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RESEARCH

Experimental Investigation of Thermal Effect on the Frictional Characteristics of HCC Friction Clutch Material

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ABSTRACT

Increasing temperature due to frictional heat from sliding between contacting surfaces leads to increased wear and friction. Therefore, the researchers continue investigations to find the most suitable friction materials with good mechanical and thermal properties for frictional facings of clutch performance under this condition. In this research paper, the behavior and performance of the friction material HCC was studied under different normal load conditions (125, 175, 225, and 275 N) and different working environment temperatures (300 K and 390 K), where the rotation speed was 300 rpm. The results of the coefficient of friction and friction forces variation under different working conditions were analyzed and discussed in detail. XTM 500 tribometer test rig was used to perform the required tests, and the samples were made of the HCC friction material. The obtained results proved that the ambient temperature of the friction system has a significant negative effect on both the coefficient of friction and the force of friction. So, when the friction system's ambient temperature increases, the magnitude of the friction coefficient will decrease, and, thus, the transmitted torque will reduce too.

1. INTRODUCTION

Mechanical systems, in general, include numerous frictional contacting elements. From a large point of view, Tribology plays a significant role in terms of considerable cost saving of production. The recent works revealed that 50% of worldwide energy utilization is steered toward handling friction issues.

Numerous researchers have been motivated in the last decades to improve tribological systems' performance by minimizing friction and wear by adopting innovative techniques. The studies trend of enhancement of the tribological systems is shown in Figure 1 through the reduction of the coefficient of friction in trucks and buses to a minimum level up to 2050. The global effects of both wear and friction are depicted in Figure 2. It reveals their significant influence on production costs, energy losses, and CO2 emissions. It also shows that the energy losses and CO2 emissions are influenced six times by friction compared to the wear effect. On the other side, friction has a triple impact on the economic cost compared to wear influence [1-5].

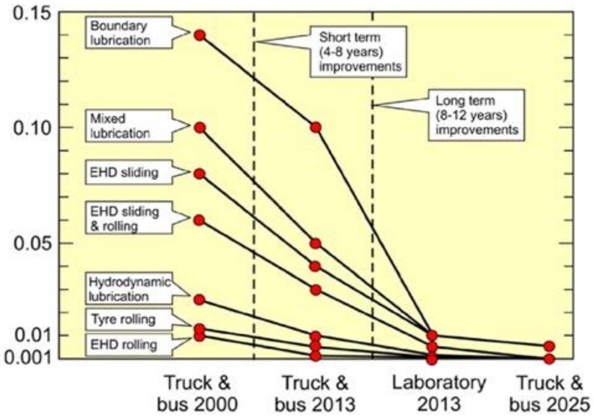


Fig. 1. The trend to reduce the friction coefficient for trucks and buses [1].

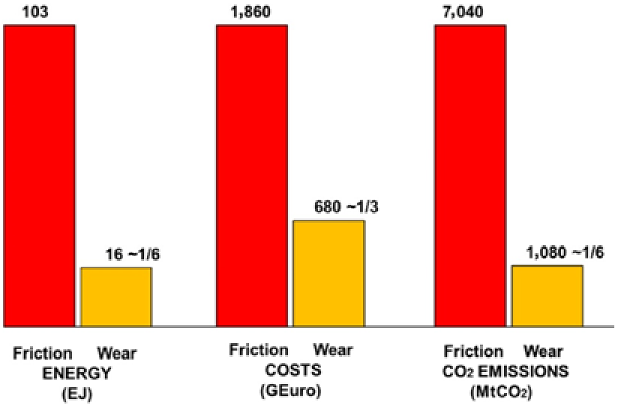


Fig. 2. The effect of wear and friction on costs, losses of energy, and CO2 [3].

As it is known, the clutch component is a vital mechanical part and is utilized in various applications, yet it is mainly included in automotive vehicles. The engagement and disengagement of the gearbox transmission system from the engine represent its role. The frictional clutch is very important to maintain smooth torque transfer from the engine to transmission during motion, detach, and run a drive for selection of gear speed. Therefore, its functions within the transmission system are clear and additionally reduction of fuel consumption. It is also responsible for minimizing transmission noise and vibration and is not limited to lowering the overload and impact within the system. Also, it is broadly utilized in machinery. Slipping occurs during clutch engagement due to speed variability of the contacted elements (i.e., clutch, pressure plate, and flywheel). Consequently, a large magnitude of thermal power will be produced at the interface of the contacted bodies. Due to the generation of high frictional heat, there will be a fast increase in the temperatures of the contacted surfaces, which may be across the limit value in some conditions. Large thermal deformation as well as thermo-elastic instability, would be induced as a result of such overheats. All these aspects could be improved by adequately selecting the friction clutch material with good friction, heat resistance, and low wear rate. The clutch friction disc is illustrated in Figure 3.

