stle Nashville
MAY 19-23, 2019

Effect of Rheological Properties of Grease on Rotational Torque of Ball Bearings Caused by Stirring Resistance

CATEGORY：GREASE

Yamashita Yurie[1], Tsuda Takeshi[1], Yoshizaki Kouji[1], Arai Hirokazu[1]

[1] Material R&D Department, JTEKT CORPORATION, Osaka, Japan

INTRODUCTION

In recent years, developing grease-lubricated ball bearings with low torque performance is required to improve energy efficiency, especially for industrial machinery and vehicles. Generally, rotational torque of ball bearings using grease lubrication is greatly affected by stirring resistance derived from grease. Although many research reports have been published about the effect of grease compositions and properties on the stirring resistance of ball bearings, hardly any reports have studied about quantifying the grease factors affecting the stirring resistance on bearing rotational torque [1]. In previous studies, the authors proposed a new concept of "viscosity reduction energy (VRE)" to quantify the influence factors of grease on stirring resistance [2-4]. This concept is an index of the channeling property and expresses the grease behavior inside bearings. It can quantify the energy used to reduce grease viscosity during continuous shear stress application. For example, we found a strong correlation between VRE and stirring loss energy which is the time integral of torque, using different types of urea grease prepared by changing amine composition and oil types. In this study, we investigated the effects of thickener morphology on the VRE using different types of urea grease prepared by changing their compositions and penetration.

MATERIALS AND METHODS

Table 1, 2, 3 and 4 show the compositions and properties of the various greases used in the tests. By using methylene diphenyl di-isocyanate (MDI) and changing amine composition, we prepared thirteen types of urea grease with differing molecular structures (S1 to S7: single thickener structures, W1 to W6: complex thickener structures). In addition, we prepared three types of urea grease with differing oil types (O1, O2 and O3) of viscosity around 30 mm^2/s using MDI and octylamine. In order to eliminate the effect of grease penetration, we controlled thickener amount and miniaturization processing conditions after synthesizing to standardize the worked penetration (JIS K2220) at 250±10. Finally, we prepared three types of urea grease with differing penetration (P1, P2 and P3), controlled by the amount of thickener using MDI, octylamine and Poly alpha olefin (S1), in order to clarify the effect of penetration on the stirring resistance.

Table 1　Compositions and properties of sample greases

Sample sign			S1	S2	S3	S4	S5	S6	S7
Thickener	Composition (Diurea)		MDI-Octylamine	MDI-Decylamine	MDI-Dodecylamine	MDI-Octadecylamine	MDI-Cyclohexylamine	MDI-*p*-Toluidine	MDI-*p*-Dodecylaniline
	Amount, mass%		15	15	15	18	12	25	19
Base Oil	Composition		Synthetic hydrocarbon oil						
	Kinematic viscosity, mm^2/s	40℃	30.5						
		100℃	5.8						
Grease	Penetration (60W)		251	248	246	258	242	249	241

Table 2 Compositions and properties of sample greases

Sample sign			W1	W2	W3	W4	W5	W6
Thickener	Composition (Diurea)		MDI-Octylamine /Octadecylamine	MDI-Octylamine /Cyclohexylamine	MDI-Octylamine /p-Toluidine	MDI-Octadecylamine /Cyclohexylamine	MDI-Octadecylamine /p-Toluidine	MDI-Cyclohexylamine /p-Toluidine
	Amount, mass%		13	10	20	13	18	19
Base Oil	Composition		Synthetic hydrocarbon oil					
	Kinematic viscosity, mm^2/s	40℃	30.5					
		100℃	5.8					
Grease	Penetration (60W)		249	247	258	247	258	240

Table 3 Compositions and properties of sample greases

Sample sign			O1	O2	O3
Thickener	Composition (Diurea)		MDI-Octylamine		
	Amount, mass%		17	15	12
Base Oil	Composition		Diester oil	Polyol ester oil	Alkyl diphenyl ether oil
	Kinematic viscosity, mm^2/s	40℃	22.6	30.5	32.3
		100℃	5.0	5.4	5.6
Grease	Penetration (60W)		247	258	247

