SKF®

Slijtage in hoogbelaste gesmeerde contacten

Presented to:

Bijeenkomst Bond voor Materialenkennis, Aludra, Vlaardingen

Presented by:

Dr. ir. Mark van Drogen,

team leader Functional Surfaces

SKF/Engineering and Research Centre

2011-04-27

1

Intro SKF

SKF Engineering & Research Centre

The SKF Engineering Research Centre (SKF ERC) is located in the SKF Business & Technology Park in Nieuwegein, the Netherlands.

The SKF Engineering & Research Centre has been established in 1972 as the core of SKF Research & Development.

SKF Engineering & Research Centre

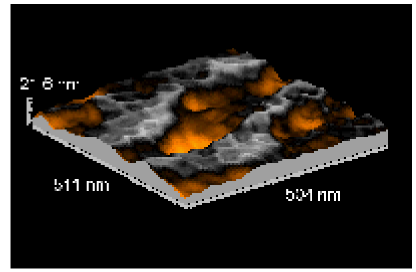
- High level R&D through over a 100 research professionals from more than 25 countries
- Technology for the SKF Platforms
- Product development support the SKF Divisions
- Specialized application support for SKF Customers

Organisation ERC

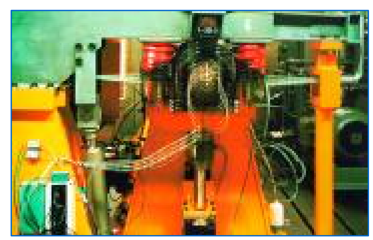
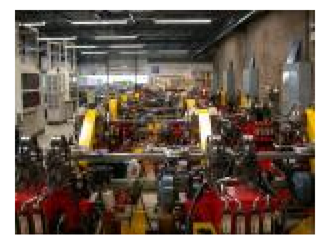
Based on Competence Areas

Located in Five departments

- Lubrication & Metallic Materials
- Sealing & Functional surfaces
- Modelling & Simulation
- Mechatronics
- Testing

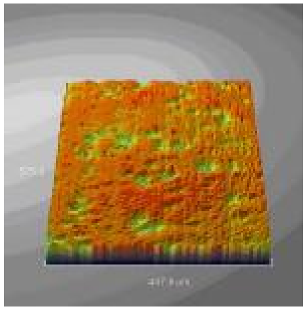


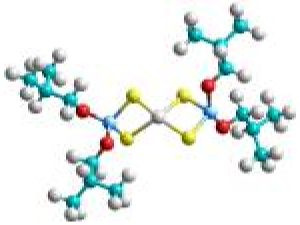
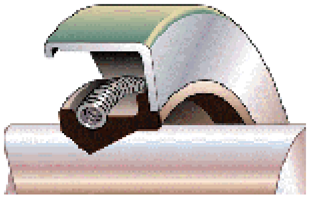


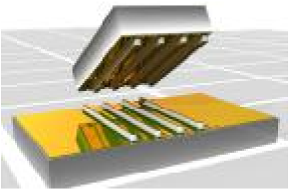
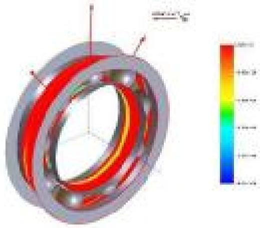



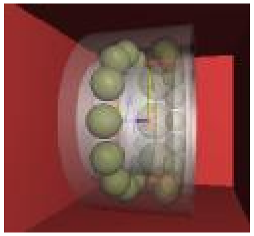
Competence Areas in SKF ERC

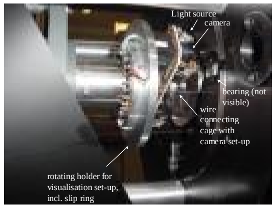
- Steel & Heat treatment
- Ceramics
- Coating
- Polymers & Elastomers
- Sealing
- Lubrication
- Tribo-Chemistry
- Computer modelling & simulation
- Mechatronics
- Testing
- Tribology & Functional Surfaces





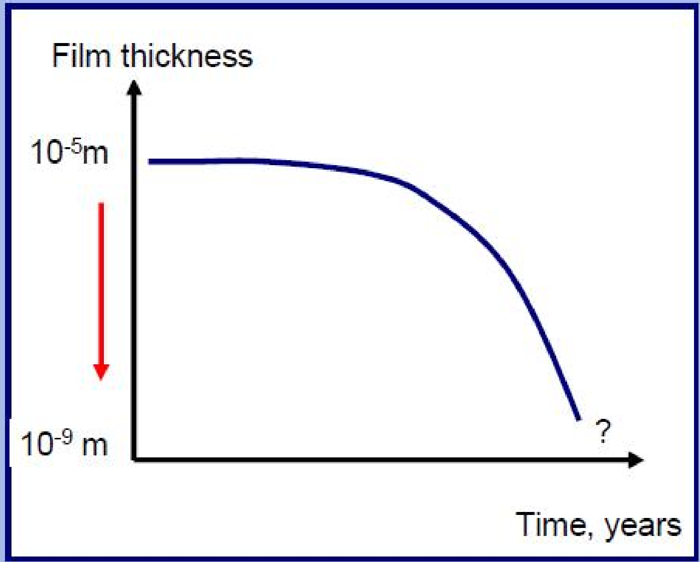


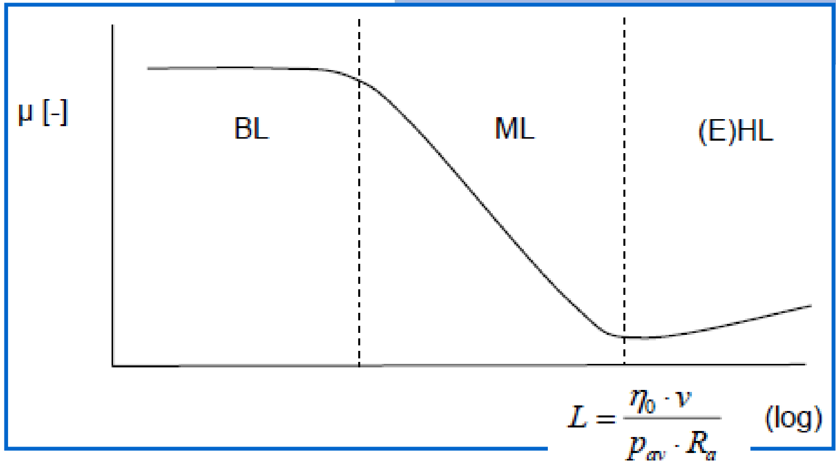
Bearing Life – Drivers

CONTEXT: Highly Loaded Lubricated Contacts

Nowadays challenges:

- Smaller
- More powerful
- Less energy losses
- More boundary regime
- More tribochemistry
- Less lubricant
- Less pollution
- Cheaper

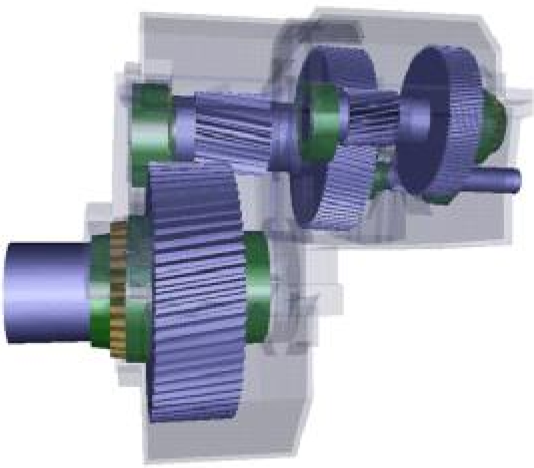




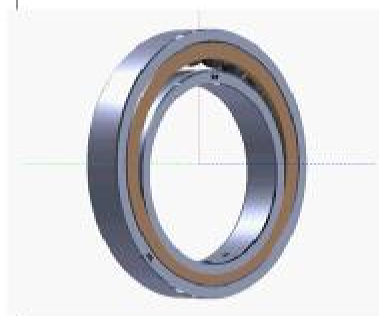
$$L = \frac{\eta_0 \cdot v}{p_{av} \cdot R_a}$$

