Material testing for valve seat of diesel engine

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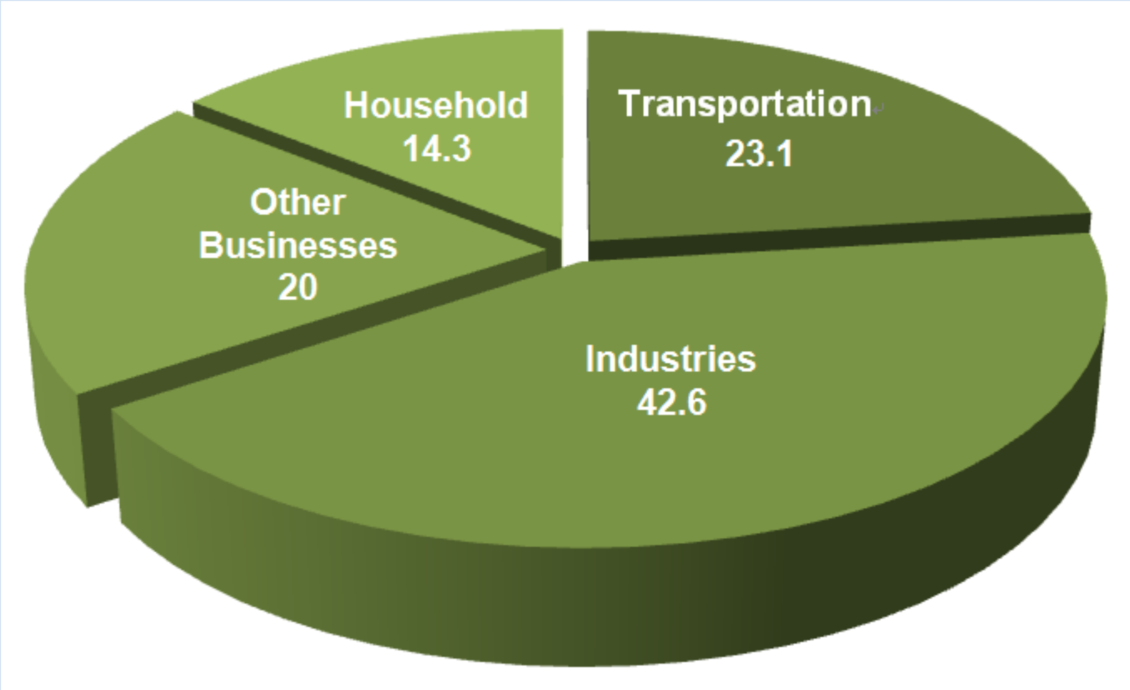
Automobiles and Energy saving…

- Cars represent an importance source of energy loss in our society.
- Various aspects have to be considered :
  - Manufacturing
  - Life of the car
  - "Treatment" of "dead" cars

During the life of a car

- Performances are important but it is necessary to limit various aspects :
  - Energy losses due to friction
  - Pollution
- Lifetime
  - Wear of various parts is determinant
- Materials are very important in order to design new cars
  - Body, engine, …
  - Need to
    - decrease the weight, the pollution, the costs, …
    - Increase the performances, the reliability and the lifetime

Sources of friction losses in our society



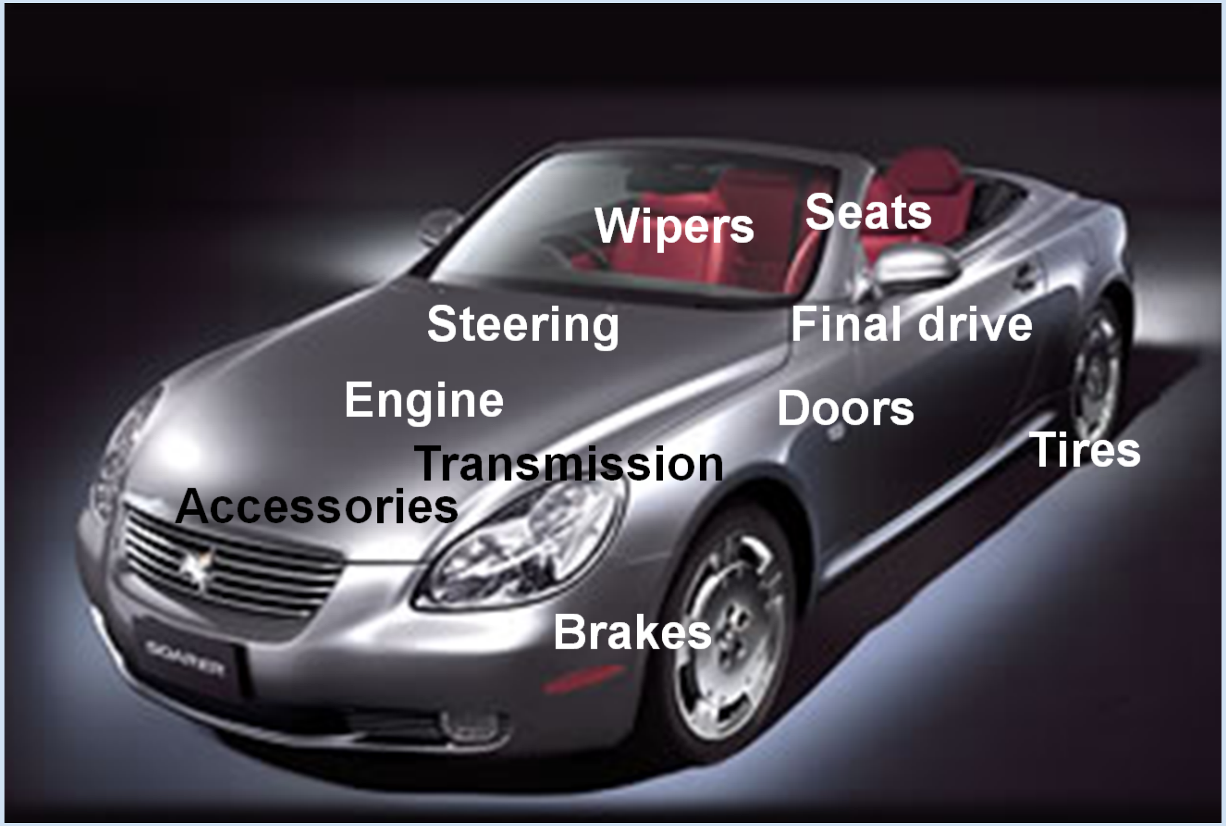
2012

Automobiles occupy 14% of total.

