EFFECTS OF THICKENER STRUCTURE ON FILM THICKNESS AND TRACTION FORCE OF LUBRICATION GREASES IN POINT EHL CONTACTS

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SUMMARY
The effects of the thickener structure on lubricating performance of greases in point elastohydrodynamic contacts are discussed on the basis of direct observation using the optical interferometry technique. Traction force is also measured. Three different categories of diurea greases without additives are used as test greases. It is found that the lubricating ability of the grease consisting of the thickening agent composed of a mixture of two mono-amines is not necessarily the same as that of the grease which is a mixture of two different greases composing of the mono-amine.

Keywords: urea grease, thickener structure, film thickness, traction force, EHL

1 INTRODUCTION
The grease film thickness in the elastohydrodynamic lubrication (EHL) regime depends largely on the viscosity of base oil and the concentration and type of thickener [1 - 4], Cann and Spikes [5, 6] have found that thickener material deposited on the contact track contributes to the surface separation, even under starved condition. These findings indicate that the thickener has a significant effect on the formation of grease EHL films.

In a previous paper [7], the authors found through direct observations using the optical interferometry technique with three different types of diurea greases without additives that the behaviour of greases in point EHL contacts is influenced very much by the thickener structure. The purpose of this investigation is to make clear the effects of the thickener structure on the lubricating performance of greases by comparing the results obtained with greases which belong to three categories.

2 EXPERIMENTAL PROCEDURE

2.1 Apparatus
An experimental apparatus used was the same as that used in the previous paper [7]. The optical interferometry technique was used to measure the film thickness in an EHL circular contact. The contacting surfaces were composed of a precision 25.4mm diameter steel ball and an optical crown glass disk of 165mm diameter, whose lower surface was sputtered with a semi-reflecting chromium layer. The reduced elastic modulus was 117GPa. The interference fringe pattern made with wavelengths of red and green was recorded with a high speed VCR (250 frames per second) attached to a microscope. A Xenon flash lamp with a flash duration of 20μs was used as a light source.

2.2 Test greases
The greases tested in this study can be classified into three main groups. The thickening agent of the greases which belong to the first group is mono-amine, i.e., aromatic (A), alicyclic (B) and aliphatic (C) diureas. We call them greases A, B and C. The thickener of the second group is composed of a mixture of 50 weight % of two mono-amines, i.e., aromatic-alicyclic, alicyclic-aliphatic and aliphatic-aromatic diureas, which will be called greases AB, BC, and CA, respectively. The greases used did not contain any additives. An alkyl-diphenyl-ether (viscosity : 97mm²/s at 40°C, 13mm²/s at 100°C) was used as the base oil. The properties of greases are listed in Table 1. The third group is a mixture of 50 weight % of two different greases composing of the mono-amine. They are termed greases A+B, B+C and C+A.

2.3 Methods
A sample of grease was applied to the glass disk around the rolling track in a thickness of 0.5mm and a width of 10mm. There was no attempt to push fresh grease into the track. A constant load of 39.2N, which gave a maximum Hertzian pressure of 0.54GPa and a Hertzian diameter of 0.37mm, was then applied. Each experiment lasted 30 minutes.

<table>
<thead>
<tr>
<th>Grease</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>AB</th>
<th>BC</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickener</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A+B</td>
<td>B+C</td>
<td>C+A</td>
</tr>
<tr>
<td>Thinner Concentration, Wt%</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Worked Penetration</td>
<td>264</td>
<td>300</td>
<td>287</td>
<td>294</td>
<td>266</td>
<td>295</td>
</tr>
<tr>
<td>Dropping Point, °C</td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>198</td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>&gt;250</td>
</tr>
<tr>
<td>Oil Separation, % (100°C, 24hr)</td>
<td>0.2</td>
<td>0.5</td>
<td>0.9</td>
<td>0.9</td>
<td>0.6</td>
<td>0.1</td>
</tr>
</tbody>
</table>

A : Aromatic diurea, B : Ayclic diurea, C : Aliphatic diurea

Table 1: Properties of greases
3 RESULTS

Figures 1, 2 and 3 show typical interference micrographs for greases tested at a rolling speed of 25mm/s and temperatures of 20±2°C. Photographs were taken at the end of testing, i.e., after 30 minutes running. The inlet is on the left-hand side. There are local fluctuations in the film thickness. The fluctuations are caused by thickener lumps passing through the contact area. The variations in film thickness are plotted in Figs. 4, 5 and 6 as a function of time. The thick line denotes the central film thickness and the thin line the minimum film thickness. The thick and thin dotted lines show the central and minimum film thickness of the base oil, respectively.

3.1 Greases composed of mono-amine

It should be noted from Fig. 4 that though the overall film thicknesses for the greases A and C become thinner with successive overrolling, the film thickness for the grease B hardly decays with time. The overall film thickness is thinner in the order, greases B, A, C.

3.2 Greases composed of mixture of two mono-amines

The film thickness for the grease AB in pure rolling hardly decays with time and keeps a thick film; the effect of the aromatic diurea is hardly recognised. The film thickness for the grease BC decreases from a rather thick value at the start to a residual value after 30 minutes running; the aliphatic diurea takes a remarkable effect. The variation in film thickness for the greases CA is similar in the tendency to that for the greases C and A. The state of thickener lumps or fringe pattern in the EHL conjunction after 30 minutes running for both greases BC and CA shows between the greases A and C. The overall film thickness for greases BC and CA was slightly thicker than that for the grease C; the film thickness for the grease CA is thinner than that of the grease A, and that of the grease...
BC is significantly thinner than that of the grease B. These facts suggest that the fibre structure made from aliphatic diurea obstructs the formation of grease EHL film.