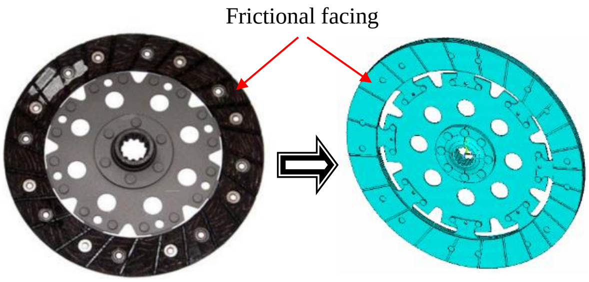


Fig. 3. The typical friction clutch disc.

A study was conducted by Lee et al. [6] to find the effects of thermal loadings. They calculated the contact pressure and centrifugal force on the diaphragm spring of the pressure plate. Their recommendations were to increase the thickness of the pressure plate because of the critical influence of thermal stresses and contact pressure to reduce the generated thermal stresses that developed on the pressure plate due to friction.

Another study was done by Yun-Hai and Wen-Ming [7] to examine the generated temperature distribution on the frictional disc and the negation reasons for utilizing wet clutch in heavy trucks according to the coupled thermal solutions. They derived an empirical formula to find the disc surface temperatures and validated it with experimental findings. Various oil groove geometries were made along a driven frictional disc to analyze their impacts on the surface temperature, transfer, and drag torques. The oil groove with double arc configuration was the optimum geometry to be used in heavy-duty trucks based on the achieved results due to its intermittent coefficient of friction, synthesis characteristics, ease of fabrication, and a small effect on the drag torque.

Deep investigations were conducted by Abdullah et al. [8-11] to determine the temperature distribution and dissipation of energy for dry clutch during single and multi-engagements under uniform wear and pressure status. They extended their work by using two methods to show the role of applied pressures on the performance of clutch systems. The first method was adopted to determine the independent heat generation for each element based on the heat partition ratio. The second one implemented the total heat generation for the whole system based on the contact model. They also examined the effect of sliding speed, engagement time, inner-to-outer radius ratio of the disc, and thermal stress to reveal the thermal performance at the beginning speed of the engaged clutch system.

An experimental approach was developed by AL-Zubaidi and Abdullah [12] to investigate the frictional characteristics of the friction material (G95) that is used in the friction clutch disc. It was used for a long test period to study the frictional force variation and friction coefficient under different working conditions. Also, the thermal influence on the frictional characteristics was studied to show the changes in characteristics at different surrounding temperatures. They proved that the increase in the ambient temperature negatively affects the performance of friction systems such as automotive clutches and brakes. Nasr A. Jabbar et al. [13] studied the thermal behavior of four different frictional materials such as LUK, Tiger, G95, and HCC. The finite element method was used to model the temperature distribution for each material separately. The results showed that the use of HCC material improves the thermal performance of the dry clutch system. In Qasim M. Doos et al. [14], the selection of the frictional-facing material of the clutch disc was investigated to obtain the optimal thermal behavior of the clutch system numerically. It used five different frictional materials ie St37-2, HCC, G95, LUK, and Tiger. It was found that the frictional material (HCC) is the superior one with the highest performance.

In previous recent works, many researchers have made an effort to examine clutches with several types of frictional material for thermal behavior. According to their mathematical models or numerical solutions, the best frictional material for a clutch is HCC, which has the lowest contact surface temperature due to its high thermal conductivity, coefficient of friction, and heat partition value. Also, it has relatively low prices and lower negative environmental effects. This resulted from the fact that HCC is a particular woven frictional material strengthened with extra copper to enhance its frictional characteristics. However, most of the researchers concentrated more on numerical solutions than on experimental work, Where experimental work necessitates high costs and a considerable amount of time to construct a reliable test rig apparatus. In the current study, the experimental approach is assessed to study the performance of frictional materials HCC for clutch systems under dry conditions. A set of normal loads was applied with a predetermined range to evaluate the frictional behavior under various surrounding temperatures, which was tuned in the new tribology test rig type XTM 500.