From Prof Y Kimura, ITC 2015, Tokyo   Annual Energy Report 2014

Energy loss

- Primary concern :
  Reducing friction losses for saving energy

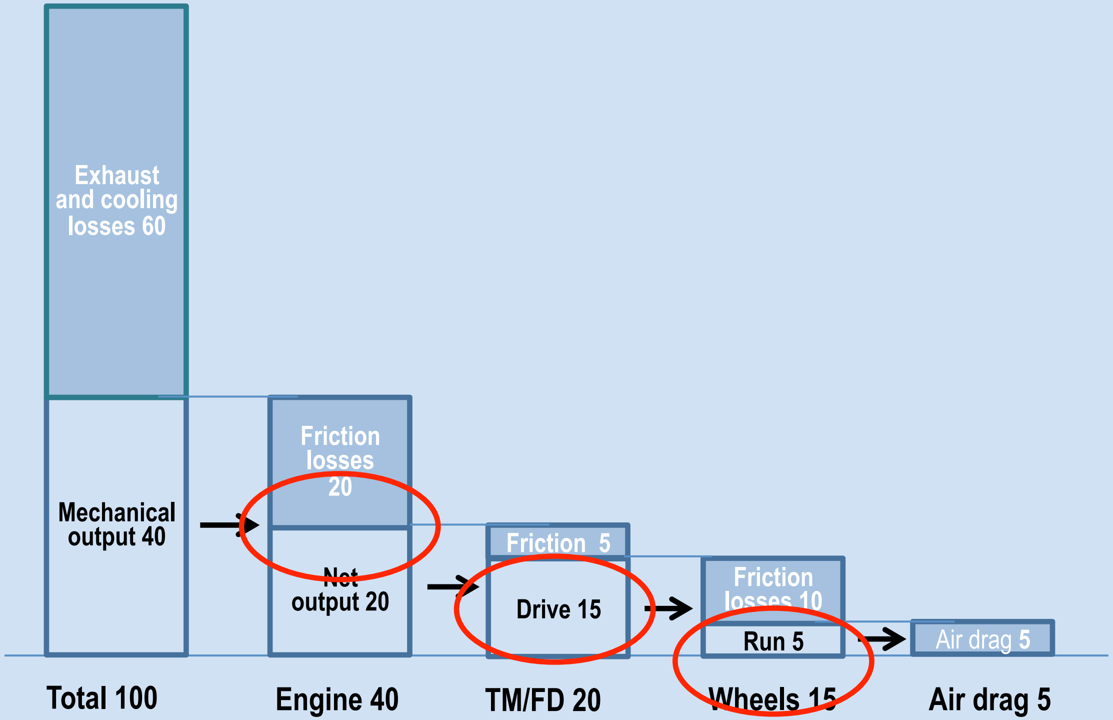


Toyota

From Prof Y Kimura, ITC 2015, Tokyo

- Breakdown of car energy consumption

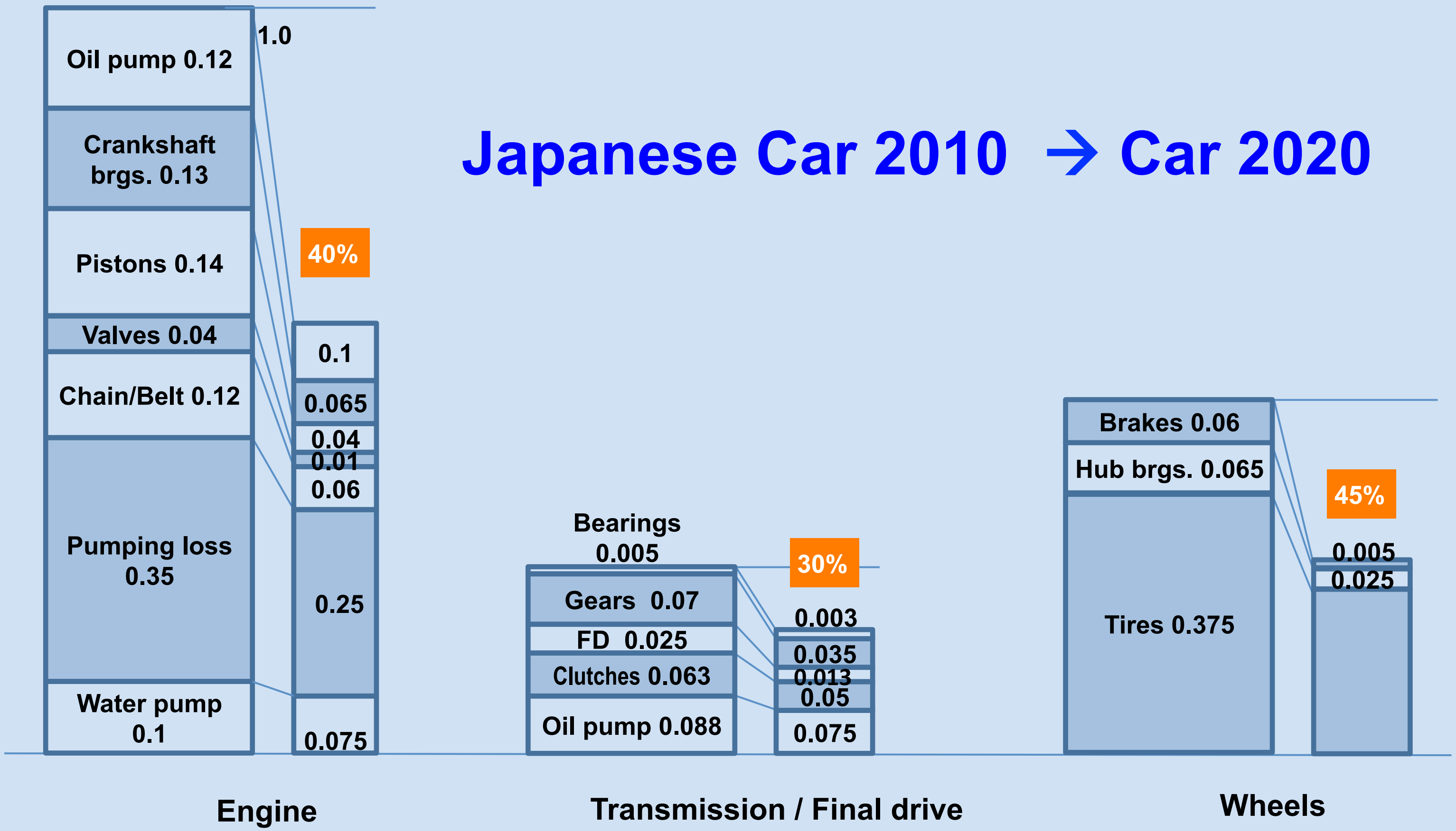
Friction losses occupy 35% of total energy.



Study group on car fuel-saving by tribology, JAST

From Prof Y Kimura, ITC 2015, Tokyo

- Estimated reduction of friction losses in each components



Study group on car fuel-saving by tribology, JAST

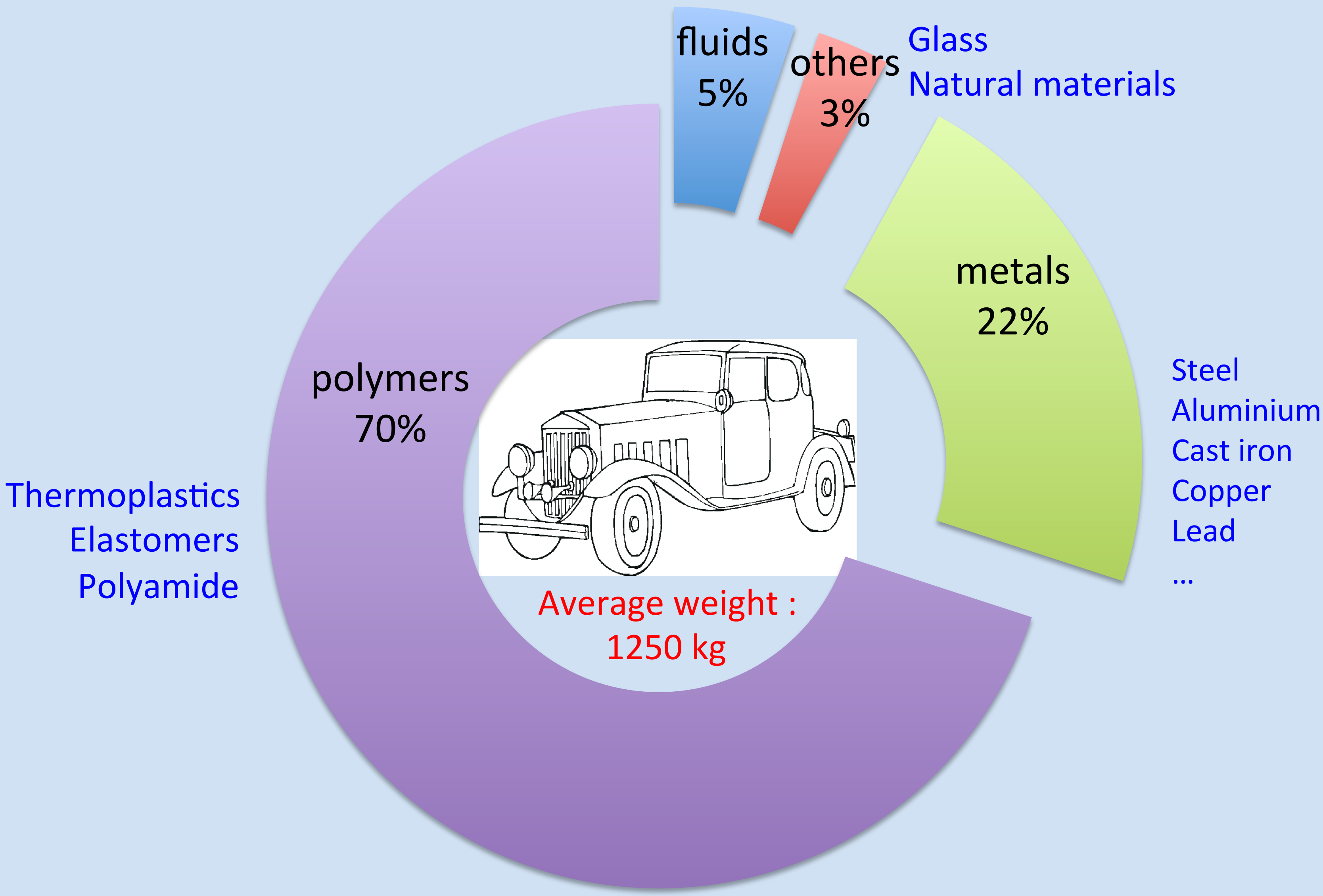
From Prof Y Kimura, ITC 2015, Tokyo

- Progress for "friction and wear" aspects are possible by modifying :
  - The design of engines and mechanical parts
  - The lubricant (viscosity, additives, …)
  - The materials (bulk, coatings, composites, …)