Table 4 Compositions and properties of sample greases

Sample sign			P1	P2	P3
Thickener	Composition (Diurea)		MDI-Octylamine		
	Amount, mass%		17	10	6
Base Oil	Composition		Synthetic hydrocarbon oil		
	Kinematic viscosity, mm^2/s	40℃	30.5		
		100℃	5.8		
Grease	Penetration (60W)		210	290	330

Table 5 shows the test conditions during measurement of the rotational torque of bearings. Rotational torque was measured at room temperature with constant axial load of 44 N, by measuring the tangential force applied to housing assembled with a test bearing in a load cell and multiplying this by half of the housing's outer diameter. We calculated the time integral of this torque and we defined it as stirring loss energy, because we believed it would make it possible to consider not only the starting torque and rotational torque during stable operation, but also all variations in rotational torque during the test period. The stirring loss energy is used to compare the rotational torque property of the grease lubricated bearings.

Table 6 shows the test conditions during measurement of the VRE of grease. Using rotational-type rheometer, the area of hysteresis loop was determined by calculating the energy differences among the flow curves which are observed during continuous increase and decrease of shear rate. We defined the area of the hysteresis loop as viscosity reduction energy (VRE) [2-5], which is the energy used to reduce grease viscosity.

Table 5 Running torque test conditions

Test bearing	62022RUCM
Axial load, N	44
Rotation speed, min^{-1}	1,800
Test time, s	1,800
Grease inclusion quantity, %	35

Table 6 Viscosity reduction energy property test conditions

Plate		Φ25 Cone plate
Measurement mode		Rotation
Shear rate, s^{-1}	Speedup	0 → 9,000
	Slowdown	9,000 → 0
Clearance, mm		0.1

RESULTS AND DISCUSSION

Figure 1 shows the relationship between stirring loss energy and VRE in test greases S1 to S7 and W1 to W6 with different thickener types. Figure 2 shows the relationship between stirring loss energy and VRE in test greases O1 to O3 and S1 with different base oil types. The results, as shown in Figure 1 and 2, indicate that there was a correlation between stirring loss energy and VRE, and the larger the VRE, the smaller the stirring loss energy represents rotational torque property. We believe that the greases which display high values of VRE on this test were more likely to maintain the channeling state [1], and the stirring resistance was reduced because transition to the churning state was prevented.

Interestingly, comparing the results obtained with single amines (S1 to S7) and complex amines (W1 to W6), their tendencies were slightly different. In the single amines, the stirring loss energy clearly decreases with improving VRE, whereas the difference in stirring loss energy wasn't particularly found in the complex amine. To investigate this difference in detail, we did TEM observation of the thickeners.

Figure 3 shows the TEM observation result of single amines (S1 to S7) and complex amines (W1 to W6). In the case of grease using complex amine, thickeners became small due to the growth inhibition of each urea crystal by mixing two different amines in synthesis process. From this, it is possible that the difference in the VRE became smaller because of the prevention of the thickener crystals' growth. Moreover, it is considered that the not big difference in VRE between the test greases was a factor for decrease of difference in stirring loss energy.

