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Fundamentals of lubrication

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Introduction to Tribology

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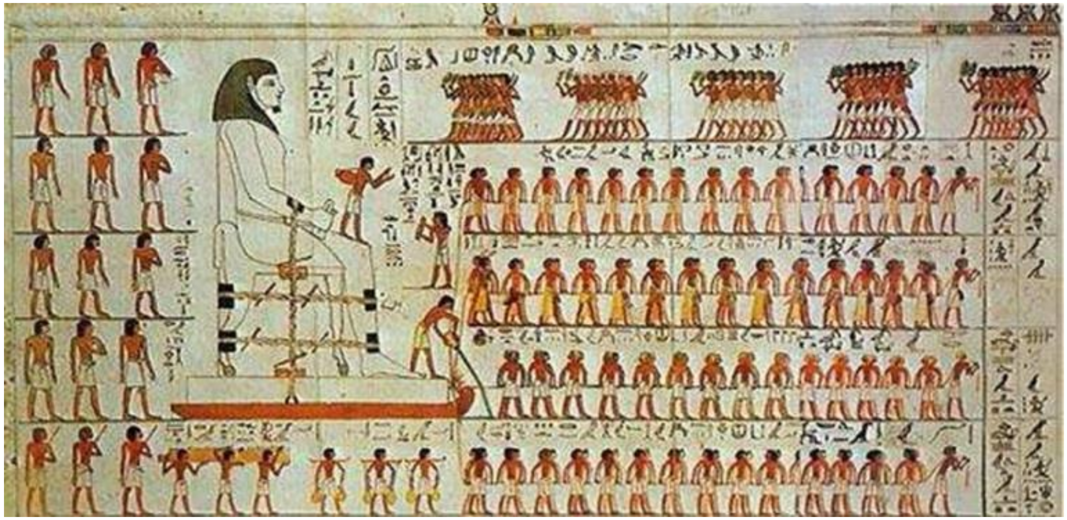
Outline

At the end of this presentation you will be able to:

- State what the word **Tribology** means
- List the main regimes of lubrication and state the conditions under which each tends to occur
- Understand our approach to lubricant performance testing

Tribology history

Tribology is study of friction, wear and lubrication between surfaces sliding against each other



Source: WSJ

While direct application of tribology by Ancient Egyptians is well documented, Leonardo Da Vinci was the first to enunciate the laws of friction

The word 'Tribology' came later and was first coined by David Tabor and Peter Jost in 1964

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Tribology solving real world problems

Tribology is about understanding, analysing, predicting and controlling interactions between moving surfaces

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Why does tribology matter?