SKF®

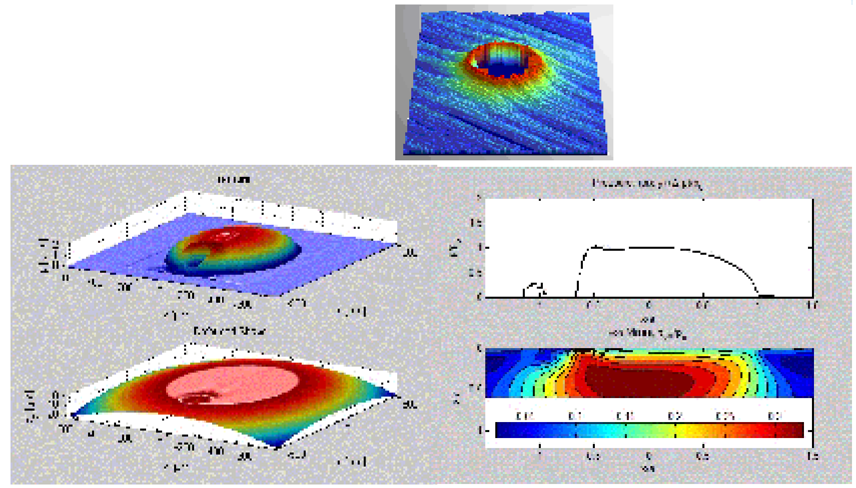
Multi-Scale Modelling in Tribology



System analysis



Bearing analysis

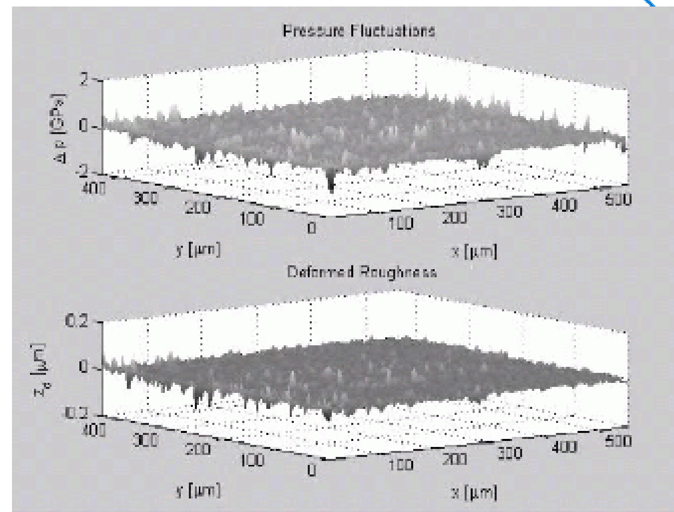


Surface analysis

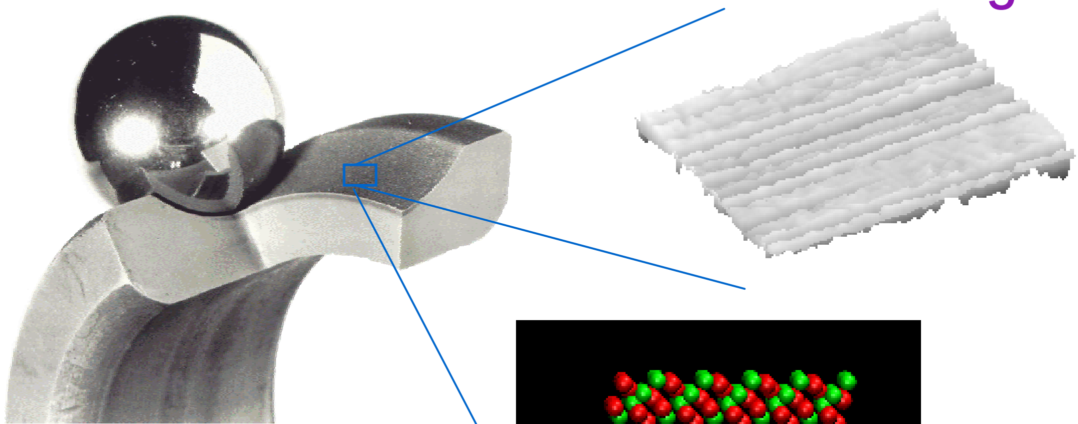
Tribology Models for In-Contact Topography and Tribochemistry Behavior

1. Fast models for gap, pressure, temperature and stress variations inside a <u>lubricated</u> contact:

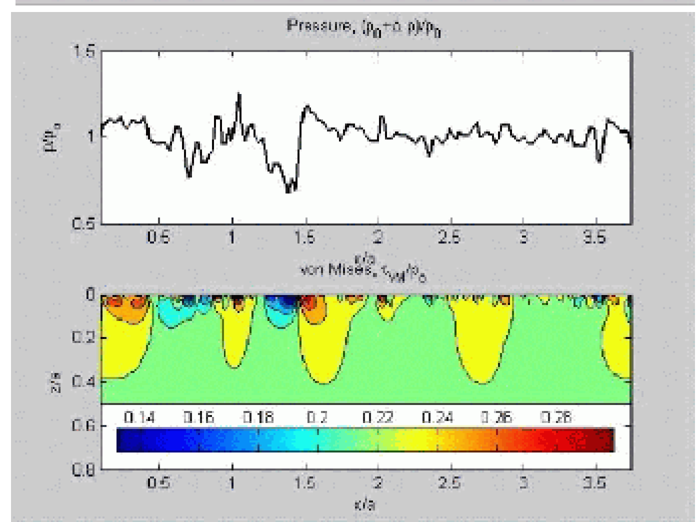
Pressures



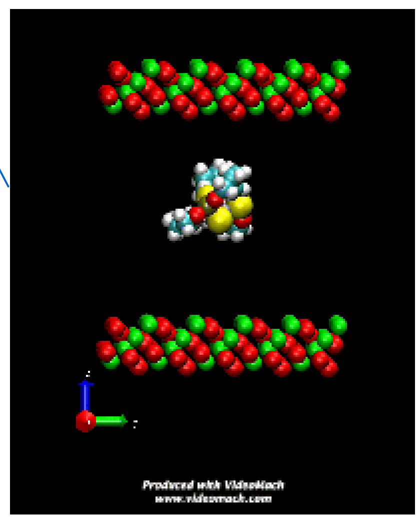
Roughness



Stresses



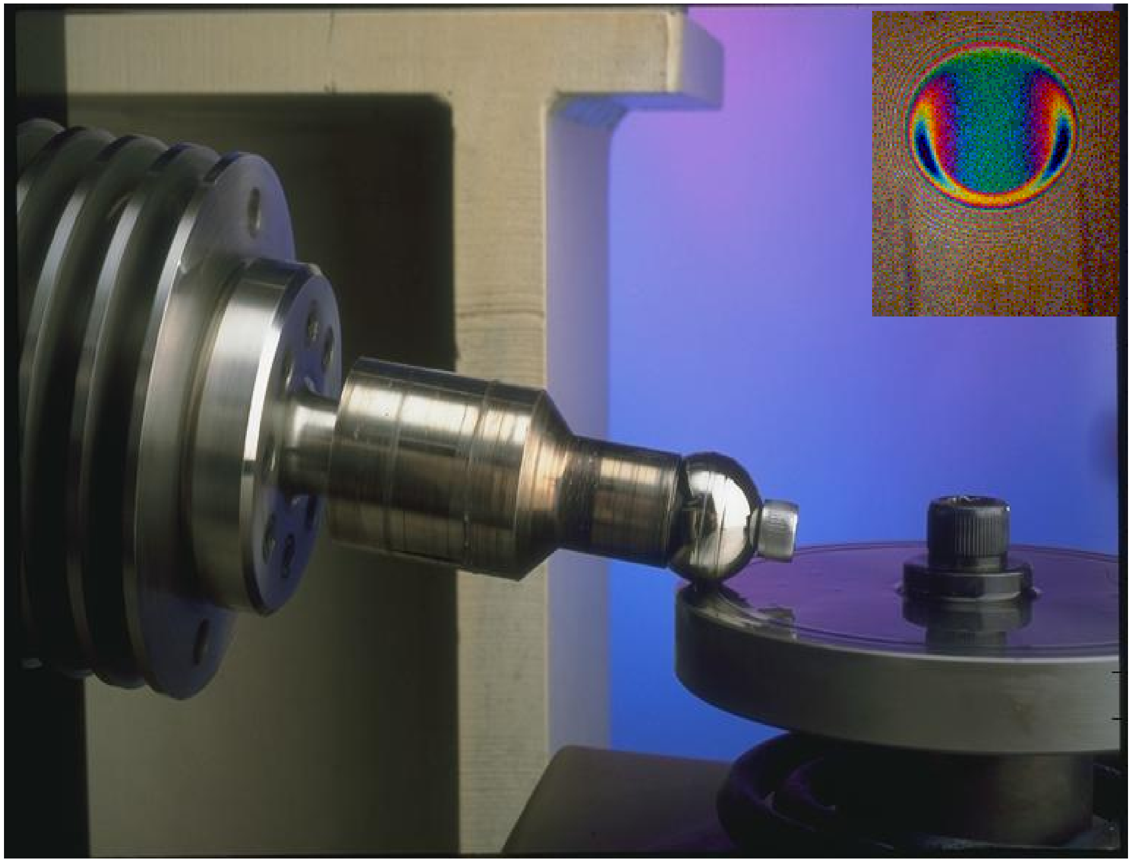
2. Tribochemisty:



