IRES²プロジェクト研究

潤滑グリースの潤滑機構の解明

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Background

Ball joint for automobile [1]

- Used as a connection parts in (Fig.1)
  - Steering system device
  - Suspension system device

  Consist of steel ball (ball stud), resin (bearing seat) and grease as lubricant. (Fig. 2)
- Lubrication mechanism have to be understood.
  - Reciprocating sliding motion
  - Metallic material against resin material
  - Lubrication by grease (thickener & base oil)

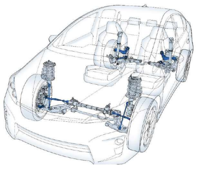


Fig. 1 Use position of ball joint [2] (shown in blue)

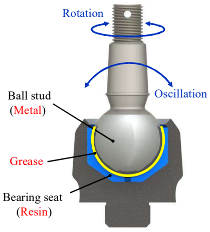


Fig. 2 Schematic figure of ball joint

Issues in improving the ball joint

Ball joints are used in various temperature atmosphere from -30 to 80°C. The viscosity of the base oils (PAO: poly-α-olefin) are changed by changing temperature that causes the change of lubricating behavior of grease in ball joints.

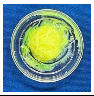
⇒ Consider using a grease consisting of silicone oil, which has low temperature dependence of viscosity, as a base oil.

Purpose of this research : Investigating the effects of different base oils on the lubricating behavior of greases

Samples

- Two types of greases (Gre_PAO, Gre_Si) and their base oils (Oil_PAO, Oil_Si) were tested as lubricant. (Table 1)
- Gre_PAO and Gre_Si consist of the same thickener, lithium stearate, and the base oil is different from PAO (poly-alpha olefin) and dimethyl silicone oil, respectively.
- Silicone oil is well known as the oil which has small temperature dependence of viscosity.
- For observing the behavior of thickener in grease by fluorescent method, 0.01% coumarin was mixed into the grease (Gre_PAO* and Gre_Si*).

Table 1 Samples

Lubricant	Grease				Oil	
	Gre_PAO	Gre_PAO*	Gre_Si	Gre_Si*	Oil_PAO	Oil_Si
Component	Thickener : Lithium stearate Base oil : PAO		Thickener : Lithium stearate Base oil : Dimethyl silicone oil		PAO	Dimethyl silicone oil
Penetration	280		290		–	–
Kinematic viscosity (40°C), mm²/s	1,240		6,050		1,240	7,570
Appearance					–	–
Note	–	Fluorescent treatment	–	Fluorescent treatment	Base oil of Gre_PAO	Base oil of Gre_Si

Experiment

Friction test

Pin-on-disk friction test (Fig. 3) was carried out in reciprocating sliding. As a combination of resin and metal in the ball joint, polyoxymethylene (POM) pin (Fig. 4) and chromium molybdenum steel (SCM440) disk were used as specimens. Grease and oil were supplied so that the contact area was sufficiently immersed. The normal load was 500N, considering the actual contact pressure of the ball joints (100MPa). The reciprocating frequency and stroke length was 1.3Hz and 3.0mm, respectively. Number of total reciprocation was 2,500.

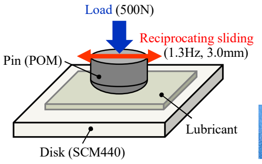


Fig. 3 Friction test

Fig. 4 Pin specimen

In-situ observation

In order to visualize and observe the contact area, a glass disk was used instead of the metal disk in both in-situ observation.

- In-situ observation 1 (Observation of the behavior of grease by high speed camera, Fig. 5)

  The purpose of this observation is to understand how the grease existing in and around the sliding area behaves due to reciprocating sliding. Fixed-area observation against glass specimen is conducted, and the contact area moves within the observation image as the pin specimen moves. Normal load is 2N, and other experimental conditions are the same as those of the friction test.
- In-situ observation 2 (Observation of the behavior of thickener by fluorescent method, Fig. 6)

  The purpose of this observation is to understand how the thickener of grease existing in and around the contact area behaves due to reciprocating sliding by using confocal laser scanning microscope (CLSM). Fixed-point observation against pin specimen is conducted, and the contact area is stationary in the observation image, and the behavior of the thickener around and inside the contact circle is observed along with the movement of the glass specimen. Although the normal load is as small as 5N, the contact surface pressure is 100MPa, which is equivalent to the contact pressure of the actual Ball Joint, because the tip radius of the POM pin is as small as 2mm.