- Lifetime is mainly related to wear.
  High tribological performance materials can increase the lifetime…

  → need to develop new materials, new process, …

Materials for automobile



Metals for engines

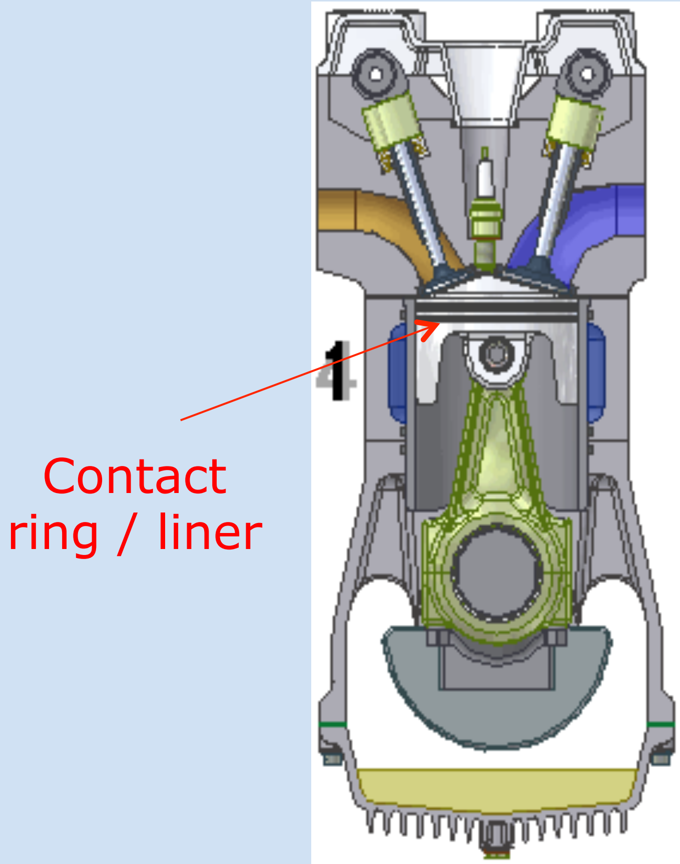
- Metals for engine parts are more and more loaded
  - Mechanical stresses, temperature, chemical aspects

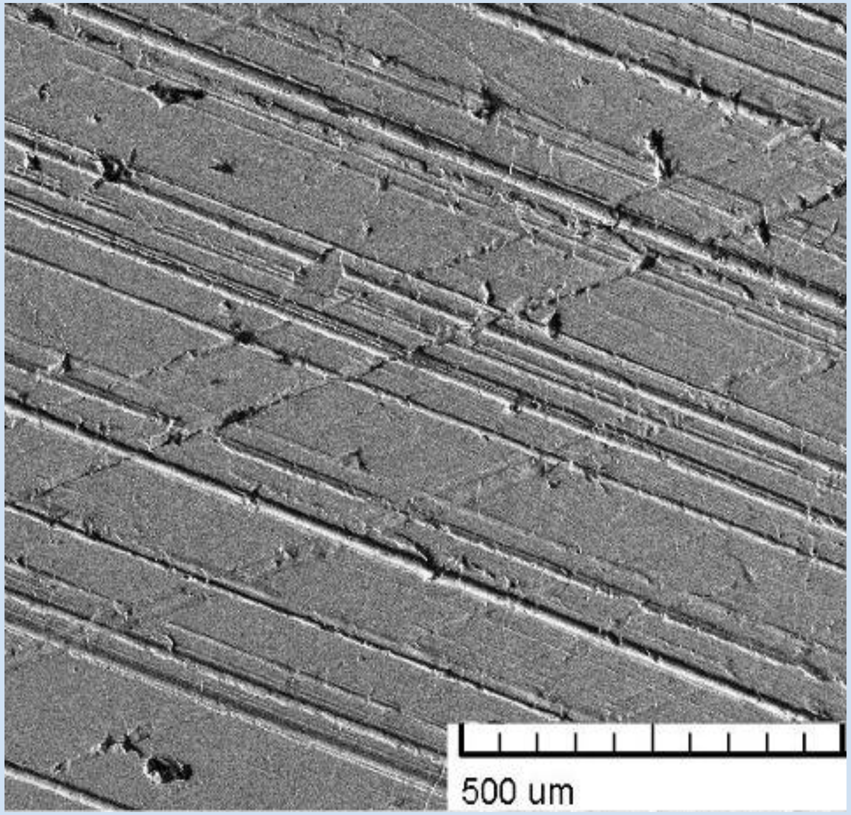
- Selection of high performance metals and coatings (surface treatments) are of primary interest

- Important need to have representative tests…
  - Field tests
  - Bench test
  - Laboratory tests

