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

Kazumi Sakai

Supervisor: prof. Ing. Křupka Ivan, Ph.D.

Institute of Machine and Industrial Design

Faculty of Mechanical Engineering

Brno University of Technology

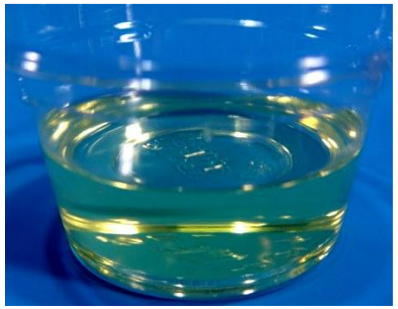
Discourse on the Dissertation Thesis
15th Feb. 2017

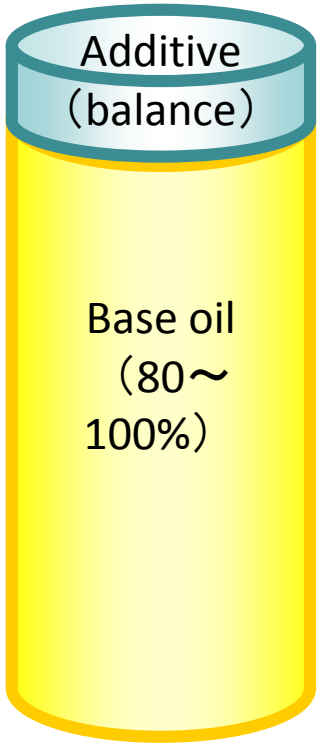
Institute of Machine and Industrial Design

