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An investigation on wear of Friction Pad in Disc Brakes

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A B S T R A C T

Brakes are used to reduce the velocity of the vehicle by applying friction between moving brake disc or drum and friction pads. Disc brakes are preferred for timely and urgent braking over drum brakes. Tribo-logical phenomenon between friction pads and brake disc is a complicated process. It needs extensive study in laboratory than on vehicle. Friction pads are made out of many metallic and nonmetallic materials which are very harmful to human health. During braking, friction takes place and friction pads wear out, as these are made from fine particles compacted by binder. Braking process converts kinetic energy in to heat energy. This generated temperature effects on the bonding of friction pad material by spreading fine particles in atmosphere.

In this paper experimentation was carried out on the brake test dynamometer to analyze the effect of temperature on friction pad material by using weighing difference method. Increasing temperature during drag braking effects on the wear rate of friction pads and brake fade. Experimental results show that when temperature generated during braking is high then the rate of friction pad wear increases up to 1.2 g per cycle of testing whereas at less temperature it reduces maximum up to 0.6 g.

Keyword : *Disc; Brake; Wear; Temperature; Fade*

1. Introduction

In braking, actuation force from master cylinder generates the friction force which opposes the direction of sliding at the interface of disc and pad; hence retardation of the vehicle is achieved. During braking friction pads transform the kinetic energy of vehicle in to heat energy in a very short braking time. This high heat develops thermal stress in braking components [1]. Therefore, it is necessary to design all components of the braking system to sustain this high sudden steep rise in temperature to avoid thermal stresses during braking. The contact forces and rotational stresses on the disc are high, are termed as mechanical loading. Normally in cars hydraulic type of brake actuation mechanism is used which are designed to generate required pressure [2].

If the heat generation is too high then braking system becomes very hot and braking performance may reduce [3]. There are many reasons for reduction in braking performance due to heating of brake such as

- Change in the properties of the rotor material at this high temperature.

- Reduction in mechanical strength of brake disc.
- Friction pad wear very fast due to loosening of bond between composite material
- High temperature affects in reduction of coefficient of friction between rotor and Pad called brake fade.
- Boiling of hydraulic fluid and deterioration of hydraulic seals in braking system.
- Surface crakes on the disc due to high thermal stresses developed.

Out of these any one or combining all the factor are involved during braking [4], then brake becomes inactive. Brake heating situation arises many times during long braking, in this situation driver complain that there was a brake failure at the time of incident but the actual phenomenon was different [5]. There might be one of the reason or combine effect of heating of system during long emergency braking situation.

The brake materials thermal capacity and coefficient of surface heat transfer are the factors responsible for rising the temperature [6]. During vehicle driving, three types of braking situations arise such as

- Single Brake application
- Series of repeated brake applications
- Continuous brake application (called Drag Braking)

Brakes are designed to work in all these three conditions [7]. For better performance of brake in all the above situations cooling provision of brake disc plays a very important role. The frictional heat developed during braking must be carried away from the friction surface of disc to avoid high temperature generation due to friction between pad and disc [8]. For this reason, rotors of disc brakes are designed in two solid friction plates/rings, each ring is called cheek, separated by small vanes [9]. These discs are called as air ventilated discs or air-cooled disc (ACD) as shown in Fig. 1. During vehicle movement air enters forcefully on these vanes as well as on the rotor surface and carry away the heat naturally. Vanes are straight or curved depend-ing on the cooling requirements of the vehicle [10].

Fig 1. Friction disc of brake and different types of vanes on ACD brake disc

Fig. 2. Plain Friction Pads and Linning Friction pads

In Fig. 2 the plain friction pads and lining friction pads are shown. The brakes are applied with the help of ac-tuator operated by mechanical, hydraulic or pneumatic pressure [11]. In single braking velocity of the vehicle reduces with constant braking torque, here deceleration can be assumed to be constant as the braking stroke is single. The braking torque develops gradually with respect to time, when driver applies brakes; braking torque starts developing and at some instance when driver applies full brake it is at maximum value [12]. The time depends upon the response of braking system. When vehicle come to rest condition braking torque becomes zero [13]. This type of braking is observed in most of the cases, here time period of brake application is less as the only objective is to stop the vehicle smoothly. Therefore, heat generation is less; also, this heat dissipates from the surface area and through vanes of disc brakes [14].

