Study of correlation between grease film formations and mechanical losses on various surfaces

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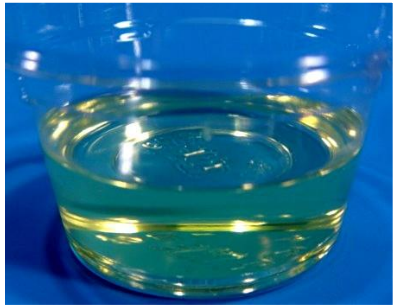
Discourse on the Dissertation Thesis
5th June 2017

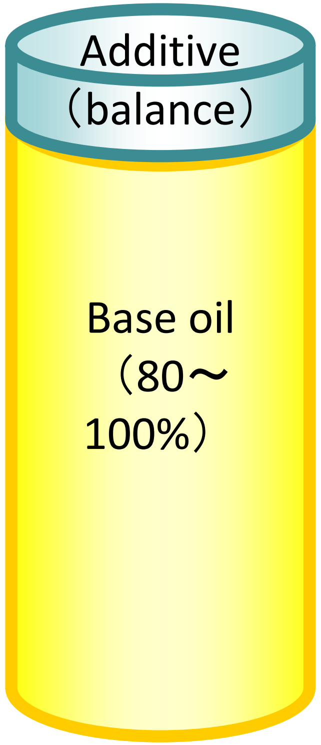
Institute of Machine and Industrial Design

Contents

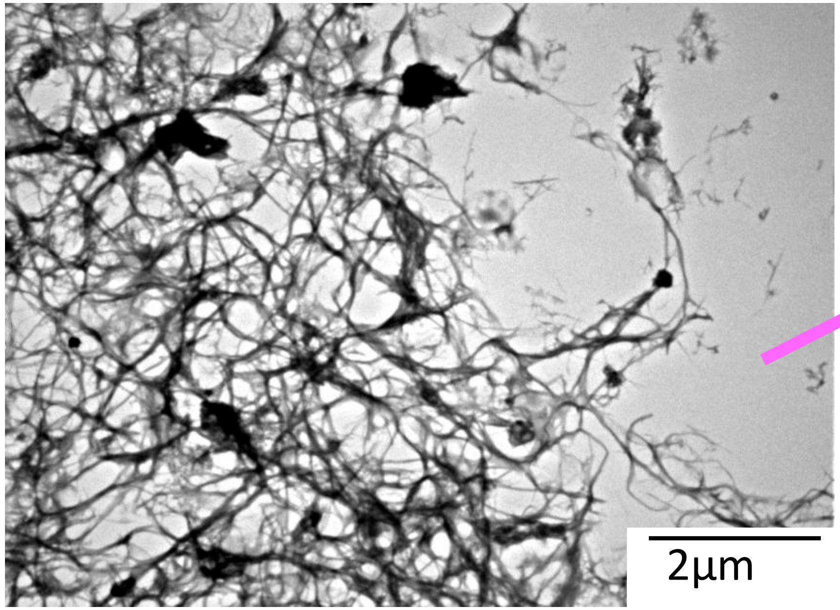
Introduction - Grease

Oil



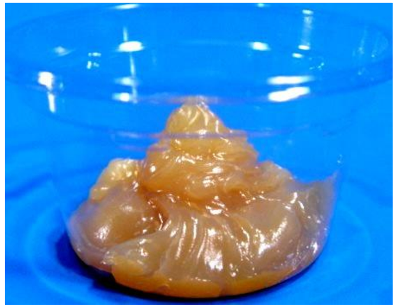


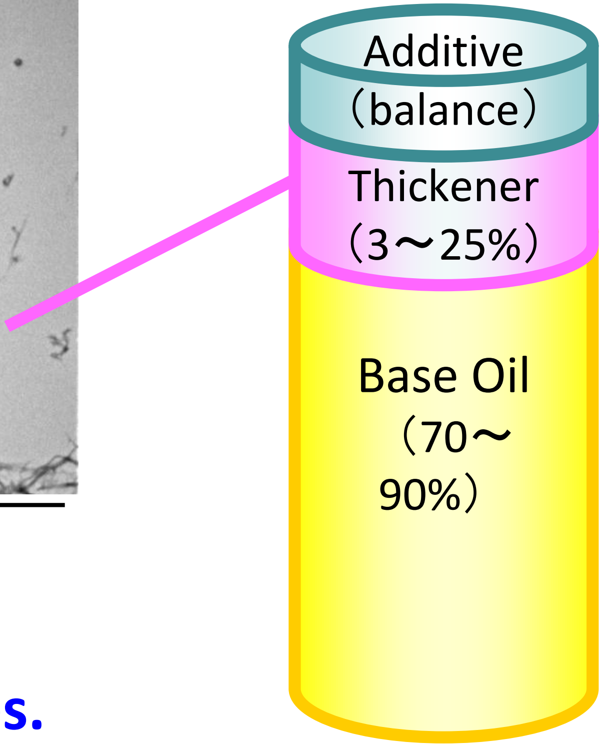
Grease is semisolid lubricant,
composed of oil and thickener.



Thickener fiber network holds oil as if sponge does.

Grease





Introduction - Grease product development

Grease

✓Not leaky
✓No circulation system
✓Low lubricant volume

Bearing lubrication

Grease lubrication > 90%

Global demand for energy-saving properties in order to reduce CO_2 emissions.

Requirement for grease development

1. High performance grease reducing bearing mechanical loss
2. Persuasive mechanisms of performance for customers

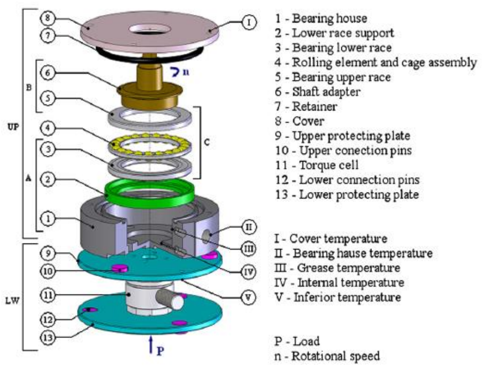
Mission Clarifying the relationship between grease formulations and mechanical losses (bearing torque)