Contents

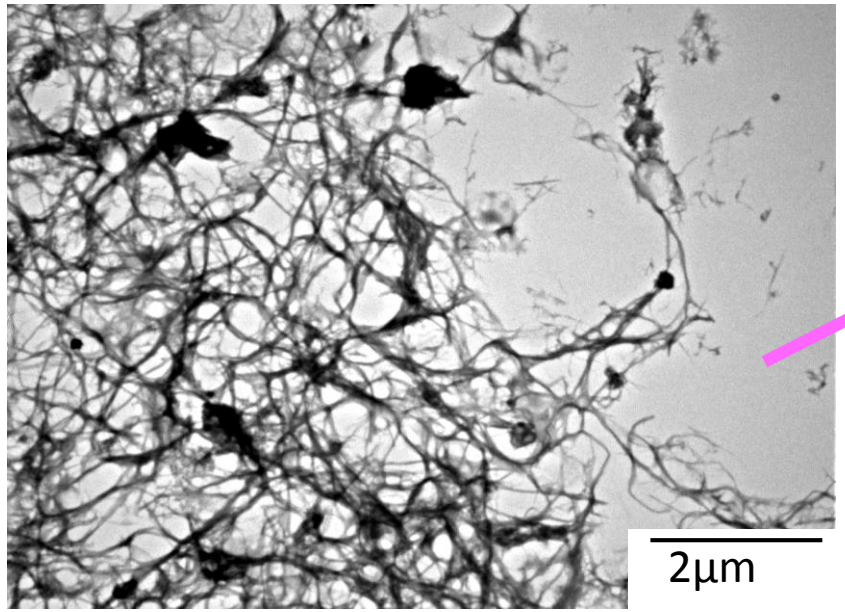
Introduction - Grease

Oil



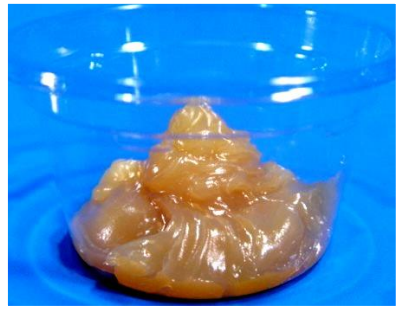


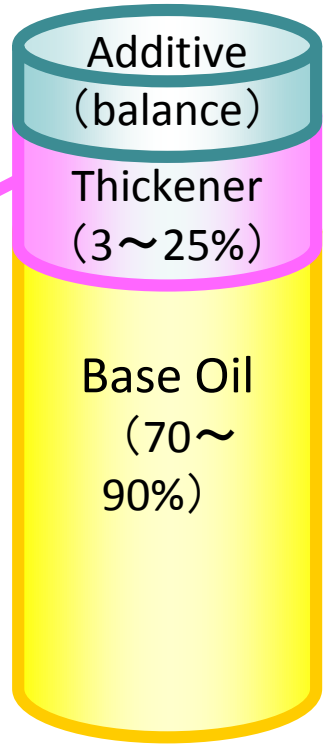
Grease is semisolid lubricant, composed of oil and thickener.



Thickener fiber network holds oil as if sponge does.

Grease





Introduction - Grease product development

Bearing lubrication

Grease

✓Not leaky
✓No circulation system
✓Low lubricant volume

Grease lubrication > 90%

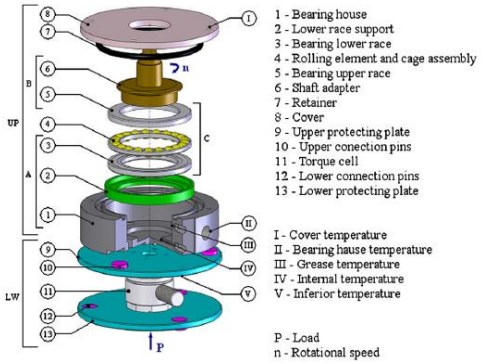
Global demand for energy-saving properties
in order to reduce CO_2 emissions.

Requirement for grease development

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

Mission Clarifying the relationship between grease formulations and mechanical losses

State of the art review and analysis

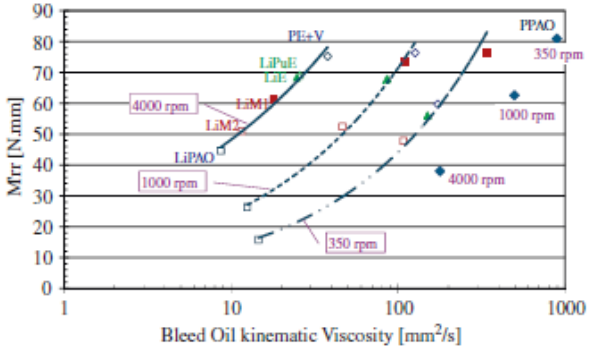


1. Bearing torque under grease lubrication

1.1 Thrust type

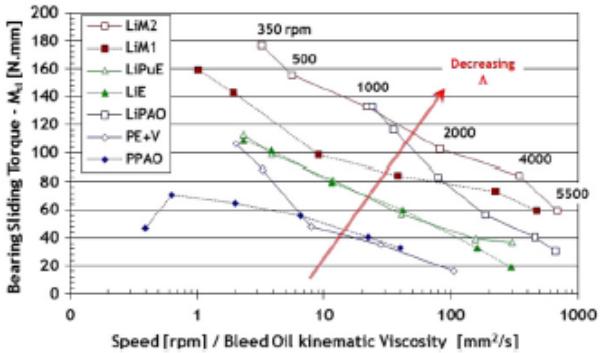
Seabra et al. decomposed a total friction torque into rolling torque and sliding torque.