Example of ring / liner contact

- A very important mechanism for the performances and the lifetime

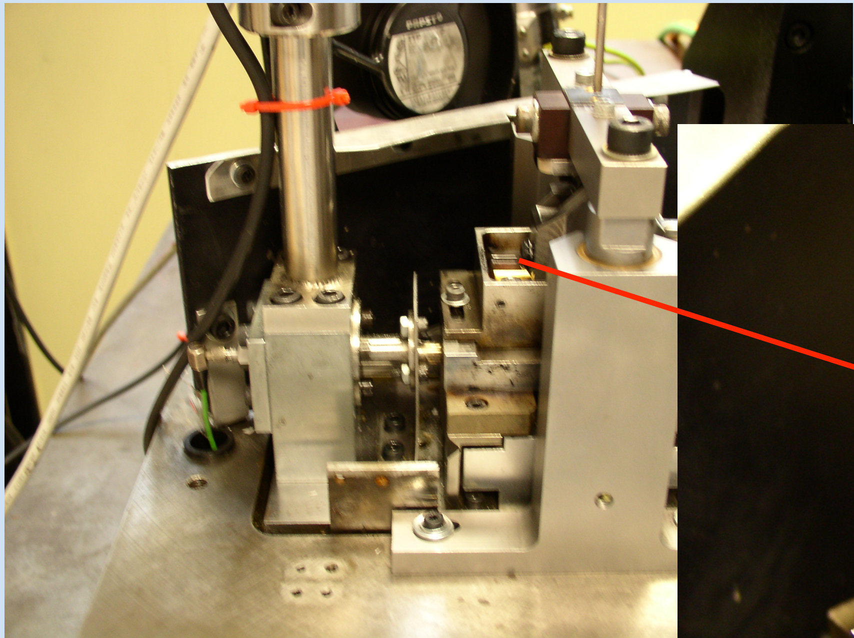


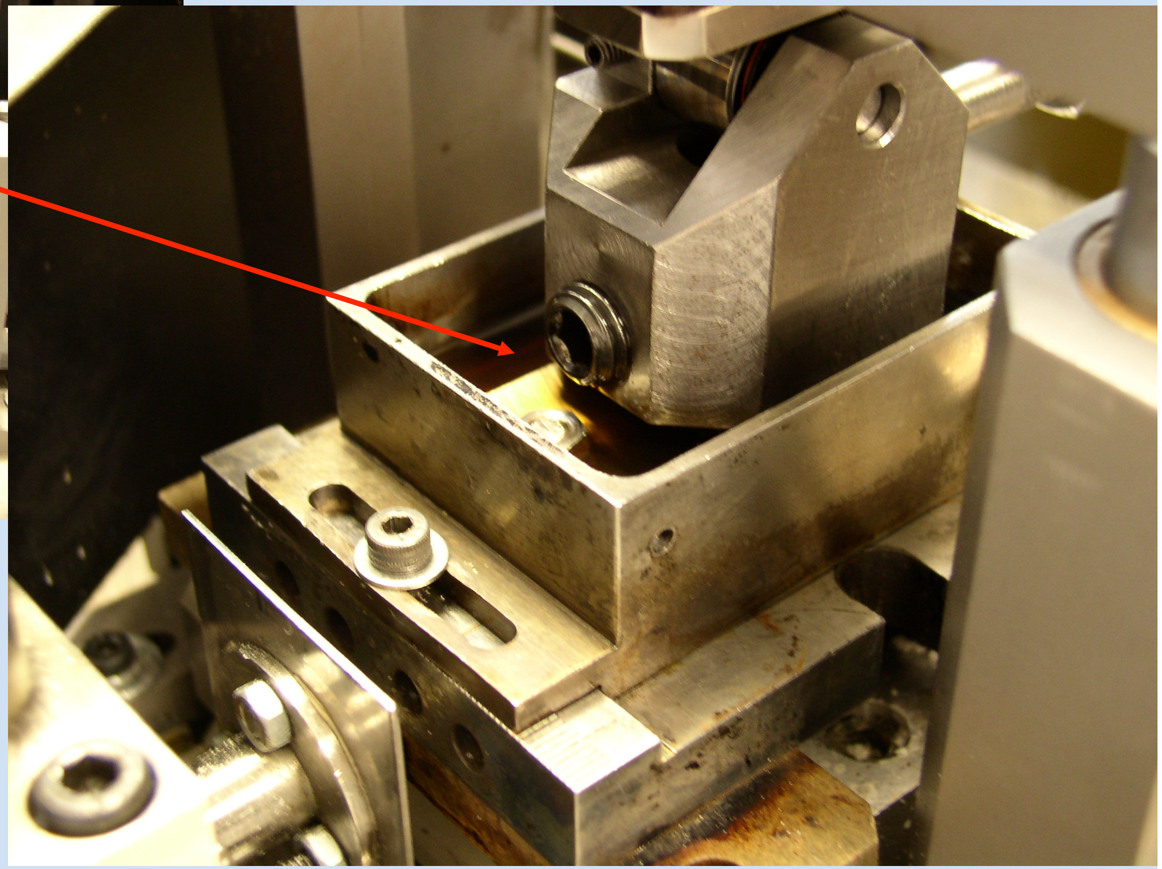


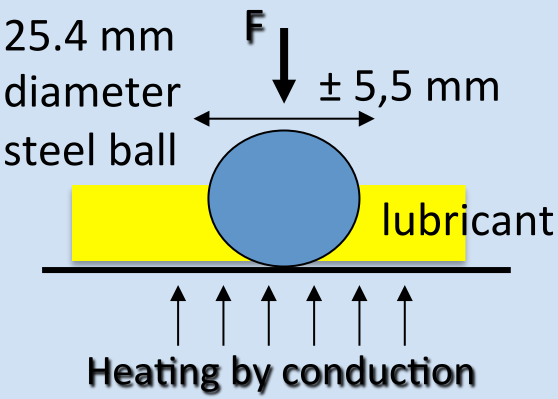
Topography of the liner obtained by honing

→ Bench tests are useful to study this contact but the cost is important

- Materials, lubricants are very often tested using a Pin on Disc (PoD) tribometer with an alternative motion.

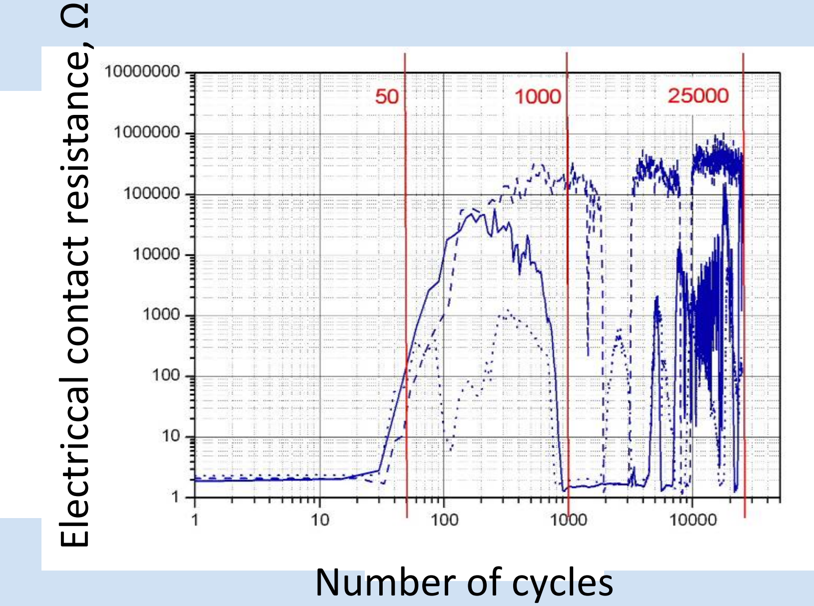


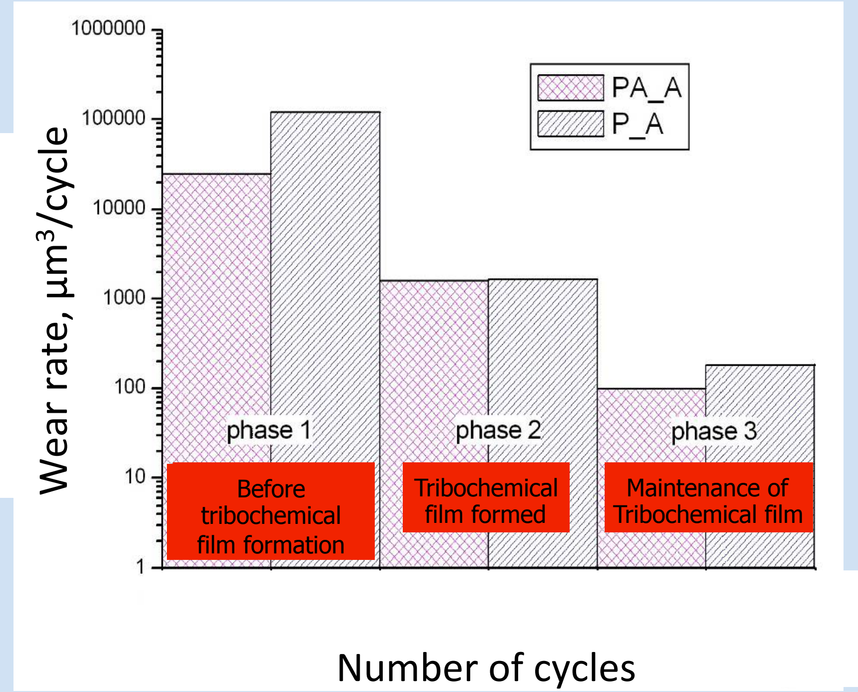


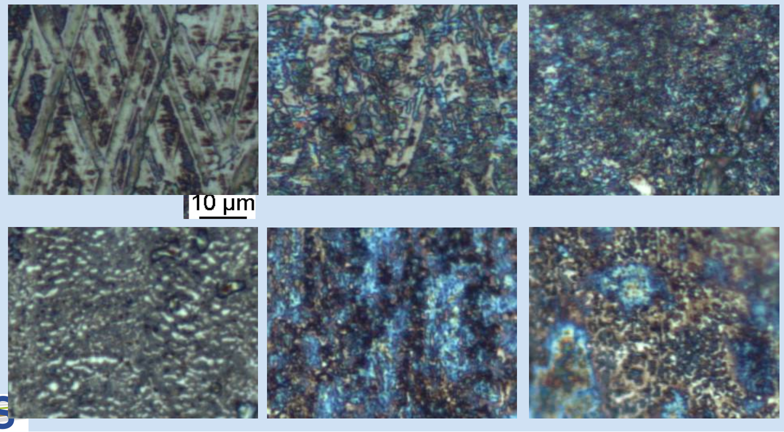


• Pin on disc test can help in lubricant, materials selection

The lubricant efficiency is related to the formation of a tribochemical film on sliding surfaces leading to a reduction of the wear rate