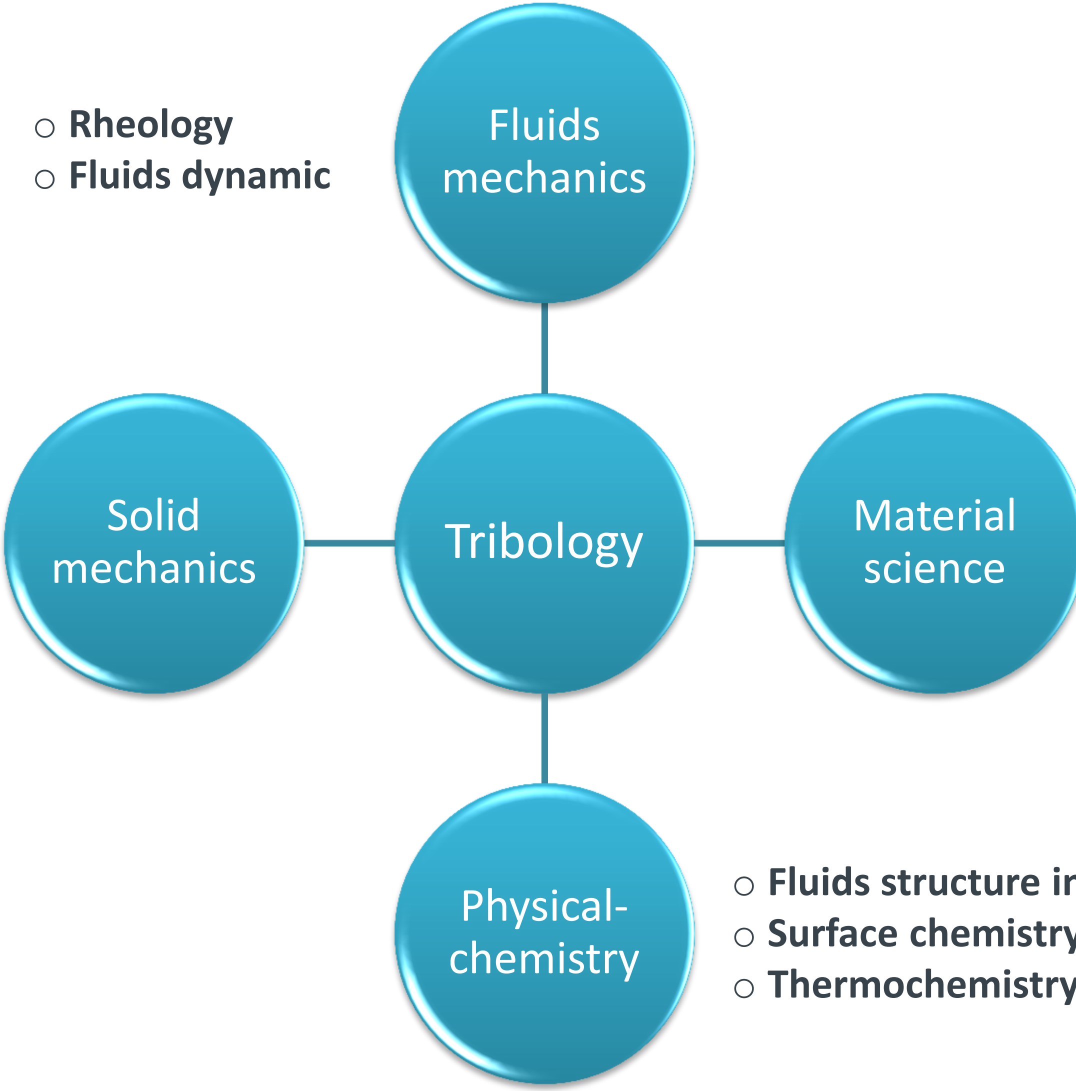
Energy

Safety

Environment

Reliability

Multi-disciplinary aspect of tribology



- Rheology
- Fluids dynamic

- Stress
- Deformation
- Motion

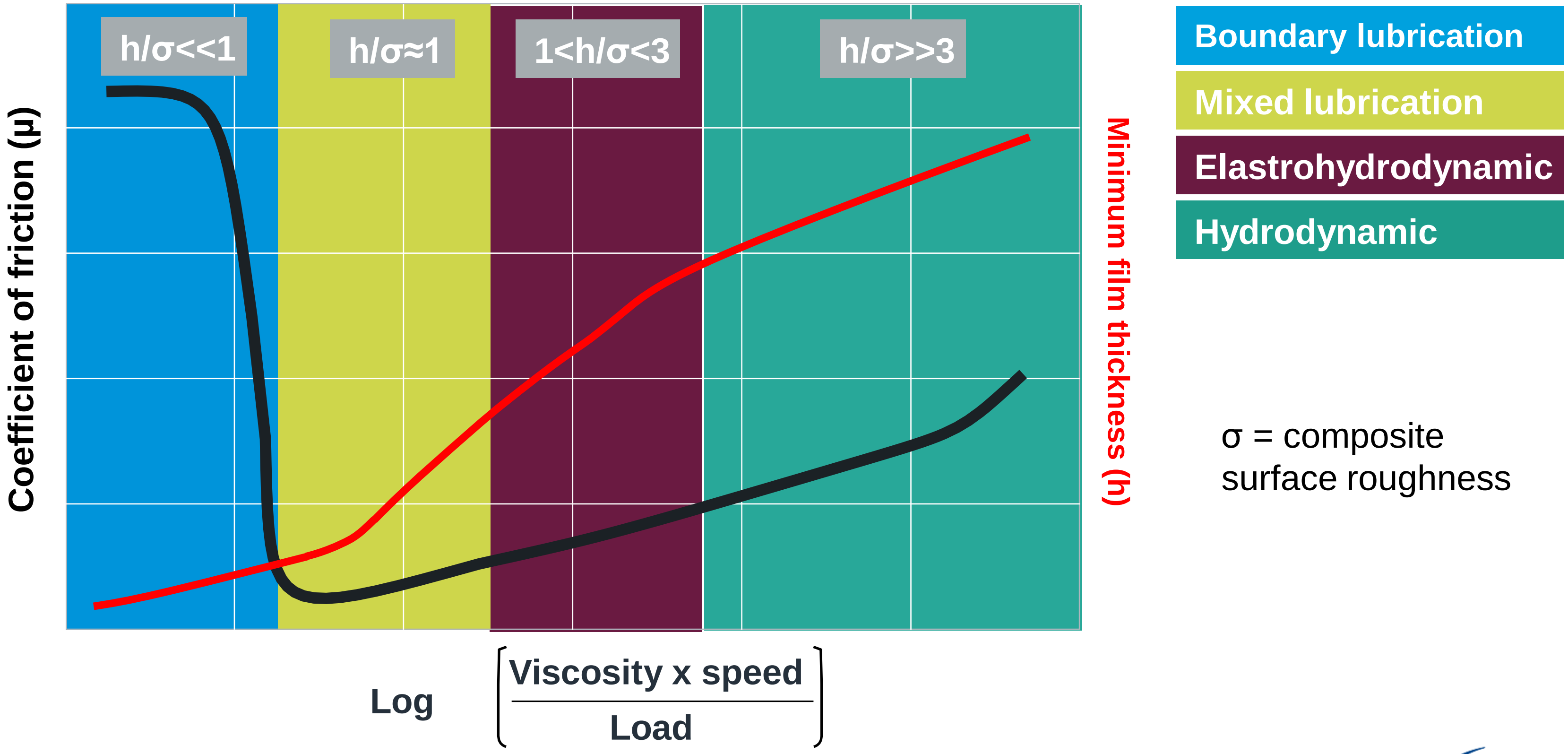
- Metallurgy
- Coatings
- Crystallography

- Fluids structure interactions
- Surface chemistry
- Thermochemistry

Stribeck curve and lubrication regimes

Stribeck curve

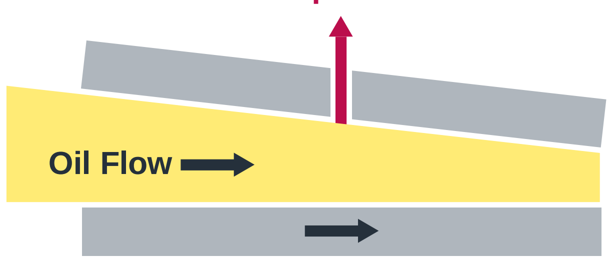
Stribeck curve is used to represent friction response of a tribological contact across different lubrication regimes

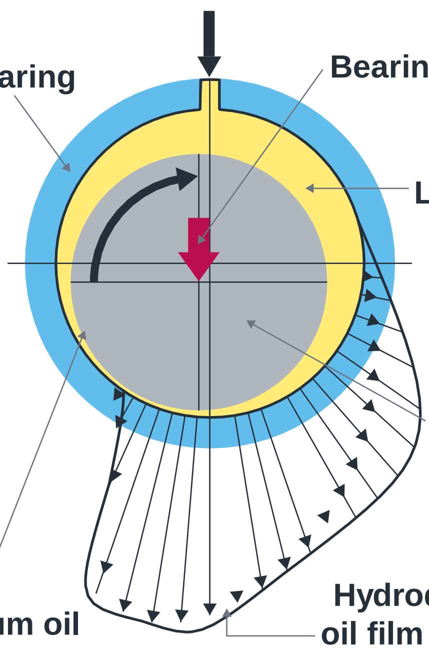


σ = composite surface roughness

Hydrodynamic lubrication (HD)

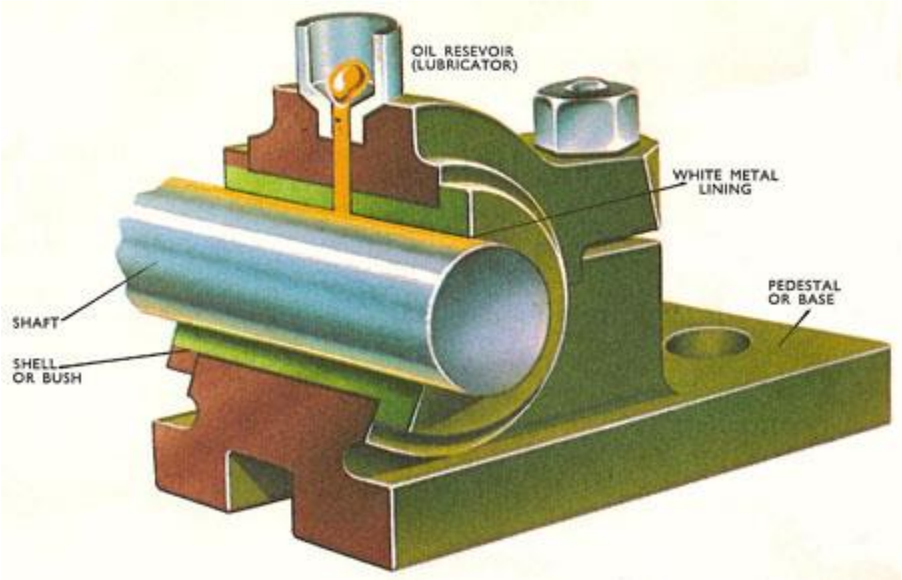
The contact is designed such that their relative motion drags (or *entrains*) lubricant in between them, forcing the lubricant to high pressures of up to 200 MPa (30,000 psi), large enough to support external loads.