Relevance; Rolling torque: base oil viscosity



High viscosity → High rolling torque

Sliding torque: film thickness



Thin film thickness → High sliding torque

-Vacancy: limited to thrust type bearing, commercial greases

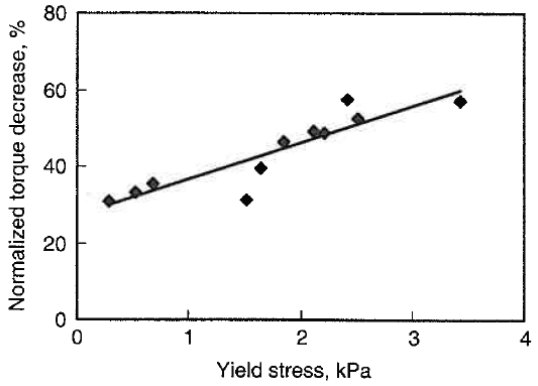
Cousseau, T., Graca, B., Campos, A., and Seabra, J., "Friction Torque in Grease Lubricated Thrust Ball Bearings," *Tribology International*, 44, 2011, 523-531.
Cousseau, T., Graca, B., Campos, A., and Seabra, J., "Experimental Measuring Procedure for the Friction Torque in Rolling Bearings," *Lubrication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

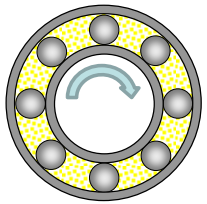
State of the art review and analysis

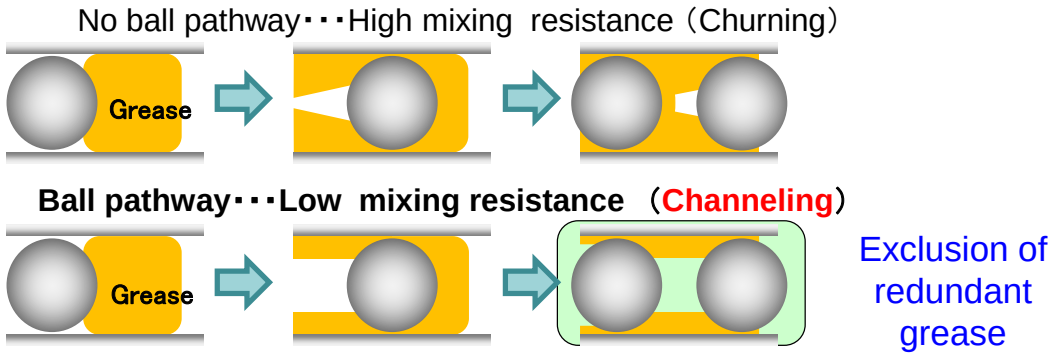
1. Bearing torque under grease lubrication

1.2 Radial type

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







*Channeling and churning of grease

High yield stress → Torque reduction

Due to grease channeling

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

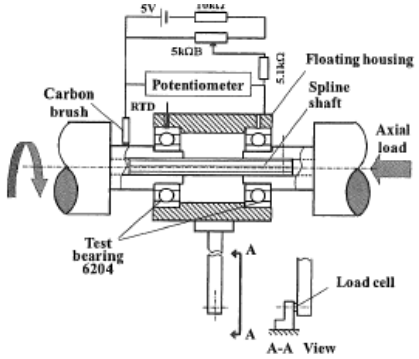
Oikawa, E., Inami, N., Hokao, M., Yokouchi, A., and Sugimura, J., “Bearing Torque Characteristics of Lithium Soap Greases with Some Synthetic Base Oils,” *Proc IMechE Part J: J Engineering Tribology*, 226, 6, 2012, 575-583.

State of the art review and analysis

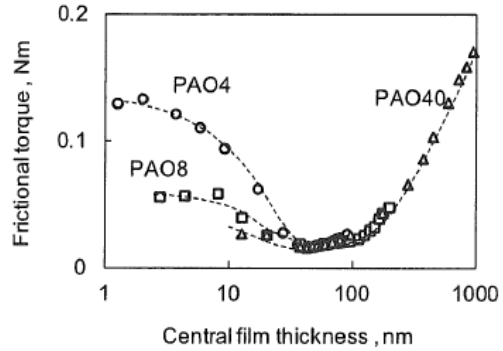
1. Bearing torque under grease lubrication

1.2 Radial type

Dong et al. reported dependence of base oil viscosity of Li greases on film thickness and bearing torque.



Electrical potential method for film thickness measurement



High film thickness →
lower torque in slow speed.

