FRICTIONAL PROPERTIES OF GREASE LUBRICATED CONTACT AT DIFFERENT OPERATING REGIMES OF LUBRICATION

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Abstract

The implementation of electric vehicles introduces new tribological challenges, specifically for bearing systems. Up to 90% of the electric motor rolling bearing is reported to be lubricated by grease. However, the improper selection of grease types can result in premature rupture of the lubricant film due to excessive heat generation during operation. This paper focuses on analysing the frictional behaviour of various commercially available greases intended for use in bearing systems of passenger cars, considering the same mineral base oil with different types of thickener. To study the frictional and wear behaviour, a ball-on-disc friction tester is used to test the selected greases. Experimentally, the studies greases showed similar Stribeck curve trend showing that thickener used in grease plays crucial role in influencing the friction and wear properties. Thus, present study helps to provide knowledge for optimisation of grease for electric motors.

Keywords

Grease; Friction; Wear; Tribology

1.0 INTRODUCTION

Friction plays a significant role in our daily lives enabling us to perform tasks without slipping. However, friction between two contacting surfaces in machinery can lead to problems. It creates resistance opposing the direction of movement and can decrease the efficiency of machine elements. Moreover, excessive friction can cause significant material wear and contribute to component failure. Completely removing friction is impossible but to minimize friction, lubrication is commonly employed [1]. Lubricants can come in any form either in the form of fluid, semi-solid or solid.

Grease, a semi-solid lubricant, is widely used in rolling bearings, accounting for up to 90% of lubrication [1]. Grease composition differs from traditional lubricants as it is a two-phased lubricant, consisting of a thickener physically dispersed in base oil [2]. Typically, grease is composed of 85-90% base oil and the remaining percentage is thickener.

Even so, lubricant additives are commonly used (10%) in grease to enhance specific aspects of grease performance [4]. Other than that, the thickener allows the grease to maintain its semi-solid state of the grease by retaining the base oil through a fibrous structure. Grease lubrication is favoured in rolling bearings due to its consistent lubrication performance. Its consistency prevents leakage from the bearing, making it easy to use. Additionally, grease provides effective sealing properties for lubricated surfaces [1].

In the transportation sector, the effort of implementing decarbonization heavily relies on the electrification of passenger cars. Consequently, new tribological challenges arise, particularly for bearing systems that are directly connected to the shafts. Typical bearing systems might not be readily designed for use with high-speed electric motors, which could operate up to 16,000 rpm [5]. Based on research, at such speeds, heat generation within the grease-lubricated contact will no longer be negligible [4]. Thus, the friction between the contacts can be significantly high. Grease has proven to do the work of minimising friction [6]. This is due to its anti-corrosion properties and natural ability to provide a good seal between contacts [7].

Improper selection of grease type could lead to premature lubricant film rupture due to excessive heat generation during operation. In addition, bearing failure has contributed to around 44% of the electric motor failure [8]. Therefore, studying the frictional performance of grease-lubricated contact under a wide lubrication regime with several operating conditions, varying the applied load and sliding speed is imperative. This will allow for a better understanding of grease application inside electric motors.

The aim of this study is to determine the frictional behaviour of different commercially available greases for application in bearing systems used in passenger cars based on their base oil and thickener. The analysis will then be conducted based on the Stribeck curve approximation to determine the frictional performance of the tested grease under different operating lubrication regimes. This study will fill a critical research gap and provide valuable insights into the use of grease in electric motors. The findings of this study could lead to the development of new grease formulations that are better suited for high-speed applications. This, in turn, can enhance the reliability, efficiency, and environmental impact of electric motors.

2.0 METHODOLOGY

Grease Selection

Before conducting the frictional test of different types of grease, the specification and composition of the greases are needed. This is essential in identifying the contributing factors toward the measured tribological characteristics of the tested grease. In this study, the grease selection is only going to be focused on the automotive sector. Upon reviewing on the types of greases relevant to this sector, three (3) types of grease have been selected to be tested for their frictional properties. With the vast available tribological knowledge on automotive lubricant base oil (e.g. mineral oil), the selection of grease is thus decided based on its thickener. The tribological properties of the selected greases are tabulated in Table 1. In order to have a consistent base oil type, the greases are selected from the same manufacturer, with mineral oil as the base oil. However, it is to note that due to the limited selection, some of the greases might contain additives in the form of extreme pressure (EP) additives, which might show varying frictional behaviour.