In case of repeated braking applications, every time braking force reaches to maximum and friction between disc and pad continue till the driver releases the brake [15]. Every time at per brake, heat is generated and before cooling again the heat is added to next braking stroke. This addition of heat accumulates and brakes become hot. The temperature generated depends upon the number of braking applications and time period of each brake. The rate of cooling of disc depends upon the design and material properties of brake disc [16].

In drag braking, pads are continuously in contact with the disc for a longer time e.g. when vehicle needs con-tinuous braking, there is continuous heat generation by the braking system. Drag braking occurs in situation where vehicle needs to control over a long distance with the application of brakes such as long down slope or vehicle moving with a very high speed and emergency braking situation arises [17]. In this type of braking heat is added continuously from the application of brake to stop the vehicle. Present vehicle braking system is dependent on air flow cooling. When vehicle is at rest the rate of heat transfer to atmosphere via convec-tion is very slow as the vehicle moves forward with the increase of speed the air flow increases and hence force cooling takes place [18]. The heat generation rate and cooling rate are not equal; cooling rate is slow as compared to heat generation. The rate of cooling also depends upon the atmospheric condition, in hot at-mospheric regions rate of cooling decreases than the normal [19]. The generated heat has an impact on every component of the braking system. Effect of rise in temperature on rotor (Disc), friction brake pads and other braking components are;

- Weakening of Friction pad bonding material.
- Drop in the coefficient of friction of pads. (Brake Fade)

Beyond the critical temperature, the failure of different components of braking system may take place. e.g. friction pads, braking fluid, piston, calliper itself, O rings, hose, clips etc.

Temperature rise also effects on disc material in the form of change in material properties leads in to cracking or conning.Same has been shown in the Fig.3, it is necessary to dissipate the heat from the local area of disc to avoid such effects on braking system.

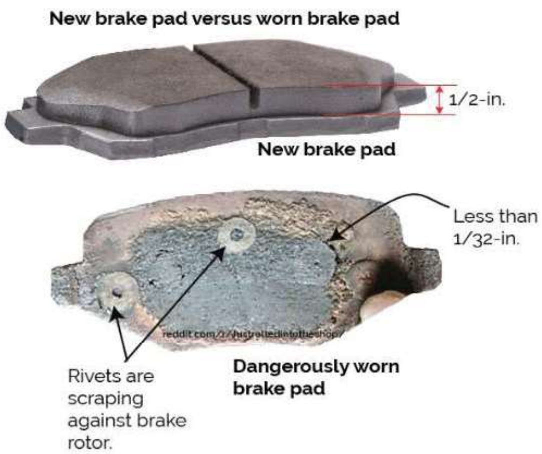


Fig. 3. Effect of Temperature on friction pads

These are the hidden by products of heat generation during braking [20]. These cannot be identified during braking operation. In the present study an attempt has been made to find the effect of temperature on wear rate of friction pads by using brake dynamometer setup [21-23].

2.0 Research Gap and Objective:

Literature review on brake pad wear suggests that there is wear of friction pads due to mechanical friction between disc and pads during braking but only acceptance does not solve the problem, therefore different problem-solving angles have been thought and found that the temperature generation might be the major cause of wear, as in almost all brake researchers have given stress on cooling of disc and this research gap has been identified for the further study. Accordingly, the main objective has been decided to find the rate of wear of friction pads with respect to temperature generation during the braking process of vehicle.

3.0 Materials and Methods:

To carry out the experimentation off-market friction pads were preferred, these pads were widely used by the local garage mechanics to replace the worn out pads. The common composition of friction pads has been obtained in testing of friction pad material before the experimentations.

Laboratory experimentation methodology is used to predict the wear rate of friction pads. To carry out the experimentations an experimental setup of dynamometer has been designed and the results were obtained as given below.

