

# Grease Lubrication Technology for Sliding Automobile Parts

R. NAKATA

*To address the issue of grease for automobile sliding parts, we took into consideration the prevention of starvation by improving inflow, friction reduction under boundary lubrication conditions, and the improvement of resin compatibility. Inflow into the sliding contact face improved by using a thickener with high gelling ability, which reduced shear viscosity in high-speed areas of over  $10^2 \text{ s}^{-1}$ . The friction coefficient under boundary lubrication conditions was reduced more than 50% by use of a stearate oiliness agent. Furthermore, penetration of the agent into resin was reduced by selecting an agent with metal elements. With these low-friction and resin-compatible technologies, we have created a grease lubrication technology that can contribute to a broad range of automobile parts.*

**Key Words:** grease, sliding contact, rheology, inflow, resin compatibility, automobile

## 1. Introduction

From the viewpoint of preventing global warming and global environmental protection, in recent years, the demand for energy conservation and the reduction of CO<sub>2</sub> emissions of cars is steadily increasing. The need for weight reduction and reduction of friction of automobile parts is also increasing. In addition, high quietness is required of hybrid vehicles. With this background in mind, resin material is often used for sliding elements for automobile parts such as gears or sliders. For lubrication of these elements, grease is often used because it simplifies the seal requirements. For these applications, high level frictional performance is required for the greases, because the heat generated by sliding directly leads to deformation or destruction of the resin parts. Further, in long-term use at a high temperature, the change in physical properties of the resin material becomes a concern, so it is necessary to minimize the promotion of change in physical properties of the resin due to the grease.

In this paper, we introduce an example for the improvement in reliability and performance of resin / steel sliding components by establishment of grease technology that combines low friction and resin compatibility.

## 2. Low Friction Technology for Grease

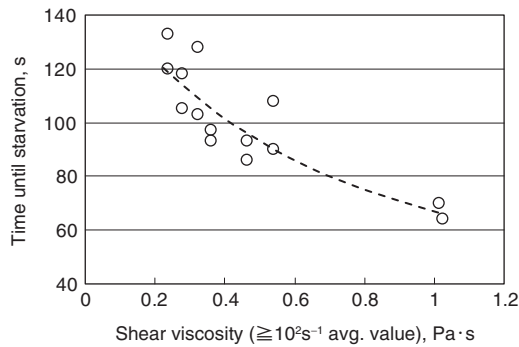
### 2.1 Improvement of inflow property into the sliding interface

In grease lubrication of the sliding contact, the

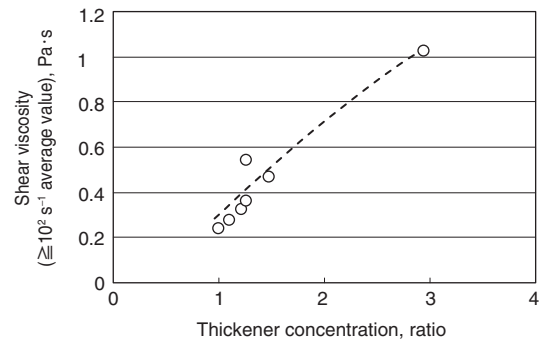
starvation due to the elimination by the motion of the elements is concern as the issue. In rolling contact, the drawing effect of grease into the contact surface can be expected because there is no difference in speed relative motion of the element. Further, the lubricating effect can be expected because of increase in the thickness of EHL film due to deposition of the thickener on the contact in the low speed range area as reported so far<sup>1)</sup>. In contrast, in sliding contact, grease is sheared simply due to the relative speed difference of the sliding parts that leads to grease removal from the contact surface. It is necessary to improve the inflow property compared to the case of rolling contact. Therefore, we focused on the control of rheological properties to improve the inflow property of grease.

In order to evaluate the inflow property quantitatively, a sliding test that simulates the sliding elements was conducted. Conditions of sufficient lubrication and small amount lubrication were compared. The starvation characteristic was evaluated by the time until difference of friction coefficient becomes apparent. The differences were regarded as starvation generation<sup>2)</sup>.