Cast iron Cylinder liner

Steel ball

Study of ring / liner contact for diesel engine :
Sphere on liner contact
Oil lubricated
Reciprocating motion
150°C

[PhD thesis, J. Keller, LTDS, 2006]

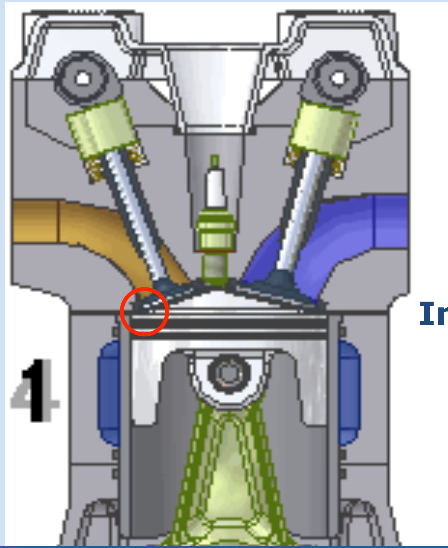
Valve on seat contact for diesel engine

Combustion cycles

1. Injection
2. Compression
3. Explosion
4. exhaust

The seat material is subject to severe conditions:

- **High temperature** (Ambiant → ≈ 750°C)
- **Double contact conditions :**
  - Impact : at the closure.
  - Sliding : due to vibration or misalignments.
- **Various angles** can be used to optimize the gas flows.
- **Sliding Contact conditions**
  - → Dry
  - → Presence of oil or combustion products



Various contact angles

complex damage

Few studies in the litterature

What test can we use ?

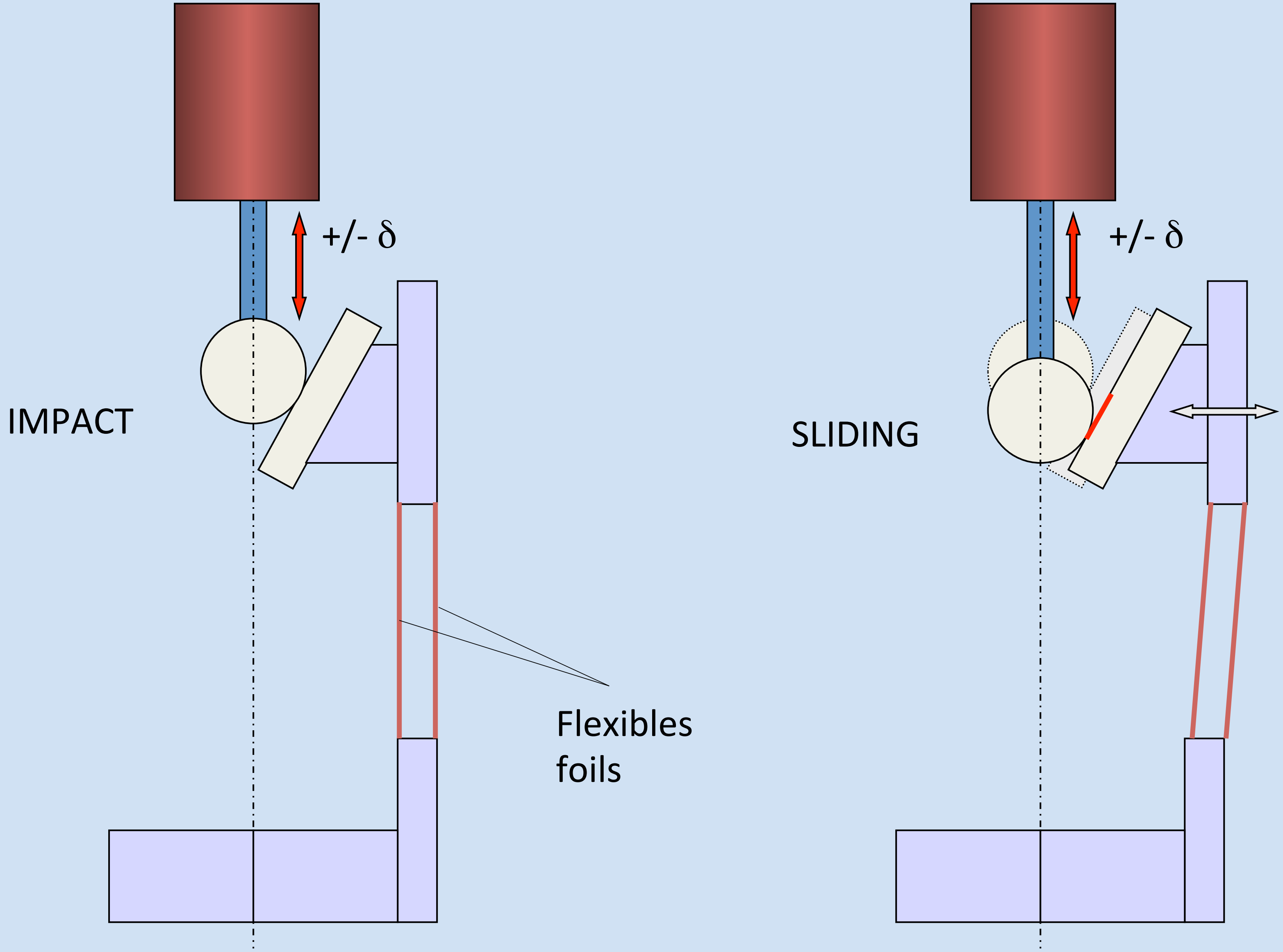
- Classical pin on disc test appeared to be intersting but not sufficient to reproduce completely the real system

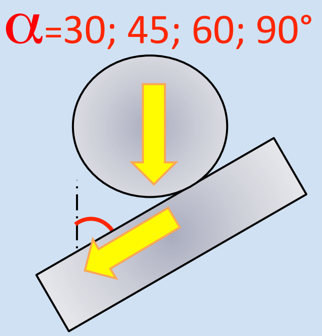
→ Development of simple specific systems

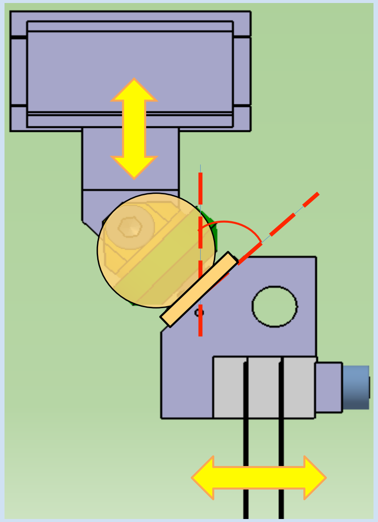
Technical requirements for the test system

- Materials, samples
  - Representative materials…
    - Steel / coating (Al alloy substrate)
- Type of contact
  - Flat on flat, Cylinder on flat, Ball on flat
- kinematic
  - Shocks --> frequency, energy, shock velocity, … to be defined
  - And sliding
- Contact pressure / force
  - Normal force ?
    - PSA information : F impact = 700 N; Sheffield studies F combustion = 13 kN
  - Constant, variable ?
- Temperature
  - Ambiant --> 400 °C
- Atmosphere
  - Combustion gaz ? NO in a first approach
- Measurements
  - Forces, displacements, temperatures
  - Observations of surfaces
  - Wear

Impact / sliding tribometer developed at LTDS







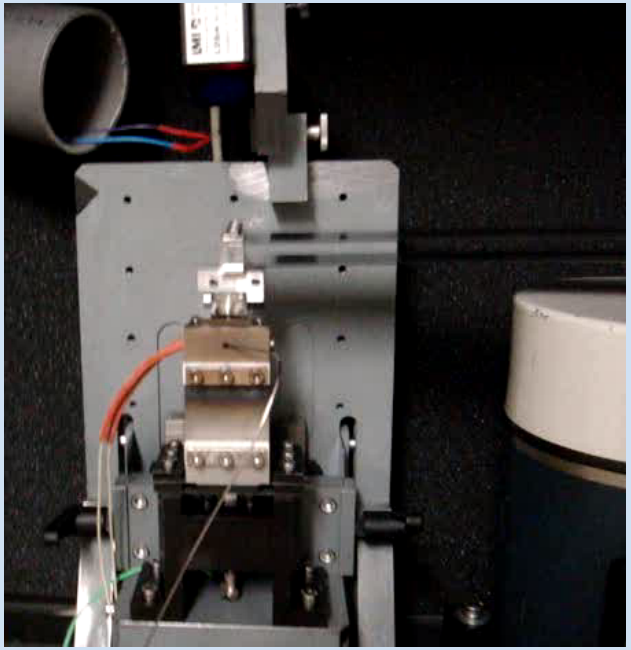
Advantages:
- Simple configuration,
- A constant impact energy,
- Possibility of temperature,
- Impact angle adjustable.