State of the art review and analysis

1. Bearing torque under grease lubrication

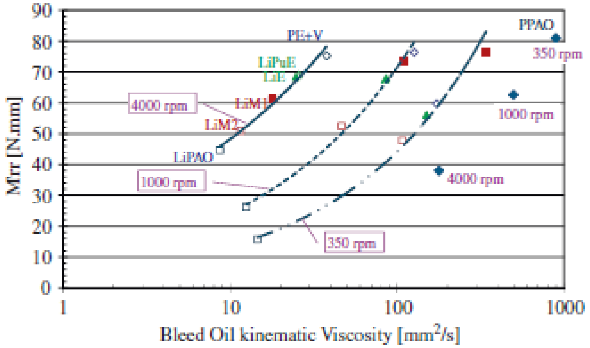
1.1 Thrust type

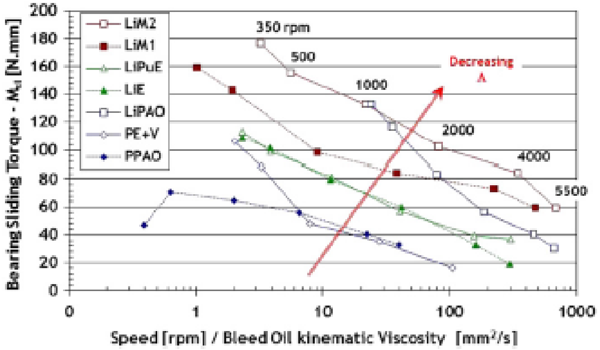
Seabra et al. decomposed a total friction torque into rolling torque and sliding torque.



Relevance; Rolling torque: base oil viscosity

Sliding torque: film thickness





High viscosity → High rolling torque

Thin film thickness → High sliding torque

-Vacancy: limited to thrust type bearing, commercial greases

Cousseau, T., Graca, B., Campos, A., and Seabra, J., "Friction Torque in Grease Lubricated Thrust Ball Bearings," *Tribology International*, 44, 2011, 523-531.

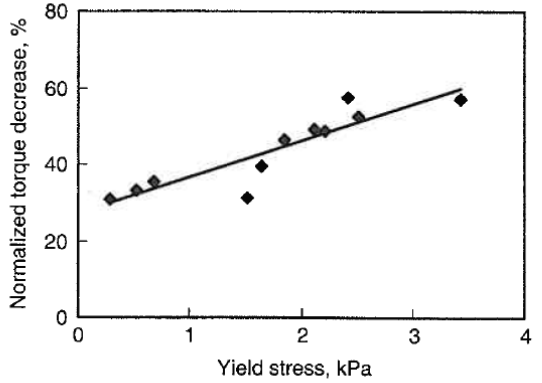
Cousseau, T., Graca, B., Campos, A., and Seabra, J., "Experimental Measuring Procedure for the Friction Torque in Rolling Bearings," *Lubrication Science*, 22, 2010, 133-147.

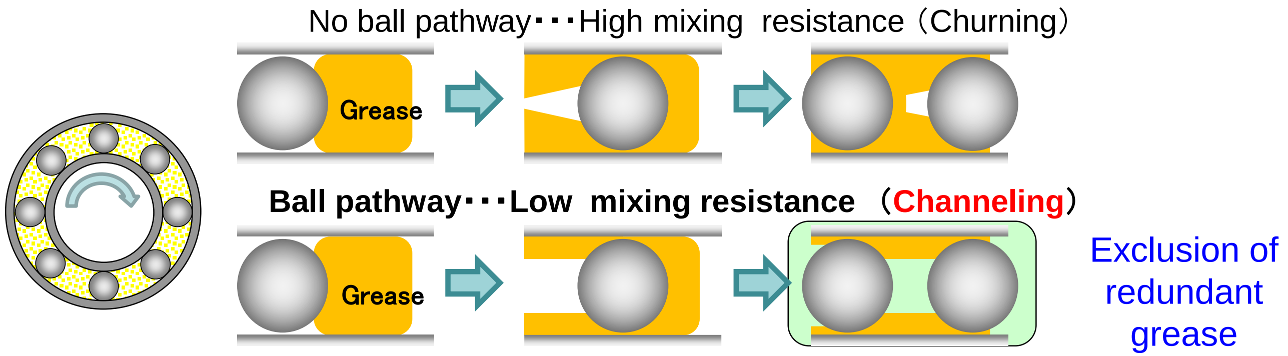
Cousseau, T., Graca, B. M., Campos, A. V., and Seabra, J. H. O., "Influence of Grease Rheology on Thrust Ball Bearings Friction Torque," *Tribology International*, 46, 2012, 106-113.

1. Bearing torque under grease lubrication

1.2 Radial type

Yokouchi et al. indicated relationship between bearing torque and yield stress of greases.





High yield stress → Torque reduction

Due to grease channeling

*Channeling and churning of grease

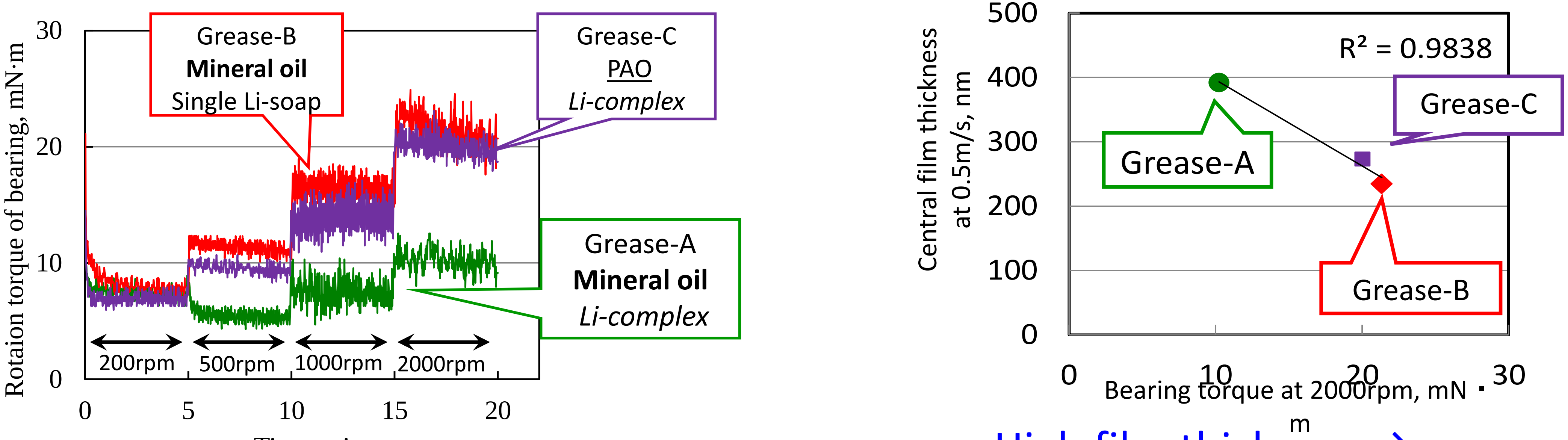
-Vacancy: limited to the same thickener type(Li-12OH-stearate)

Oikawa, E., Inami, N., Hokao, M., Yokouchi, A., and Sugimura, J., "Bearing Torque Characteristics of Lithium Soap Greases with Some Synthetic Base Oils," *Proc IMechE Part J: J Engineering Tribology*, 226, 6, 2012, 575-583.