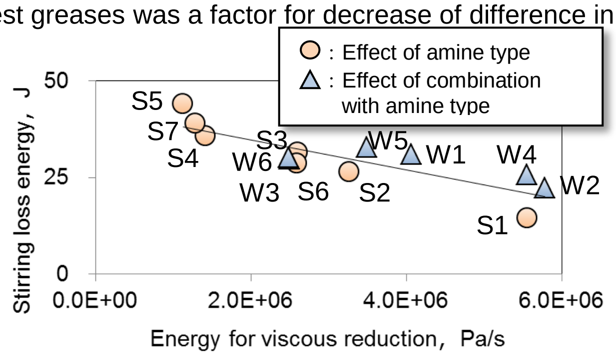


Fig. 1 Correlation between VRE and stirring loss energy

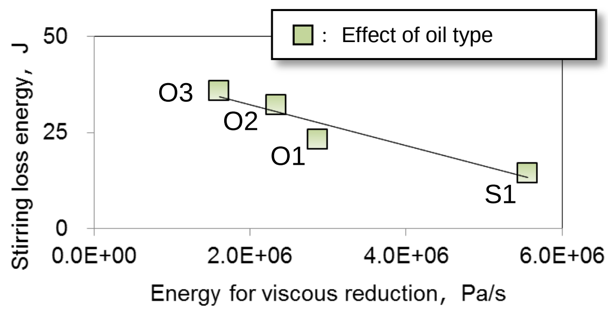


Fig. 2 Correlation between VRE and stirring loss energy

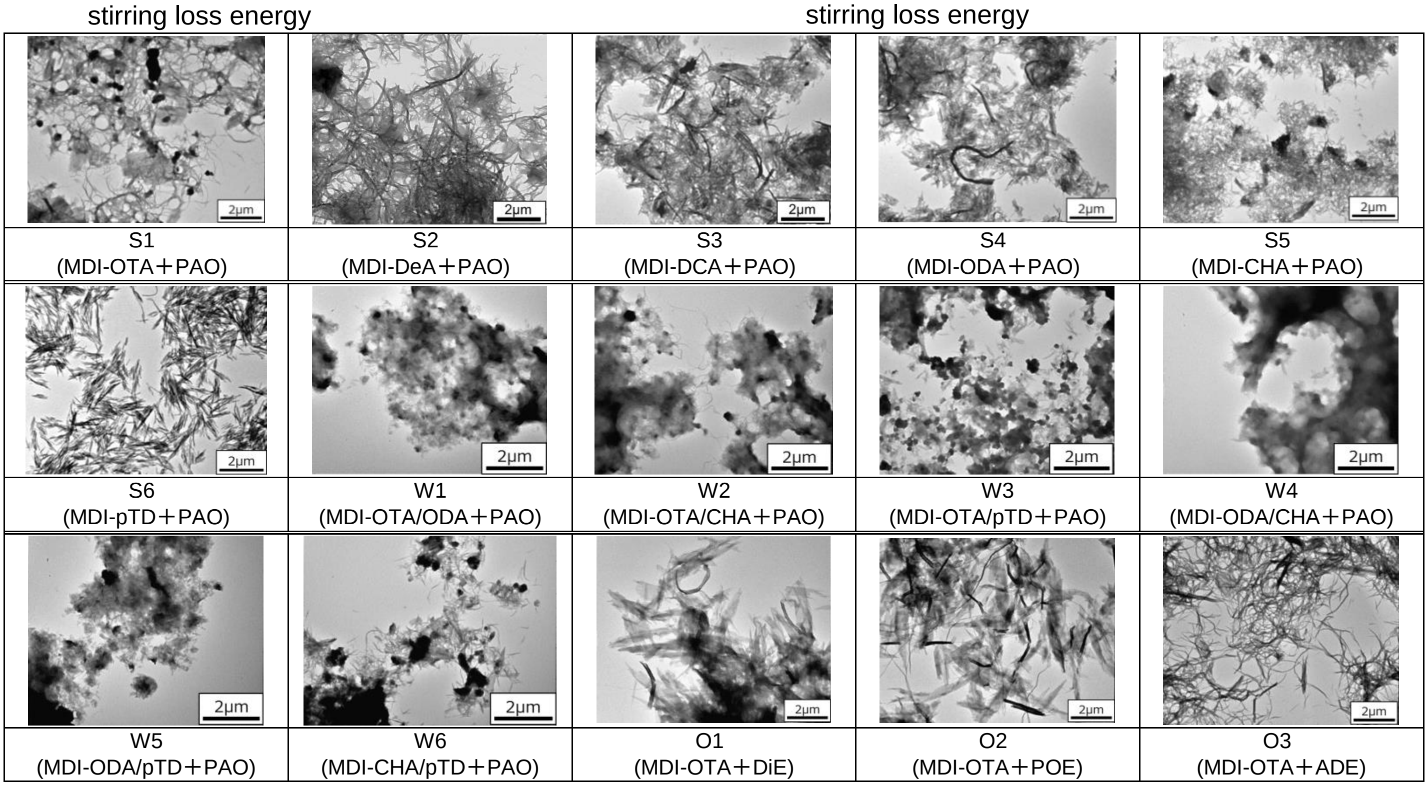
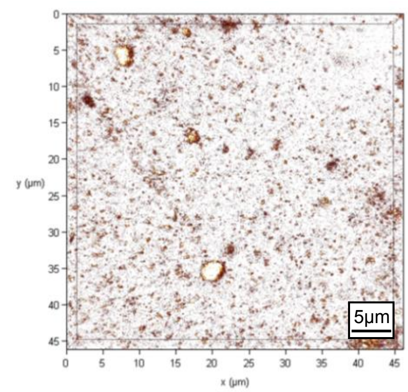
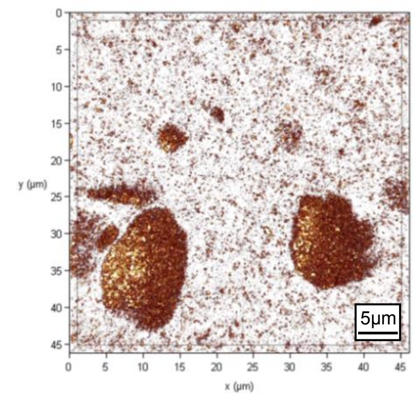