3.1 Experimental setup:

Experimental setup is essential to perform the different experimentations on brake disc [24]. In this research disc brake has been taken for the study. Experimentations are performed keeping light motor vehicle in to consideration therefore, car braking system has been installed on brake dynamometer. The basic components required for setup of disc brake are; disc brake assembly with caliper, friction pads, master cylinder, operating paddle, rotating device i.e. electric motor and inertia wheel [25]. Apart from these basic components some measuring equipment's are also necessary to record the different readings such as pressure gauge, ABB system for rpm measurement, thermocouple to record the heat generated and fan to create realistic situation for cooling the disc [26].

Inertia brake dynamometers is laboratory-based testing equipment and is designed for brake testing as shown in Fig. 4. In this type of dynamometer brake disc is attached to the motor driven shaft (AC variable drive electric motor) on which flywheel is fitted to simulate the vehicles inertia and kinetic energy [27]. The brake stator which includes caliper and brake actuation mechanism, mounted on the frame of dynamometer. The shaft is free to rotate on the bearings and torque arm is installed on tail end to measure the torque [28]. Elec-tric motor drives the complete assembly of flywheel and disc brake mountings; when sufficient speed of the flywheel is achieved then brakes are applied to decelerate the flywheel and at the same time motor drive are disconnected [29]. Many simulated situations can be installed on dynamometer to create the realistic situation for brake test. Brake disc is provided with K-type rubbing thermocouple as shown in Fig. 5, which detects the temperature generated on disc surface during braking [30]. This laboratory data then can be validating in actual vehicle testing.

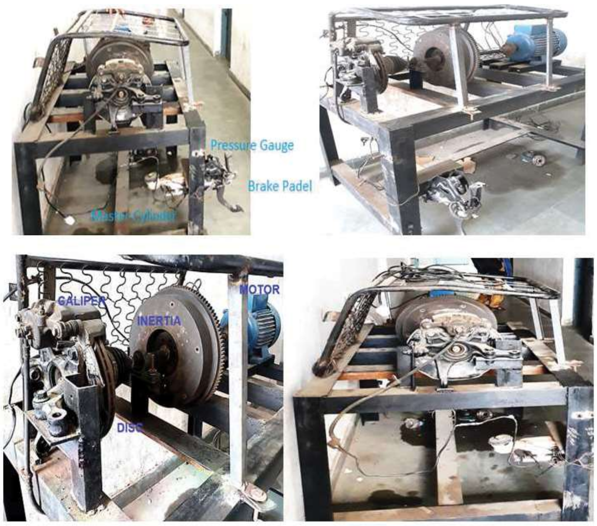


Fig.4. Experimental setup of Inertia Brake Dynamometer

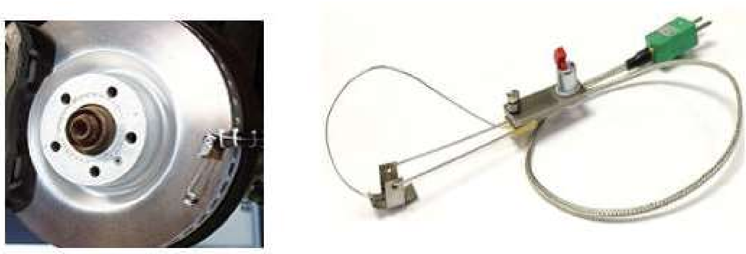


Fig.5. Rubbing K-type thermocouple

3.2 Experimentation:

To evaluate experimentally the thermal effect on brake pads by using weighing difference method for brake fade and pad wear [31-33]. Experiments were carried out on the inertia brake dynamometer to observe the performance of friction pads against the temperature generated during braking.