1. Bearing torque under grease lubrication

1.2 Radial type

Sakai et al. reported dependence of several types of base oil and thickener types in bearing torque.



High film thickness → lower torque in high speed.

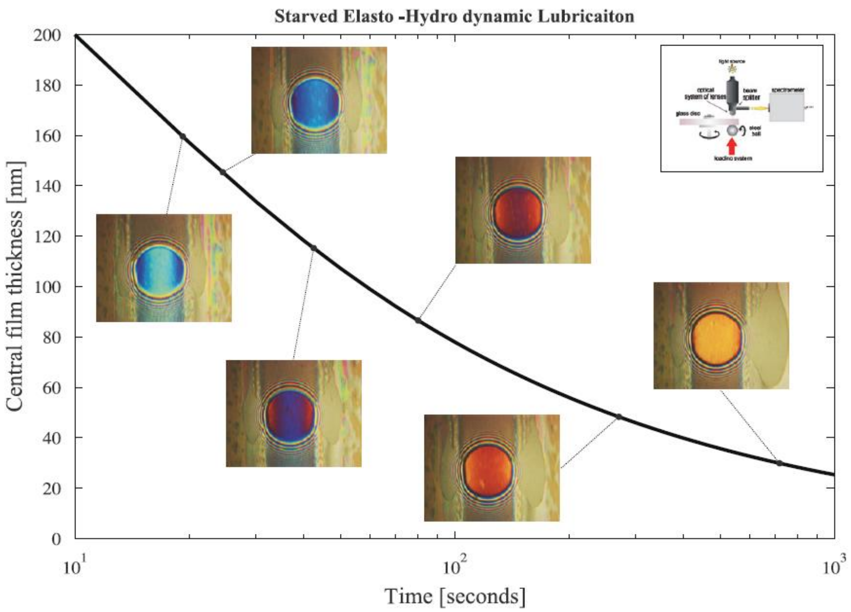
-Vacancy: limitation of the thickener and base oil types

Sakai, K., Tokumo, Y., Ayame, Y., Shitara, Y., Tanaka, H., and Sugimura, J., "Effect of Formulation of Li Greases on Their Flow and Ball bearing Torque," *Tribology Online*, 11, 2, 2016, 168-173.

State of the art review and analysis

2. Grease behaviors in a bearing

Venner et al. estimated the reduction of the grease film thickness in bearings by numerical simulations of grease flows.



The transition from flooded region to heavily starved contact

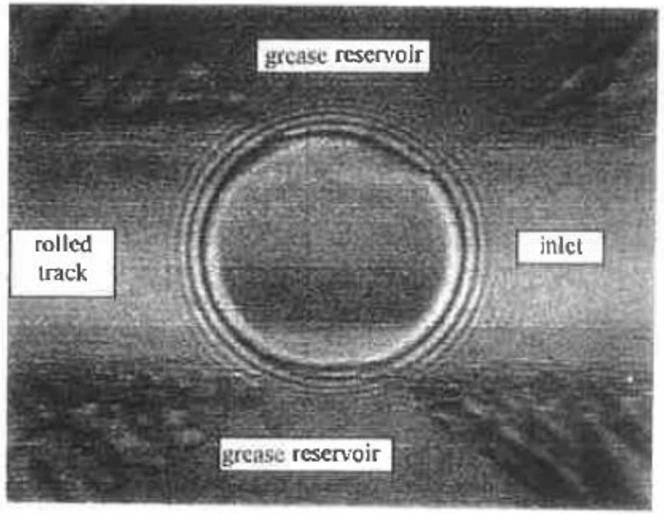
This indicates bearings can be operated in not only flooded but also starved conditions.

-Vacancy: no direct information about relationship with bearing torque

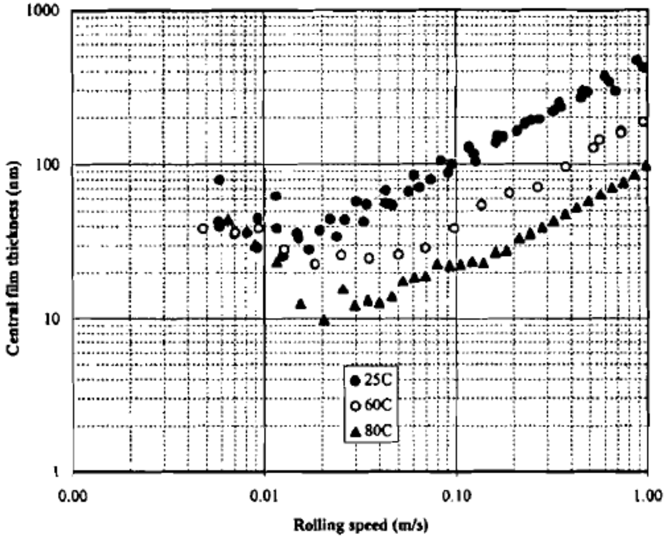
Venner, C. H., van Zoelen, M. T., and Lugt, P. M, "Thin Layer Flow and Film Decay Modeling for Grease Lubricated Rolling Bearings," *Tribology International*, 47, 2012, 175-187.

3. Film thickness under grease lubrication

Cann et al. reported the behaviors of grease film thickness in EHL.



Grease is pushed away with disk rotation.



Under fully flooded condition, greases augment film thickness in slow speed.