On the other hand, the rheological parameter that corresponds with the inflow property of grease was evaluated. As a result, the shear viscosity  $\eta = \tau / \dot{\gamma}$  ( $\tau$ : shear stress) in the high shear rate range of shear rate  $\dot{\gamma} = 10^2 \text{ s}^{-1}$  or more corresponds between the time until starvation generation and the grease of low shear viscosity indicates higher inflow properties. The relationship between the shear viscosity and the time until starvation of various greases are shown in **Fig. 1**.



**Fig. 1** Relationship between shear viscosity and time until starvation



**Fig. 2** Relationship between thickener concentrations and shear viscosity (cone penetration 280)

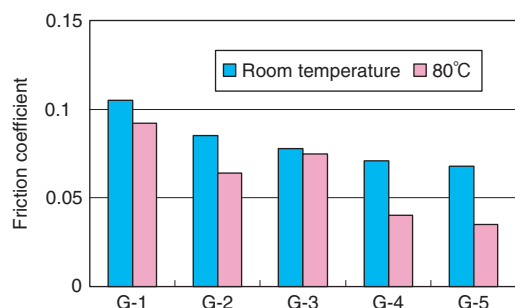
Increase in consistency (softening) can be considered for the design of grease to reduce the shear viscosity, but this lowers the adhesion to the device. For this reason, we tried to find a balance between retention of hardness and low shear viscosity by means of improving of the thickener composition. Grease shows Bingham plastic flow that flows only when shear stress exceeds the yield value, and the shear viscosity decreases with shear rate. That is, it behaves as a solid under static condition, which must be due to the internal structure of the network formed by the thickener fibers<sup>3)</sup>. Also, the shear viscosity decreases with increasing shear rate, and asymptotically approaches the viscosity of the base oil, which is due to the orientation of the thickener fibers by shear<sup>3)</sup>. As a measure to lower the viscosity in the dynamic while maintaining the hardness in the static, we aimed at concentration reduction of the thickener by improving gelling ability (hardness per unit mass) of the thickener. We assumed that the concentration reduction of the thickener leads to low viscous resistance when the fiber oriented due to shear. The relationship between thickener concentration and shear viscosity for greases that use various kinds of thickener (cone penetration of 280) is shown in **Fig. 2**. Even if the hardness is equivalent in static, the viscosity of grease is different when the shear is applied dynamically, the shear viscosity of the grease tends to become low, as the thickener concentration is low. From these results, we found that the gelation ability of the diurea thickener composed from aliphatic amine (hereinafter, aliphatic diurea) of specific chemical structure is very high. Furthermore, the grease that consists of the aliphatic diurea thickener mentioned above has low shear viscosity. From the study described above, it is possible to reduce the shear viscosity in a dynamic state while maintaining the hardness required. As a consequence, the inflow property of the grease into the sliding contact surface was improved without compromising the adhesion to the device.

## 2. 2 Friction reduction under Boundary Lubrication

In the lubrication of the sliding element, measures against the break of the oil film that are assumed in poor lubrication state are important as well as the improvement of the inflow property. The film thickness of grease decreases to 0.5-0.7 times thinner than that of the base oil even in a stable state<sup>4)</sup>. Moreover if starvation of grease is involved, there is a possibility of decreasing of the film thickness leading to breakdown of the oil film. To compensate for this, we selected friction modifiers to reduce friction under the boundary lubrication condition. The contact pressure in a resin/steel sliding pair is on the order of a few 100 MPa at most. Under this contact pressure, the extreme pressure additive that is used frequently as a friction modifier in steel/steel contact tends to have poor effect due to its mechanisms of action<sup>5)</sup>. For this reason, selection of the solid lubricant or the oiliness agent that are expected to have an effect in the range of this contact pressure was studied.