-Vacancy: limited to the same thickener type(Li-12OH-stearate) and the same type base oil (PAO)

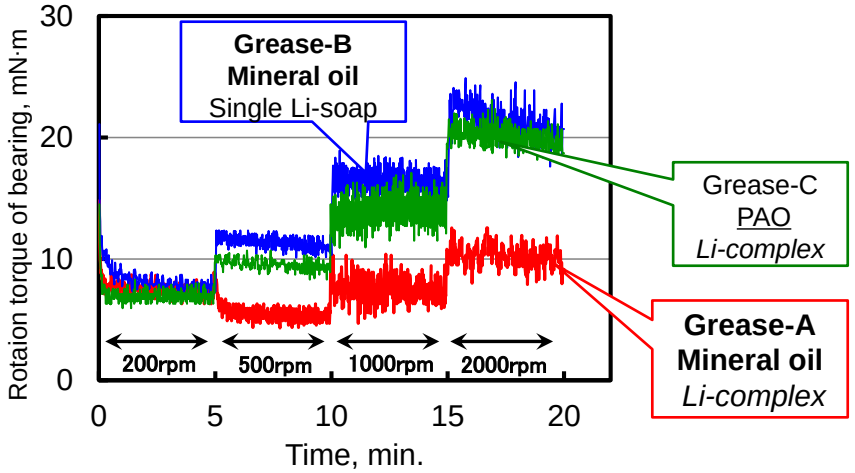
Dong, D., Komoriya, T., Endo, T., and Kimura, Y., "Formation of EHL Film with Grease in Ball Bearings at Low Speeds," *Journal of Japanese Society of Tribologist*, 57, 8, 2012, 568-574 (in Japanese).

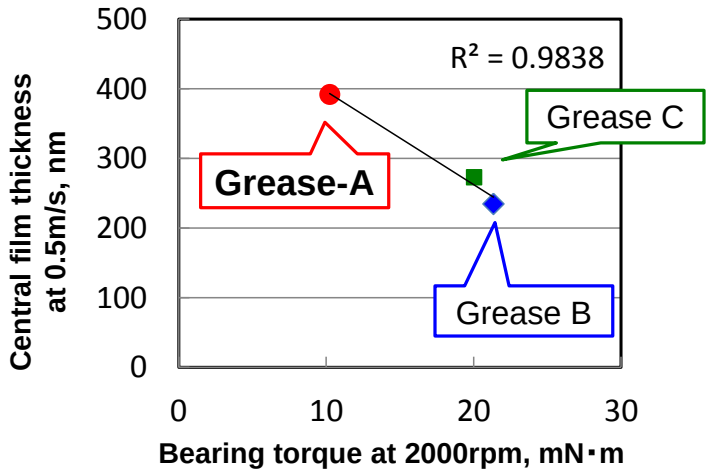
State of the art review and analysis

1. Bearing torque under grease lubrication

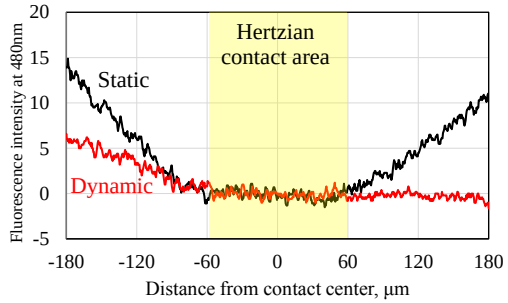
1.2 Radial type

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

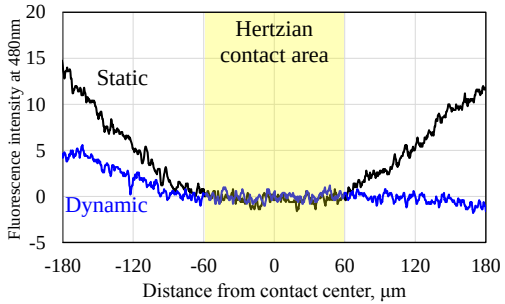




High film thickness →
lower torque in high speed.