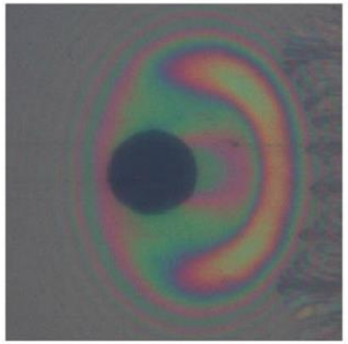
-Vacancy: no direct information about relationship with bearing torque

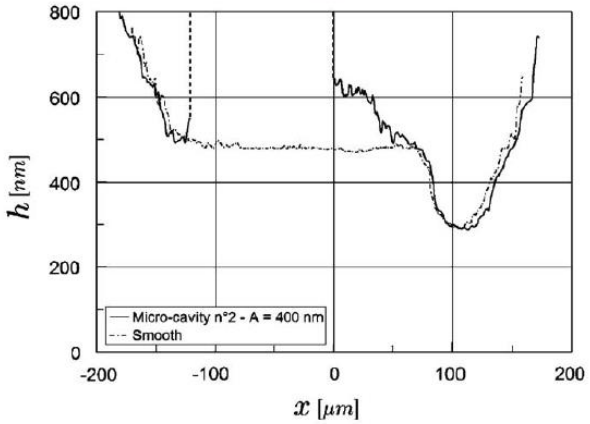
Cann, P., and Lubrecht, A. A., "An Analysis of the Mechanisms of Grease Lubrication in Rolling Element Bearings," *Lubrication Science*, 11-3, 1999, 227-245.
Cann, P., "Starved Grease Lubrication of Rolling Contacts," *Tribology Transactions*, 42, 4, 1999, 867-873.

5. Surface texturing for film thickness (only for oil lubrication)

Mourier et al. indicated shallow micro cavity can increase
Film thickness under rolling/sliding condition.

Krupka et al. showed deep micro dents decrease film thickness
but shallow micro dents increase.





Possibility of improvement of film thickness by surface texturing depending on the specific conditions in spite of non-conformal contacts

-Vacancy: no application to grease lubrication

Mourier, L., Mazuyer, D., Lubrecht, A. A., and Donnet, C., “Transient Increase of Film Thickness in Micro-Textured EHL Contacts,” *Tribology International*, 39, 2006, 1745-1756.
Krupka, I. and Hartl, M., “The Effect of Surface Texturing on Thin EHD Lubrication Films,” *Tribology International*, 40, 2007, 1100-1110.
Krupka, I. and Hartl, M., “The Effect of Surface Texturing on Very Thin Film EHD Lubricated Contacts,” *Tribology Transactions*, 52, 2009, 21-28.

State of the art review and analysis

Bearing torque with grease

Loss Factors

Unknown parameters for Bearing torque

Thrust type

Seabra (Cousseau)
✓Rolling/Sliding torque factor
✗Only commercial grease

Rheology
Yield stress

Yokouchi
✓Channeling effect
✗Only 1 type Li thickener

Main focus

Radial type

Yokouchi(Oikawa), Dong

For reduction of torque…

Film thickness

Dong
✓High thickness in slow speed
✗Only 1 type Li thickener and base oil

In bearing simulation

Venner
✓Film decay in operation

Starved condition

Cann
✓viscosity, thickener content effect

Chemical Analysis (IR)

Cann
✓thickener deposition on track
Mori (Hoshi)
✓urea thickener's entrainment

Surface texturing

Mourier, Krupka
✓shallow cavity/dent increase the thickness

Track pattern

Sugimura (Chen)
✓Related to starvation

Essence and goals of the PhD thesis

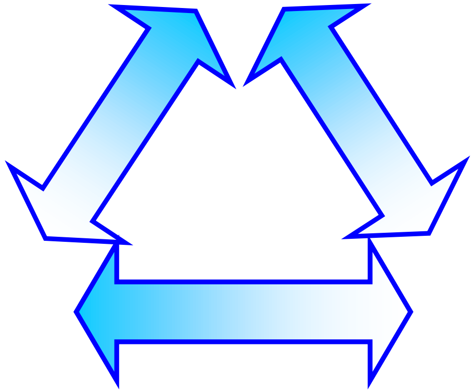
1. **Understanding of influence of grease formulation (focused on Li thickener) on radial ball bearing torque**
2. **Analysis of grease properties for clarification of lubrication mechanism**
3. **New approach as EHL grease film observation including surface texturing**

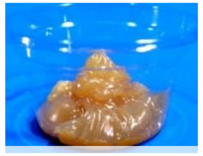
New findings for future grease product development

Essence and goals of the PhD thesis

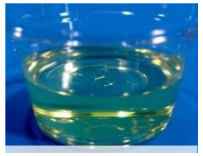
◎Study of the relationship between grease formulations and bearing torque

Bearing torque

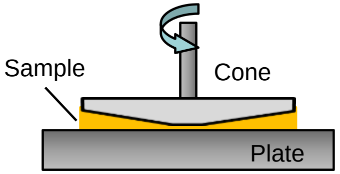


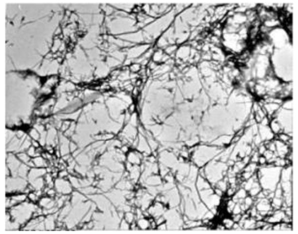


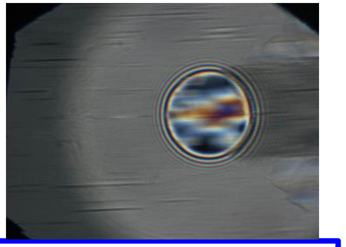
- Base oil
- Thickener



Grease formulation







- Rheology
- Thickener fiber structure
- Film thickness including surface texturing

Factor evaluation

Scientific questions and working hypotheses

Questions

How do properties of grease affect the radial ball bearing torque?

Are there relationships among the properties?