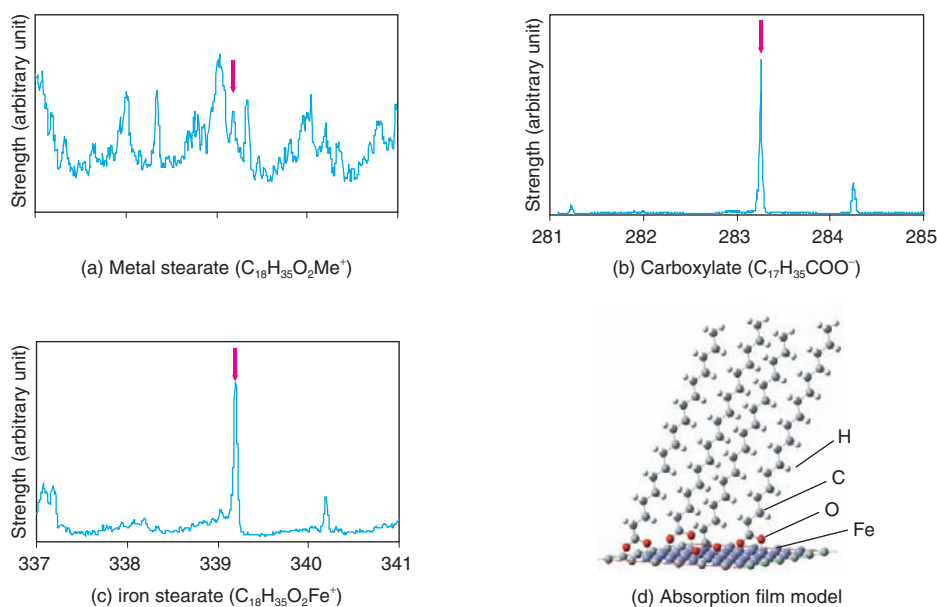
Friction coefficients of sample greases are shown in **Fig. 3**. Various solid lubricants and oiliness agents were added to the base grease that consists of the specific aliphatic diurea as thickener and of synthetic hydrocarbon as base oil (G-1). Whereas the friction coefficient of the base grease (G-1) is more than 0.15 at room temperature and more than 0.1 at 80°C, each sample resulted in lower friction effect by adding various additives. The grease (G-2) with the addition of solid lubricant S-1 and grease (G-3) with the addition of solid lubricant S-2 had the effect of decreasing the friction coefficient of about 25% at room temperature and at 80°C. On the other hand, both the grease (G-4) with the addition of stearate-based oiliness agent ST-1 and the grease (G-5) with the addition of the stearate-based oiliness agent ST-2 indicated a low friction of high level, it was found that these additives have the effect of decreasing the friction coefficient of 50% at 80°C compared to the base grease. These differences can be explained by the difference in the mechanism of action. That is, the solid lubricant exhibits low friction effect by the physical adsorption or by weak

shear between layers. On the other hand, the stearate-based oiliness agent indicated a low friction of high level due to chemical adsorption, and it is presumed that this action exhibits a low-friction effect at the resin / steel sliding interface.



**Fig. 3** Reduction effect of friction coefficient by additives

To verify the mechanism of friction reduction by the stearate-based oiliness agent, the absorbate on the steel side of the friction surface after the friction test with G-5 were analyzed by TOF-SIMS (Time-of-flight secondary ion mass spectrometer) as shown in **Fig. 4**. The mass peak of the metal stearate additive (ST-2) itself was not detected (**indicated 4-a**), but the peaks attributed to the carboxylate ( $C_{17}H_{35}COO^-$ , **indicated 4-b**) and iron stearate ( $C_{18}H_{35}O_2Fe^+$ , **indicated 4-c**) were clearly detected. From this fact, the mechanism of low friction can be explained as follows. The carboxylate decomposed from metal stearate additive by tribo-chemical reaction adsorbed chemically with Fe on the frictional surface, this acted stably as the lubrication film that has low shear strength (the model shown in **Fig. 4(d)**).