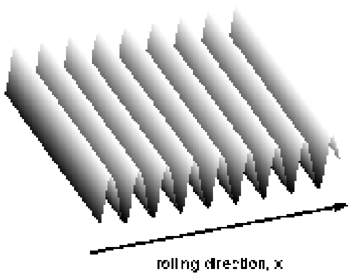
SKF®

Friction

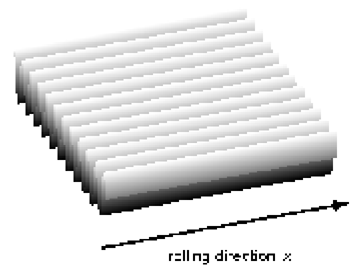
Film Thickness & Friction Detailed Measurement



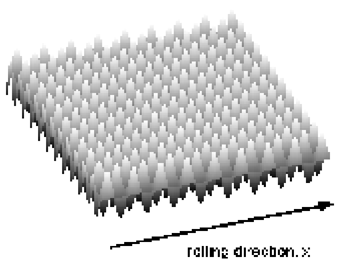
Surface Topography Optimisation



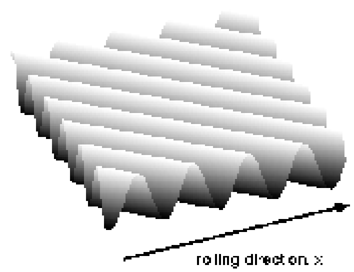
transverse



longitudinal



bi-sinusoidal



combined orientation

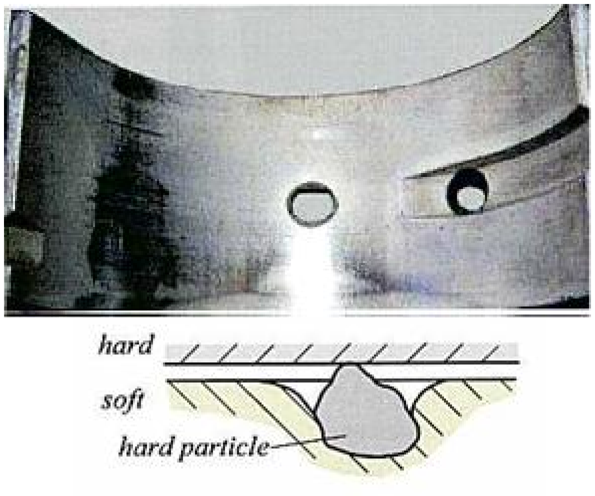
- Film Build-up
- Friction
- Temperatures
- Pressures
- Life

2

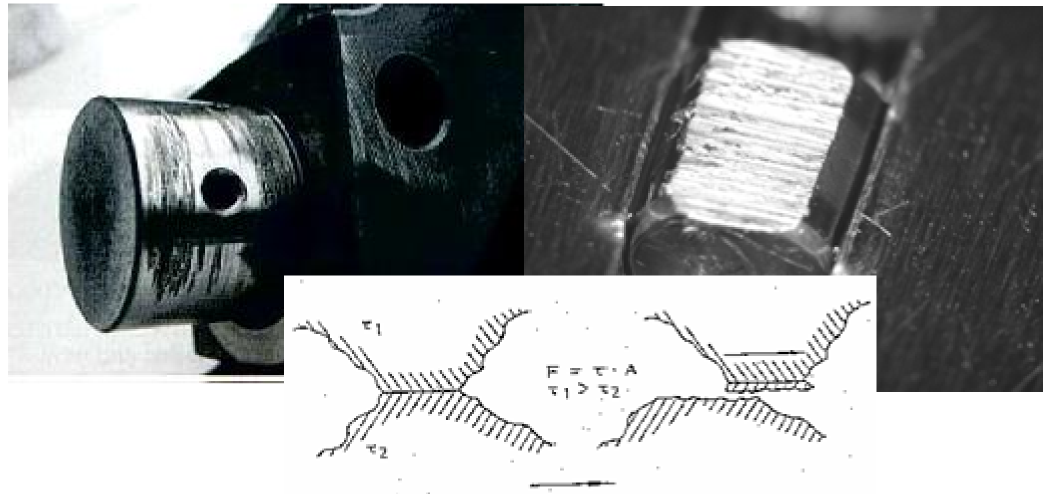
Wear and Failure diagrams

Lubricated Wear Mechanisms

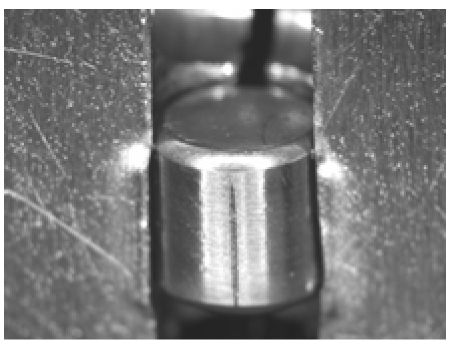
1. Abrasive wear



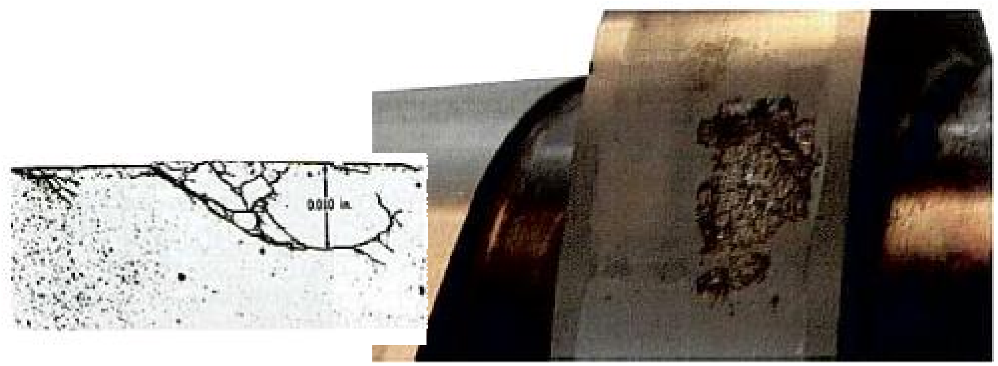
2. Adhesive wear



3. Tribo-Chemical wear

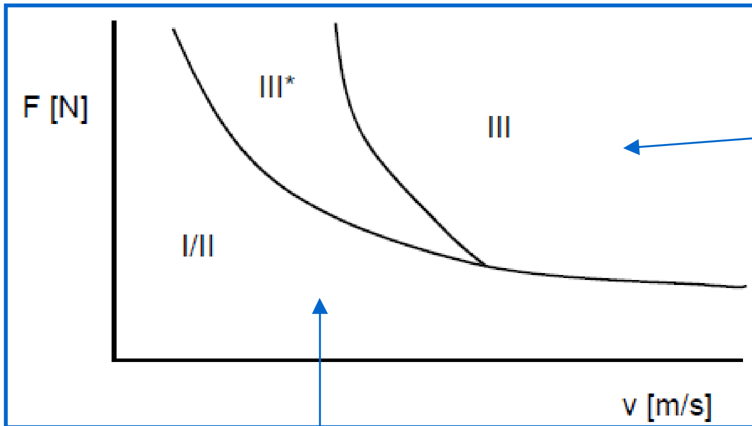


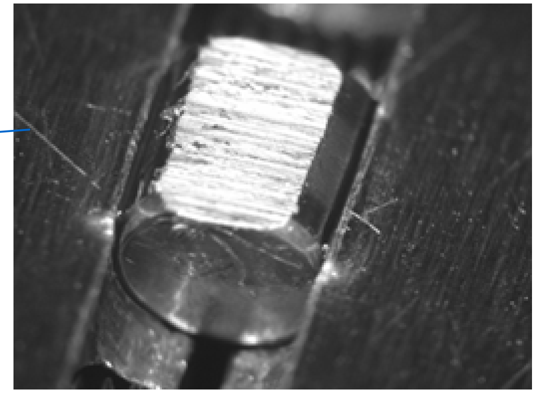
4. (sub)surface Fatigue wear

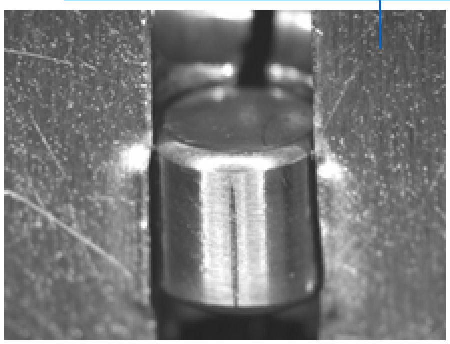


...and combinations!