Friction Test Using Ball-on-Disc Tribometer

A ball-on-disk tribometer was used to measure the frictional properties of selected greases. The ball is stainless steel with a dimension of 8 mm diameter. The wear disk is made from JISSKD-11 tool steel and the wear track radius is 20 mm [9,10]. The applied normal load is ranging from 1 kg to 5 kg with an increment of 1 kg for each test. The rotating speed is ranging from 20 rpm to 2000 rpm with an increment of 200 rpm. For each configuration, the test is run for 210 seconds. The result of the friction test is then plotted on Stribeck curve approximation to be further analysed on the tribological performance of tested grease. Based on reported articles, Stribeck curve is one of the tools to analyse the friction behaviour of the grease under several speeds [11].

Table 1: Tribological Properties of Tested Greases

Grease (Thickener-Base-oil)	Clay-Mi	Li-Mi	Ca-Mi
NLGI grade	2	2	2
Worked penetration @ 25 °C/ 77 F (dmm)	265-285	265-285	265-285
Thickener type	Clay Non-Soap	Lithium-12 Hydroxyl	Calcium-12 Hydroxyl
Base oil type	Mineral base oil	Mineral base oil	Mineral base oil
Additives	No	Extreme pressure (ep)	Extreme pressure (ep)
Dropping point, ASTM D-2265	Non-melt	210 °C	125 °C
Working temperature range	-20 °C to 150 °C	-20 °C to 136 °C	90 °C
Colour	Red	Brownish black	Brownish black
Viscosity index, ASTM D-2270	95-105	95-105	min. 95

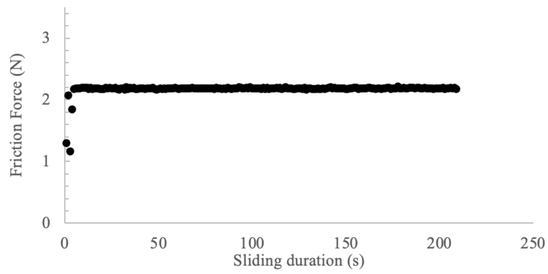
3.0 RESULTS AND DISCUSSION

Friction Force against Sliding Duration

The relationship between friction force and sliding duration for three (3) types of tested greases are plotted in Figure 1. These graphs are to demonstrate that steady-state has been achieved for the friction measurement of grease using the ball-on-disc tribometer. It is noted that this is to ensure that the selected sliding duration set-up is sufficient to capture the frictional properties of the grease at stead-state condition, which is determined to be approximately 210 seconds. The graphs are taken at the same speed and the same load, which is 200 rpm and 10 N for each type of the tested greases (Clay-Mi, Li-Mi and Ca-Mi greases).

Based on Figure 1(a) and Figure 1(b), it can be seen that both graphs give a steady state trendline. On the other hand, Figure 1(c) gives a step-trendline up to 150 seconds. After that, the contact lubricated by the Ca-Mi grease managed to reach a steady state. This indicates that the 210 seconds selected for the sliding duration is sufficient for the present analysis. In the meantime, this friction force against the sliding duration graph will also be used to help in determining the data that should be considered for the present frictional force analysis.

From Figure 1, any data below 30 seconds will be neglected because the data is unstable and has a large variance during the initial running-in phase of the measured friction. As for Ca-Mi grease, the friction analysis that is taken into consideration is from 150 seconds onwards. Therefore, the selected and usable data after 30 seconds (except to calcium grease) will be taken to calculate the average friction force at all sliding velocity conditions.



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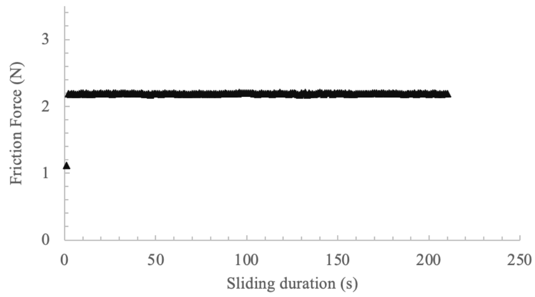

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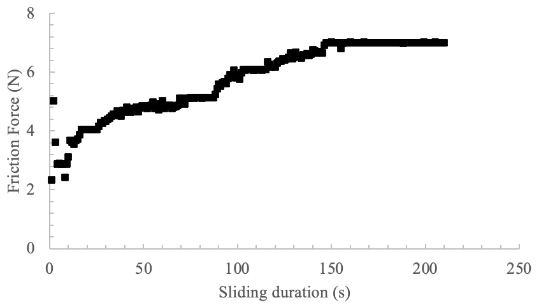