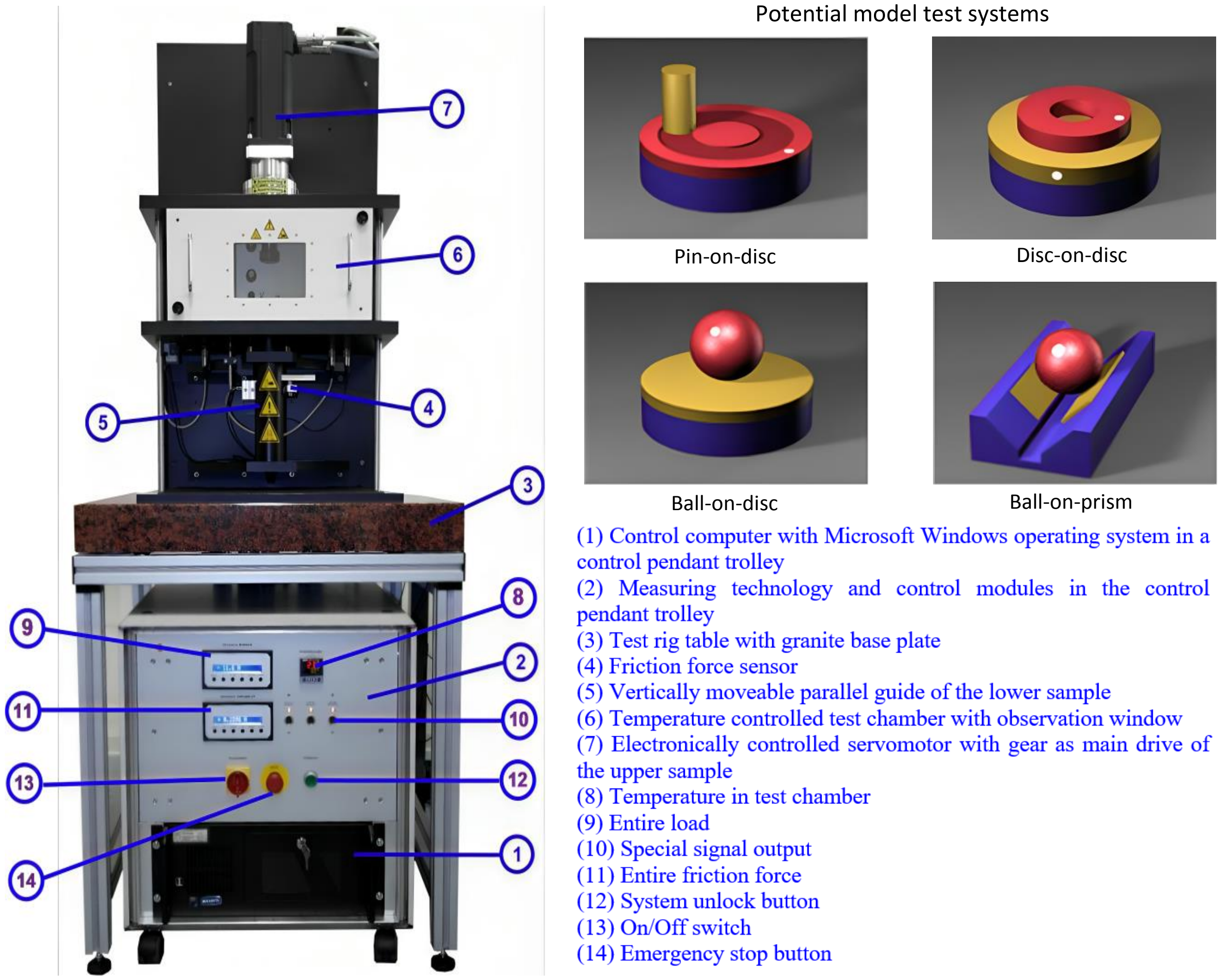
2. MATERIALS AND EXPERIMENTAL PROCEDURE

In this study, a new test rig XTM 500, was used to investigate the frictional and wear performance of HCC frictional materials under various operating conditions. The test rig incorporates numerous parameters that are able to be tuned, such as; working time, sliding speed, working time, applied loads, temperature, and contact pressure. Also, it can work under wet and dry circumstances.

As indicated in Figure 4, the test apparatus is powered by an electric motor. The shaft center transmits the torque to the steel pressure disc. Both frictional specimen and adapter are joined together and operated with ±0.5 mm working distance set by a digitalized indicator. Each element of the test rig was labeled and illustrated respectively. Further, the potential model test systems were presented, including pin on disc, disc on disc, ball on disc, and ball on prism.

Due to its sturdy mechanical design with the parallel guiding frame, this test rig (XTM 500 type) has reliable performance and is able to sense extremely small forces. The frame is connected to the vertical load on one side using a spring. A force sensor is also fixed on the support shaft, which supports and controls the adapter's perpendicular movement.

The test rig offers flexibility in assembling and disassembling test specimens on the matching adaptor. In addition, the adapter on the friction torque measurement platform can be assembled and disassembled easily. The normal load is generated and determined by the force sensor and the motor traction spring. Furthermore, a heating chamber is equipped for the test rig in conditions where the experiment requires the involvement of ambient temperature as a parameter. The thermal sensor is connected to the chamber, and the assembly is fixed on the test box to study the influence of these parameters on the performance of selected frictional material.



(1) Control computer with Microsoft Windows operating system in a control pendant trolley
(2) Measuring technology and control modules in the control pendant trolley
(3) Test rig table with granite base plate
(4) Friction force sensor
(5) Vertically moveable parallel guide of the lower sample
(6) Temperature controlled test chamber with observation window
(7) Electronically controlled servomotor with gear as main drive of the upper sample
(8) Temperature in test chamber
(9) Entire load
(10) Special signal output
(11) Entire friction force
(12) System unlock button
(13) On/Off switch
(14) Emergency stop button

Fig. 4. Tribology test rig XTM 500.

In this study, HCC high frictional material was selected with 15 mm and 3.5 mm thicknesses. Thus, the dimensions of the chosen disk are suitable for the adaptor of the test trig, which has a diameter of 40 mm.

