Effect of Temperature on Wear of Amorphous Carbon Coated Stainless Steel Lubricated by Palm Methyl Ester (PME)

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Abstract

Palm Methyl Ester has been used as diesel fuel substitute, whether pure or as a blend in petro diesel oil. On the other hands, amorphous carbon coatings have been applied to the mechanical components of the fuel system such as fuel pump and fuel injection to improve their tribological performance. However, the tribological performance of amorphous carbon coatings in Palm Methyl Ester and Palm Methyl Ester blended diesel fuel has not been fully understood yet. Previously, it has been found that at ambient temperature, the wear resistant of a-C coated stainless steel improved with the presence of PME components in the diesel oil up to 14%. However, its wear resistant at real operation temperature has not been clarified yet. In this paper, the effect of temperature on the wear performance of a-C coated stainless steel SUS304 is discussed. The friction tests were conducted using a ball on disk tribometer at high temperature. The coating was deposited on the ball, which is sliding against the SUS304 disk lubricated with pure PME oil. A heater was used to increase the oil temperature to 80^{o}C. The results show that at oil temperature of 80^{o}C, the wear of the coated steel is higher than that at ambient temperature. The wear of the coated ball increased by 30%.

Kata kunci : Amorphous carbon coatings, stainless steel, wear, palm methyl ester.

Introduction

The consumption of bio-based oil is increasing rapidly nowadays due to environment issues and the shortage of fossil fuel. One of bio-based oils that experienced rapid increase in consumption is biodiesel oil, which reached 29.1 million tons in 2014 [1]. According to the report, almost one third of the biodiesel product is made of palm oil; the Palm Methyl Ester (PME). In Indonesia, it becomes mandatory to include 7.5% bio-based oil in the biodiesel since 2009.

The use of biodiesel, whether pure or as a mixture in petro diesel has implications on the tribological performances of related mechanical components, for example the components of oil pumps and injection system. It is reported previously that the wear of stainless steel 304 decreases with the presence of PME components in the diesel oil [2]. In the case of amorphous carbon coated stainless steel, the presence of PME reduces the wear of the material up to 50% [3]. However, the tests were conducted at ambient temperature. However, the wear performance of the materials at high temperature is still not clarified yet.

The objective of this study is to find out the effect of temperature of wear of amorphous carbon coated stainless steel lubricated by pure PME oil. The result is compared to that of non coated stainless steel.

Methodology

The wear tests were conducted using a ball on disk tribometer. The schematic diagram of the tribometer is given in Fig. 1. The tribometer is equipped with a heater system for oil temperature control.

In this test, the disk has a 30 mm in diameter and 5 mm thick. The ball is 8 mm in diameter. The disk is made of stainless steel 304, polished to a surface roughness of Ra=0.03 µm. The ball is coated with amorphous carbon coating using PVD-CVD method. Both coated and uncoated ball were used in the tests in order to compare the result. The material of the ball is stainless steel SUS304.

The test were conducted at two different temperature; ambient and 80°C. The contact pair is SUS304 disk against SUS304 ball and SUS304 disk and amorphous carbon coated SUS ball. The entire tests were conducted with a normal force of 5 N at 100 rpm. The low sliding speed was chosen to provide the contact with boundary lubrication condition.

The wear tests were conducted inside an oil chamber filled with palm methyl ester oil.

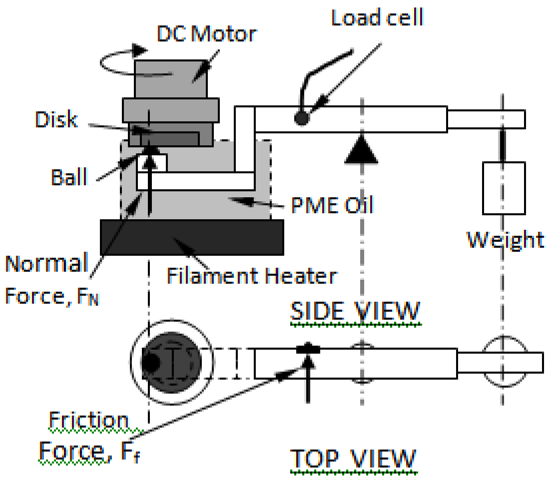
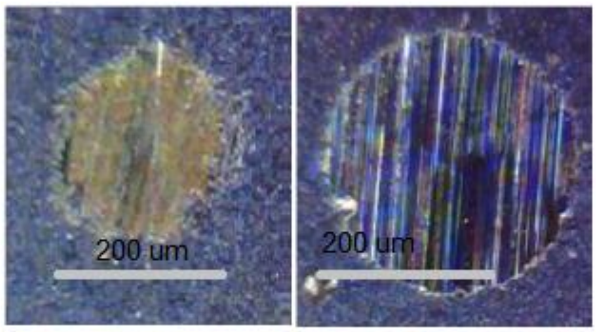