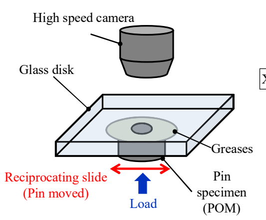
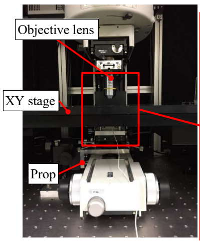


Fig. 5 In-situ observation 1



CLSM

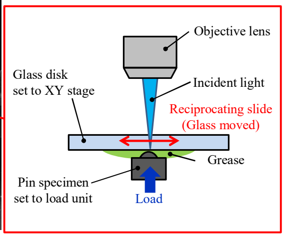


Fig. 6 In-situ observation 2

Result : Friction test

The graph (Fig. 7) show the results of friction tests using two types of base oils and greases composed of these base oils as lubricants. All friction tests were performed three times. Although the viscosity of Oil_Si is 6 times higher than that of Oil_PAO, the friction coefficient of Oil_Si was lower than that of Oil_PAO. This suggests that this lubrication condition is in a mixed lubrication mode, and that the higher viscosity oil prevents direct contact of specimens.

In contrast, the results for grease lubrication differed from the trends expected from the results for oil lubrication. Gre_Si showed a lower coefficient of friction than Gre_PAO at the beginning of friction, and this trend was similar to that of oil lubrication. However, after 200 cycles, the friction coefficient for Gre_Si increased and showed unstable fluctuations. On the other hand, Gre_PAO maintained a relatively low value, although the coefficient of friction gradually increased.