Working hypotheses

1. **Rheological factor ⇒ Yield stress and/or viscosity**
2. **Thickener structure ⇒ Thickener shape and chemical structure**
3. **Ability of film thickness and adaptability to surface conditions**
   ⇒ Thicker film on both smooth and textured surfaces is better
4. **Those factors correlate each other**

Research method

1. Grease samples

- Low viscosity grade oil : Reflecting recent energy-saving grease formulation
- Lithium type thickener : Considering recent trend of grease development

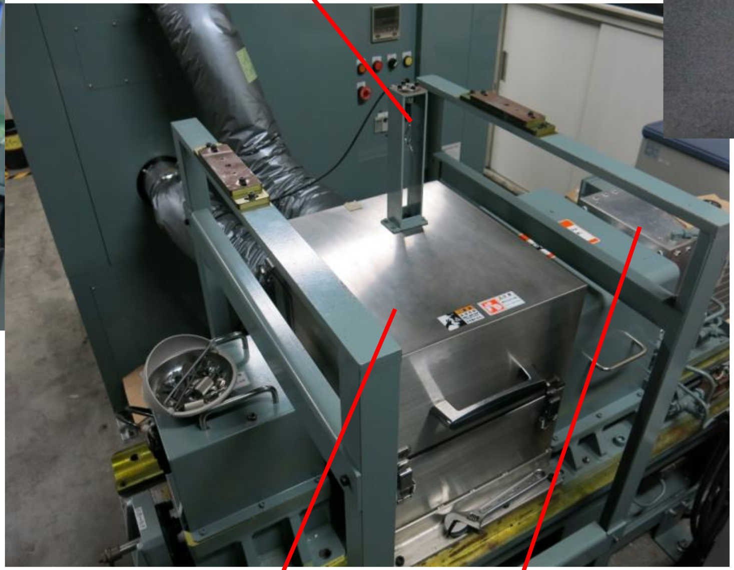
Samples	**Grease-A (Li-Complex)**	**Grease-B (Single Li)**	**Grease-C (Single Li)**	**Base oil**
Base oil	Mineral oil(API Group-I), Kinetic viscosity(40℃): 33.2 mm^2/s, VI:107			
Thickener	12OH-stearic/ azelaic-Li	Stearic-Li	12OH-stearic-Li	-
Dropping point	250 ℃	200 ℃	200 ℃	-
Penetration(60W)	265	293	359	-

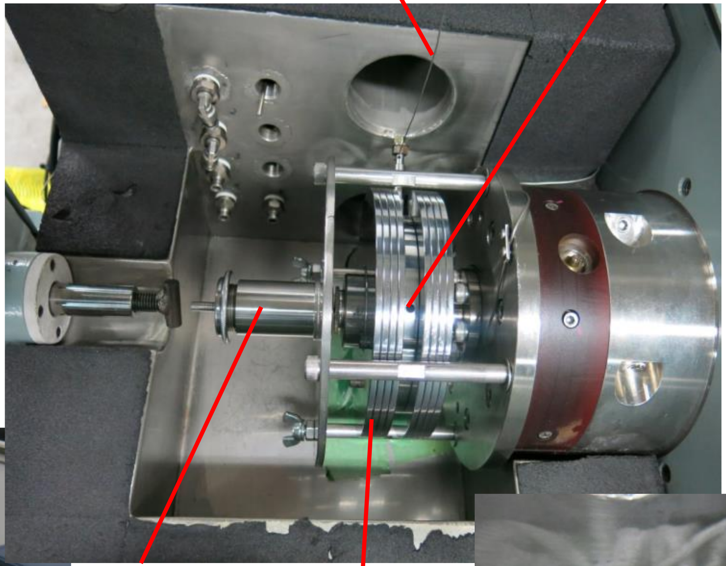
Group-I : Solvent refined oil, containing aromatic hydrocarbon

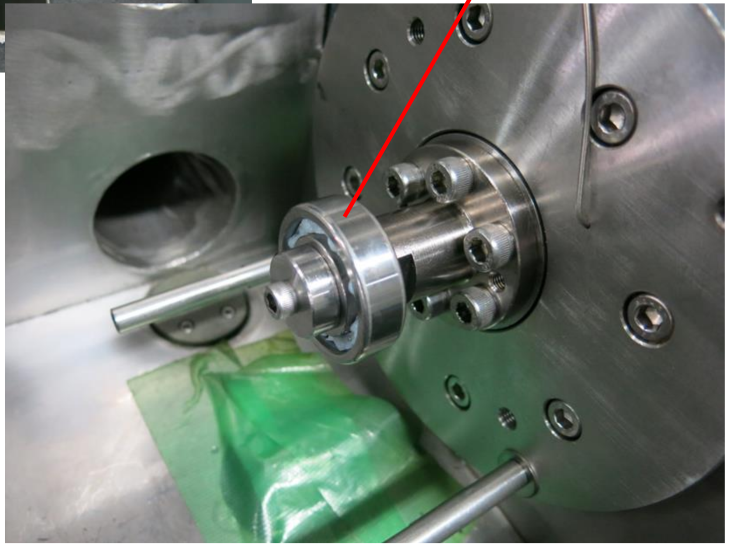
Research method

2. Bearing torque (JXTG)

- Original frictional torque measuring rig for grease
- Rotation speed dependence for each grease