Oil film thickness typically 1 to 100µm

Hydrodynamic lubrication - examples

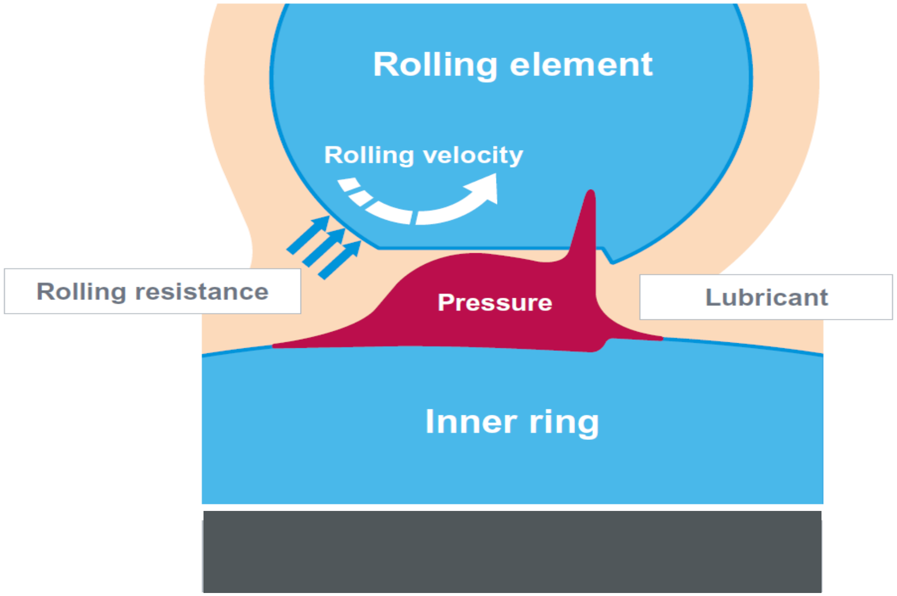


Plain journal bearings

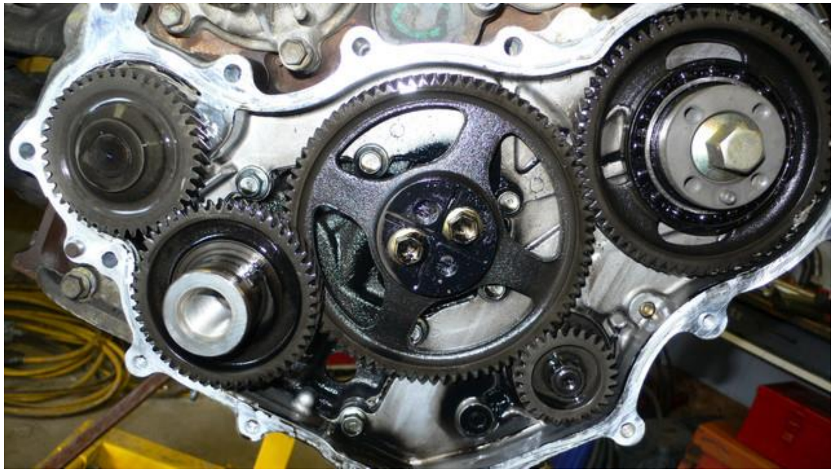
Elastohydrodynamic lubrication (EHL)

When all the loading is concentrated over a small contact area.

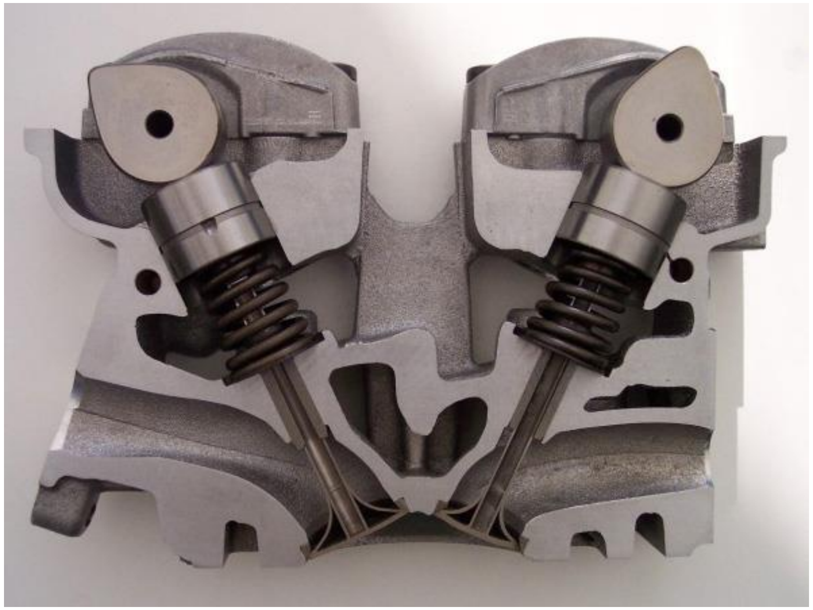
- High localised stresses cause elastic deformation of the surfaces
- An exponential rise in viscosity of the lubricant as it is squeezed through the contact
- Thin fluid film is formed due to surface deformation and viscosity increase