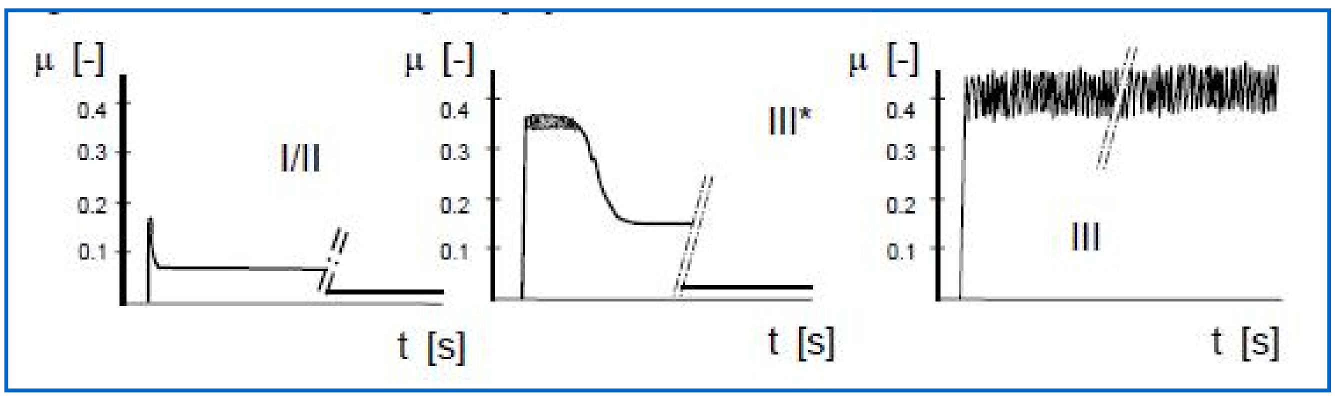
F/v Transition Diagram







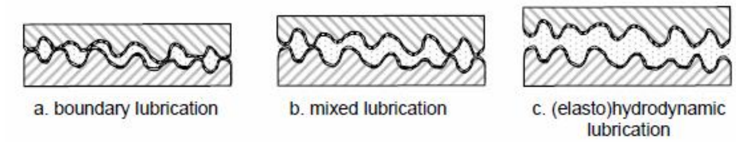
Transition from mild to severe adhesive wear

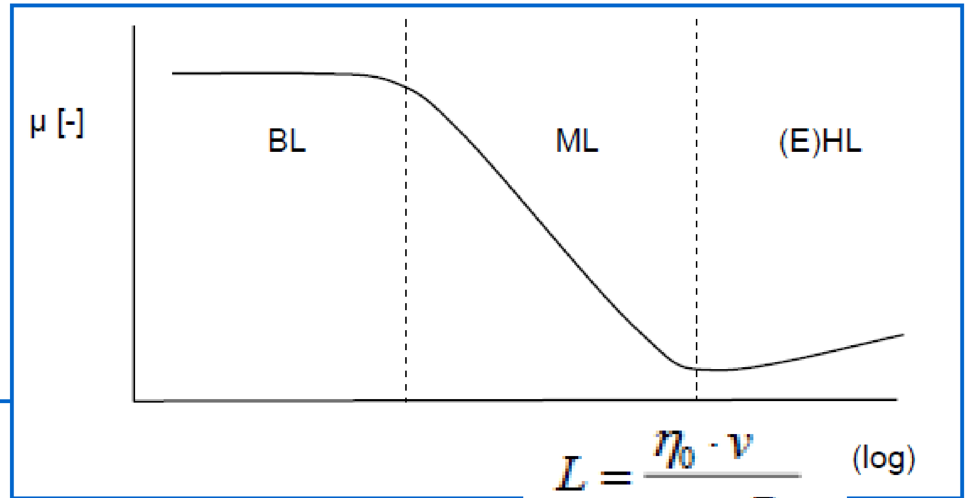


SKF®

Lines of defense against adhesive wear

1. EHL films
2. Surface/boundary films
3. Material strength

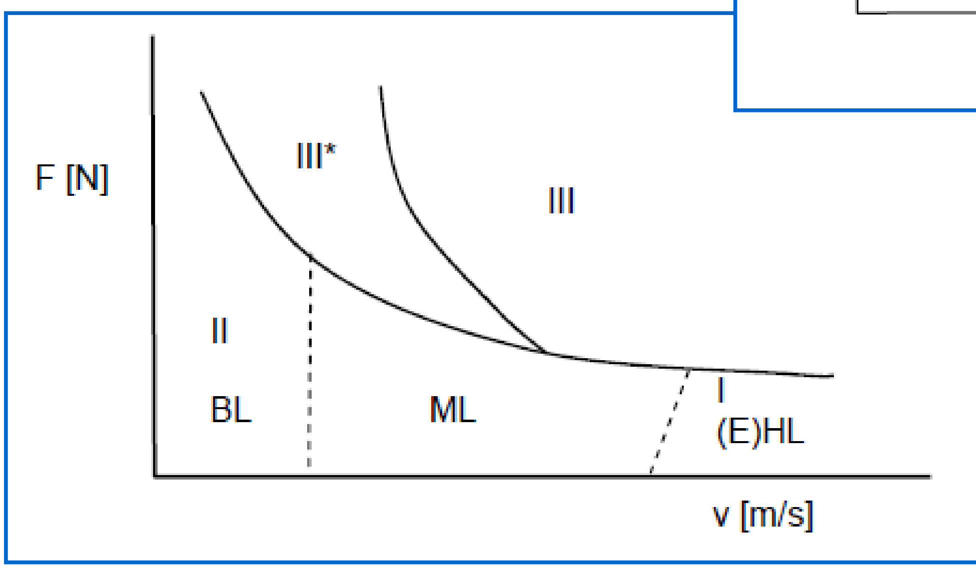




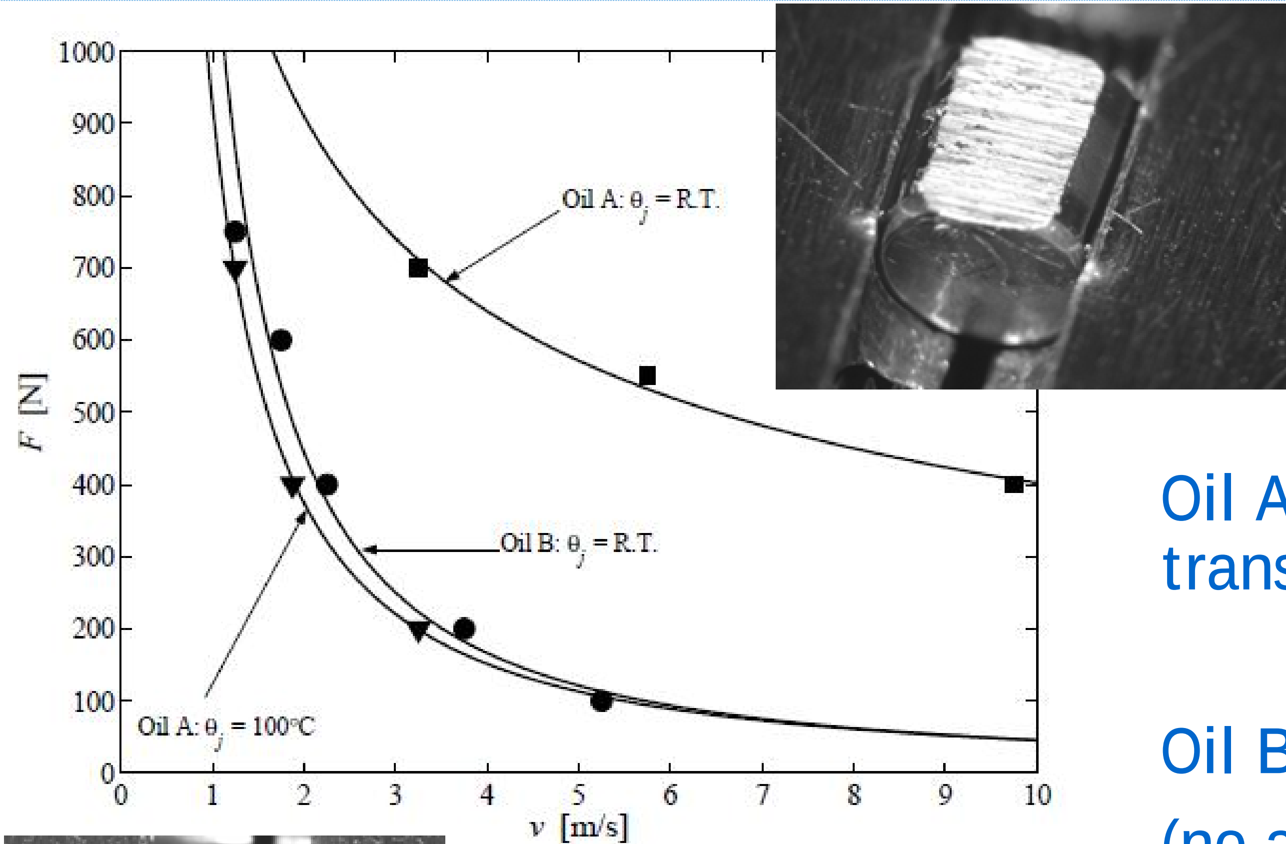
$$L = \frac{\eta_0 \cdot v}{p_{av} \cdot R_a}$$

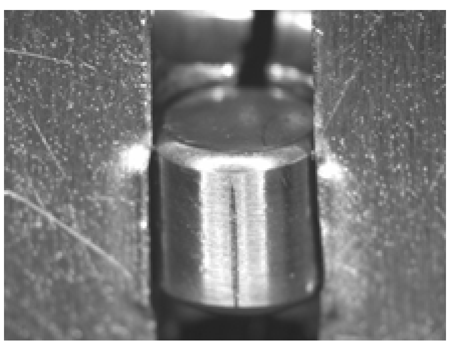
1 à 2 Stribeck curve:

mild wear



Pin-on-disk measurements





Oil A: fully formulated transmission oil

Oil B: mineral white oil (no additives)

3

F/v Transition Diagram Modelling

F/v Transition Diagram Modelling

Failure Hypothesis: critical oil temperature **à**
boundary layers cannot withstand the heat in the contact.