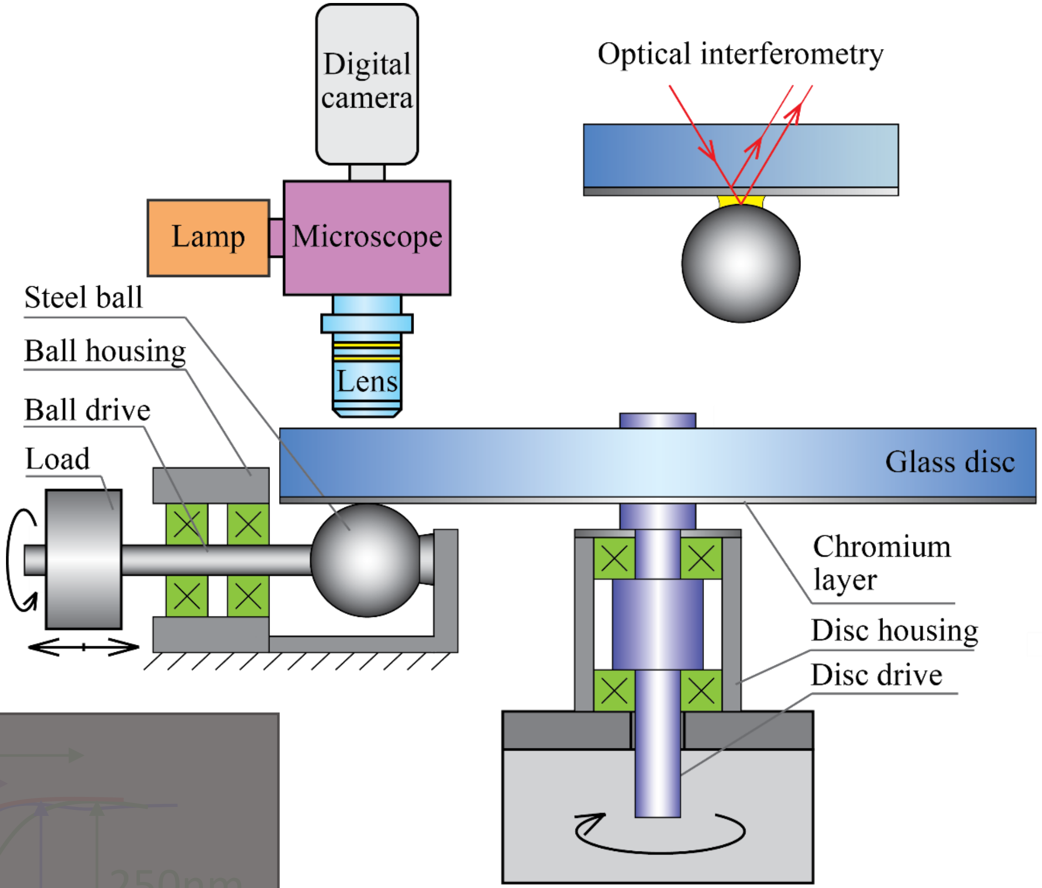






3. Film thickness

- Colorimetric interferometry technique
- Smooth / dented steel ball on glass disk
- Fully-flooded / starved condition



Target depth: 200-500nm depth

→Tungsten carbide ball indentation

Dimeter: 3mm, 2.5mm, 1.6mm, 1.27mm

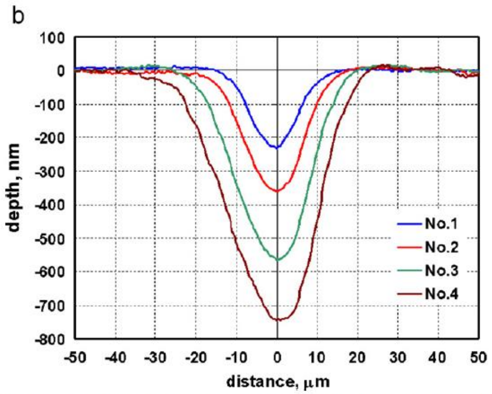
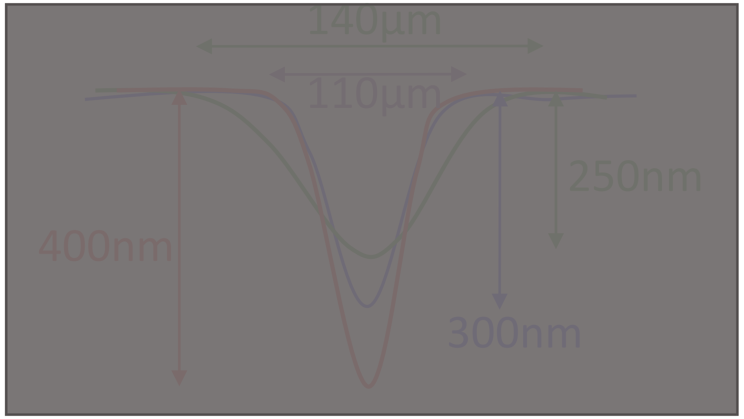


Fig. 3. Dents of various depths produced on the ball surface before (a) and after (b) surface polishing.



Krupka, I., Poliscuk, R., and Hartl, M., "Behavior of Thin Viscous Boundary Films in Lubricated Contacts between Micro-Textured Surfaces," *Tribology International*, 42, 2009, 535-541.

Current state of thesis (Presented in STLE)

Relationship between bearing torque and film thickness on smooth surface and grease rheology

Grease		A	B	C
Base oil	**Mineral oil** (G-I), %	88	88	92
Thickener	Li complex, %	12	-	-
	Li stearate, %	-	12	-
	Li-12OH-stearate, %	-	-	8
Penetration (60W)		265	293	359

	Test condition
Bearing	6204 without seal
Lubricant content	2g
Rotation speed	200-4000 rpm
Duration	10 min. each
Temperature	25 ℃
Thrust load	50 N
Radial load	50 N
Evaluation	Friction torque

Bearing torque results

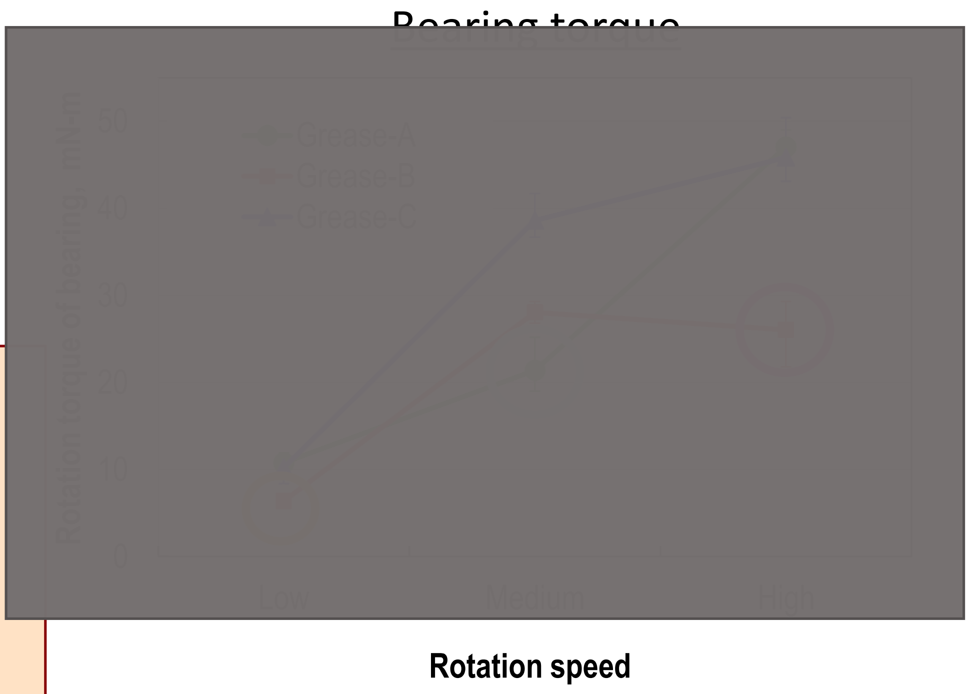
Grease-A: the lowest torque in
medium (2000 rpm) rotation speed

Grease-B: the lowest torque in
low (200 rpm) and high (4000 rpm) rotation speed

Detailed results are omitted…

Current state of thesis (Presented in STLE)

Grease-A: Li-complex
Grease-B: Single Li-Stearate
Grease-C: Single Li-12OH-Stearate



Grease film thickness (fully flooded conditions)

Li-stearate thickeners were not dragged into contact surfaces.