Figure 5 shows how the upper adapter is joined with a pressure disc via a metallic screw and filled inside the collet chuck in a deep and complete manner. The frictional specimen is connected to the steel pallet with a metal screw, and all the combined elements must be put under the adaptor part. On the other hand, the lower adapter is attached to the mechanical parallel guiding shaft with two screws from the underside.

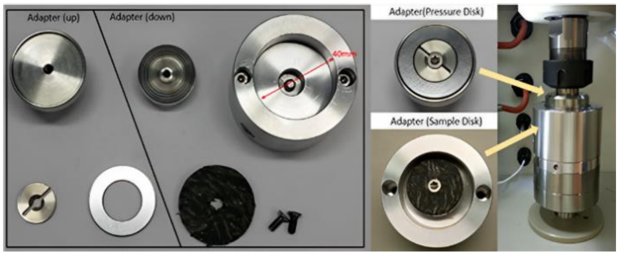
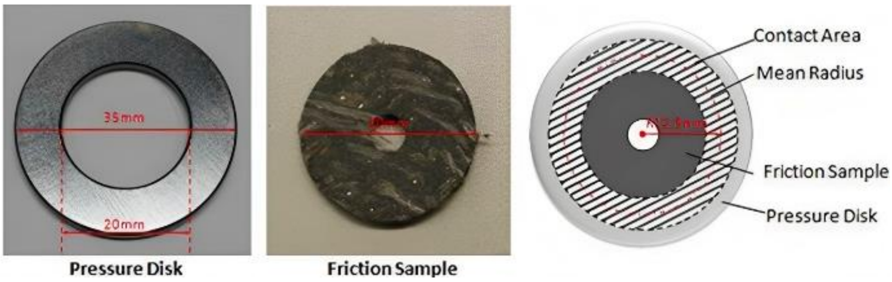


Fig. 5. Pressure disc, adapter, and friction disc sample.

The test rig's adapter is divided into two sections: top and bottom sides. A screw is put into the bottom section of the adaptor to secure the frictional disc to the metallic pallet. The upwards adapter has a mounted steel pressure disc and a small tension disc that are screwed together to be completely integrated into the shaft that is operated by the motor to generate a normal load on the frictional test sample.

There is a restriction to the upward rotational motion between the frictional specimen fixed on the metallic ballet and the pressure disc due to the adapter-blocked joint. The average radius of the disc specimen, which refers to the distance between the center of the shaft and the average sample radius, is used to calculate the frictional force, as shown in Figure 6. It is feasible to install particular software to determine the sensor location. The steel pressure ring has an external diameter of 35 mm and an internal diameter of 20 mm, respectively. In contrast, the diameter of the frictional sample is 15 mm, and therefore, the contact area between the ring and sample is covered under the ring with a mean radius of 12.5 m. The frictional force is measured with the help of a force sensor fixed on the test rig.



Pressure Disk

Friction Sample

Fig. 6. Dimensions of contact area and mean radius.

Before performing the experimental work, some parameters have to be adjusted, like the type of experiment, test time, initial and final speed, initial load, angle of the frictional specimen, air heater temperature, sampling rate, and the distance between the contact area and shaft center, etc. The XTM 500 test rig is provided with a self-developed package to adjust and set up all the required parameters.

The control screen displays the retrieved information and measures the determined values, as Figure 7 shows. The top diagram, for example, displays the measured values of the carried-out experiment. The period of the experiment, including time sequence along a rotational speed of 300 rpm, takes around 22 minutes.

The fuchsia and blue colors represent the wear rate and normal load, respectively, where both outputs show relatively constant behavior during the experiment. The green color represents the time sequence for the coefficient of friction with an initial steep increase and then maintains stability over the rest time. The red color resembles the produced frictional force in a similar circumstance thereby.

The fuchsia-colored curve in Figure 8 depicts the position sensor's time sequence, whereas the blue curve reveals the generated ramp for the 0-300 set rotational speed range. The additional measured values of the time sequence can be plotted in other graphs. Some readings were excluded from the present work, and therefore, they were canceled.

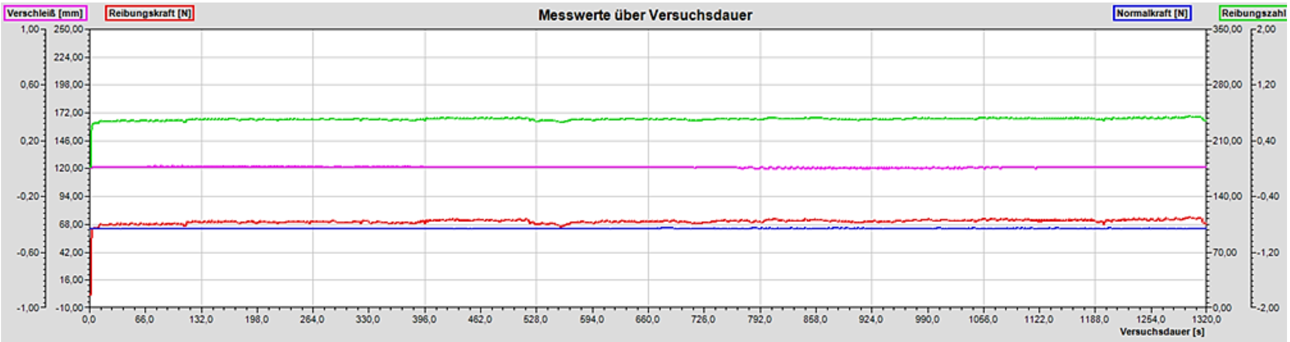


Fig. 7. The experimental measurements over the test period.