Fig. 3 TEM observation results of grease thickeners

Further, in the TEM image of the sample grease W2 and W5, remarkable difference was not observed whereas the difference in the VRE was relatively large. This is because when TEM observation was carried out, the base oil and thickener were completely separated in solvents and the fiber which has been loosened into one was observed, so state of aggregation of the thickener in the grease was lost.

Therefore, we considered observation method of confocal laser fluorescence microscope. The method using the confocal laser fluorescence microscope is characterized by detecting the fluorescence emission from the di-urea molecules. Therefore, with confocal laser fluorescence microscope, it is possible to observe the grease as it is without any pretreatment in three dimensions. This makes it possible to study the agglomeration morphology of thickeners in the greases. As a result of comparing the sample greases W2 and W5 using a confocal laser fluorescence microscope, W2 had less aggregates of the thickener, and the average volume W2 is estimated to be 0.02 μm^3 and W5 to 0.04 μm^3. When the specific surface area of the thickener was large, it is possible the amount of oil retained is increased, and it caused an increase of VRE, which is the energy used to reduce the viscosity.





W2	W5
(MDI-OTA/CHA＋PAO)	(MDI-ODA/pTD＋PAO)
Low torque and high VRE	High torque and low VRE

Fig. 4 Confocal laser fluorescence microscope observation results of grease thickeners

Figure 5 shows the relationship between stirring loss energy and VRE in sample grease S1, P1, P2 and P3 with different Penetration. As Figure 5 shows, there was clear correlation between VRE and stirring loss energy. There was decrease of stirring loss energy associated with increase of VRE. And the lower the grease penetration, the higher the VRE.

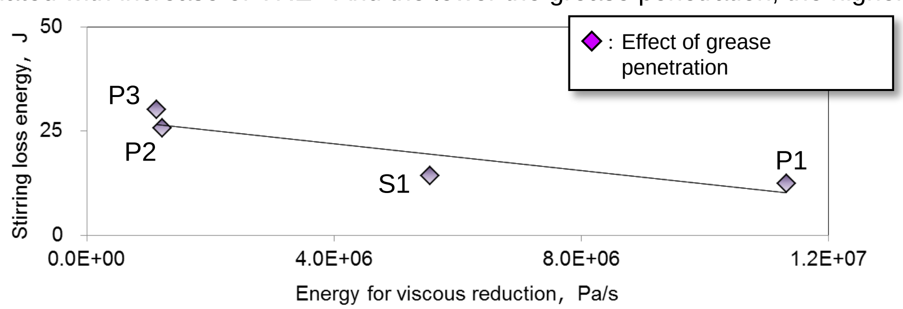
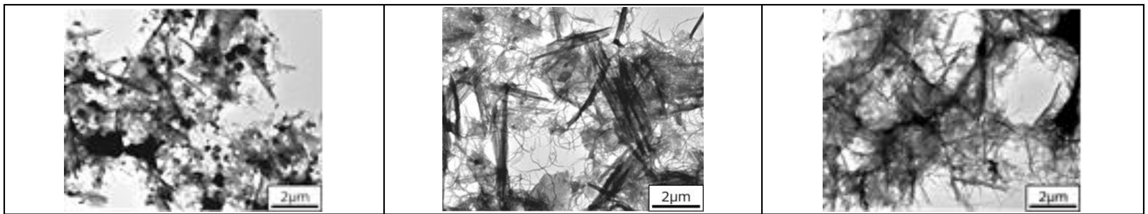


Fig. 5 Correlation between VRE and stirring loss energy

Figure 6 and figure 7 show the results of TEM observation of the grease and confocal laser fluorescence microscopy of these greases. The results of TEM observation shows that the thickener morphology changed depending on the concentration of the thickener even with the same molecular structure. On the other hand, confocal laser fluorescence microscopy observation shows that the average volume of the aggregates of the thickener, 0.02 μm^3 each, did not depend on the concentration of the thickener. These results show that when penetration was increased as the concentration of the thickener was increased, it was possible to retain a large amount of oil without changing the size of the thickener aggregate, and thereby increasing VRE was possible. As a result, it seems that it was possible to maintain channeling state and reduce the rotational torque.