EHL - examples



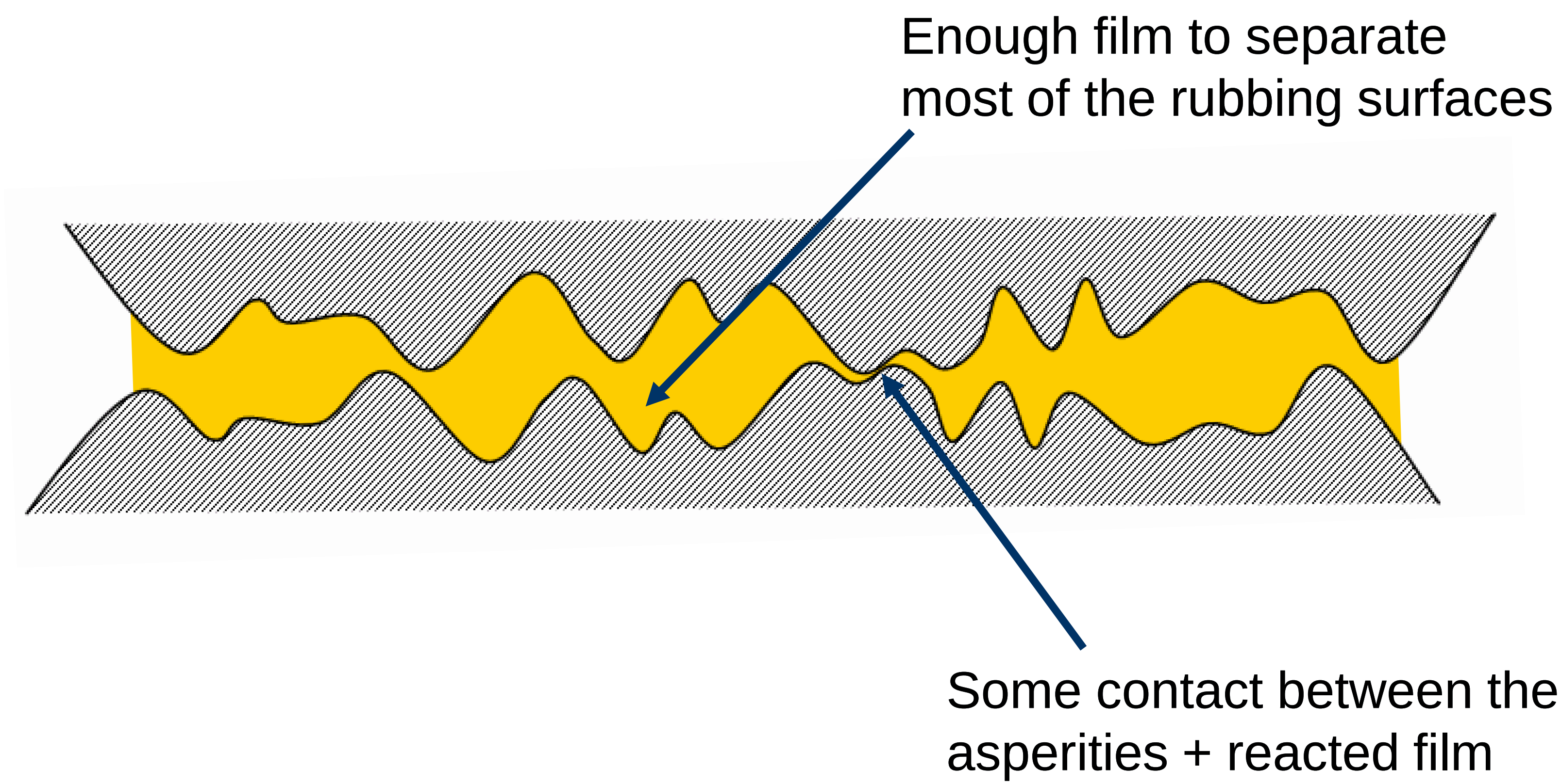
Toyota 1HZ timing gear



Valve train – cam and lifter experience EHL at cam nose

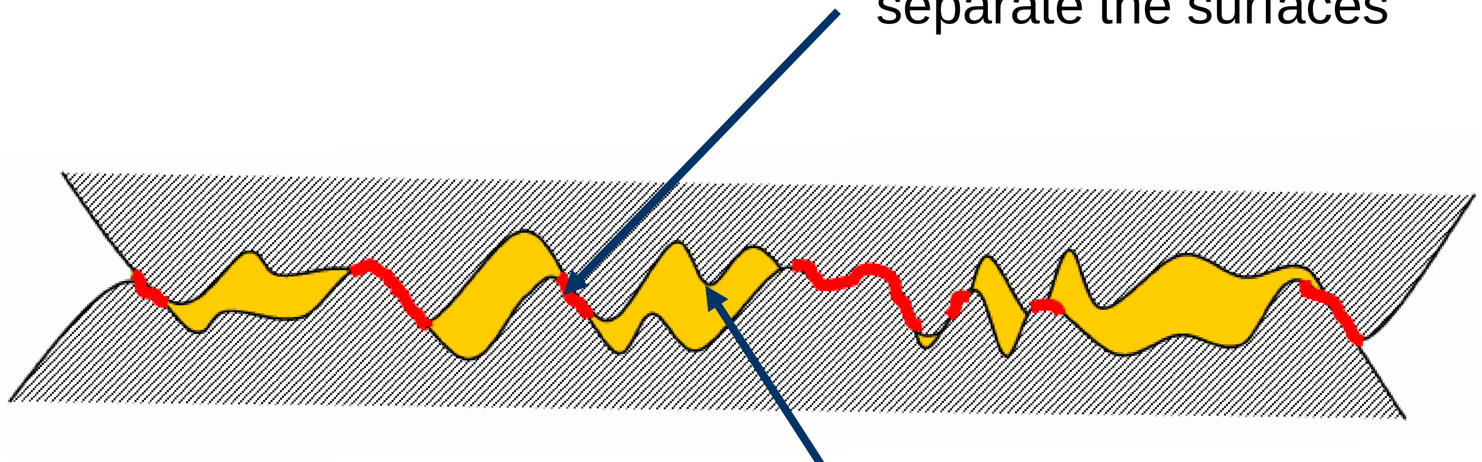
Example of a component experiencing elastohydrodynamic lubrication

Mixed lubrication



Oil film thickness typically 1 to 100 nm (roughness dependent)

Boundary lubrication

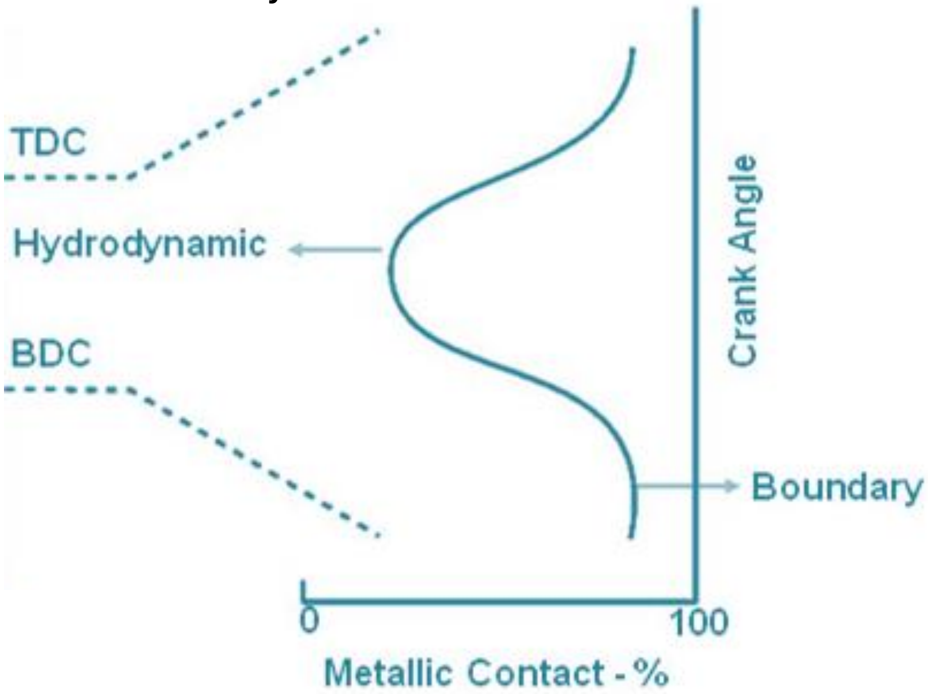


Oil film thickness typically 20 to 100 nm (roughness dependent)

Mixed and boundary lubrication examples

Piston rings experience all lubrication regimes as piston slides from TDC to BDC

Mixed/boundary to EHL



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Applied tribology and key properties

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Functional Requirements of Lubricants

- **Keep surfaces separate** under all loads, temperatures and speeds, thus minimising friction and wear.
- **Act as a cooling fluid** removing the heat produced by friction or from external sources
- **Remain adequately stable** in order to guarantee constant behavior over the forecasted useful life
- **Protect surfaces** from the attack of aggressive products formed during operation
- **Fulfil detersive and dispersive** functions in order to remove residue and debris that may form during operation

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Parameters to consider in tribology

- Material
  - Roughness
  - Metallurgy
  - Hardness

- Fluid properties
  - Viscosity
  - Newtonian vs. Non-Newtonian
  - Pressure viscosity coefficient

- Contact conditions
  - Pressure
  - Temperature
  - Rubbing part entrainment speed

- Surface active additives

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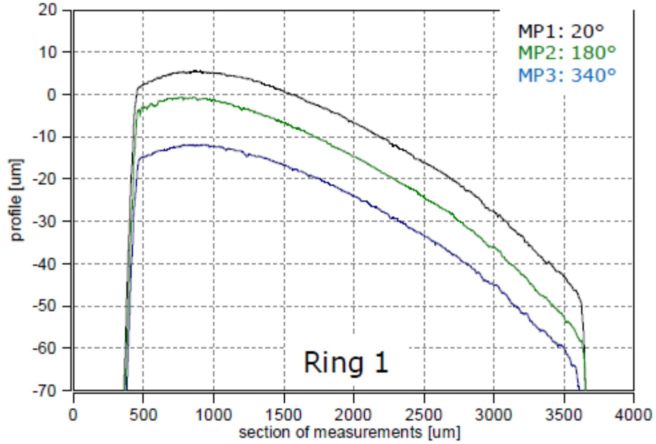
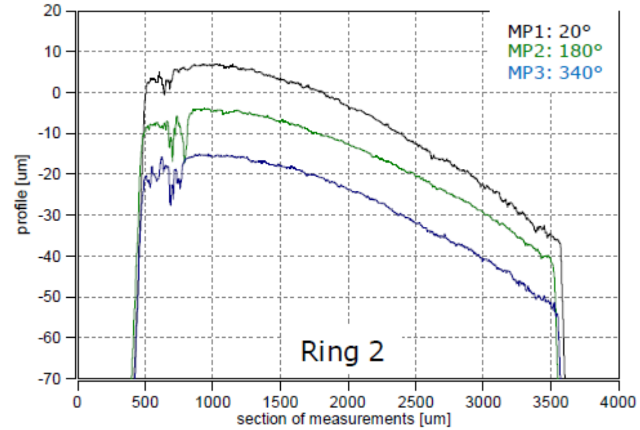
Material properties - examples