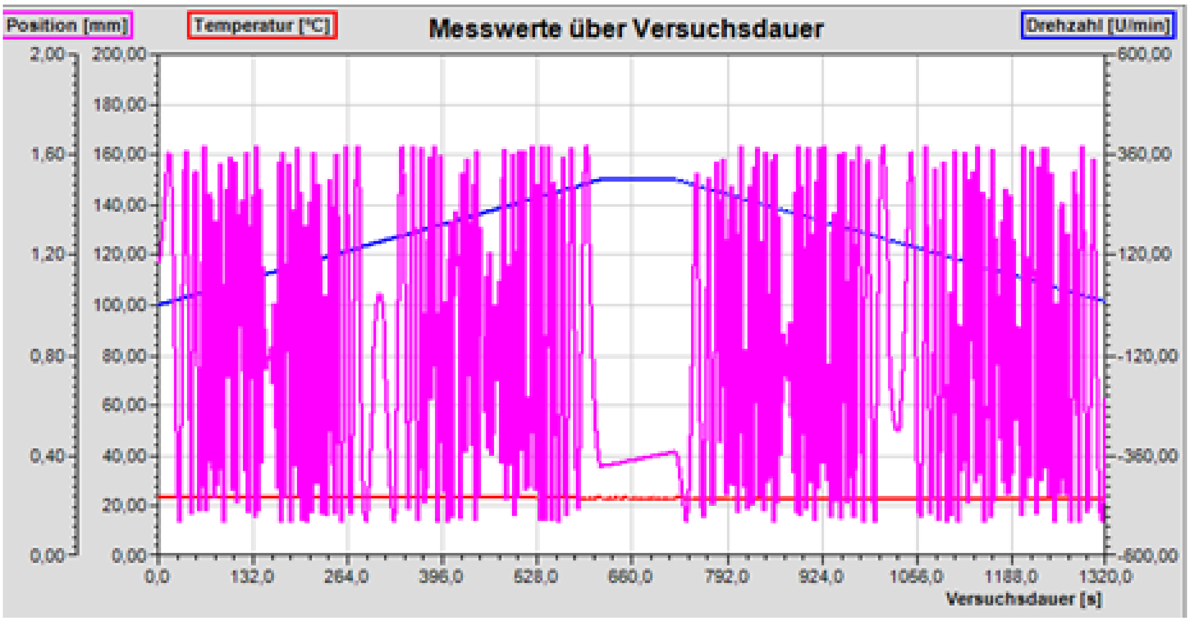
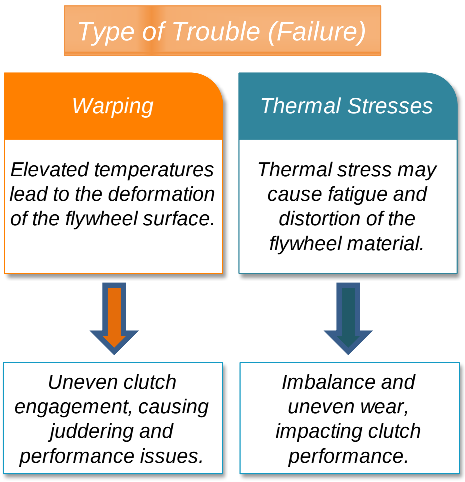


Fig. 8. Position/Temperature/Rotational Speed during the test period.

Based on what was presented in the introduction section, it is clear that there is a significant effect of high-temperature levels on the behavior and performance of the friction clutch system. Where the thermal effect will cause various types of issues and failures in parts of the clutch system [1-16]. Figure 9 summarizes the main trouble/ failure that happened in the frictional facing/ lining of the clutch system, flywheel, and pressure plate due to the thermal effect (high temperature). Also, it can be seen the characterization of these troubles/failures and the overall effect on behavior and performance of the clutch System.



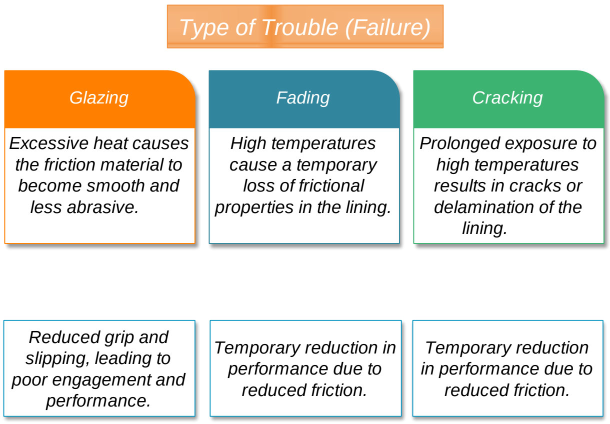
Elevated temperatures lead to the deformation of the flywheel surface.