Different grease existence in the inlet by fluorescence technique



-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

1. Bearing torque under grease lubrication

Summary

- Thrust type: base oil viscosity / grease film thickness related to rolling / sliding torque
- Radial type: yield stress of greases relates to channeling
  high grease film thickness reduces torque

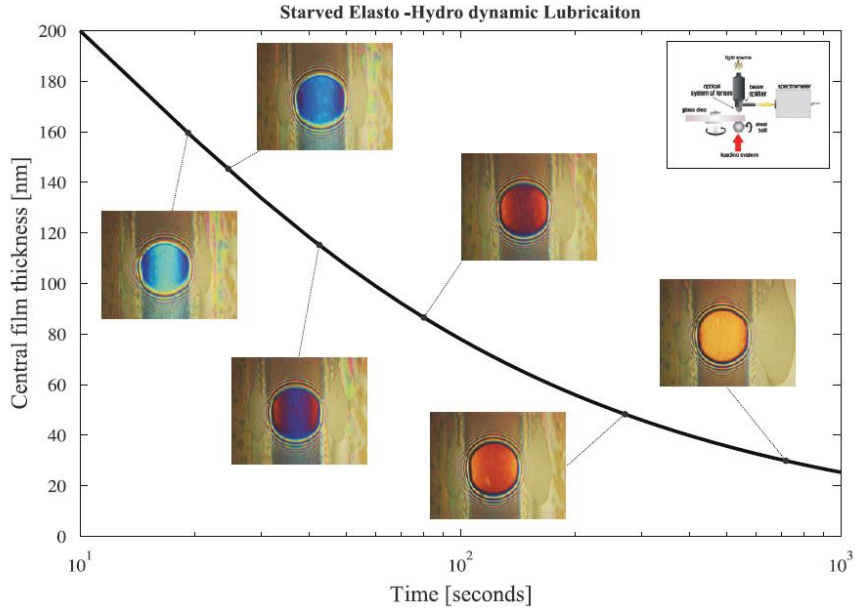
Can these tendency be applicable to all type greases ?

How about other approaches for understanding bearing lubrication with greases?

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.

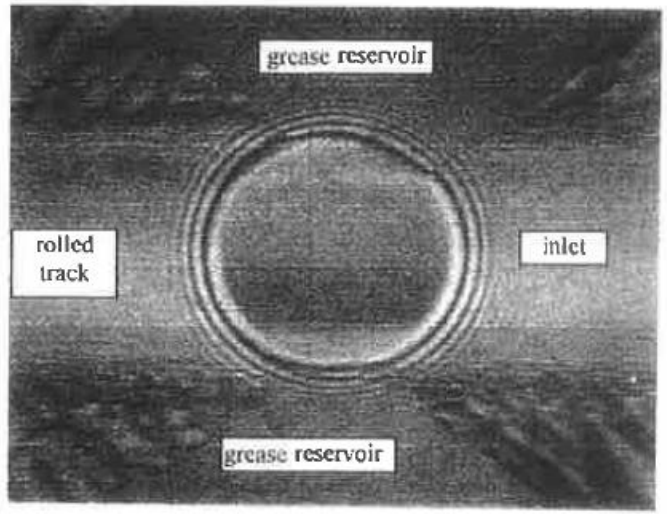
-Vacancy: no direct information about relationship with bearing torque

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.