**Fig. 4** Frictional surface analysis by TOF-SIMS

### 3. Technologies Improving Compatibility with Resin

Change in physical properties of the resin due to grease is a concern during long-term use at high temperature. Even in the case of grease that consists of synthetic hydrocarbon base oil that is generally compatible with resin, there are some cases that change of physical properties promoting is observed. In this study, we focused on additive composition in order to inhibit the changes in physical properties of the resin by grease<sup>6</sup>.

Greases (G-4) and (G-5) samples were prepared with stearate-based oiliness agent ST-1 and ST-2 respectively including different metal element added to the base grease that consist of specific aliphatic diurea and of synthetic hydrocarbon. Furthermore, grease sample BC, which consists of Barium complex soap thickener and is generally said to have excellent compatibility with resins is evaluated as a comparison. **Fig. 5** shows the change in physical properties of the dumbbell specimen of polyamide 66, which is a general-purpose resin used for the sliding parts, after 1 500 h × 140°C when the sample greases were applied to it.

Under these test conditions, reduction of 5% in strength and of 46% in elongation was confirmed for the test piece without grease applied. In contrast, reduction in strength and in elongation of the test pieces was observed in all cases when greases consisting of synthetic hydrocarbon base oil with generally good compatibility to the resin were applied. In particular, the decrease in elongation is significant in the case of base grease (G-1) and the case of the grease (G-4) which is formulated with the stearate-based oiliness agent ST-1. On the other hand, the observed change in elongation was smaller in the case

of grease (G-5) which was formulated with the stearate-based oiliness agent ST2 containing the different metal elements than Barium complex soap grease BC. Thus, a large difference in resin compatibility occurs due to the difference in the metal elements contained in the stearate-based oil agent.

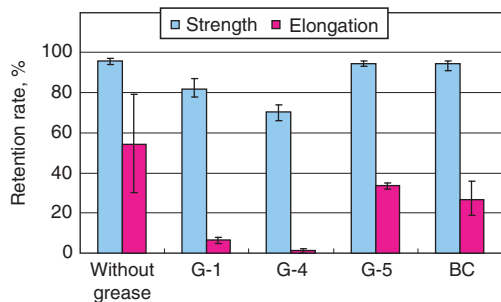


Fig. 5 Compatibility against PA66 at 140°C x 1 500 h

In order to validate the mechanisms of the difference of the effects the grease composition has on the change in physical properties of the resin, the degradation state of test pieces made of 66 polyamide was analyzed after immersion into grease (G-4), (G-5), and (BC) under 140°C x 1 500 hr respectively and compared to the case of without grease applied<sup>7)</sup>. The oxidation state of the resin specimen surface analyzed by FT-IR (Fourier Transform Infrared Spectroscopy) is shown in Fig. 6. Increase of absorbance in the wave number range from 1 660 to 1 780 cm<sup>-1</sup>, which is due to the carbonyl group, was observed on the resin surface after immersion into the grease (G-4) that showed a large property change. In other words, the progress of oxidation degradation of the resin surface was observed compared to the case of other greases. From this result, the difference in change in physical properties of the specimen shown in Fig. 5 is suggested to be due to the influence of oxidation degradation promotion derived from grease composition.

The distribution of the molecular weight in the depth direction from the surface analyzed by GPC (Gel Permeation Chromatography) after TFA (Trifluoroacetic acid) treatment is shown in Fig. 7. The molecular weight reduction of the resin surface is evident in the G-4 sample, which has greater change of properties after immersion. These changes are associated with the oxidation degradation mentioned above. On the other hand, after immersion in (G-5), and (BC), the molecular weight reduction is proceeding clearly to 500 μm depth in comparison with "without grease". Therefore, the change in physical properties of the resin caused by the grease is considered to be not only due to the influence of oxidation of the surface, but also due to the breaking of the molecule chain of polyamide that has progressed in the depth direction and resulted in decrease of molecular weight.