Fig. 1 Ball-on-disk Tribometer

Results and Discussion

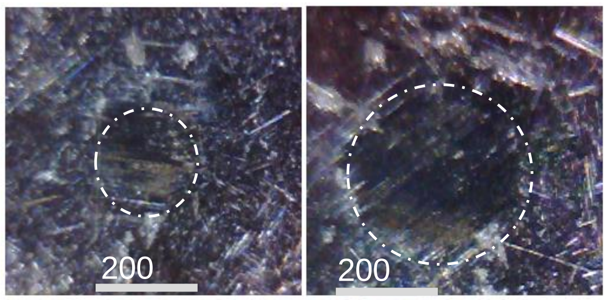
The tests were conducted at normal load of 5 N for 1000 cycles. At this normal load, the contact pressure at the end of the test ranges from 40 MPa to 152 MPa, depending on the area of contact. At sliding speed of 100 rpm, the contact condition can be classified as boundary lubrication. This contact condition is designed to simulate the severe contact condition. Since wear is the main interest of this paper, the discussion is limited only to the wear of the ball. Friction behavior of the contact is not discussed but in general, the coefficient of friction ranges from 0.2 to 0.3.

Figure 2 shows the wear scar of the coated ball under different lubrication condition. In both cases, the disk was SUS304. It can be seen in the figure that the word diameter of the coated ball is 200 µm at 27 °C. The worn scar diameter increased to 270 µm when the test was conducted at oil temperature of 80°C.



Wear at ambient oil temperature | Weat at 80 C oil temperature

Fig. 2 Wear scars of the coated ball under different temperature



Wear at ambient oil temperature | Wear at 80 C oil temperature

Fig. 3 Wear scars of the uncoated SUS304 sliding against SUS304 under different temperature.

Figure 3 shows the worn scar of the uncoated stainless steel ball under both ambient and 80 °C oil temperature.

Similarly, in both cases, the disk was SUS304. The comparison of wear scar diameter of all four conditions was given in Table 1.

Tabel 1. Worn scar diameter

Condition	Wear Dia.
SUS vs SUS, 27 °C	200 μm
SUS vs SUS, 80 °C	360 μm
a-C vs SUS, 27 °C	190 μm
a-C vs SUS, 80 °C	270 μm

The wear rate of the material is given in Figure 4. For the coated ball, the wear rate is $5.31x10^{-5}$ mm^3/N.m at ambient temperature. The wear rate increased to $1.07x10^{-4}$ mm^3/N.m at temperature of 80 °C. For the uncoated ball, the values are $5.88x10^{-5}$ mm^3/N.m and $1.91x10^{-4}$ mm^3/N.m for the ambient and 80 °C temperature of oil, respectively.

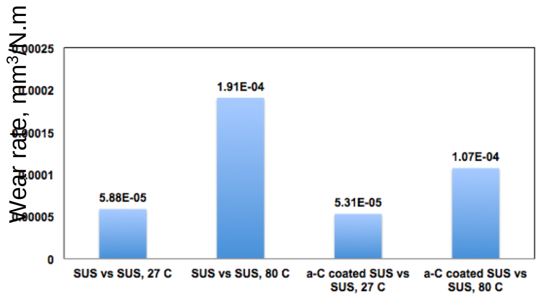


Fig. 4 Wear rate of the ball under various conditions

From the result it can be seen that the wear of both amorphous coated stainless steel anh uncoated stainless steel ball increases at high temperature. For the coated ball, the wear rate increased by 101%. While for the uncoated ball it is increased by 224%. One of the reasons for this increase is the change in the oil's viscosity due to temperature increase. However, the amorphous coating applied to the material have significantly reduced the wear rate of the ball at higher temperature. While at ambient temperature of 27 °C, the wear rates are relatively similar for the two cases/

Conclusions

The investigation on the temperature effect on wear of amorphous carbon coated stainless steel sliding against stainless steel SUS 304 has been conducted. It is found that the wear rate of the coated material at 80 °C is twice larger that that at ambient temperature. However, the wear rate of the coated material at high temperature is significantly better that that of the uncoated one.

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