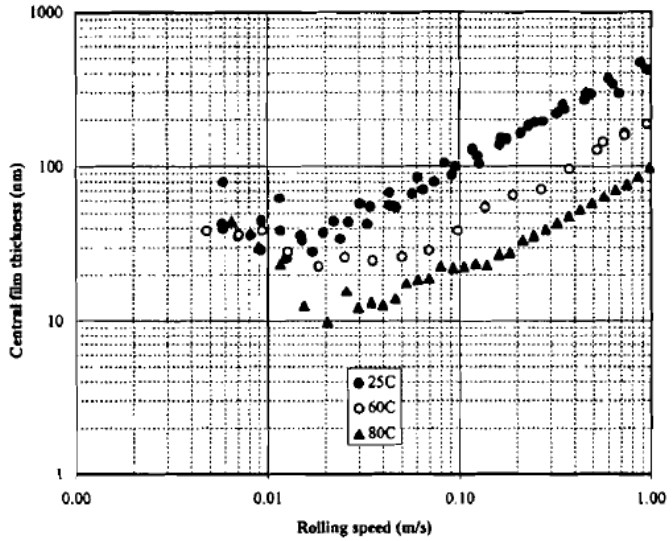
State of the art review and analysis

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.

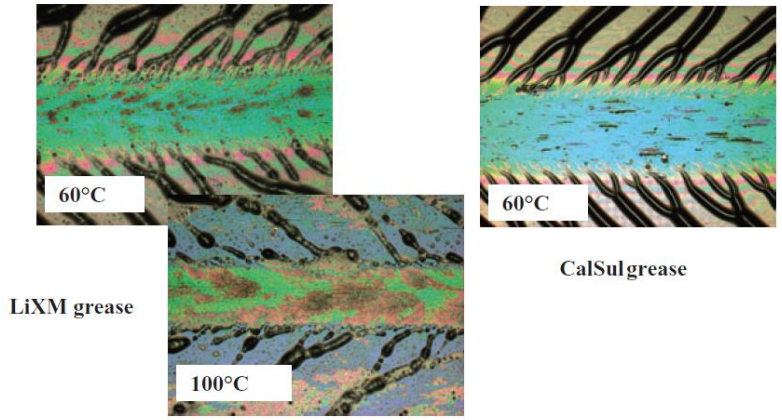
-Vacancy: no direct information about relationship with bearing torque

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.

State of the art review and analysis

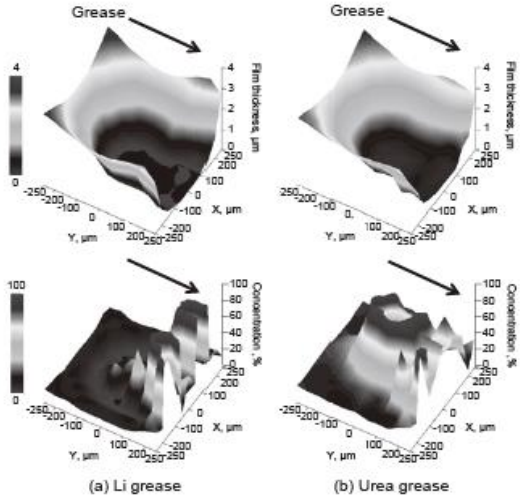
4. Chemical analysis of grease film thickness

Cann et al. analyzed deposited solid layer on tracks with each thickener type grease by FT-IR.



High thickener concentration on tracks

Hoshi et al. reported IR in-situ observation by using steel ball and silicon disk tribometer.



In contact areas, thickener concentration decreased in Li type and increased in urea type.

-Vacancy: no direct information about relationship with bearing torque

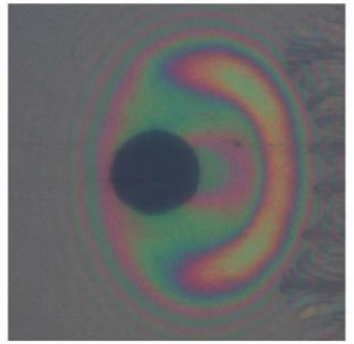
Cann, P. M., "Grease Lubrication of Rolling Element Bearings – Role of the Grease Thickener," *Lubrication Science*, 19, 2007, 183-196.
Hoshi, Y., Takiwatari, K., Nanao, H., Yashiro, H., and Mori, S., "In Situ Observation of EHL Films of Greases by a Micro Infrared Spectroscopy," *Journal of Japanese Society of Tribologist*, 60, 2, 2015, 153-159(in Japanese).