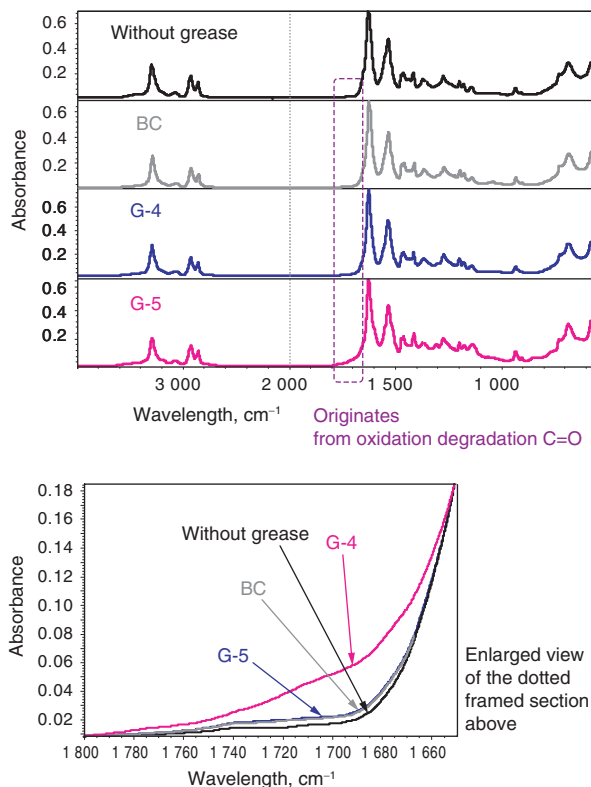


Fig. 6 Surface oxidation of typical specimens by FT-IR

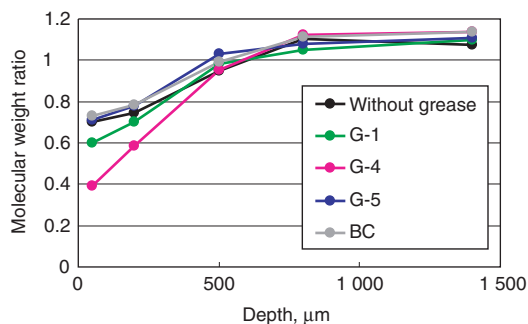
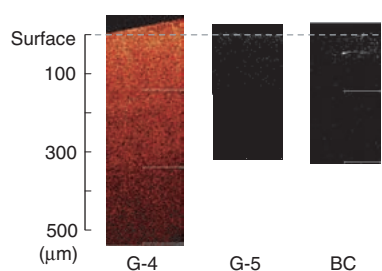


Fig. 7 Depth distribution of resin molecular weight by GPC

Elemental mapping by means of TOF-SIMS was performed on resin cross section after immersion into the grease (G-4), (G-5), and (BC) under 140°C x 1 500 hr. The distribution of the metal elements derived from the greases in depth direction is shown in Fig. 8. Penetration of the metal element contained in grease was hardly recognized and segregated at the surface in grease (G-5) and (BC) that showed small change of physical properties. On the other hand for the (G-4) sample, which showed greater change in physical properties, observation of the metal element derived from the grease at a depth of 500 μm revealed that the grease component has penetrated into the resin. Since the progress depth of molecular weight reduction described above and the penetration depth of the grease component are substantially identical, the change of physical property was considered to be

influence of the grease component that penetrated. Namely, it seems that the selection of the grease components with low penetration into the polyamide 66 is the key technology that suppresses the change in physical properties. From these result, it was found that the reduction of penetration into resin by selection of the metal elements contained in the stearate-based oiliness agent is effective for preventing changes in the physical properties of the resin.

Based on the above study, we developed optimally designed grease. The properties and composition are shown in **Table 1**. Aliphatic diurea with high gelation ability, synthetic hydrocarbon base oil, and stearate-based oiliness agent were selected. Furthermore, the worked penetration was adjusted to 300 (soft) as that achieves low shear viscosity. Moreover, improvement of heat resistance by selection of the antioxidant, and improvement of corrosion resistance by selection of rust inhibitors were studied guarantee a sufficient grease performance required by the actual vehicle.