P1 (MDI-OTA＋PAO)	P2 (MDI-OTA＋PAO)	P3 (MDI-OTA＋PAO)

Fig. 6 TEM observation results of grease thickeners

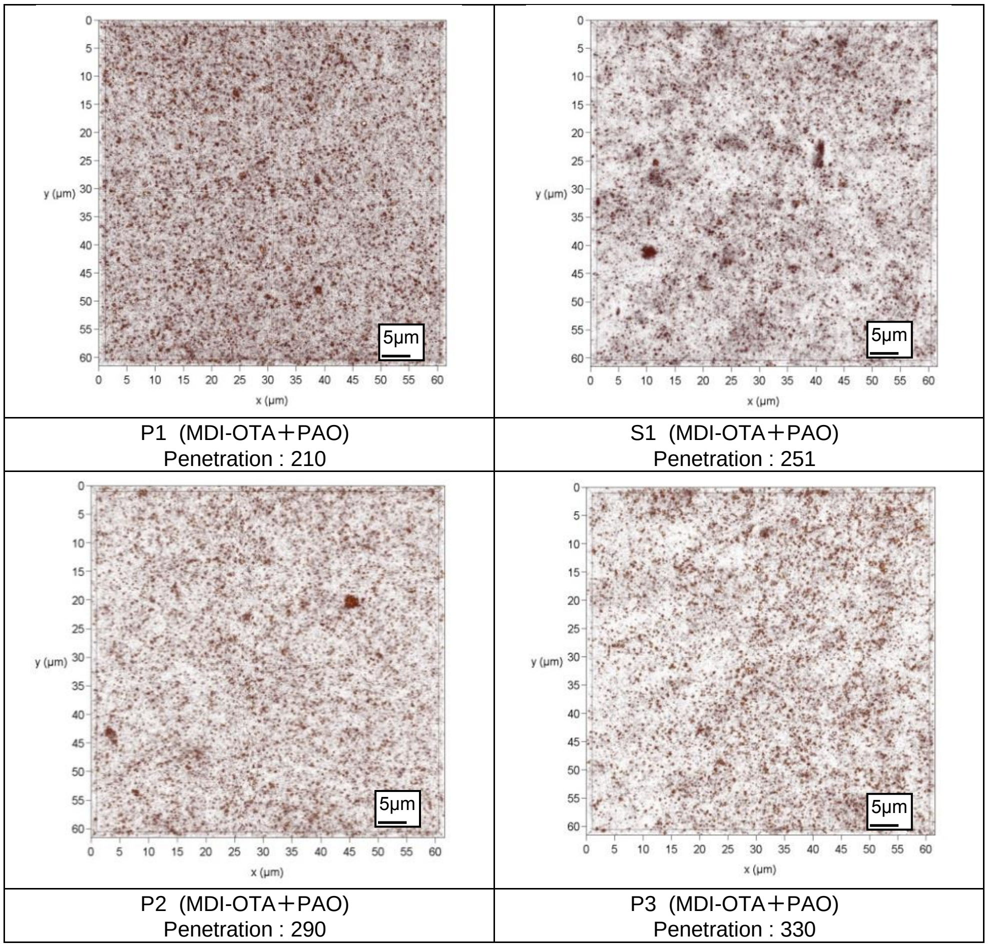


Fig. 7 Confocal laser fluorescence microscope observation results of grease thickeners

Figure 8 shows the relationship between stirring loss energy and VRE for all sample greases used in this study. Even if the thickener type, base oil type and penetration range are different in the study, the stirring loss energy tended to decrease as VRE was larger. In addition, Figure 9 shows bearing photos after the test using sample grease S1 which was the lowest torque in this study and using sample grease S5 which was the highest torque in this study. As for the observation result, in S1 which VRE was large, the grease in bearing kept the channeling state, stirring resistance could be reduced, and in the S5 which VRE was small, transitioned to the churning state. From these series of test results, it was suggested that it is possible to reduce rotational torque of bearings lubricating grease by increasing the VRE regardless of the type of grease.