3.3  Mixed greases of two mono-amine greases

For example, the grease AB seems to be composed of greases A, AB and B. Therefore, it seems to be necessary to investigate tribo-characteristics of grease A+B, which is produced by a mixing of greases A and B. Under pure rolling condition, the film behaviour of grease A+B, B+C and C+A resemble that of greases AB, BC and CA, respectively, fairly well in the tendency. With greases AB and A+B, thickener layer of grease B deposited on the track seems to suppress the effect of grease A. With greases BC, CA, B+C and C+A, the fibre structure consisting of the grease C seems to prevent the grease A and grease CA or the grease B and grease BC from entering the EHL conjunction.

3.4  Traction characteristics

Within the limits of the present experiments, the overall film thickness of greases is thicker than that of the base oil. One of the reasons may depend on the formation of a thickener layer deposited on the contact track [4 - 6]. Such an adhesive layer of the thickener may mechanically come off by a relative slip between contacting surfaces. Therefore, the rolling and sliding running (speeds of the glass disk and steel ball were 25mm/s and 100mm/s, respectively) was carried out for 15 minutes after 15 minutes pure rolling running at a constant rolling speed of 25 mm/s.

Figures 7, 8 and 9 show the relationship between film thickness and time. The film behaviours in pure rolling are almost the same as those shown in Figs. 4 to 6. Note that the overall film thicknesses after 15 minutes running for greases A, B and C under the sliding condition are almost the same and thinner than the film thickness for the base oil. This means that the adhesive layer of thickener formed during the period of pure rolling come off by the sliding motion or a plenty of thickener lamps do not enter the EHL conjunction.

Figure 10 summarises the variation in the coefficient of traction for a period of rolling with sliding. The coefficient of traction for the base oil is also shown. The coefficient of traction for the base oil is lowest of all of greases tested. As a whole, the coefficient of traction for the greases A, B and C increases in the following order; greases C, B, A.

The overall film thickness after 15 minutes sliding becomes thinner in the following order; greases CA, BC, AB. That is, thinner film thickness gives higher coefficient of traction. The coefficient of traction for the greases A+B, B+C and C+A decreases in the order; greases A+B, B+C, C+A. This order is the same as the cases of greases AB, BC and CA. However, the values for greases B+C and C+A are larger than those for greases BC and CA.

4  DISCUSSION

The grease A+B can form thicker films in pure rolling. In sliding, however, the film thickness becomes thin and the coefficient of traction becomes high, and their values close to those for the grease A. That is, the grease B is unlikely to influence the tribo-characteristics of the grease A+B.
Such phenomena suggest that in pure rolling thickener lumps of the grease B adhere on the contact track, but in sliding the deposited lumps are tore off and consequently, the grease B hardly contributes to lubricating the track. That is, in pure rolling the grease A hardly obstructs the separation of contacting surfaces due to the grease B. However, in sliding the grease A controls mainly the lubricating performance of the grease A+B. In sliding, the traction behaviour of the grease B+C looks like that of the grease B. This fact suggests that the grease B prevents the lubrication due to the base oil which ooze out from the fibre network of the grease C. The authors have suggested through the experimental results in pure rolling that the grease C prevents the grease B from lubricating the rolling track. We can therefore conclude that each merit of the greases B and C according to the kinematics is inhibited by the mixture of both greases.

The coefficient of traction for the grease C+A is similar to that for the grease C. That is, the grease C improves lubricating ability of the grease A under the sliding condition. It can be considered that the base oil oozed out from the thickener fibre network of the grease C can lubricate the track.

In pure rolling, the film thickness-time relationship and fringe pattern for the grease AB are similar to those for the grease B and grease A+B; the greases B, AB and A+B bring about thicker film thickness. However, the coefficient of friction at the end of run in sliding closes to the grease A and the grease A+B. We can therefore conclude that the greases AB and A+B have similar tendency in film and traction behaviour, but they do not improve lubricating ability of the greases A and B in sliding.

The time variation in film thickness for the grease BC in pure rolling differs from that for the grease B and decays as time passes. The tendency is also similar to the grease B+C. However, there is a big difference in the traction characteristics between the greases BC and B+C. The coefficient of traction at the end of sliding run is much higher for the grease B+C than for the grease BC. The relationship between greases CA and C+A is similar to that between greases BC and B+C. These facts mean that the fibre network of the greases BC and CA provides easily the base oil to the track. The aliphatic diurea improves the traction characteristics remarkably. These facts suggest that the lubricating ability of the grease consists of the thickening agent composed of a mixture of two mono-amines is not necessarily the same as that of the grease which is a mixture of two different greases composing of the mono-amine.

5 CONCLUSIONS

1. The overall film thickness in pure rolling for the greases having different mono-amine as the thickener is thinner in the order, alicyclic, aromatic, aliphatic greases, i.e., greases B, A, C. The traction force in sliding decreases in the order, greases A, B, C.

2. A thicker layer of thickener deposition brings about an increase in the traction coefficient.

3. Although the greases AB and A+B have similar tendency in film and traction behaviour, they do not improve lubricating ability of the greases A and B in sliding.

4. In pure rolling, the film thickness for the grease BC and B+C is influenced by the aliphatic diurea and grease C, and decays with time. The film thickness behaviour for the greases CA and C+A is between greases C and A.

5. Each merit of the greases B and C is inhibited by the mixture of both greases.

6. The greases BC and CA bring about low traction forces. That is, the aliphatic diurea improves the traction characteristics remarkably.

6 ACKNOWLEDGMENTS

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7 REFERENCES