3.3. Experimentation for Thermal Brake Fade:

Thermal brake fade experimentation was carried out on the inertia dynamometer to observe the temperature of brake fade for ventilated brake disc. Series of brake trials were taken for the observation of brake fade [34]. Before starting actual experimentation, bedding and burnishing of brake pads was done by dry run braking at 180^{0}C as it is essential for new pads to be used for experimentation [35]. In actual experimentation each time electric motor is rotated at an 1800 rpm to rotate the disc and brakes were applied by keeping all other parameters constant [36]. Brakes are applied to stop the rotating disc and stopping time is noted for each braking cycle. Braking cycles were repeated with a gap of 1 min (60 seconds) at room temperature and without force cooling [37]. The start time of brake and stop time was noted as given in Table 1. For each braking cycle, temperature generated also noted with the help of rubbing thermocouple. Temperature of disc increases with the number of braking cycles, after 9 cycles temperature reaches to 269^{0}C and there was no change in disc stopping time. In next 3 braking cycles there was slight change in stopping time and also tem-perature increase observed. After 14 cycles of braking operation temperature reaches to 307^{0}C and stopping time also increase significantly. In another 2 braking cycles temperature reaches to 314^{0}C and there was sig-nificant change in stopping time of disc. This shows that after 300^{0}C temperature brake fade is observed in disc brake [38]. The obtained reading was plotted on graph as shown in Fig. 6. After experimentation actual pad wear can be observed on friction pads as shown in Fig. 7. The procedure adopted for measuring the wear rate in this experimentation was by change in mass of friction pads. Initial mass readings of both the brake pads (after bedding and burnishing) were noted with the help of accurate weighing balance machine then after experimentation the weight of the friction pads were again noted as shown in figure 8 [39].

3.4 Observations:

The weight difference after experimentation of friction pads was observed to be 1.2 gm. Brake pad wear was on higher side, these wear particles spreads in atmosphere.

Table 1 Observations for 1 min. gap braking cycles (March 18, 2020)

Sr. No.	Flywheel weight in Kg	Hy-draulic Pressure in Mpa	Initial RPM	Final RPM	Braking start time	Braking stop time	Braking time in sec	Initial Temp of Ventilated disc ^{0}C	Max. Temp recorded of Ventilated disc ^{0}C
No	02	03	04	05	06	07	08	09	10
1	42	2.7	1800	0	11:30:00	11:30:02	02	28	78
2	42	2.7	1800	0	11:31:02	11:31:04	02		92
3	42	2.7	1800	0	11:32:04	11:32:06	02		119
4	42	2.7	1800	0	11:33:06	11:33:08	02		142
5	42	2.7	1800	0	11:34:08	11:34:10	02		171
6	42	2.7	1800	0	11:35:10	11:35:12	02		192
7	42	2.7	1800	0	11:36:12	11:36:14	02		218
8	42	2.7	1800	0	11:37:14	11:37:16	02		233
9	42	2.7	1800	0	11:38:16	11:38:19	02		269
10	42	2.7	1800	0	11:39:19	11:39:22	03		278
11	42	2.7	1800	0	11:40:22	11:40:25	03		291
12	42	2.7	1800	0	11:41:25	11:41:28	03		298
13	42	2.7	1800	0	11:42:28	11:42:31	03		302
14	42	2.7	1800	0	11:43:31	11:43:35	04		307
15	42	2.7	1800	0	11:44:35	11:44:39	04		310
16	42	2.7	1800	0	11:45:39	11:45:43	04		314

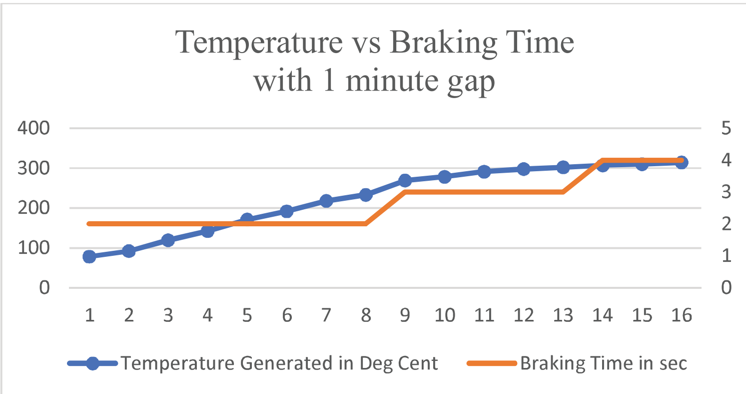


Fig. 6 Graphical representation of temperature rise and braking time

Figure 7: Brake Pads Surface after Experimentation

1. Weight before Experimentation for first pad 2. After Experimentation (1.2 gm Difference)

3. Weight before Experimentation for second pad 2. After Experimentation (1.2 gm diff.)

Fig.8. Brake Pads weight before and after Wear Experimentation

The weight difference after experimentation of friction pads was observed to be 1.2 gm. Brake pad wear was on higher side, these wear particles spreads in atmosphere.