Analytical Modelling Approach

1. Deformation Model
2. Friction Model
3. Temperature Model

Include deterministic roughness description

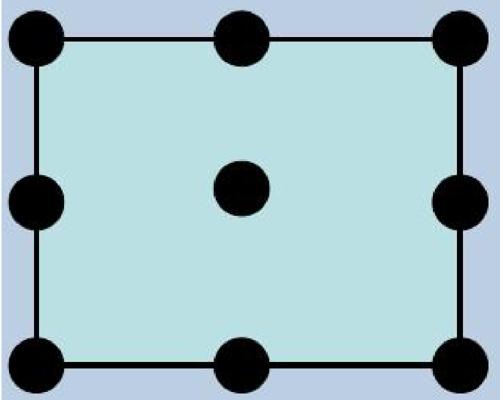
Source: M. van Drogen, 2005, *Transition to adhesive wear in lubricated concentrated contacts*, Ph.D. Thesis, University of Twente.

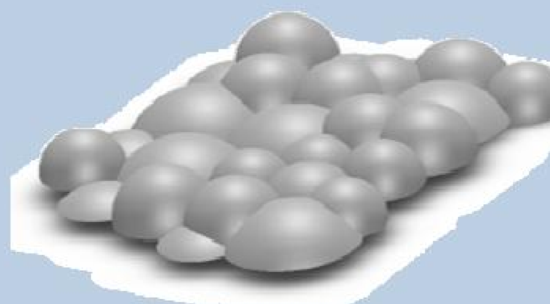
Roughess description: 9 points summit definition

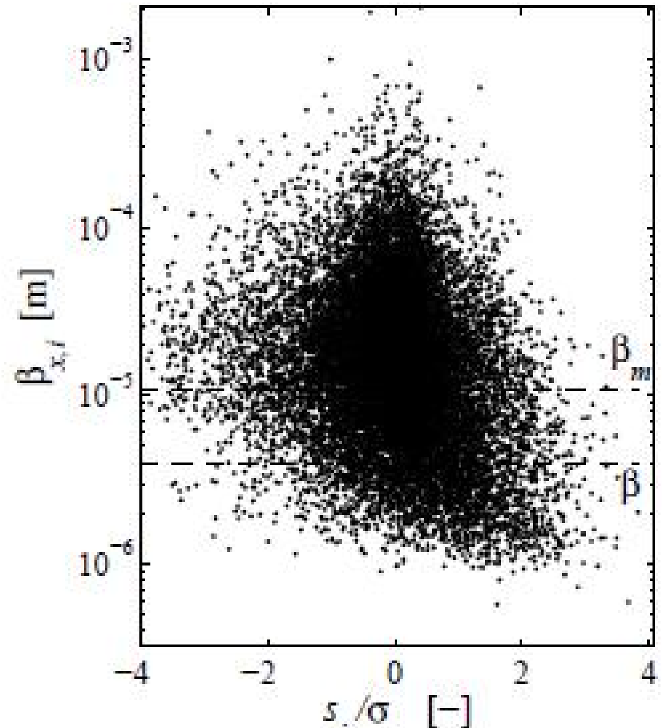
$$z_{x,y} > z_{x\text{-}1,y\text{-}1}, z_{x\text{-}1,y}, z_{x\text{-}1,y+1}, z_{x,y\text{-}1}, z_{x,y+1}, z_{x+1,y\text{-}1}, z_{x+1,y}, z_{x+1,y-}$$

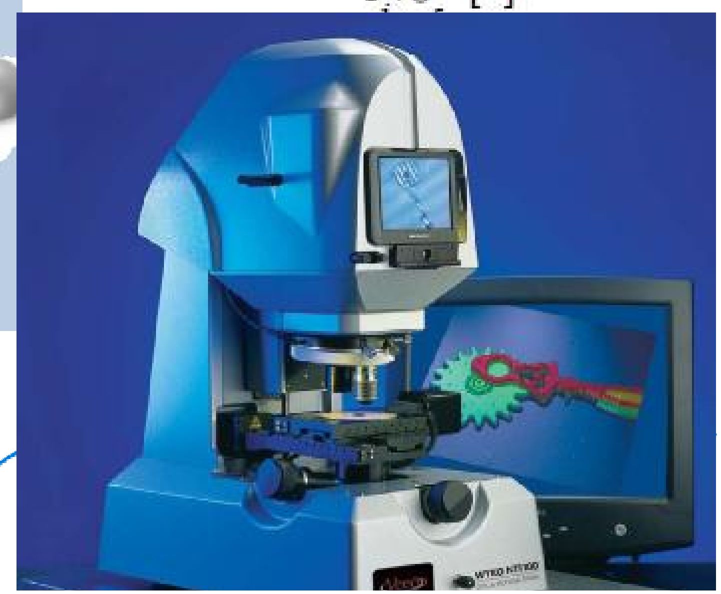
$$\rho_{x,i} = -\frac{1}{\beta_{x,i}} = \frac{z_{x\text{-}1,y} - 2z_{x,y} + z_{x+1,y}}{\Delta_x^2}$$

$$\rho_{y,i} = -\frac{1}{\beta_{y,i}} = \frac{z_{x,y\text{-}1} - 2z_{x,y} + z_{x,y+1}}{\Delta_y^2}$$



