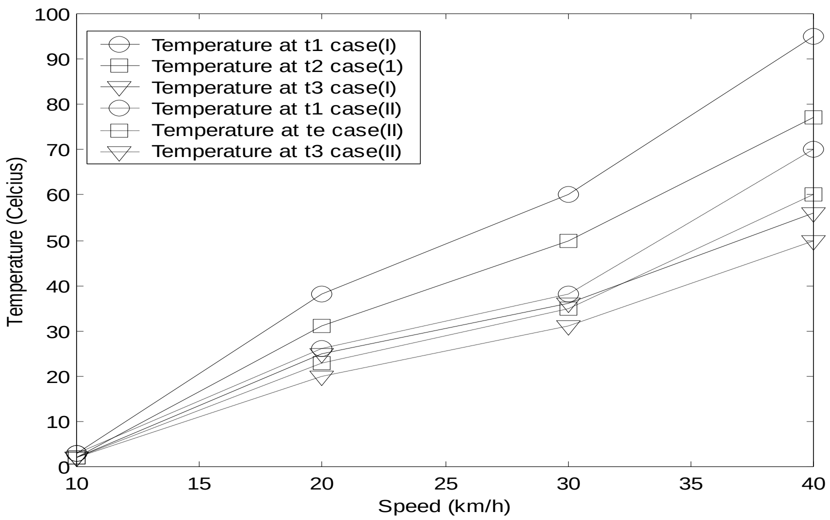


Fig. 8: Temperature distributions at slow rate of brake pedal travel on disc brake [case (I) & case (II)]

4.2 Effects of brake-line pressure and disc speed (operating conditions)

Figure 9 compares directly between the temperatures distributions on a disc brake contact surface at brake line pressure 15, 30 bar and speed 10, 20, 30, 40 km/h, when hatched pad used in test. As indicated in this figure changed according operating conditions such as brake-line pressure, disc speed.

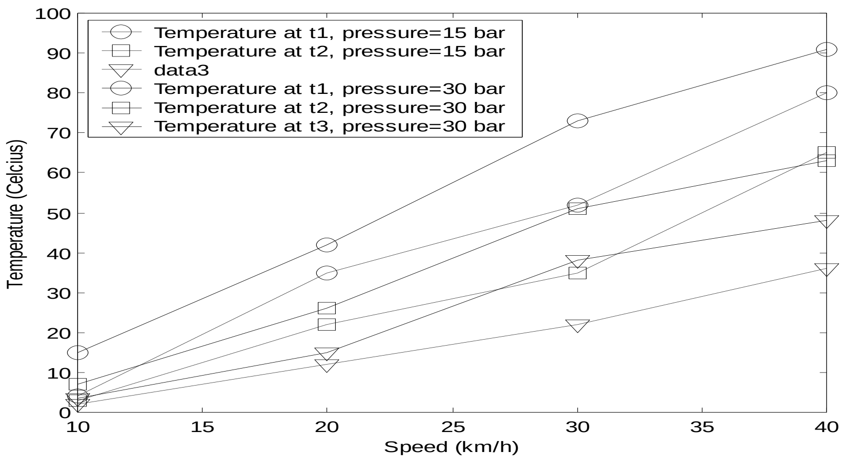


Fig. 9: Temperature distributions at brake pressure 15, 30 bar on disc brake [case (II)]

Figures 7 to 9 show disc temperature surface variations along radial direction obtained with experimental results. The change of temperature depends on disc geometry [14].

V. CONCULATION

1-The analysis of the laboratory results indicated that the temperature distribution on a disc brake is greatly affected by the type of brake pads shapes.
2- The temperature generated depending on the operating conditions, rate of pedal brake travel and disc geometry.
3- The test results also showed that the friction with hatched pad better fade resistance than the others

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