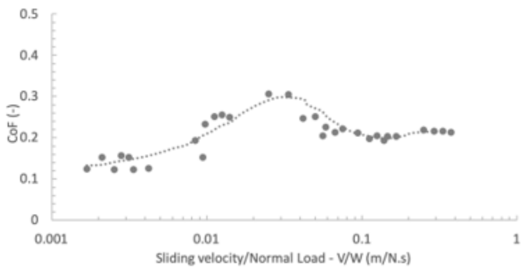
(c)

Figure 1: Friction force against sliding duration for (a) Clay-Mi (b) Li-Mi (c) Ca-Mi

Stribeck Curve

Using the measured friction force at different applied normal load and sliding speeds, the Stribeck Curves for three (3) types of tested greases are plotted individually as a function of the ratio between sliding velocity (V) and normal load (W). In Figure 2(a), it can be observed that the coefficient of friction (CoF) measured for Clay-Mi grease increases from V/W of 0.002 m/N.s before peaking at 0.03 m/N.s, corresponding to the increase in CoF from 0.1334 and 0.2986. At this range, it can be assumed that the contact is operating at a boundary lubrication regime. According to literature, such increment in CoF at this regime is possibly dominated by the thickener (clay non-soap type) and beyond 0.02 m/N.s, the CoF begins to decrease, likely exhibiting frictional trend that is dominated by the mineral type base oil [12]. The saturation value of the CoF is shown to be approximately 0.2136. In view of the range of CoF values (>0.1), it can be said that the base oil is still operating at boundary lubrication regime. It is to note that the mixed and fluid film lubrication regime is expected to occur when CoF is below 0.1. The Stribeck curve for Li-Mi and Ca-Mi grease is given in Figure 2(b) and 2(c), respectively. Similar CoF trends to the one for Clay-Mi grease are also observed for both of these greases. One of the differences is the operating condition where the peak CoF occurs. For Li-Mi, this occurs at V/W of approximately 0.04 m/N.s with a CoF value of 0.3196. On the other hand, the peak CoF of 0.4131 is measured for Ca-Mi at V/W of approximately 0.02. Saturation of CoF values for Li-Mi and Ca-Mi under base oil-dominated region (after the peak at larger V/W ratios) are 0.2187 and 0.2141, respectively. It is to note that the CoF values at this region measured for all tested greases do not vary much. This is because the tested greases used mineral oil as the base oil.

For a better comparison, Figure 3 summarises the Stribeck curves measured for all the tested greases. It is to note that the experimental data points are removed for clarity purposes. From this Figure, Clay-Mi demonstrated better friction properties, where the CoF values are on average lower and more consistent as compared to the other greases. This is followed by Li-Mi and Ca-Mi. Even though the base oil operating range is larger for Ca-Mi grease, the more drastic change in the CoF trend along with larger magnitudes of CoF has made this grease the less desirable of the tested greases.



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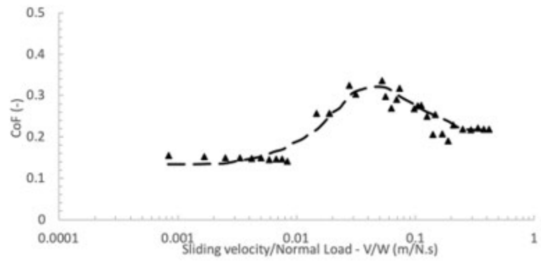

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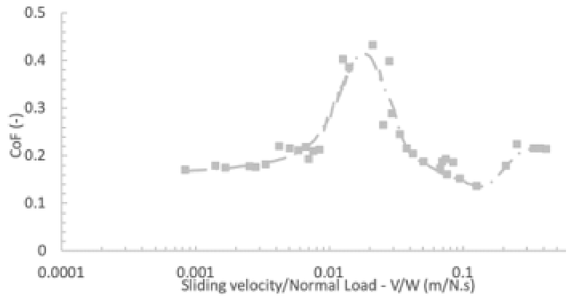


(c)