Thermal stress may cause fatigue and distortion of the flywheel material.

Uneven clutch engagement, causing juddering and performance issues.

Imbalance and uneven wear, impacting clutch performance.

(b) Flywheel



Excessive heat causes the friction material to become smooth and less abrasive.

High temperatures cause a temporary loss of frictional properties in the lining.

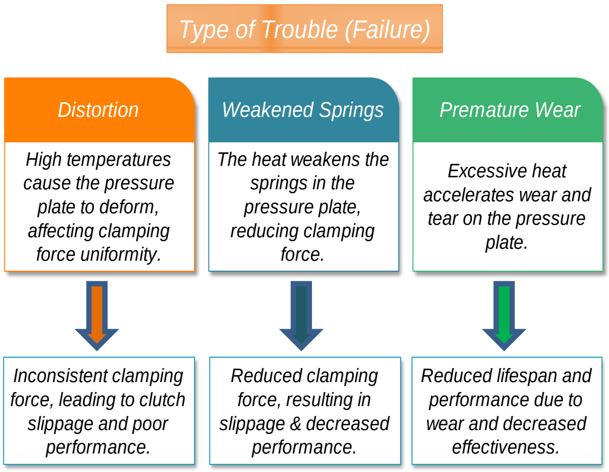
Prolonged exposure to high temperatures results in cracks or delamination of the lining.

Reduced grip and slipping, leading to poor engagement and performance.

Temporary reduction in performance due to reduced friction.

Temporary reduction in performance due to reduced friction.

(a) Frictional facing



High temperatures cause the pressure plate to deform, affecting clamping force uniformity.

The heat weakens the springs in the pressure plate, reducing clamping force.

Excessive heat accelerates wear and tear on the pressure plate.

Inconsistent clamping force, leading to clutch slippage and poor performance.

Reduced clamping force, resulting in slippage & decreased performance.

Reduced lifespan and performance due to wear and decreased effectiveness.

(c) Pressure plate

Fig. 9. The main trouble/ failure that happened in the main elements of the clutch system due to the high temperature.

3. RESULTS AND DISCUSSIONS

This section presents and discusses the main achieved findings. Four levels of normal loads were selected, which are; 125 N, 175 N, 225 N, and 275 N. The average frictional disc radius is 0.0125 m. The experimental runs were carried out under two different temperatures: 300 K and 390 K as summarized in Table 1.

Table 1. The test conditions.

Test Temperature (K)	Applied Normal Loads (N)	Measured Output Responses
300	125, 175, 225, and 275	Frictional force; Coefficient of friction
390	125, 175, 225, and 275	Frictional force; Coefficient of friction

Figure 10 depicts the frictional forces at room temperature (Ta= 300 K) during the sliding duration (2500 s) based on the applied normal loads (125, 175, 225, and 275 N).

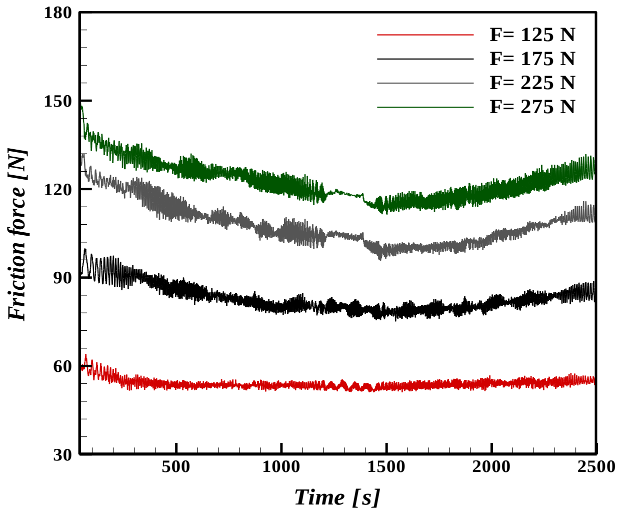


Fig. 10. Frictional forces when applied different values of normal load at temperature (Ta= 300 K).

It can be shown that when the normal force (F=125 N) is applied, the frictional force is the most stable during the test, with an average value of 54 N. When F= 175, the same pattern may be seen, but with a smaller stability region than when F= 125 N. During the entire test period, the average frictional force was found to be roughly 83 N.

It can be seen that as the value of normal force was increased, the frictional force's stability was reduced. Where both situations (F= 225 N and 275 N) have almost similar conduct. The frictional force began with large values (133.8 N and 160.8 N) within a very short period, as corresponds to F= 225 N and 275 N cases. After 1500 s, the frictional forces then fell to their minimum levels before gradually increasing to their final levels at the test end. The mean frictional forces for the cases of (F= 225 N and 275 N) are roughly 108.3 and 123 N, respectively.