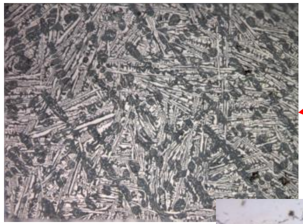


Roughness

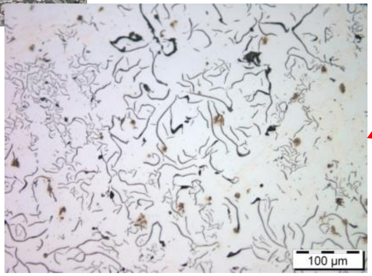
Real example of top ring roughness discrepancy



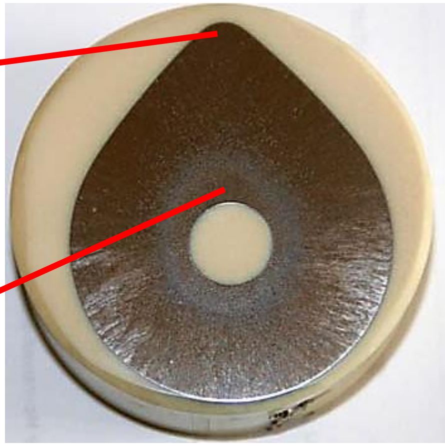
Metallurgy



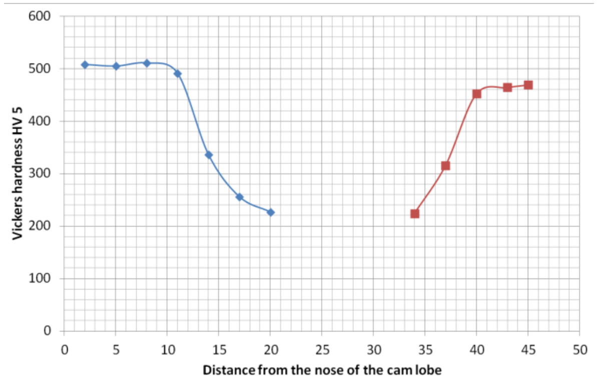
Chilled cast iron



Grey cast iron



Hardness



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Fluids Properties - Viscosity

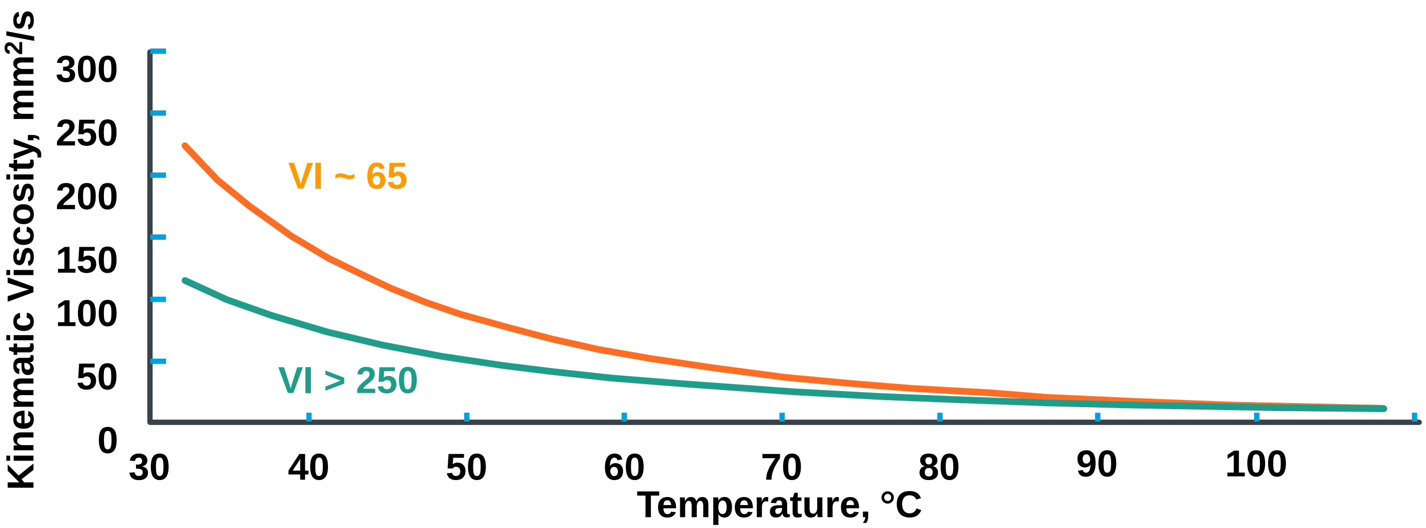
- **Dynamic viscosity:** resistance to shearing flow

$$\eta = \frac{\tau}{\dot{\gamma}} \quad \frac{Shear\ stress\ (\frac{N}{m^2})}{Shear\ rate\ (s^{-1})} \text{ [Pa.s]}$$

- **Kinematic viscosity:** flow response to gravity

$$\vartheta = \frac{\eta}{\rho} \quad \frac{Dynamic\ viscosity}{density} \ [m^2/s]$$

- **Viscosity Index:** VI is an empirical parameter that compares kinematic viscosity of a given oil to the viscosities of two reference oils that have appreciable difference in sensitivity of viscosity to temperature.



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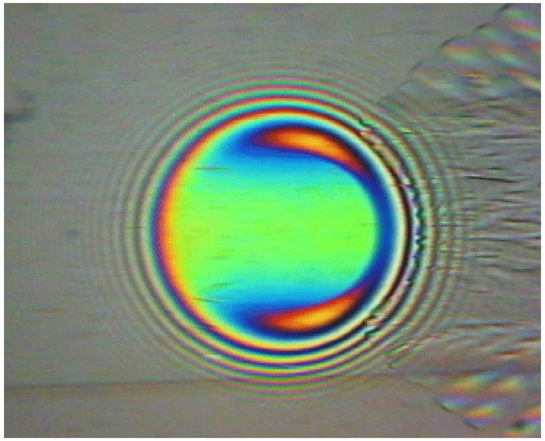
Fluids Properties – High pressure

- **Viscosity pressure relationship:** lubricant viscosity increases with pressure and this effect is generally greater than the effect of temperature.
  - Barus equation is most commonly used to show the relationship:

$$\eta_p = \eta_0 e^{\alpha p}$$



η_p viscosity at pressure '**p**' [Pa.s]

η_0 viscosity at atmospheric pressure [Pa.s]

α is the pressure viscosity coefficient [m^2/N]