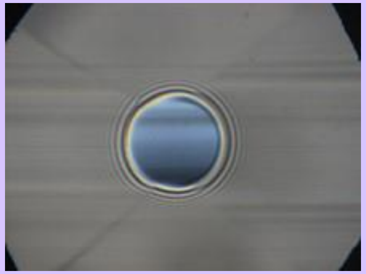
Thin film thickness could relate to lowering bearing torque.

Viscoelasticity

High yield stress of Grease-A could lead to cause quick channeling in a bearing.

Grease film thickness (starved conditions)

Grease-B



Early starvation of Grease-B could reduce bearing torque.

※Only Grease-B showed torque drop in spite of hydrodynamic conditions.

Expected outcome and publications

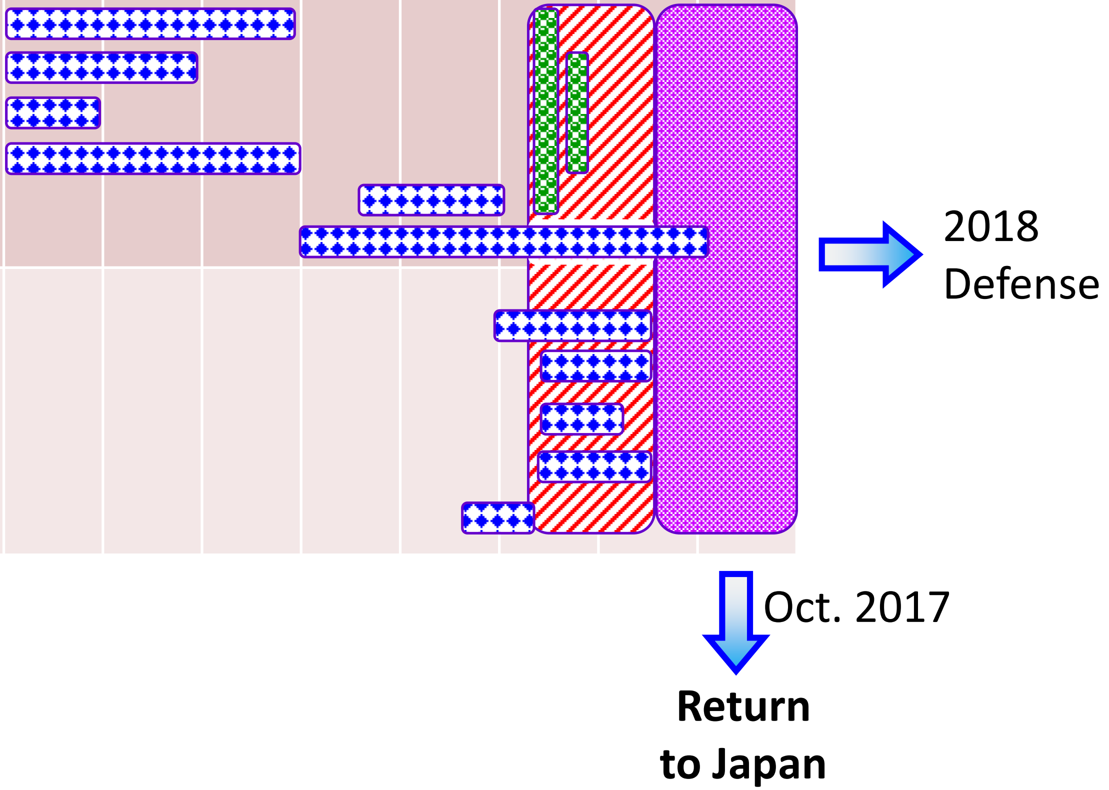
Publication and presentation plan

- Tribology International or Tribology Online ← non-textured surface results (2017)
- STLE 72nd Annual Meeting & Exhibition ← non-textured surface results (2017 May)
- 6th European Conference on Tribology (ECOTRIB 2017) ← film thickness and their track pattern (2017 June)

⇒ 1 paper and 2 presentations

Future work

Task	Description of works	2016	2017
A	Li thickener type dependence (3 types) - Bearing torque (JXTG) - Rheological parameter (JXTG) - Thickener structure (JXTG) - Film thickness for smooth surface under flooded/starved - Traction coefficient **- Film thickness for textured surface**		
B	Li grease penetration dependence (6 types) - Bearing torque (JXTG) - Rheological parameter (JXTG) - Thickener structure (JXTG) - Film thickness for smooth surface under flooded/starved - Traction coefficient		



- Experiments and data analyses
- Results publication preparation
- Presentation in conference
- Dissertation preparation

Film thickness on dented surfaces and penetration dependence (260, 300, 360) will be investigated.

Thank you for attention

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Answer to reviewer

General comments

For the experimental work, only three different thickeners are used. The level of generalization of the obtained results is then questionable, as the experimental data are slightly restricted.

Grease thickener			Maximum usable temperature	Water resistance	Mechanical shear stability
Soap	Single soap	Ca soap	70℃	○	△
		Al soap	80℃	×	×
		Li soap	130℃	○	○
	Complex	Ca-complex	150℃	○	○
		Li-complex	150℃	○	◎
Non-soap	Organic	Urea	160℃	◎	◎
		PTFE	２００℃	◎	◎
	Inorganic	Bentonite	150℃	△	○
		Silica gel	150℃	×	×

◎: Very good ○: Good △: Inferior ✕: Bad

Lithium type thickeners were selected for this study considering the recent grease development and the application.

Current results are shown in this presentation.
In addition to them, penetration dependence and film thickness on dented surfaces were investigated for proceeding deep discussion.

Answer to reviewer

General comments

Is it possible to present a list of publications?