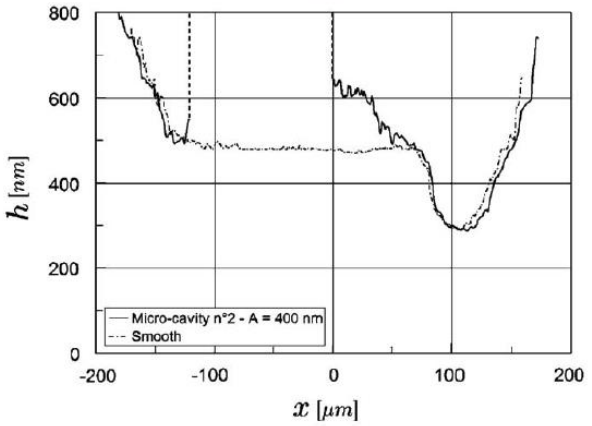
State of the art review and analysis

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

Thrust type

Seabra (Cousseau)

✓Rolling/Sliding torque factor

✗Only commercial grease

Main focus

Radial type

Yokouchi(Oikawa), Dong

Loss Factors

For reduction of torque…

Rheology Yield stress

Yokouchi

✓Channeling effect

✗Only 1 type Li thickener

Film thickness

Dong

✓High thickness in slow speed

✗Only 1 type Li thickener and base oil

Unknown parameters for Bearing torque

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

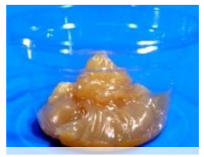
Essence and goals of the PhD thesis

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

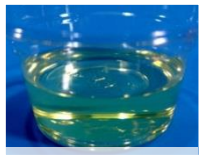
New findings for future grease product development