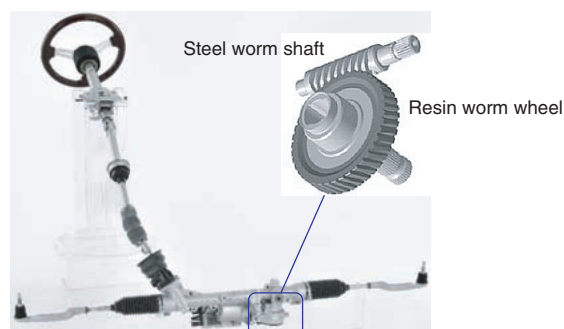
**Fig. 8** Depth profile of grease ingredient on the section of the resin by TOF-SIMS

**Table 1** Composition and properties of developed grease

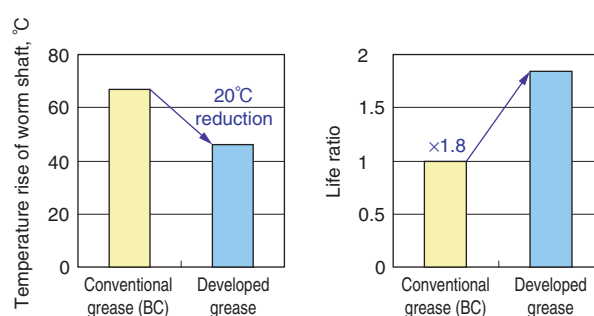
Thickener	Aliphatic diurea
Base oil	Synthetic hydrocarbon
Kinematic viscosity mm <sup>2</sup> /s@40°C	48
Cone penetration	300
Additives	Stearate-based oiliness agent Antioxidant Rust inhibitor

#### 4. Performance in the actual vehicle

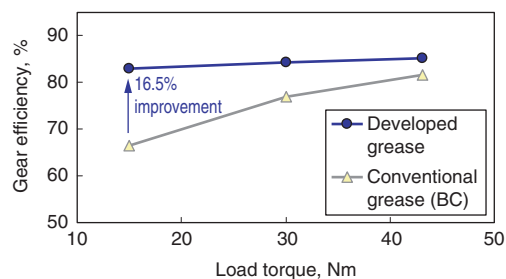
The motor reducer worm gear, which represent resin/ steel sliding element (steel warm shaft / resin worm wheel) in the electric power steering for a automobile is shown in **Fig. 9**. We applied the grease based on the technology mentioned above to engagement of the gear. The temperature rise of the worm shaft and the resin gear life until breakage is shown in **Fig. 10**. The efficiency of the reduction gear is shown in **Fig. 11**.



**Fig. 9** Worm reducer for motor



**Fig. 10** Temperature rise of worm shaft and resin gear life up until breakage



**Fig. 11** Reducer efficiency

The temperature rise of the worm shaft was reduced by 20°C due to low friction effect at the tooth meshing in the case of the developed grease compared to the Barium complex soap-based conventional grease B. In addition, life until breakage of the resin gear extended 1.8 times compared to conventional grease due to the improvement of resin compatibility and low temperature rise effect mentioned above. Furthermore, the gear efficiency improved significantly by 16.5% in the low load range due to the effect of low friction grease.

## 5. Conclusion

We created the grease technology that combines resin compatibility with low friction for applications in resin/steel sliding elements. High performance and improvement of reliability of the sliding element made of resin material were achieved by reduction of friction heat generation and the suppression of the change of physical properties of the resin. It is expected that the ratio of resin materials used for automobile parts will further increase. We will contribute to improvement of the performance and reliability of automobile parts by means of the grease lubrication technology that was introduced in this report.

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R. NAKATA \*

\* *Material Engineering R&D Dept., Research & Development Headquarters*