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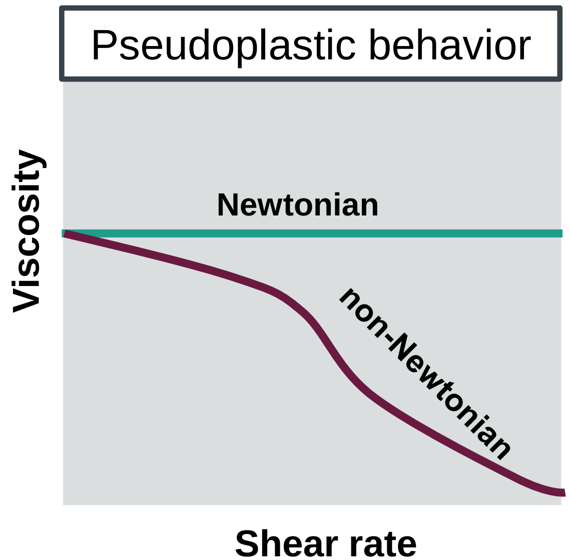
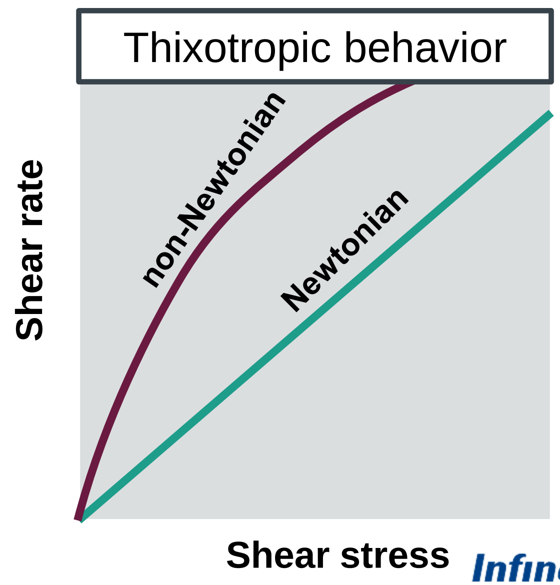
Physical Properties of Lubricants

- **Viscosity-shear rate relationship:** Almost all lubricants behave as non-Newtonian under high shear rates (~10^6 s^{-1} and above), i.e., shear stress and shear rate are not directly proportional
  - **Pseudoplastic behavior:** during the shearing process the randomly oriented long molecules tend to align resulting in reduction in apparent viscosity. This is also referred to as **shear thinning.**
  - **Thixotropic behavior:** is associated with a loss of consistency of the fluid as the duration of shear increases. This is also known as shear duration thinning.





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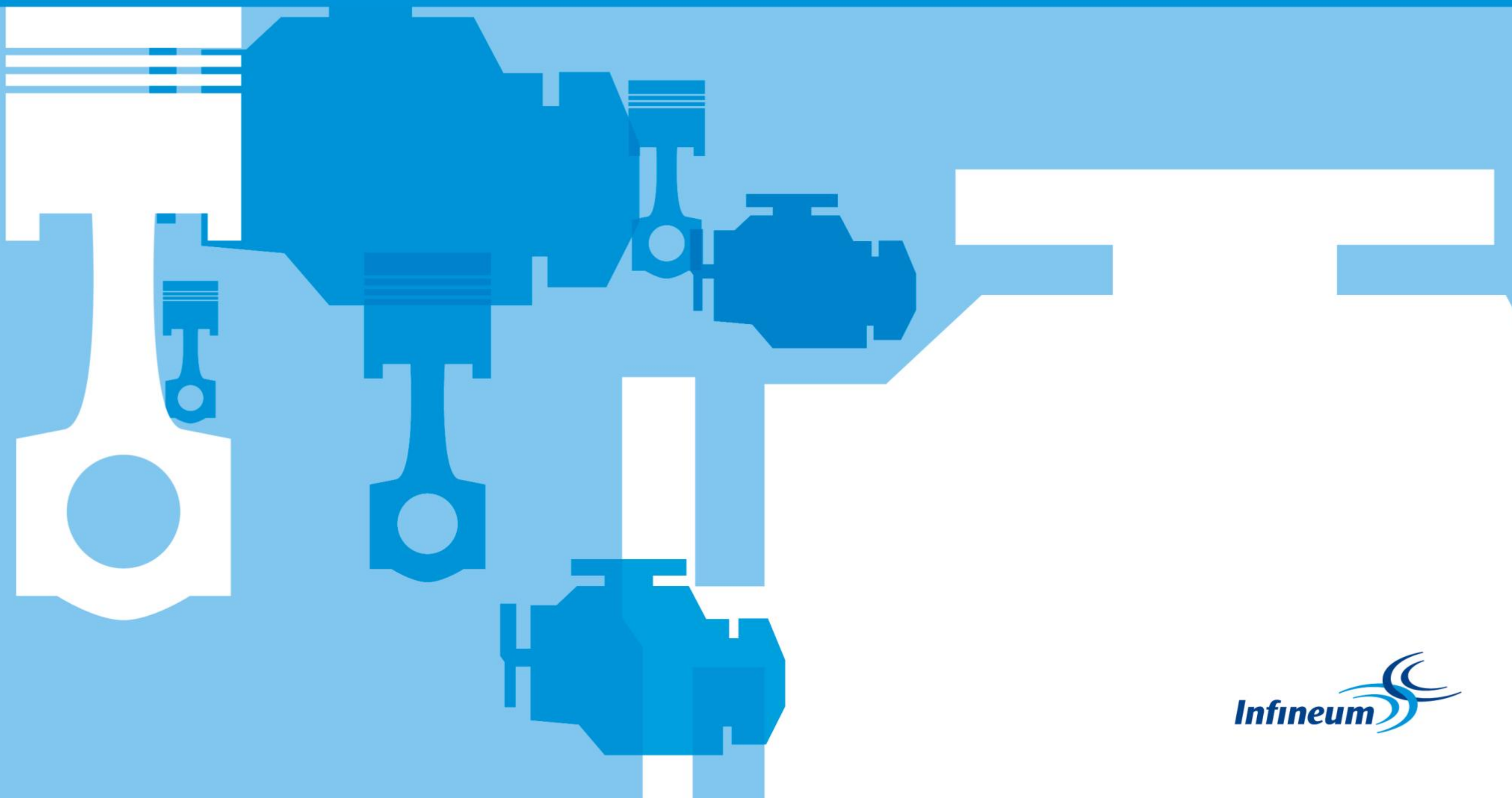
Tribology and Infineum



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Why study friction and wear in an engine?

- Combustion engine contains many moving metal parts
- Movement between parts can lead to surfaces wearing away
- Affect durability
- Certain engines are more prone to wear
- As such these troublesome engines tend to be used for the qualification of a formulated oil