Essence and goals of the PhD thesis

◎Study of the relationship between grease formulations and bearing torque

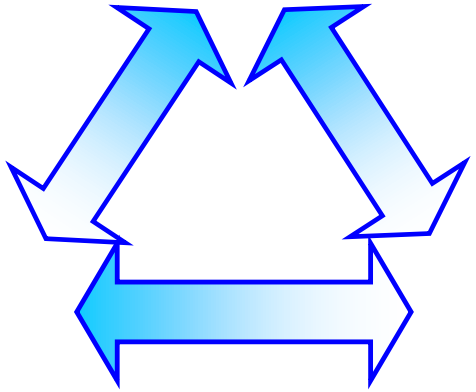


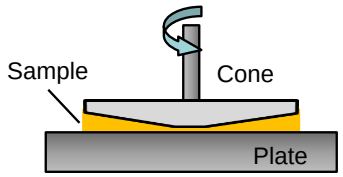
- Base oil
- Thickener



Grease formulation

Bearing torque





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

Factor evaluation

Research method

2. Bearing torque

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

Research method

3. Film thickness

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

Texture: 200-1000nm depth

→Tungsten carbide ball indentation

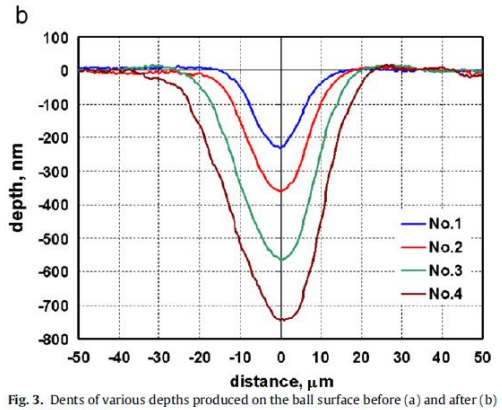
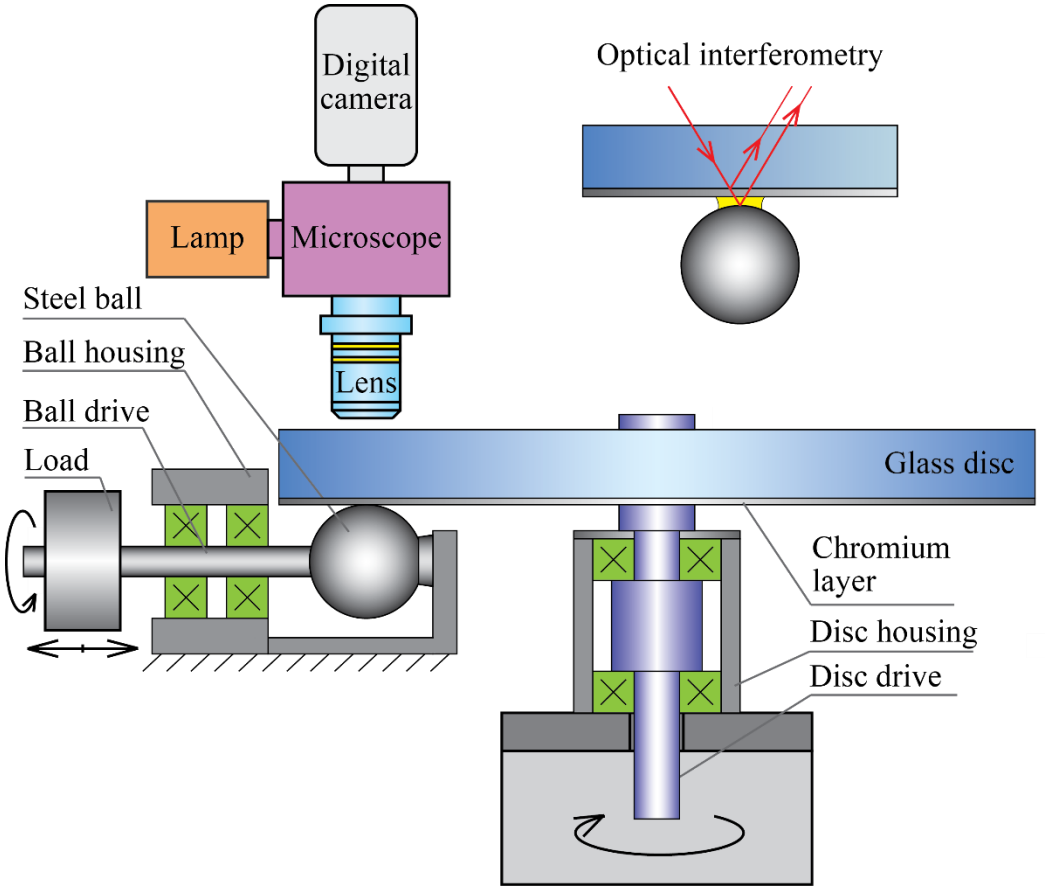


Fig. 3. Dents of various depths produced on the ball surface before (a) and after (b) surface polishing.



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.

Expected outcome and publications

Publication and presentation plan

- Tribology International ← 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)
- 44th Leeds-Lyon Symposium ← textured surface results (2017 Sep.)

⇒ 1 paper and 3 presentations

Future work

Grease preparation

✓ Grease thickener dependence

✕ **Grease penetration dependence (Focused on G-I base oil)**

Grease film thickness considering surface conditions

✓ Measurement on smooth surfaces

✓ Indenter manufacture and calibration

✕ **Measurement on dented surface (dent depth dependence)**

Grease characterization (Bearing torque, Rheology, thickener fiber, traction coefficient)

✓ Bearing torque (Except for penetration dependence)

✓ Viscosity, viscoelasticity (Except for penetration dependence)

✓ Transmission Electron Microscope (Except for penetration dependence)

✕ **MTM**

Scientific biography

Kazumi Sakai

Presentation in International 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.

Thank you for attention

Kazumi Sakai
zzw30rs@gmail.com

http://**uk.fme.vutbr.cz/**

Institute of Machine and Industrial Design