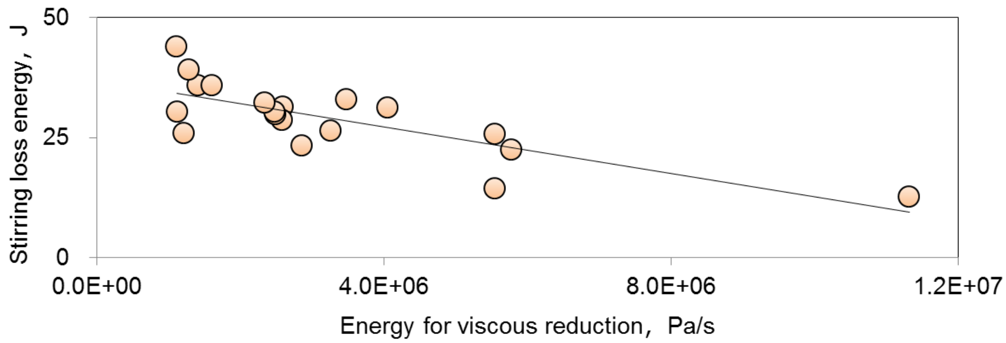


Fig. 8 Correlation between VRE and stirring loss energy

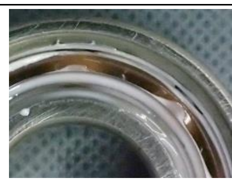
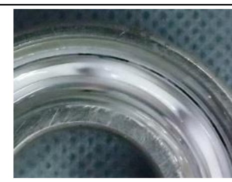
 Side of tabs	 Back side	 Side of tabs	 Back side
S1 (MDI-OTA＋PAO)		S5 (MDI-CHA＋PAO)	
Channeling Type		Churning Type	

Fig. 9 Observation results of test bearings

CONCLUSION

According to our results, the VRE of grease is affected not only by nano-scale thickener morphology, obtained by TEM observations, but also macro-scale thickener aggregates, obtained by confocal laser scanning fluorescence microscopy. We found correlation between VRE and stirring loss energy which is the time integral of torque, using different types of urea grease prepared by changing their compositions and penetration. It is suggested that the higher the VRE, the lower the bearing rotational torque. Further studies quantitatively investigating how thickener morphology affects the VRE are needed in order to improve low torque property of grease lubricated bearings.

ACKNOWLEDGMENTS

The authors thank JXTG Nippon Oil & Energy Corporation for their support with providing sample greases and TEM observation photographs.

REFERENCES

[1] Miyake K., Tsuda T., Yoshizaki K., 2018, “Low Torque and Low Noise Technology for Ball Bearings under Grease Lubrication”, JTEKT ENGINEERING JOURNAL English Edition No.1015E pp. 26-36

[2] Tsuda T., Yoshizaki K., Yamamoto K., Arai H., 2016, “Effect of Grease Rheological Properties in the Running Torque Caused by Agitating Resistance of Ball Bearings”, Proceedings of JAST Tribology Conference Tokyo, A12

[3] Tsuda T., Yamashita Y., Yoshizaki K., 2018, “Effect of Grease Rheological Properties in the Running Torque Caused by Agitating Resistance of Ball Bearings (Part2)”, Proceedings of JAST Tribology Conference Ise, F15

[4] Tsuda T., Yamashita Y., Yoshizaki K., Arai H., 2019, “Effect of Grease Rheological Properties in the Running Torque Caused by Agitating Resistance of Ball Bearings (Part3)”, Proceedings of JAST Tribology Conference Tokyo, E21

[5] Akutsu T., Masuko M. Suzuki A., 2016, “Structual Change of Lubricating Grease Considered from Viscous Reduction by Shear”, J. Jpn. Soc. Tribologists, 61(10), pp. 699-708

KEYWORDS

Lubricants: Greases, Lubricant Physical Analysis: Rheology, Rolling Bearings: Ball Bearings, Rotational Torque of Ball Bearings, Viscosity Reduction Energy Property, Thickeners, Base Oils