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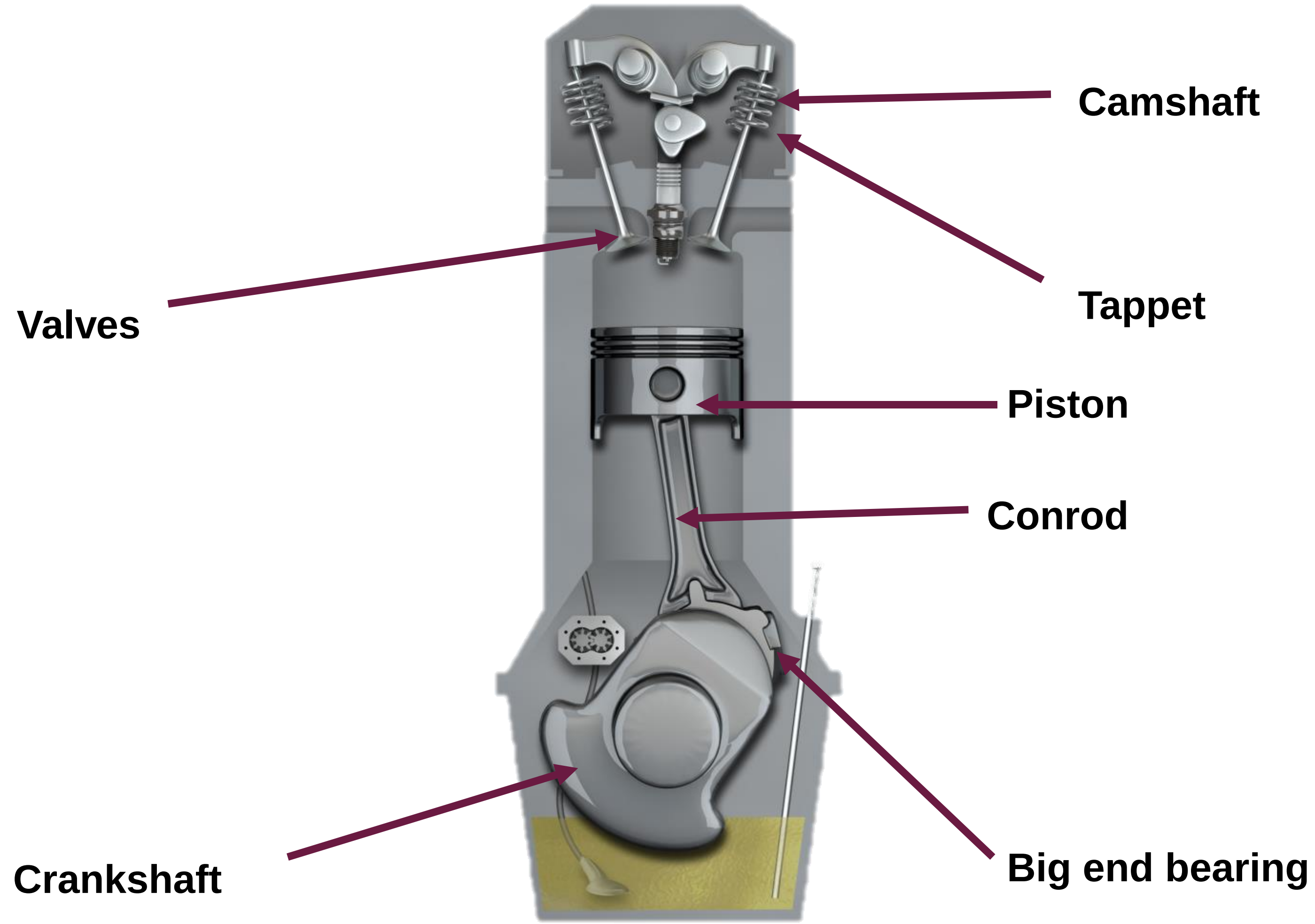
Tribology of an internal combustion engine



Levels of tribo-testing

- Level A. Vehicle on- and/or off-road tests
- Level B. Full-size dynamometer test stand (entire vehicle)
- Level C. Full-scale engine tests (engine test cells)
- Level D. Sub-assembly tests (full-scale mating parts)
- Level E. Coupon tests (sub-scale tests, part sections or simple coupons)

- The complexity and the cost of testing goes up as the testing moves from Level E to Level A
- Control of operating variables and fundamental learnings increase as the testing moves from Level A to Level E

Factors determining design of a tribo-test

Designing a tribo-test a correlate performance of materials (metals and/or lubricants) across various levels of testing requires consideration of several factors

Mechanical factors
surface geometry, design, relative motion, contact stress, vibrations

Thermal factors
heat generation and dissipation rate

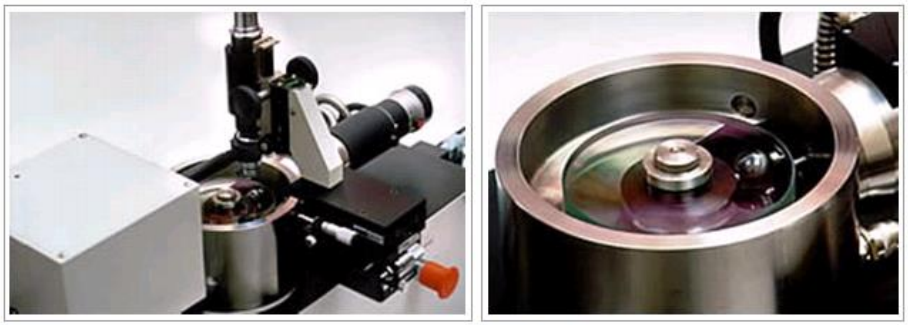
Third bodies
wear debris, contaminants

Material factors
composition, processing, surface treatments

Chemical factors
lubricant chemistry, tribo-chemistry, oxidation, corrosion

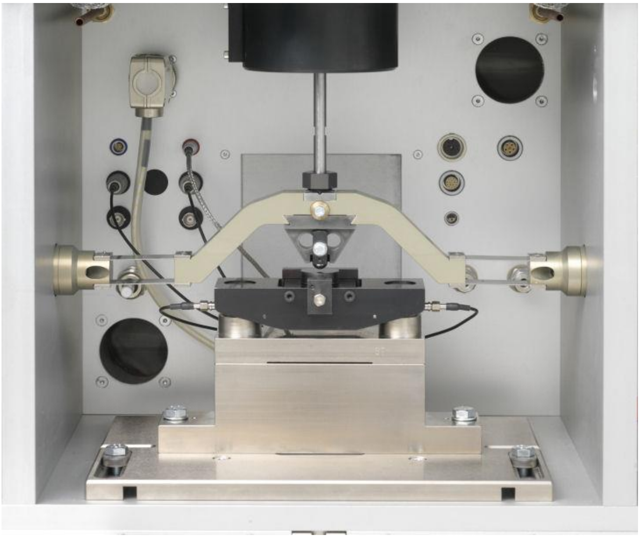
Lubrication factors
lubrication regime, fluid flow, film thickness

Bench test rigs (Level E)