Figure 11 illustrates the variations in friction coefficients during 2500 s when different normal loads (125, 175, 225, and 275 N) were applied under a surrounding temperature of 300 K. According to the collected findings, the average coefficient of friction was found to be roughly 0.43 when F=125 N.

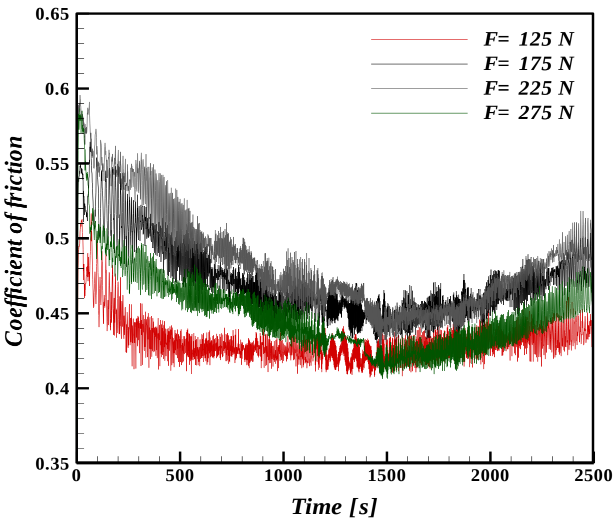


Fig. 11. Frictional coefficients when applied different values of normal load at temperature (Ta= 300 K).

When F= 175 N, on the other side, the average frictional coefficient was found to be roughly 0.46. The average coefficient of friction for the other two examples (F= 225 N and F= 275 N) was found to be 0.48 and 0.45, respectively. In general, the coefficient of friction values started at the highest levels at the beginning of the test period, then reduced to the minimum levels at the midpoint of the test, and then progressively climbed to the end values at the finish of the test. This is because the surface temperature values increase from their initial value to the maximum temperature approximately at the middle sliding time during the slipping period. Later, the temperature decreases to the final temperature at the end of the sliding period [10,15].

However, the difference between the coefficient of friction values at the beginning of the slipping period and the end values is small. This refers to the fact that the HCC frictional material tries to sustain its frictional characteristics during slipping time.

Moreover, it is clear from Figure 11 that there is a small effect of applied loads, and the coefficient of friction curves are close to each other.

The influence of the ambient operating temperature on the behavior of the frictional material that is utilized in sliding subsystems such as automotive clutches and brakes is also investigated in this work. The test rig is confined to the range of 300 K-400 K because of the imposed restrictions on the utilized Tribology test equipment. Two temperature levels were selected: low temperature (Ta= 300 K) and high temperature (Ta= 390).

Figure 12 shows the fluctuation of frictional forces at F=125 N with a sliding test period of (2500 s) at two various working temperatures (Ta= 300 K and 390 K). The high level of working temperatures had a substantially detrimental influence on the frictional force, as can be seen. For instance, the frictional force is dramatically reduced from 54 N to 36.98 N when increasing the working temperature from 300 K to 390 K.

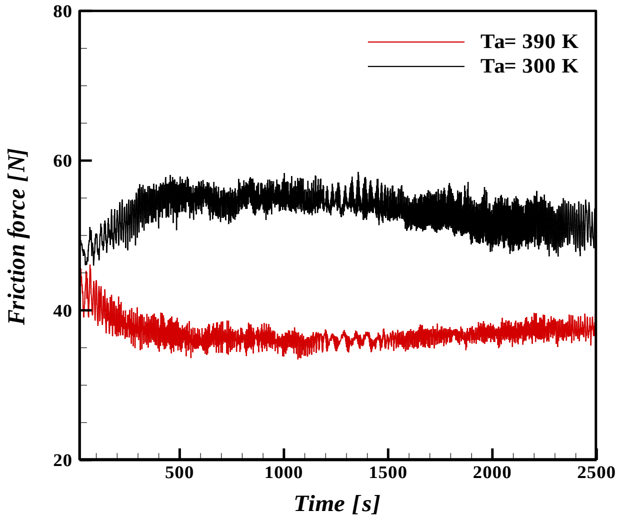


Fig. 12. Fiction force when applied at different ambient temperatures.

A rapid increase in frictional force was observed at ambient temperature (300 K). Later in the sliding test, the frictional force values gradually reduced until the end. The test time can be segmented into two zones: the first is the transient area, which includes the periods at the start and end of the test, and the second is the steady-state period, which includes the midpoint zone of the sliding test.

The whole thermal impact on the contact surfaces comes from two main sources, namely; heat generation due to the frictional sliding test and heat from the applied test working temperature.

Figure 13 depicts the variance in coefficient of friction values when two different operating temperatures are used (300 K and 390 K). The findings demonstrated that a high ambient temperature has a considerable impact on the coefficient of friction. Whereas, at Ta= 390 K, the average coefficient of friction decreased from 0.43 at 300 K to 0.3 at 390 K.