3.5 Experimentation for Thermal Brake Wear:

With the guidelines from standard test procedures for the brake, wear experiments were carried out on the inertia dynamometer [40]. All the operating parameters were kept constant as if it was maintained for above brake fade test. The procedure adopted for measuring the wear rate was by change in mass of pads. Initial mass readings of both the brake pads (after bedding and burnishing) were noted with the help of accurate weighing balance machine. In experimentation pair of brake pad was fitted and 16 braking cycles were re-peated for stopping the disc, from 1800 rpm to stop the disc [41]. The duration between braking cycle time for this test was 12 minutes, so that the temperature of the disc between two cycles reduces substantially in natural cooling [42]. After each trial start and stop time was noted and at the same time temperature also noted as shown in Table 2. The main aim of this experimentations was to determine the rate of wear during braking without generating temperature on the surface of pad. In this experimentation up to reading number 12 there was no change in braking time and the temperature was also 112^{0}C, which is lower as compared to 1 minute braking cycle. The temperature generated during this experimentation was plotted on the graph as shown in Fig 9. After reading number 13 there was a change of 1 second in braking time at the temperature of 116^{0}C. This implies that the temperature effects on braking time. The wear of friction pads can be observed in Fig. 10.

Table 2. Observations for 12 min. braking cycle (March 19, 2020)

Sr. No.	Flywheel weight in Kg	Hy-draulic Pressure in Mpa	Initial RPM	Final RPM	Braking start time	Braking stop time	Braking time in sec	Initial Temp of Ventilated disc ^{0}C	Max. Temp recorded of Ventilated disc ^{0}C
No	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
1	42	2.7	1800	0	12:30:00	12:30:02	02	30	71
2	42	2.7	1800	0	12:42:02	12:42:04	02		89
3	42	2.7	1800	0	12:54:04	12:54:06	02		85
4	42	2.7	1800	0	1:06:06	1:06:08	02		91
5	42	2.7	1800	0	1:18:08	1:18:10	02		92
6	42	2.7	1800	0	1:30:10	1:30:12	02		97
7	42	2.7	1800	0	1:42:12	1:42:14	02		95
8	42	2.7	1800	0	1:54:14	1:54:16	02		101
9	42	2.7	1800	0	2:06:16	2:06:18	02		99
10	42	2.7	1800	0	2:18:49	2:18:51	02		102
11	42	2.7	1800	0	2:30:51	2:30:53	02		105
12	42	2.7	1800	0	2:30:53	2:30:55	02		112
13	42	2.7	1800	0	2:42:55	2:42:58	03		116
14	42	2.7	1800	0	2:54:58	2:55:01	03		116
15	42	2.7	1800	0	3:07:01	3:07:04	03		120
16	42	2.7	1800	0	3:19:04	3:19:07	03		122

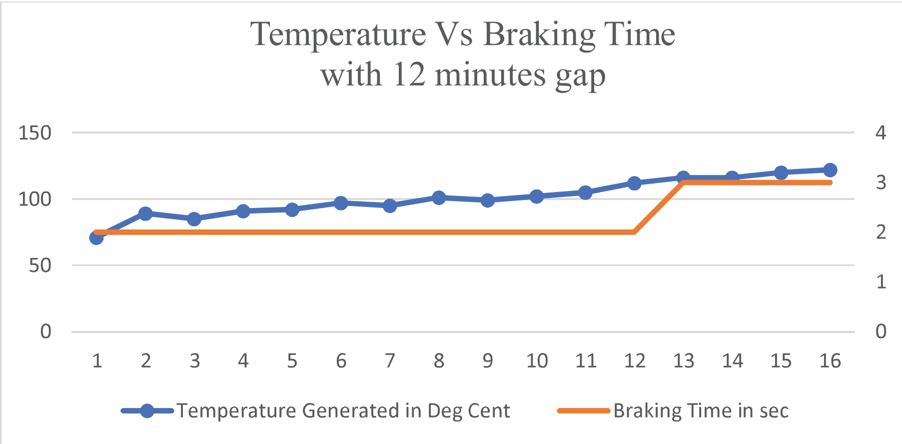
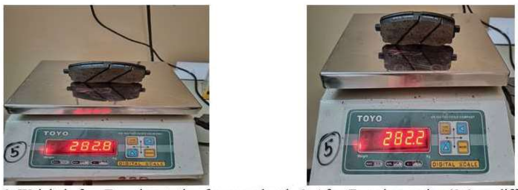