Measurements during tests
- Ball position
- Impact force
- Electrical contact resistance

Measurements after test
- Profilometry,
- Wear scar observations.

IMPACT-SLIDING test

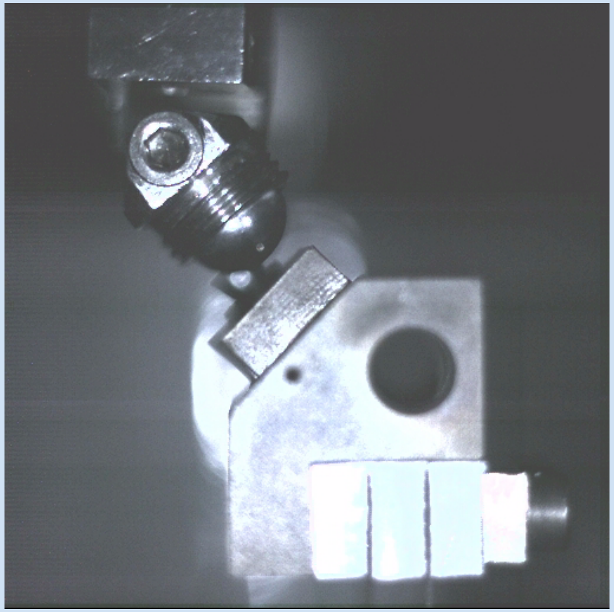
??? → what is the exact motion ?



Test, 4 mJ à 16 Hz.

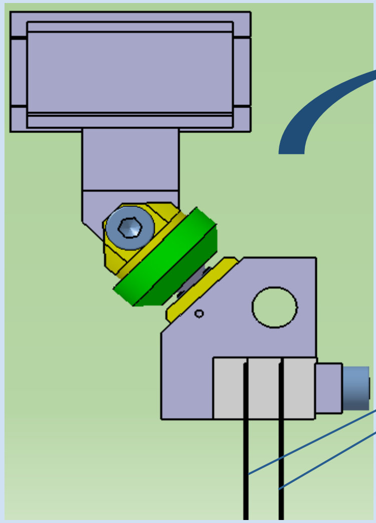
Tools :

- High speed video camera
- Electrical contact resistance
- Finite elements modelling.

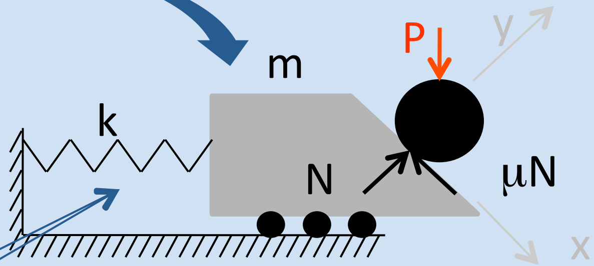


Observation with high speed video camera 4 mJ à 16 Hz.

Analytical model for contact and kinematics (A. Ramalho)



Impact / sliding tester



Model with 1 degree of freedom.

Equation of motion:

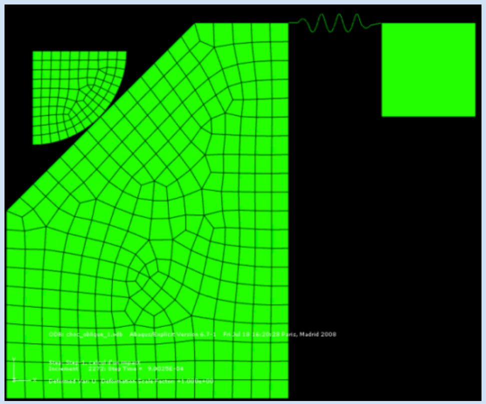
$$F_1 = \frac{P}{2}(\cos 45 - \mu)$$

$$m\ddot{x} + kx = F_1 \sin \omega t$$

FEM quasi static contact

- Kinematics for 45° impact
- Friction

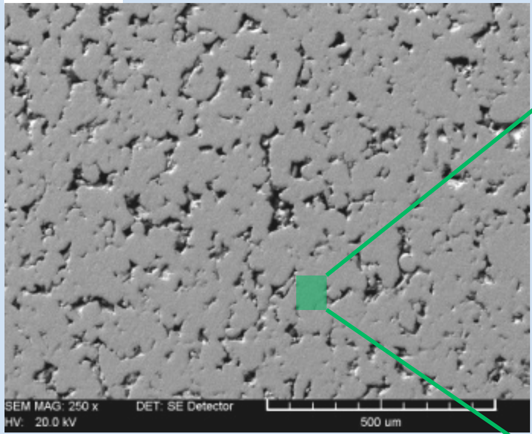
→ Dynamic phenomena are negligible.



FEM model.

Experiments with 2 steels: M2 and OB1

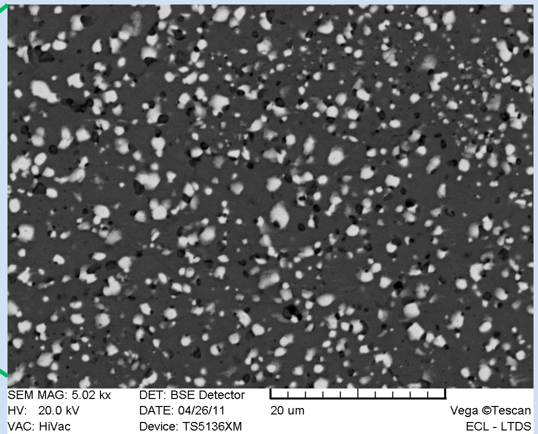
M2



SEM Observation polished surface M2.

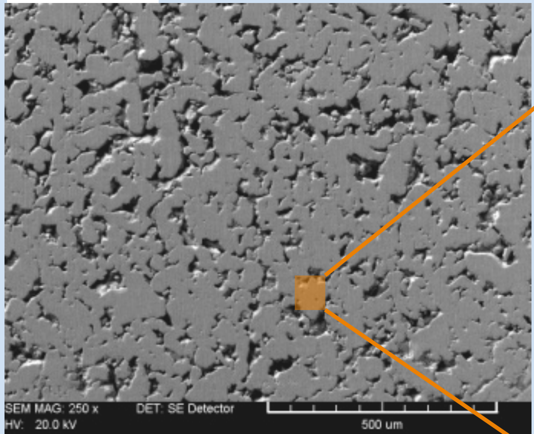
Carbure M_6C : 1500 $Hv_{0,02}$

Carbure MC : 3000 $Hv_{0,02}$



- Surface porosity: 22%,
→ Density: 8.16 g/cm³
- Carbide size: 10 µm.
- Carbides:
  - M_6C
  - MC
- Hardness HV: 504

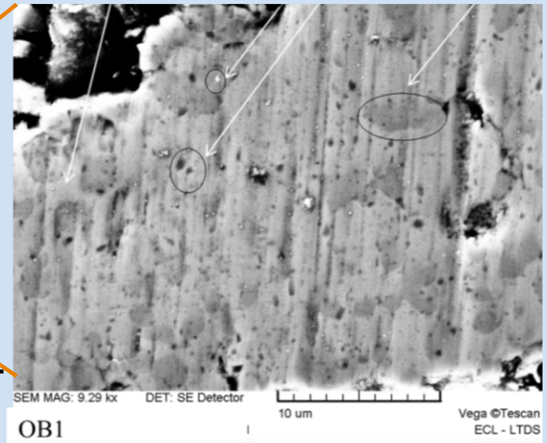
OB1



SEM Observation polished surface OB1.