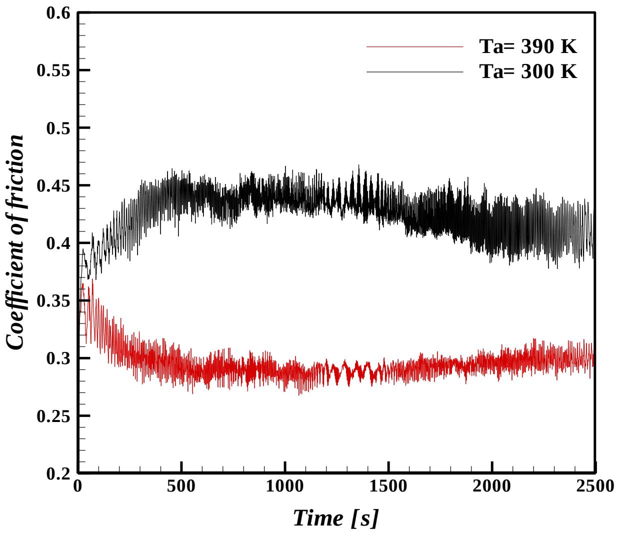


Fig. 13. Coefficient of Fiction when applied to different ambient temperatures.

Discussion of the typical performance of frictional materials is illustrated in Figure 14, which shows the effect of working temperature on the friction behavior of good-quality frictional materials. Whereas as the temperature increases, the level of the coefficient of friction decreases considerably. This is in good agreement with the acquired findings that are consistent with Baker's [16], as shown in Figure 15.

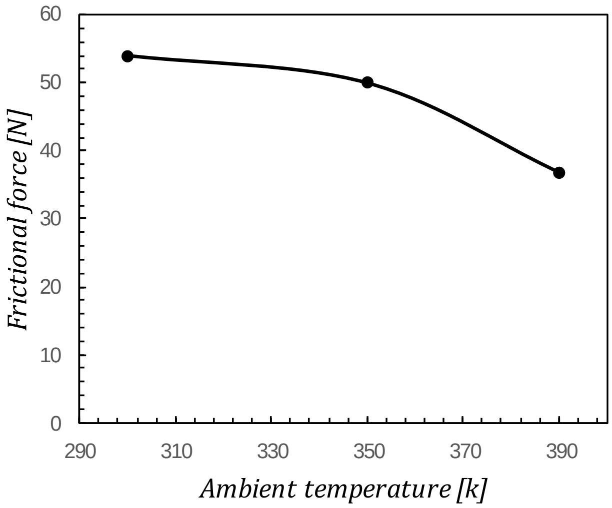


Fig. 14. Fiction force vs. ambient temperatures.

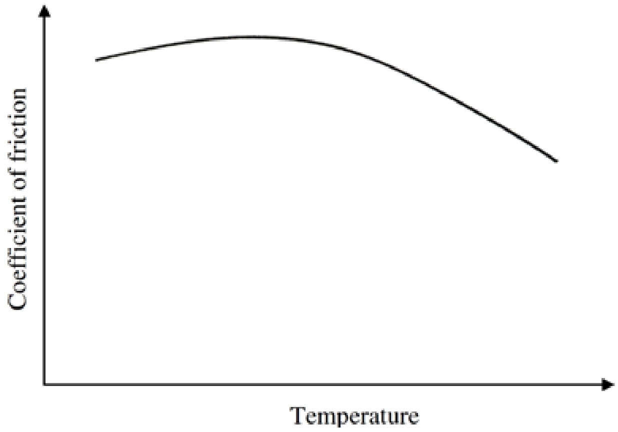


Fig. 15. Typical curve of friction/temperature of a good quality woven material [16]

4. CONCLUSIONS AND REMARKS

This research presented an experimental investigation of the behavior of the frictional characteristics of HCC friction material for long periods of test time. This type of frictional material is used as frictional facing for the clutch disc. It was focused on understanding and analyzing the variation that occurred in the values of each coefficient of friction and frictional force under different working temperature conditions.

The accuracy and capability of the XTM500 tribometer test rig have the ability to study the compound effect of several variables simultaneously (e.g., ambient temperatures, rotational speeds, and normal load) on the behavior and performance of the HCC friction disc. Also, this test rig has adopted different configurations (Ball/disk drilling, Ball/prism rotating, Disc/disc rotating, and Pin/Disc Pin rotates).

The frictional materials HCC have a low reduction in the coefficient of friction values during a slipping time. Also, the effect of the applied load was low, and the stability of the friction coefficient was remarkable with the increase in ambient temperatures.

The results also proved that the ambient temperature significantly negatively influences the frictional characteristics of the contacting surfaces. As the ambient temperature increases, the values of both the frictional force and the coefficient of friction decrease. Therefore, the ambient temperature of the frictional system is considered an essential factor and should be considered, especially in hot climates countries or particularly in the summer season. Because if the ambient temperature rises, the performance of the friction systems will decrease significantly, and this may lead to the failure of the contact surfaces before their lifetime. Finally, this reduction will negatively affect the performance of the friction systems, such as automotive clutches and brakes, and may lead to early failures in the contacting surfaces.

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