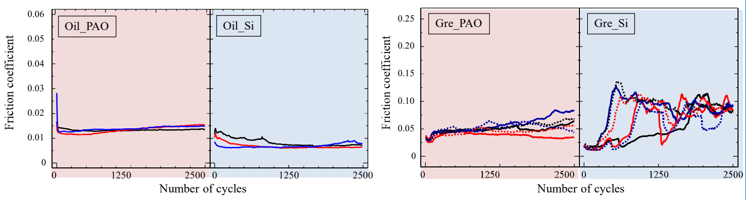


Fig. 7 Friction coefficient

Result : In-situ observation

In-situ observation 1 : Behavior of grease

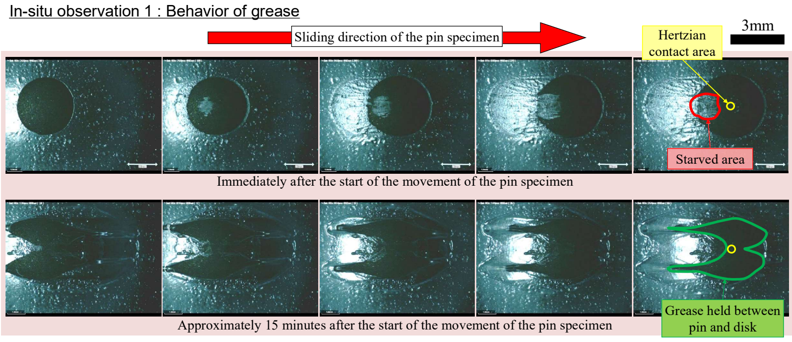


Fig. 8 Behavior of Gre_PAO around the pin specimen

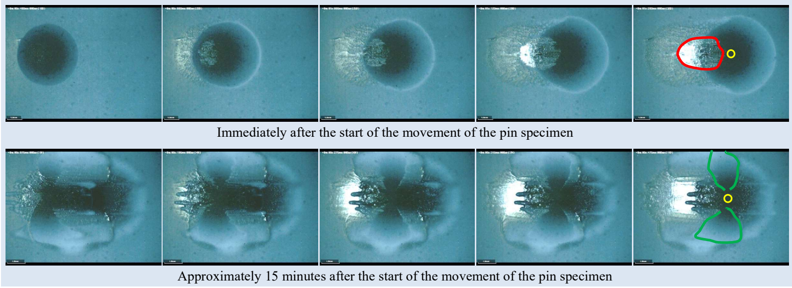


Fig. 9 Behavior of Gre_Si around the pin specimen

- Features of behavior of Gre_PAO (Fig. 8)
  - Immediately after the pin specimen began to slide, a starved area of grease was observed behind the contact area in the moving direction.
  - Approximately 15 minutes after the start of the sliding, it was observed that grease was retained in the gap between the pin and disk specimens. This grease formed a wing-like shape (encircled in green) and was supplied forward the contact area in the moving direction.
- Features of behavior of Gre_Si (Fig.9)
  - Starved area of grease such as observed in Gre_PAO was observed and its area was larger than that in Gre_PAO.
  - Although there was retained grease in the gap between the pin and disk specimens as shown in Gre_PAO, it was not supplied to the contact area, but only moved following the movement of the pin specimen. This behavior of grease is considered to be one of the causes of the rapid increase in the friction coefficient in Gre_Si.

In-situ observation 2 : Behavior of thickener

- Statical observation of thickeners

  In both greases, fluorescent by thickeners[3] are shown as green bright area. (Fig. 10) In Gre_PAO*, fine and dispersed thickener were observed. On the other hand, uneven distribution of thickener were observed in Gre_Si*.
- Dynamical observation of thickeners

  It was observed that the thickener is stretched out as the pin specimen is pressed. (Fig.11) The brightness inside of the contact area of Gre_PAO* was darker than Gre_Si* even though around contact area was brighter. This means that there were fewer thickeners of Gre_PAO* in the contact area.

  In both greases, island-like thickener remains in the contact area during sliding. It is considered that the lumps of this thickener were captured by the small dents present on the surface of the pin specimen. It can be seen that the thickener gradually decreases from the contact area as the number of reciprocations increases. In Gre_PAO*, it is difficult for the thickener dragged out from the contact area due to sliding to return to the contact area during reversal sliding. On the other hand, Gre_Si* tends to retain the thickener in the contact area more than Gre_PAO*. Such differences in behavior of thickener are thought to be affected by differences in the separability of the base oil from thickener, and differences in adhesiveness of the thickener to the glass or POM.

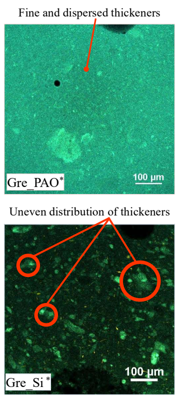


Fig. 10 Statical observation of thickeners

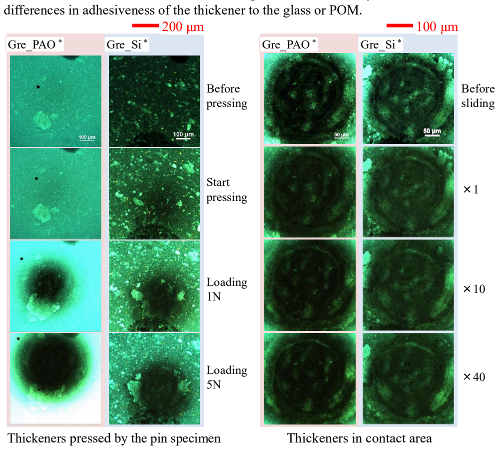


Fig. 11 Dynamical observation of thickeners

Summary

In this research, the effects of difference of the base oil of grease on lubrication were investigated by friction test and in-situ observation.

- Oil_Si showed lower friction coefficient than Oil_PAO, however, the greases composed of each base oil showed the opposite result, Gre_Si showed higher friction coefficient than Gre_PAO.
- Gre_PAO and Gre_Si around the contact area showed different behaviors during sliding, and this difference was considered to greatly affect the ability of grease supply to the contact area.
- Differences in the behavior of thickeners in the contact area lubricated with Gre_PAO* and Gre_Si* were observed, and this difference was considered to affect lubrication properties.

References

[1] M. Suzuki, T. Shirai : Technical Trends and Tribology of Chassis Ball Joint, Journal of Japanese Society of Tribology, 54, 9(2009) 604-609
[2] SOMIC ISHIKAWA INC. home page < http://www.somic.co.jp >
[3] K. Maruyama, T. Nawata, T. Ando, Y. Takeichi, R. Morita, K. Arakawa : Observation of behavior of thikener at grease lubicated friction interface by fluorescence method, International Tribology Conference Sendai 2019

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SUSTAINABLE DEVELOPMENT GOALS