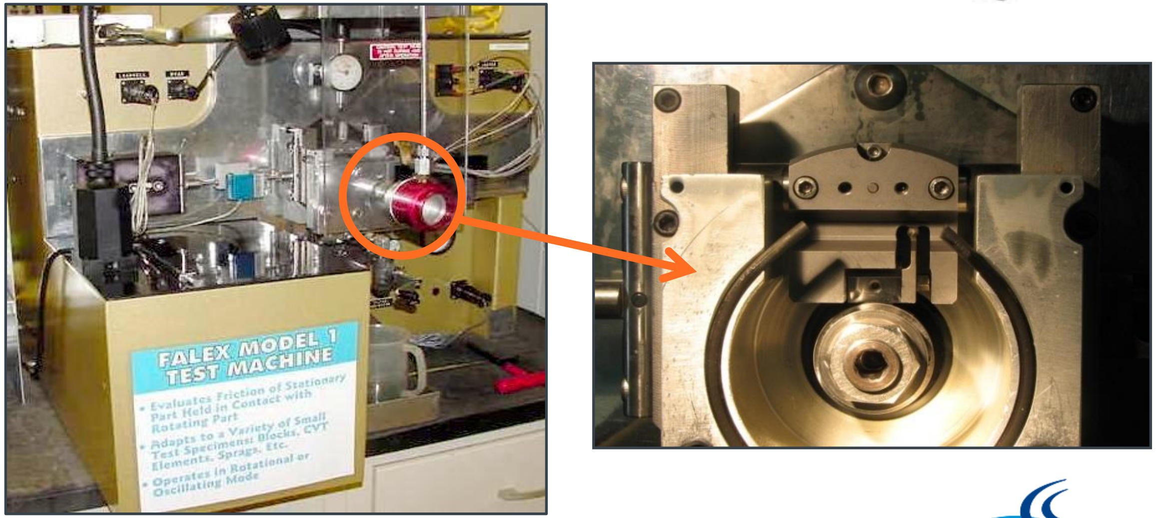


EHL Mechanical Unit   EHL Pot Close Up

Examples of Level E tribo-testing



SRV-5 reciprocating test rig



Block-on-ring test rig

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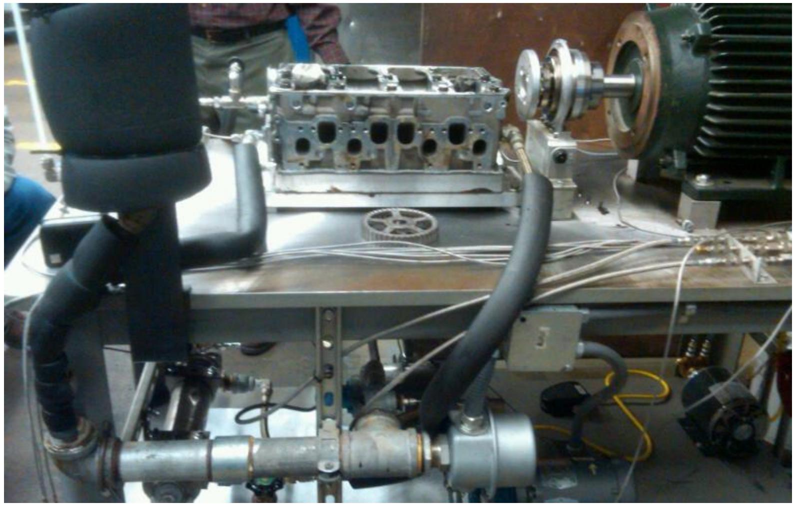
Sub-system testing (Level D)



Examples of sub-assembly test rigs

Valve-train test rigs developed by Infineum used for formulation development and fundamental understanding

Engine testing (Level C)

Examples of engine test installation used for evaluation and validation of lubricant performance

Vehicle testing (Level B)

Examples of vehicle testing on a dynamometer to evaluate lubricant performance in real driving condition in a very control and repeatable environment

Vehicle testing (Level A)

Examples of field testing to validate lubricant performance in a very variable but representative of the end-user utilisation environment

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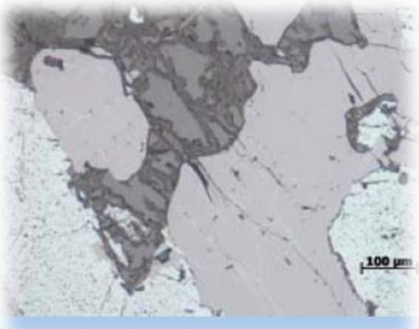
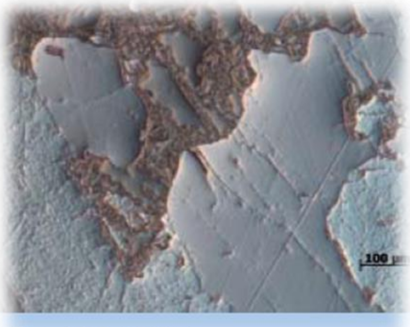
Surface examination tools

5x to 100x

25x to 1000x





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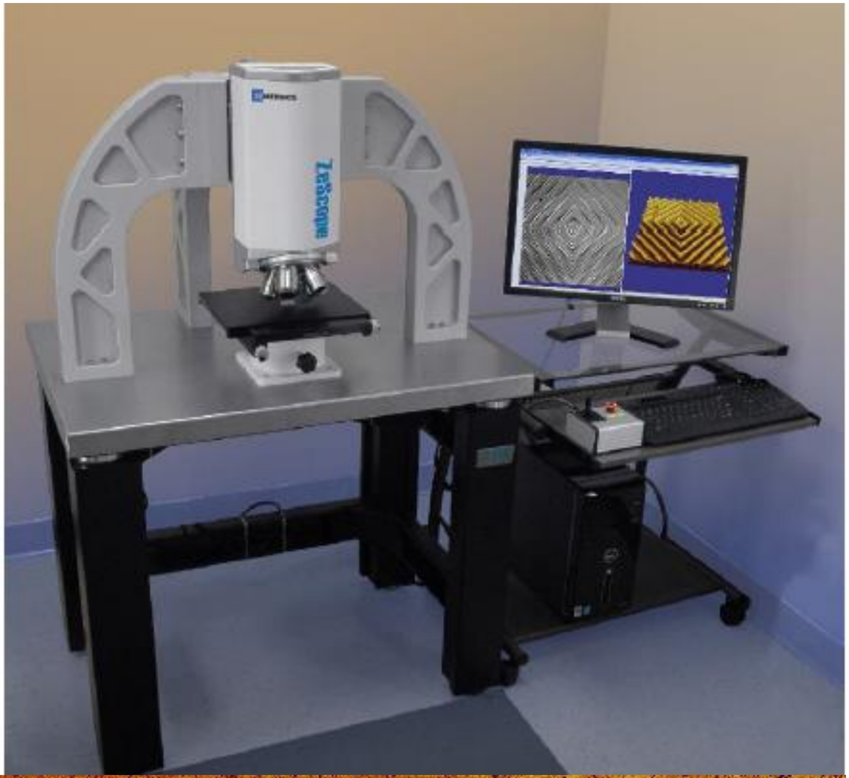
Surface examination tools: Optical interferometer

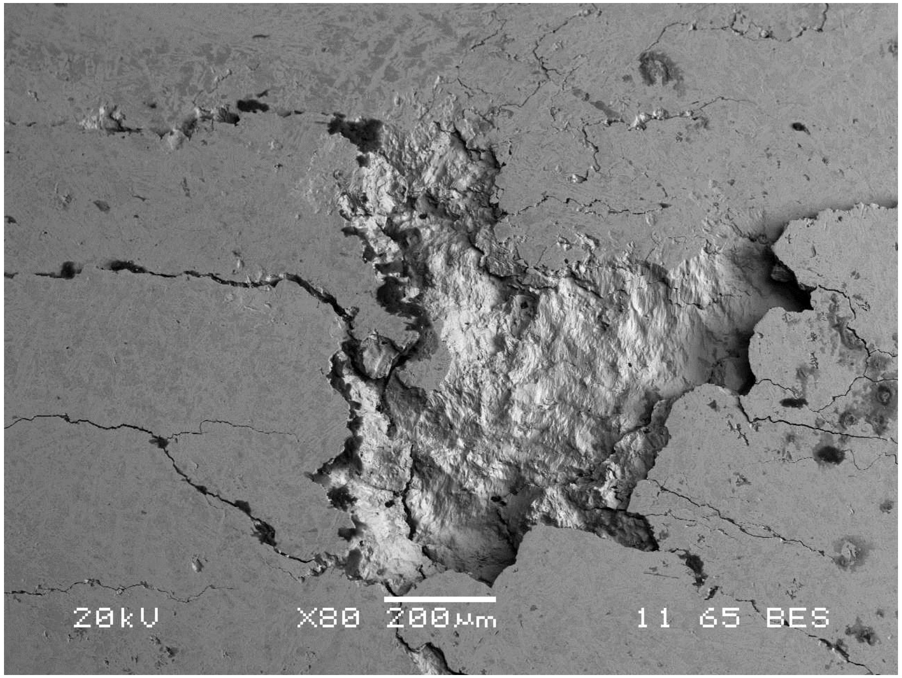
- Zemetrics Ze-scope
- 5x to 50x objective
- Max field of view 3.35mm x 2.58mm
- 1nm vertical resolution
- HD imaging camera
- Fully motorised
- Greater vertical resolution



Example – HD resolution measurement of a liner honing marks (HDD engine)

Surface examination tools: Scanning electron microscope

Range of magnification: 10x – 1000,000x



Summary

This presentation should have helped you to understand more about:

- What Tribology is and how we use it in developing new lubricants
- The main lubrication regimes and conditions under which they occur
- Different levels of tribo-testing
- Understand our approach to lubricant performance testing and surface analysis techniques

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