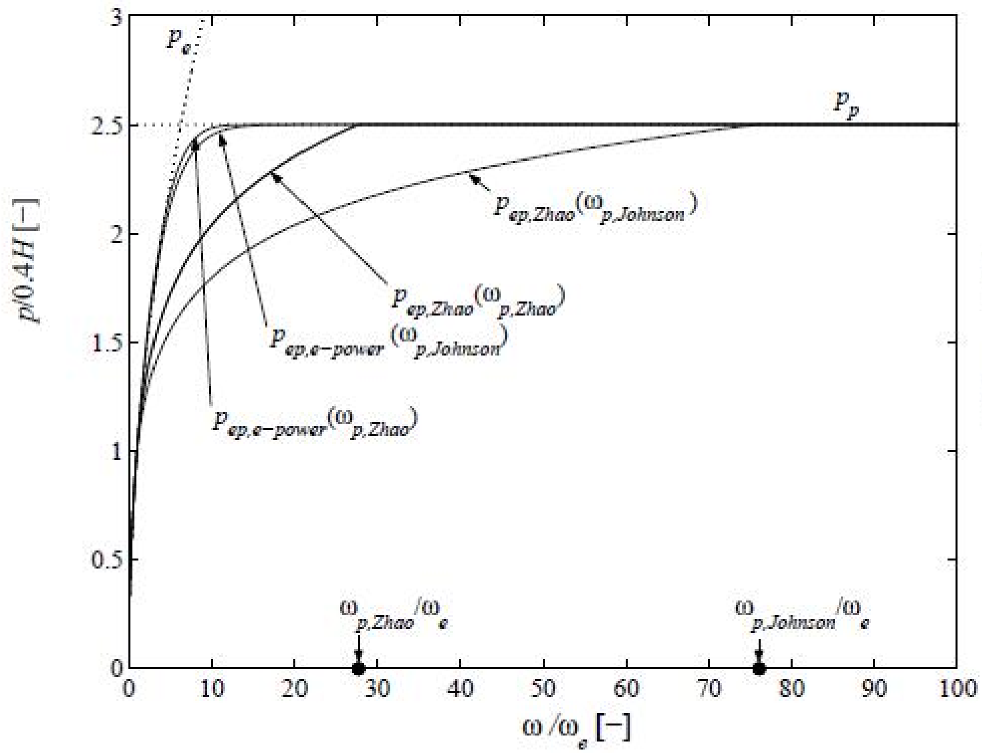


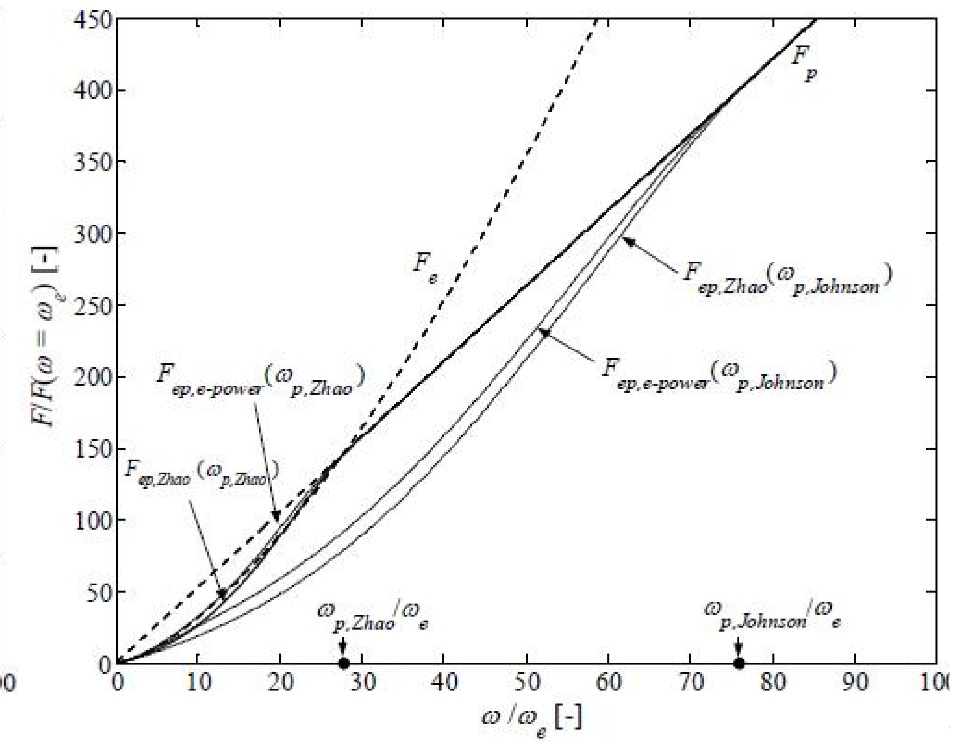




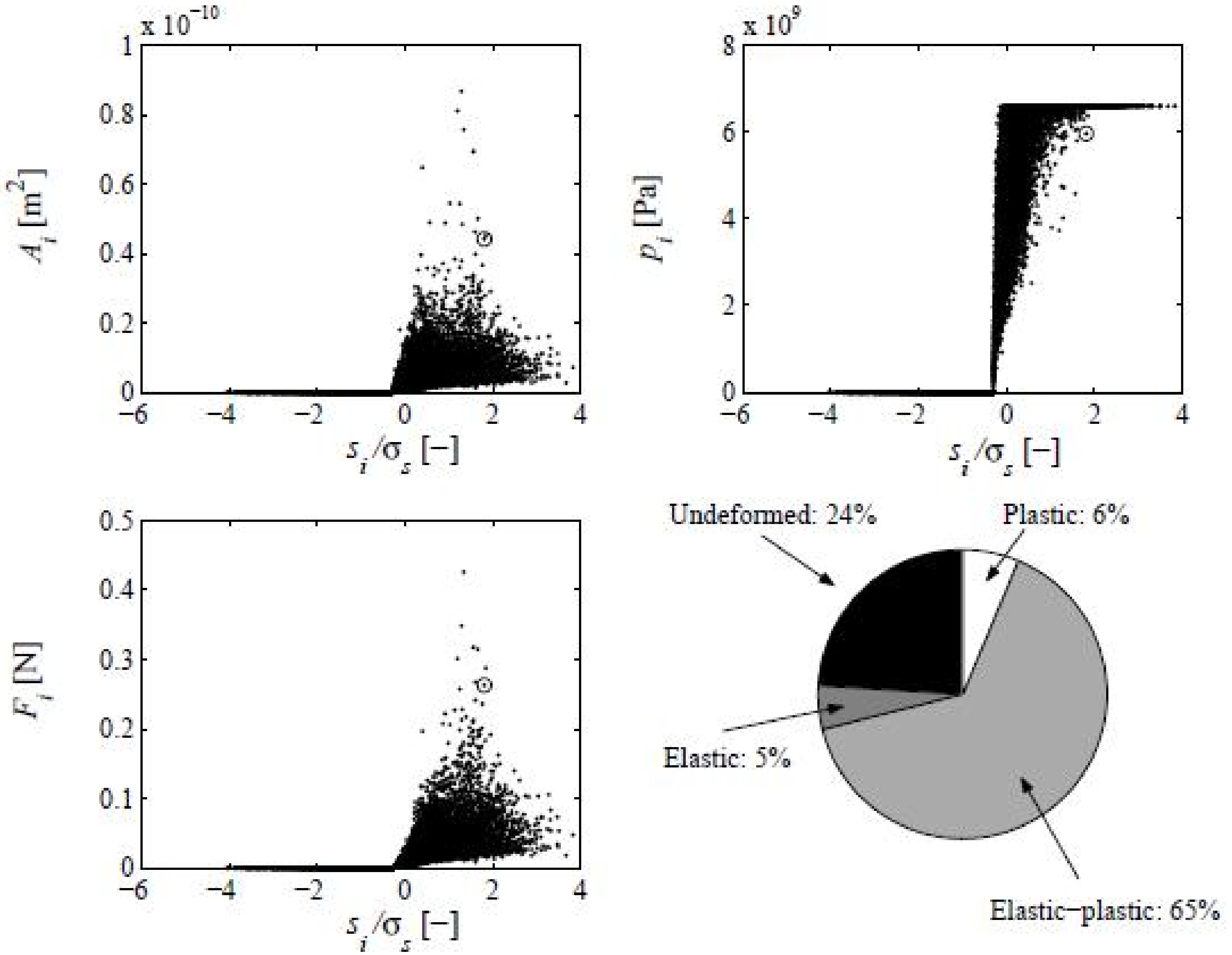
Deformation/Pressure Model

- Macroscopic deformation: Hertzian
- Microscopic/Summit deformation:
  (1) Elastic, (2) Elasto-Plastic or (3) Plastic





Deformation Modelling - example

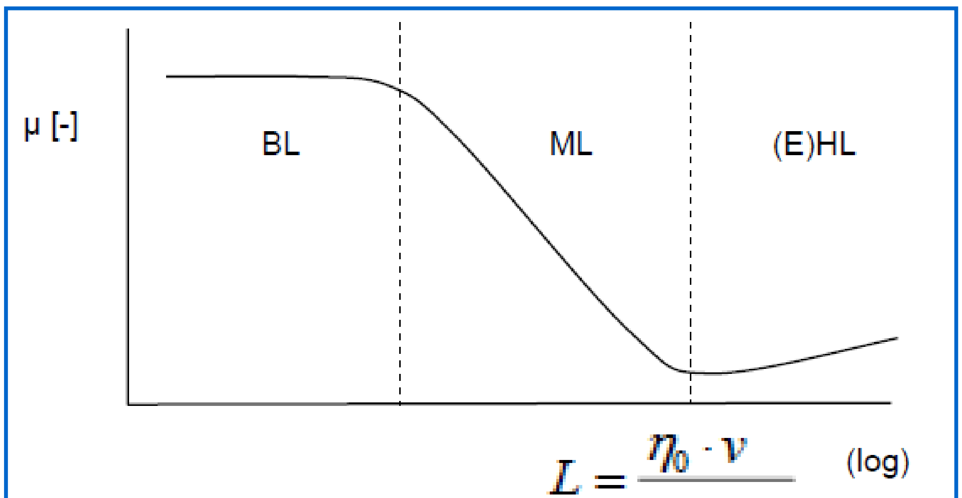


Friction Model

Stribeck curve included, according to

$$\mu = \frac{\sum_{i=1}^{n} \iint_{A_{C_i}} \tau_{C_i}\, dA_{C_i} + \iint_{A_{EHL}} \tau_{EHL}\, dA_{EHL}}{F} = \frac{\mu_C F_C + \mu_{EHL} F_{EHL}}{F},$$