Carbure M_7C_3 2700 $Hv_{0.02}$

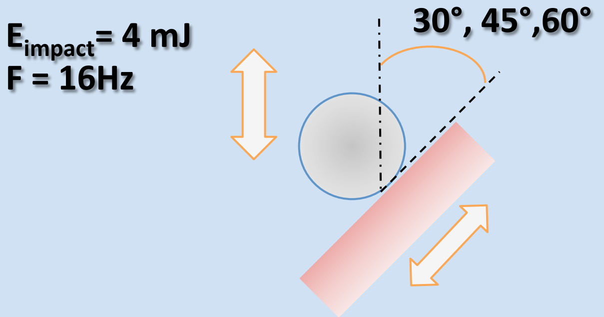
Carbure $M_{23}C_6$ 1300 $Hv_{0.02}$

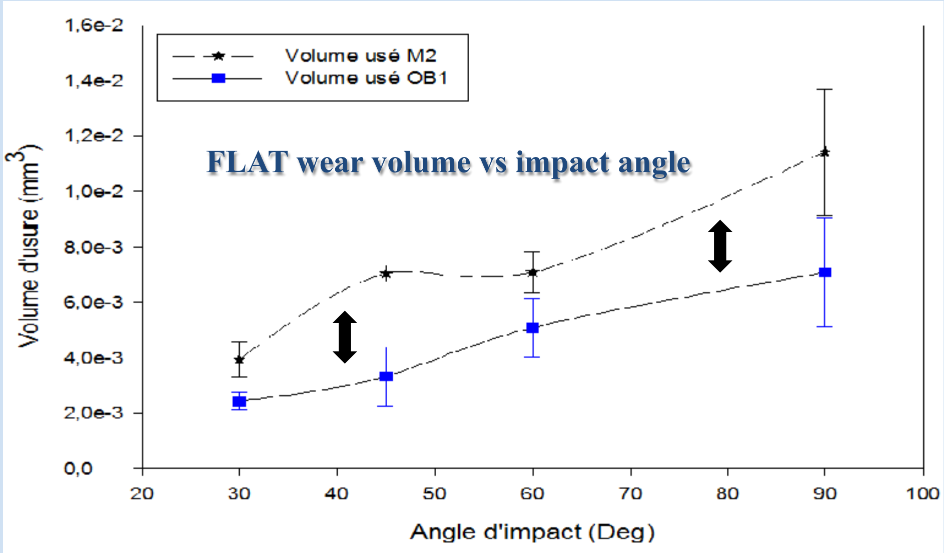


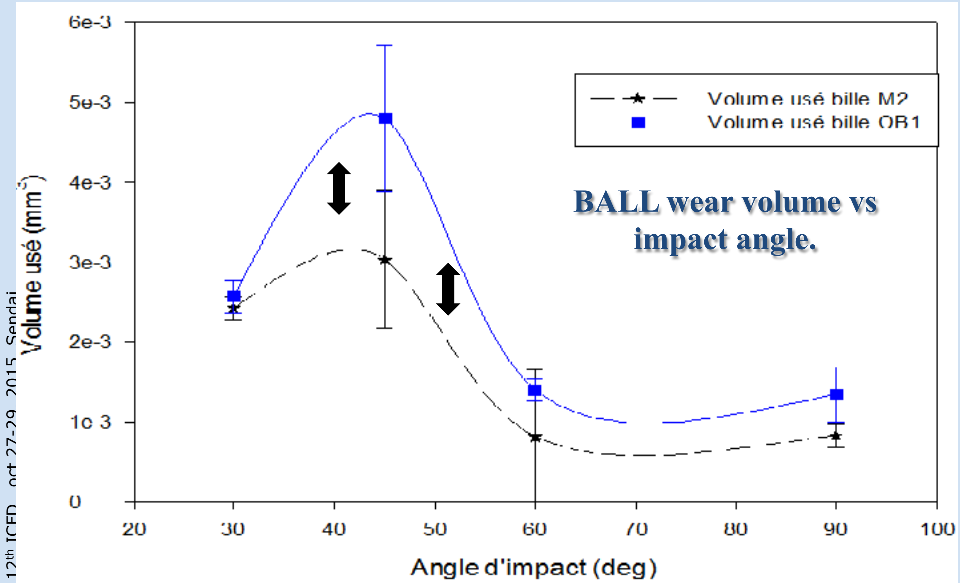
- Surface porosity: 28%,
→ Density: 7.75 g/cm³
- Carbide size 5 µm.
- Carbides
  - $M_{23}C_6$
  - M_7C_3
- Hardness HV: 733

Test results: dry conditions

Impact / slidling tests



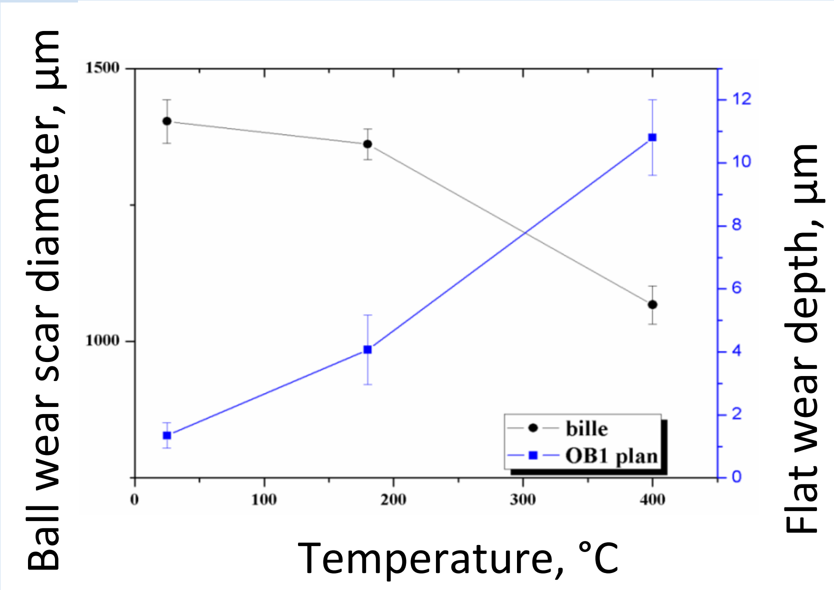




- FLAT wear volume increases with impact angle
- OB1 presents the lowest wear.
- Antagonist material of OB1 presnets the highest wear.
- Maximal wear volume is observed for 45°.

Test results: dry conditions, effect of temperature

Wear for reciprocating PoD at various temperatures

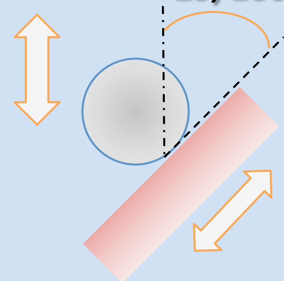


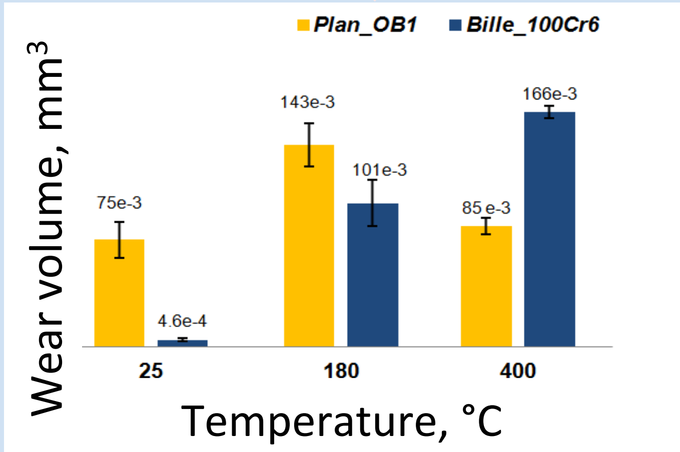
- Wear volume of ball decreases with temperature
- Wear volume for OB1 flat increases with temperature

Impact / sliding tests

E_{impact}= 4 mJ
F = 16Hz

25, 180, 400°C





- Wear volume of ball is maximum at **400°C**.
- Wear volume of OB1 flat is ùmaximum at **180°C**.