Fig 9. Graphical representation of temperature rise and braking time

Fig. 10. Brake Pads after Wear Experimentation

After experimentation the brake pads were removed from the caliper and weight was noted [43]. The weight of this pads was noted as shown in Fig. 11 and compared with the initial weights and found that there is difference between weights of pads. The weight difference after wear is observed to be 0.2-0.6 gm where as in 1 minute braking cycle after wear the weight difference was 1.2 gm. Thus, with the rise of temperature on the surface of the friction pads increases the wear rate and was experimentally verified [44].

1. Weight before Experimentation for first pad 2. After Experimentation (0.2 gm Difference)



3. Weight before Experimentation for second pad 2. After Experimentation (0.6 gm diff.)

Fig 11 Brake Pads weight before and after Wear Experimentation

4. Results and Discussion:

Experimental interpretation can be summarized as; with the increase of temperature friction pad wear also increases. During braking heat generates and to dissipate the heat in the atmosphere positive cooling is essential. Presently in all most all vehicle's braking system is cooled with the help of natural air flow during vehicle movement. This cooling is termed as natural convection cooling process, from the surface of brake components. The radiation also observed in most of the cases when heat generation is more but researchers in this area neglected it while calculating heat transfer as it is small in quantity. The cooling time provided in second set of experimentation in above experimentations clearly indicates that, if sufficient cooling time is provided to cool the braking components, then the wear rate can be reduced drastically. When the cooling time was 1 min, then the wear of friction pads observed was 1.2 gm whereas when the cooling time was 12 min then the friction pad wear observed was 0.2 to 0.6 gm. Generated heat greatly effects on the bonding properties of friction pad material, as the temperature increases the friction pad material particles were gets loosed and spreads in to atmosphere causing wear of pad and pollution in the atmosphere. Heating also effects on the braking time of vehicle. In first set of experimentation of 1 min gap braking time increases rapidly as com-pared to second set of 12 min gap and this leads in to brake fade, the major cause of accidents as shown in Figs. 6 and 9.

5. Conclusions :

Thermal behavior at the interface between brake disc and pad is very complicated process to understand. Tribological changes during braking are atmospherically influenced and time dependent. Temperature generation during braking plays a very important role in smooth operation of brakes. During low speed of vehicle air circulation through the ventilated disc dissipates less amount of heat and also, during high speed because of the more air accumulation and opposing pressure there is less dissipation of heat. Overall temperature effects on the operational performance of brakes. Brake fades with the rise in temperature, fading occurs due to loss of coefficient of friction of pads at high temperature and this has been proved experimentally. Brake pads are manufactured from the fine metallic particles, hence at high operating temperature these particles also lose their bonding from resin and spread in to air at a higher rate in the form of brake wear; this has been proved from the above experimentations. From the experimentations carried out by different researchers also it has been observed that the critical temperature for disc brake is in between 307^{0}C to 314^{0}C, at this temperature both brake fade and brake wear observed. The results also correlate with the literature made available by different friction pad manufacturers in India. For the modern vehicles, speed and engine power is high therefore, need long braking for stopping which may results in to increase in temperature requires stronger cooling system to avoid the thermal effect. From the experimentation conclusion can be drawn that the temperature increase during braking has effect on the brake pad wear rate and brake fade.

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