Load is carried by both EHL film and BL-asperities

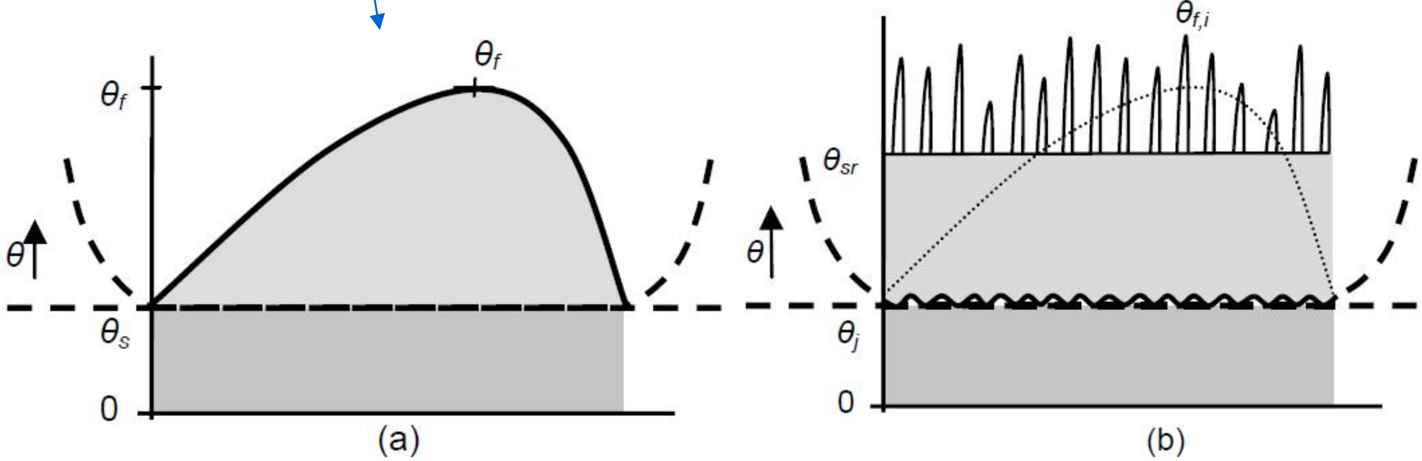


$$L = \frac{\eta_0 \cdot v}{p_{av} \cdot R_a}$$

Temperature Model

Blok's flash temperatures: no roughness

Microscale flash temperatures: so incl. roughness



$$\theta_c = \theta_s + \theta_f \geq \theta_{cr} \,.$$

$$\theta_{c,i} = \theta_s + \theta_{f,i} = \theta_j + \theta_{sr} + \theta_{f,i} \geq \theta_{cr}$$

Asperity temperatures

$$\theta = \frac{\mu F v}{\left(\frac{K_1}{\bar{\theta}_1} + \frac{K_2}{\bar{\theta}_2}\right)\sqrt{a_x a_y}},$$

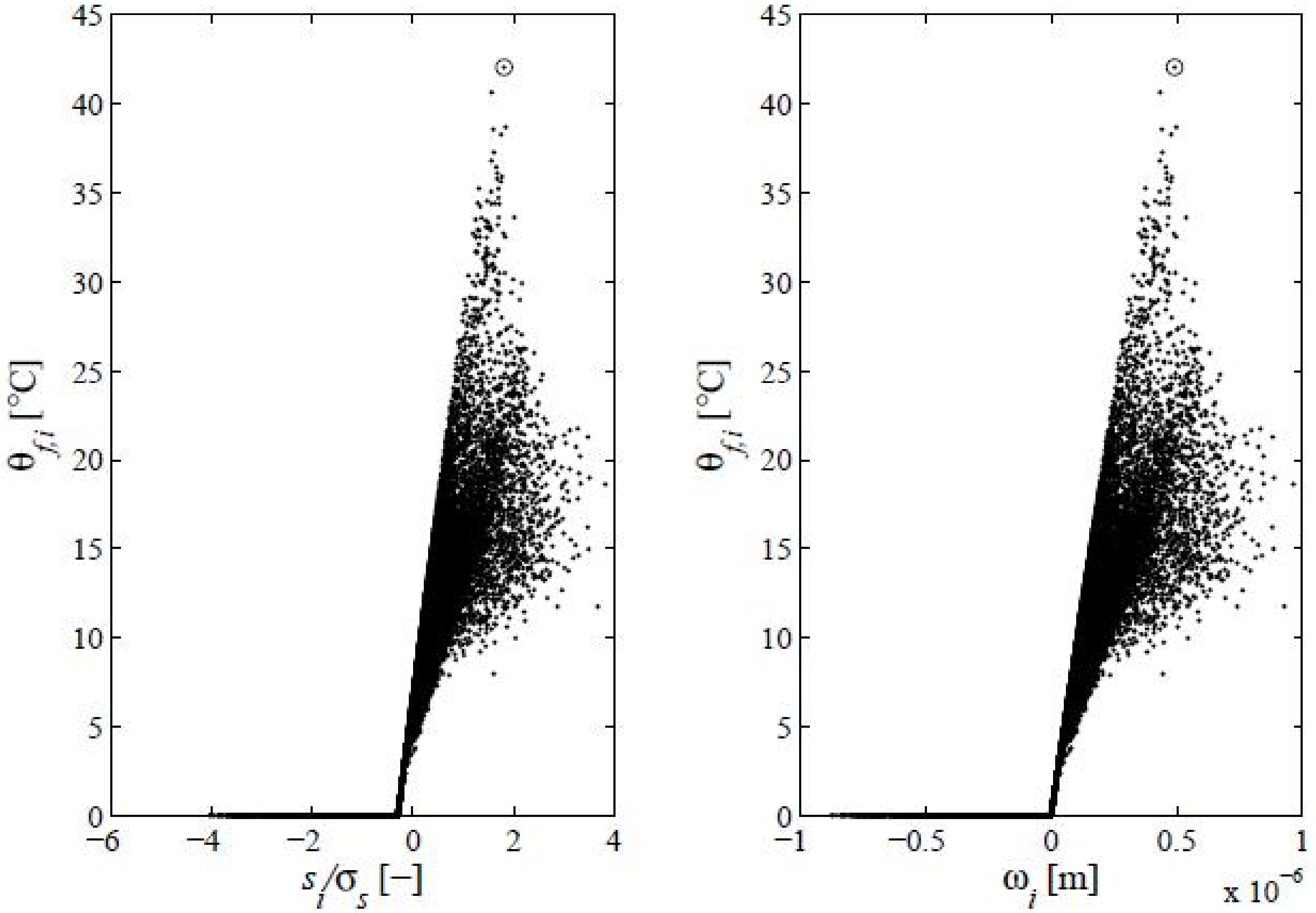
Temperature rise

$$\bar{\theta}_1 = \left[\left\{ \bar{\theta}_l^{kl} \mathbf{S}(\kappa) \right\}^s + \left(\bar{\theta}_h^{kl} \sqrt{\frac{\kappa}{Pe_1}} \right)^s \right]^{\frac{1}{s}}$$