Figure 2: Stribeck curve for (a) Clay-Mi (b) Li-Mi (c) Ca-Mi

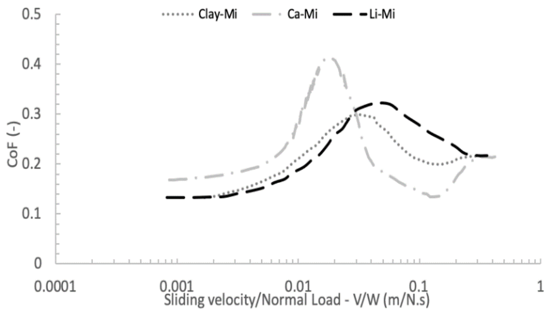


Figure 3: Stribeck curve comparison between different samples of tested greases

Wear Measurement

The images of wear scars of the ball and the average measurement for the wear track for three (3) types of greases are taken using digital microscope and presented in this section. Table 2 represents the wear measurement of the ball and the wear track on the wear disk. Figure 4 represents the wear scar image for the balls lubricated by Clay-Mi, Li-Mi and Ca-Mi greases. From the wear measurements, it can be observed that Clay-Mi produces the least wear, followed by Li-Mi and Ca-Mi. This shows that the thickener composition is still essential in producing lower wear when compared with the inclusion of EP additives, such as for Li-Mi and Ca-Mi. The observed wear measurement are observed to correlate with the observed frictional behaviour analysed by the Stribeck curve. By having the smallest wear scar diameter on the ball and wear track width on the disk, Clay-Mi grease is observed to have the better frictional performance. On the other side, Ca-Mi has the biggest wear scar diameter and the wear track disk reflecting its inconsistent friction coefficient via the Stribeck curve.

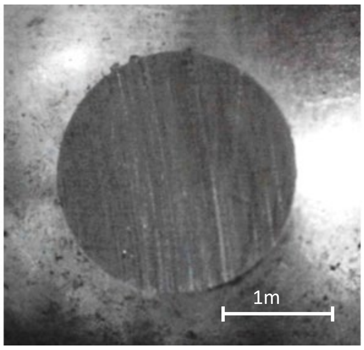
Table 2: Average Wear and Scar Measurement

Grease	Wear Scar Diameter on Ball (mm)	Wear Track on Disc (mm)
Clay-Mi	2.23	1.770
Li-Mi	2.68	2.498
Ca-Mi	2.90	2.560

4.0 CONCLUSION

An analysis has been conducted based on Stribeck curve approximation to determine the frictional performance of tested grease under different operating lubrication regimes. The selected commercially available greases are mineral oil-based grease with different thickeners: Clay-Mi, Li-Mi and Ca-Mi. All the friction tests have been conducted using a ball-on-disc tribometer. Friction measurement is conducted by taking the 20 mm of wear track and applying normal load from 1 kg to 5 kg. The rotating speed of wear disc is rotated from 20 rpm to 2000 rpm. The friction data is used to plot the Stribeck curve to analyse the frictional performance of the selected greases. In addition, the wear scar on the balls are captured and presented. The diameter of the scar and the wear track width is measured, to support the analysis.

Comparing the Stribeck curves of all tested greases, Clay-Mi demonstrated better frictional properties, with lower and more consistent CoF values compared to the other greases. Ca-Mi showing more drastic changes in the CoF trend and larger CoF magnitudes, making it the least desirable among the tested greases.



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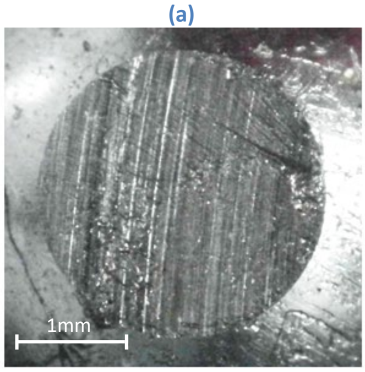

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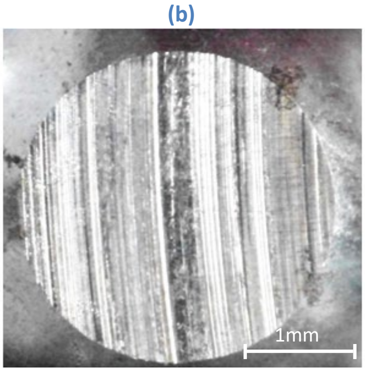

(c)

Figure 4: Wear Scar Diameter for (a) Clay-Mi (b) Li-Mi (c) Ca-Mi

Based on the wear measurement, Clay-Mi showed smallest wear scar diameter on the ball and wear track width on the disk. Meanwhie, Clay-Mi has the largest measurement. Thus, the wear on the ball and disc correlates with the friction data of all studied greases.

Overall, this study provides valuable insights into the frictional behavior of different greases used in bearing systems for passenger cars. It shows that thickener plays a significant role in determining a good grease for the industry. The findings can aid in the selection and optimization of greases for improved performance and efficiency, particularly in high-speed electric motor applications.

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