The contact loading modifies the oxidation process and the wear

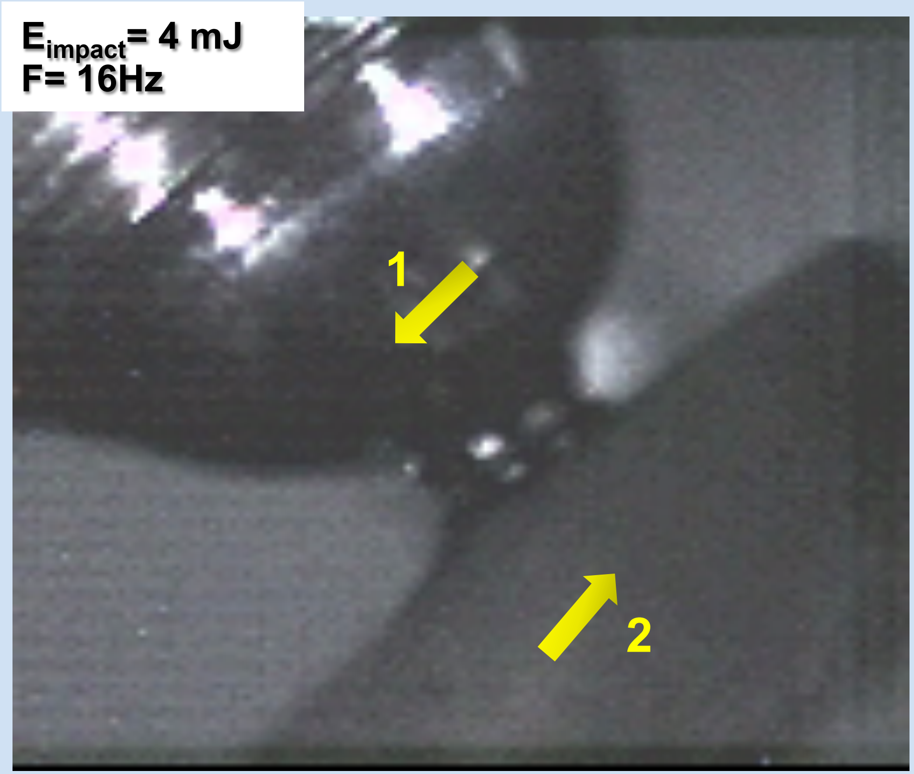
Test results: lubricated conditions

Reciprocating PoD test in lubricated conditions:

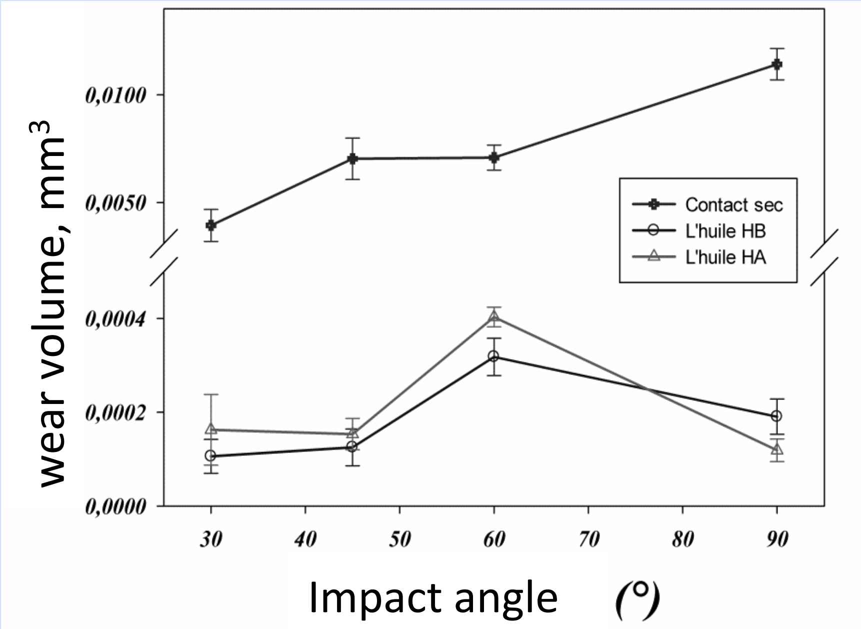
- The friction coefficient decreases when a lubricant is present

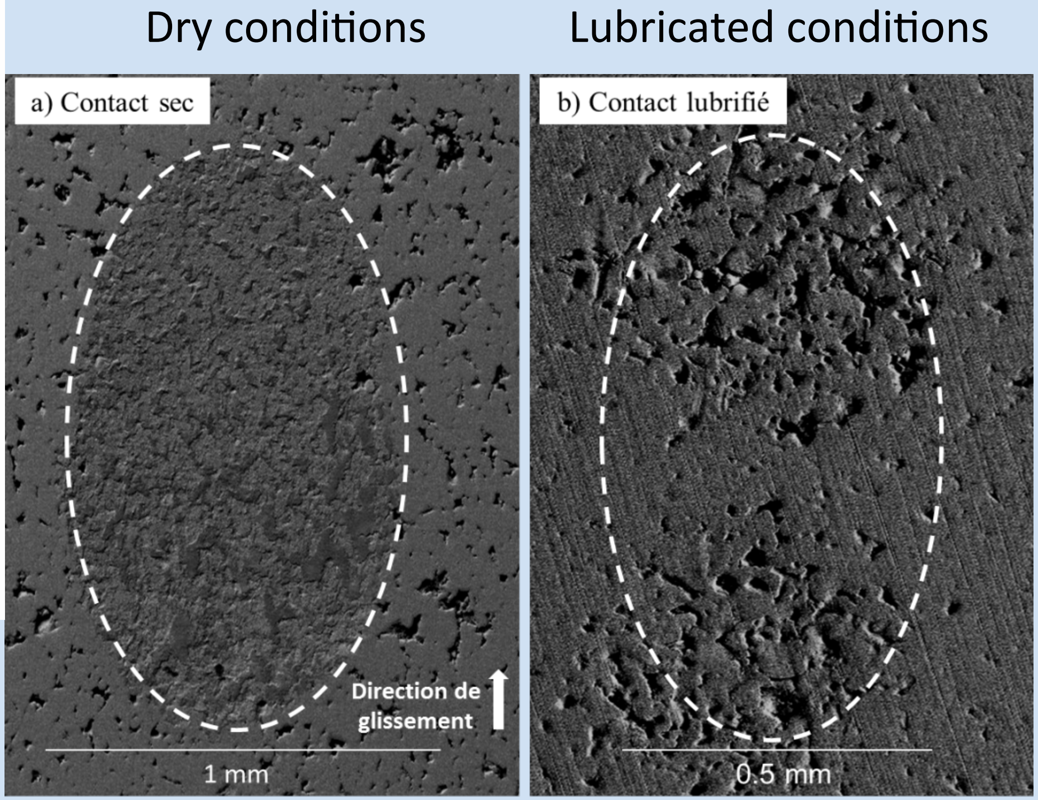
Impact / slidng test with lubricant

- The lubricant remains in the contact
- A metal / metal contact is detected by ECR measurements. Longer than without lubricant
- Impact force is decreased by the lubricant
- Impact force decreases with lubricant viscosity



Observation with high speed camera.
Lubricated contact, 45°





- Reduction of adhesion.
- Observed for all angles
- Damage for lubricated case are initiated at the pores

Conclusions

- Automobiles for the future: energy loss and pollution ➘
- Materials (and surface treatments) are a key factor
  - New materials, coatings, surface texturation, …
- It is necessary to develop specific test systems adapted to "limited parts"
- Example: Valve / seat contact
  - A specific test system have been developed and characterized
  - 2 materials have been tested in dry and lubricated conditions
  - Progress in the understanding to imagine new materials

- Interest to associate experiments to modeling