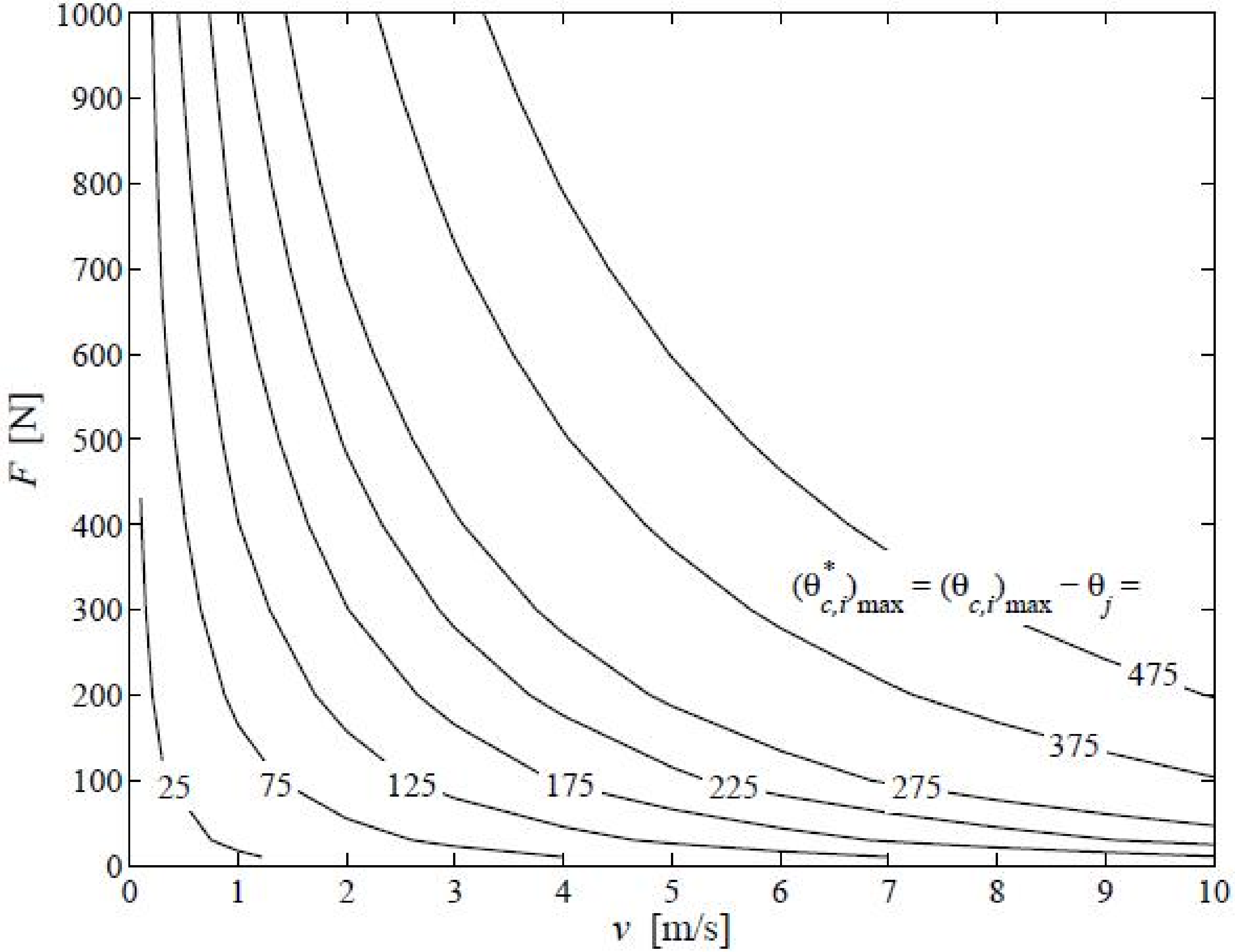
Low speed/Péclet: mainly conduction

High speed/Peclet: mainly convection

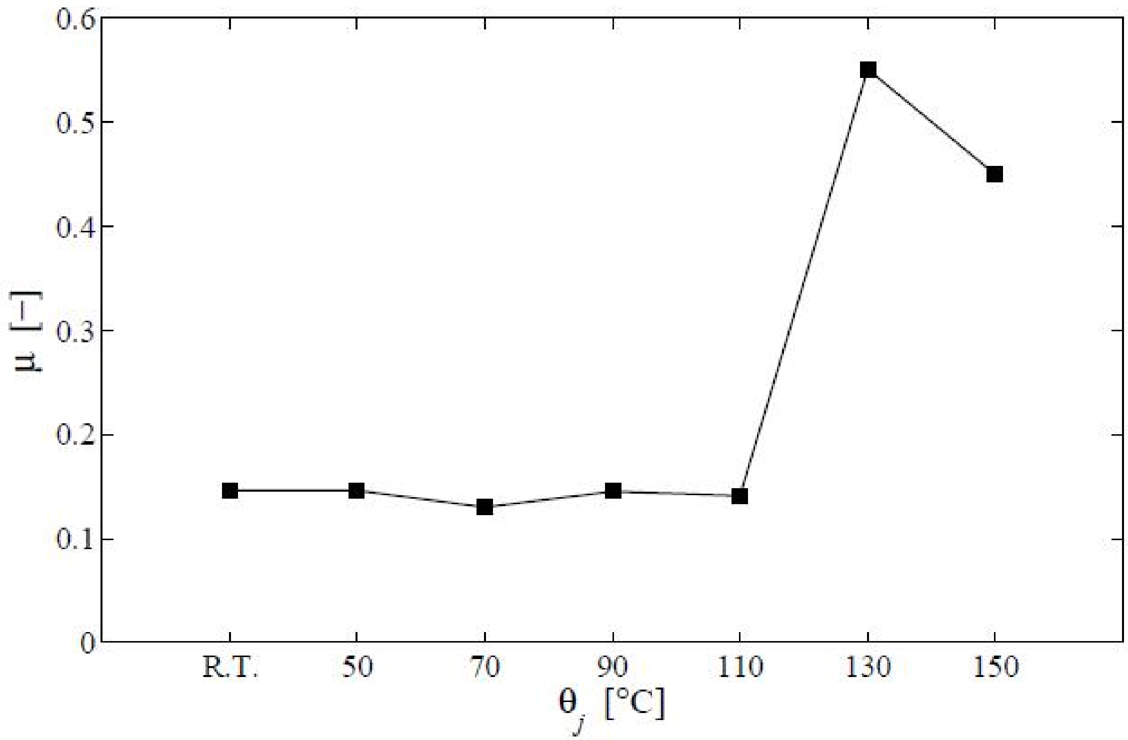
Flash Temperatures - example



F/v diagram modelling – critical temperatures



Critical oil temperature determination

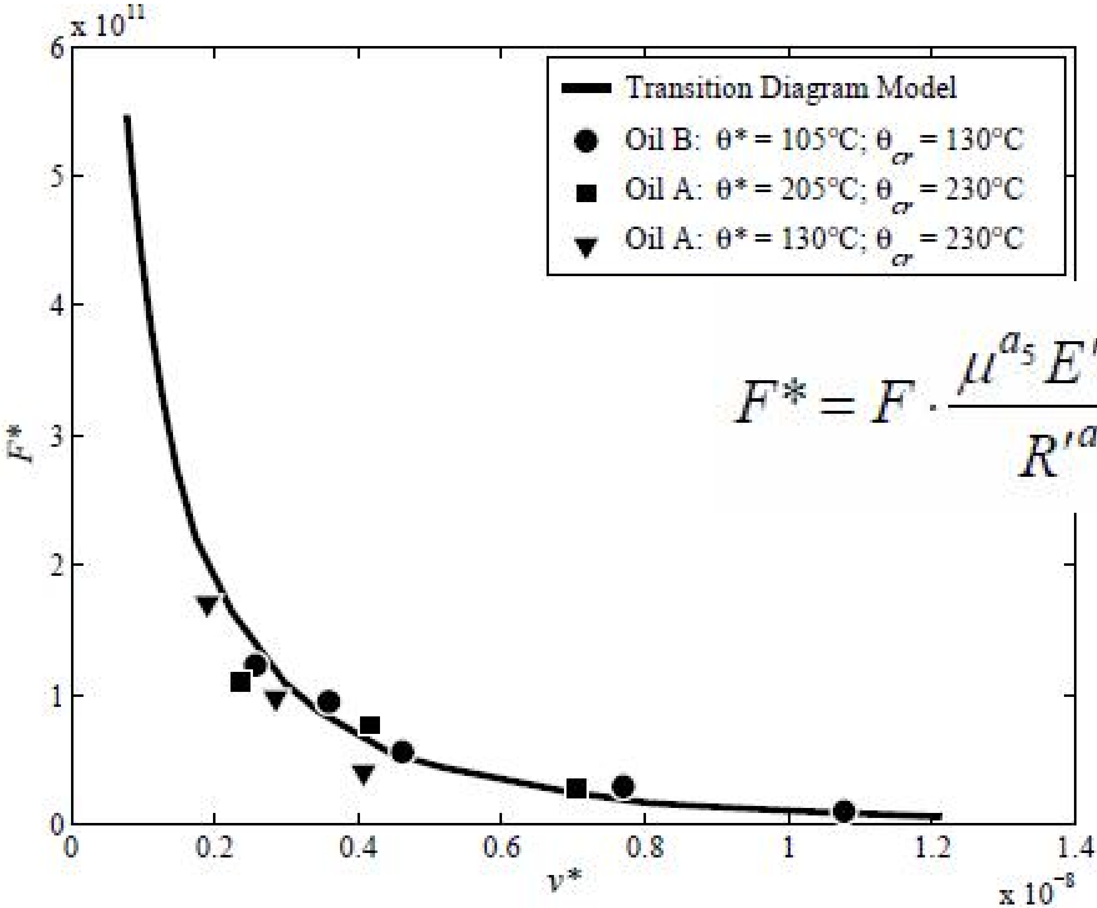


Pin-on-disk experiment for mineral white oil (oil B):

low F and low v (no frictional heat)

and heat up the oil until adhesive wear

Parameter study and validation



$$F^* = F \cdot \frac{\mu^{a_5} E'^{a_2} H^{a_4}}{R'^{a_1} \ell^{a_3}} \approx F \cdot \frac{\mu^{1.29} E'^{0.50} H^{0.07}}{R'^{0.35} \ell^{0.97}}$$

$$v^* = v \cdot \frac{\mu_C^{b_1}}{K_1^{b_5} K_2^{b_6} \left(\theta_{cr} - \theta_j\right)^{b_3}} \cdot \frac{\sigma_s^{b_7}}{\eta^{b_8}} \approx v \cdot \frac{\mu_C^{1.24}}{K_1^{0.38} K_2^{0.47} \left(\theta_{cr} - \theta_j\right)^{1.21}} \cdot \frac{\sigma_s^{0.25}}{\eta^{0.20}}$$

Bedankt voor uw aandacht!