Conferences

・2015 ITC2015 Tokyo (Tokyo, Japan)
・2014 NORDTRIB2014 (Aarhus, Denmark)
・2013 Advanced Forum on Tribology (Beijing, China)
・2009 WTC2009 (Kyoto, Japan)

Publication to International Journals

・Sakai, K., Tokumo, Y., Ayame, Y., Shitara, Y., Tanaka, H., and Sugimura, J., “Effect of Formulation of Li Greases on Their Flow and Ball bearing Torque,” *Tribology Online*, 11, 2, 2016, 168-173. ←ITC Tokyo 2015 Young Researcher Paper Award

・Sakai, K. and Shitara, Y., “Influence of Physical States of Amide Type Gel-Lubricants on Their Tribological and Rheological Properties,” *Finnish Journal of Tribology*, 32, 2, 2014, 20-28.

・Sakai, K., Shitara, Y., Takahashi, K., Yoshida,K., Kaimai, T., “Tribological Properties of Thermo-Reversible Gel-Lubricants Containing Solid Lubricants,” *Tribology Online*, 6, 1, 2010, 26-31.

Answer to reviewer

Grease-A: Li-complex
Grease-B: Single Li-Stearate
Grease-C: Single Li-12OH-Stearate

Additional question 1

Which criteria was used for selection of the greases for experimental work?

- Low viscosity grade oil : Reflecting recent energy-saving grease formulation
- Lithium type thickener : Considering recent trend of grease development

Samples	Grease-A (Li-Complex)	Grease-B (Single Li)	Grease-C (Single Li)	Base oil
Base oil	Mineral oil(API Group-I), Kinetic viscosity(40℃): 33.2 mm^2/s, VI:107			
Thickener	12OH-stearic/ azelaic-Li	Stearic-Li	12OH-stearic-Li	-
Dropping point	250 ℃	200 ℃	200 ℃	-
Penetration(60W)	265	293	359	-

In addition to these greases, penetration dependence (260, 300, 360) will be confirmed in the future work.

Answer to reviewer

Additional question 2

According to the obtained results, is it possible to draw some recommendations on which operating conditions fits the studied greases best?

Grease film thickness (fully flooded conditions)

Li-stearate thickeners were not dragged into contact surfaces.

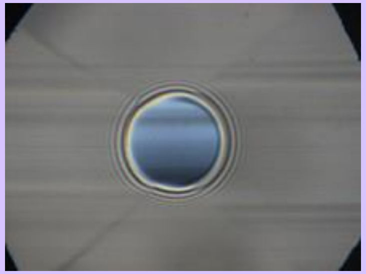
Thin film thickness could relate to lowering bearing torque.

Viscoelasticity

High yield stress of Grease-A could lead to cause quick channeling in a bearing.

Grease film thickness (starved conditions)

Grease-B



Early starvation of Grease-B could reduce bearing torque.

※Only Grease-B showed torque drop in spite of hydrodynamic conditions.

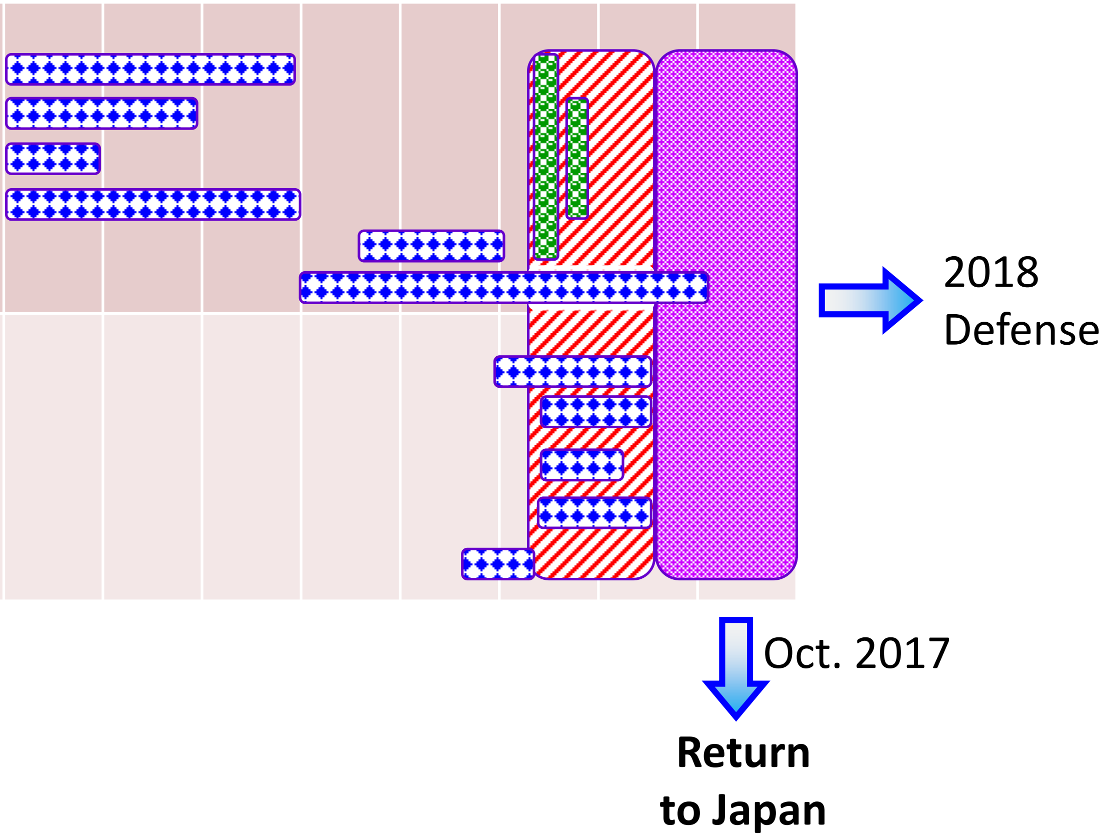
Grease-A is the best for reducing bearing torque in this samples since its lowest bearing torque in medium speed with late starvation property.

Answer to reviewer

Additional question 3

Can you describe experimental program for following years?

Task	Description of works	2016	2017
A	Li thickener type dependence (3 types) - Bearing torque - Rheological parameter - Thickener structure - Film thickness for smooth surface under flooded/starved - Traction coefficient - Film thickness for textured surface		
B	Li grease penetration dependence (6 types) - Bearing torque - Rheological parameter - Thickener structure - Film thickness for smooth surface under flooded/starved - Traction coefficient		



- Experiments and data analyses
- Results publication preparation
- Presentation in conference
- Dissertation preparation