EPFL

Chapter 8
Coatings and Surface Treatments

MSE 485
Tribology

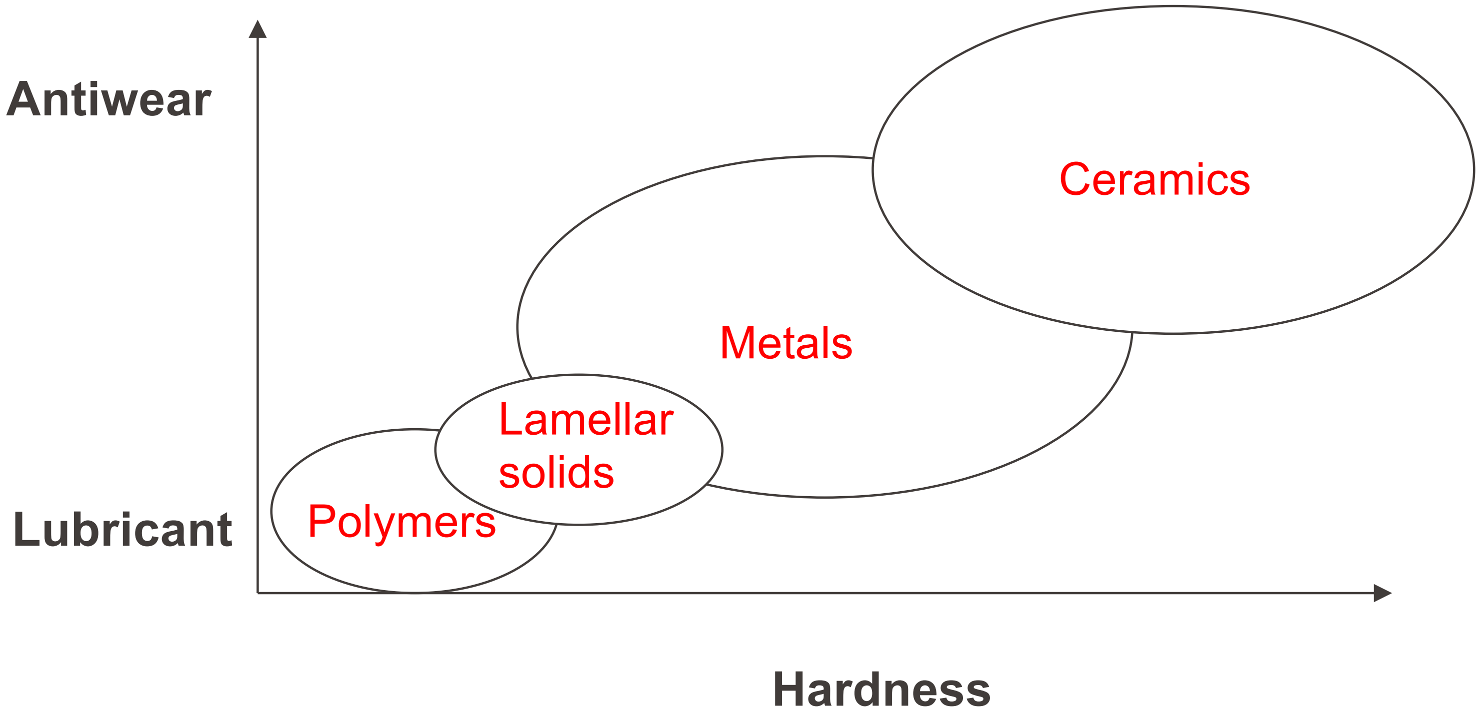
1. Classifications and crucial parameters

2. Soft and Hard coatings

3. MoS2 self-lubricating coating

Zambelli & Vincent Ch. 19 à 21, Hutchings Ch. 8

Classifications



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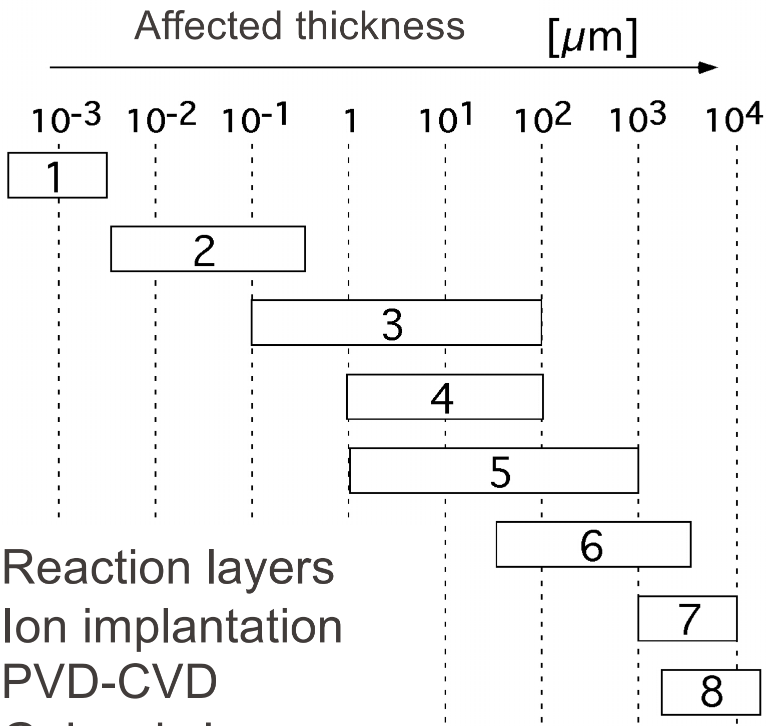
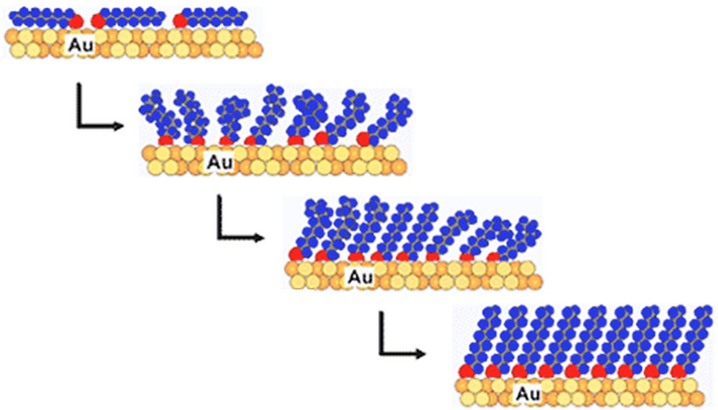
Surface treatments and affected thickness

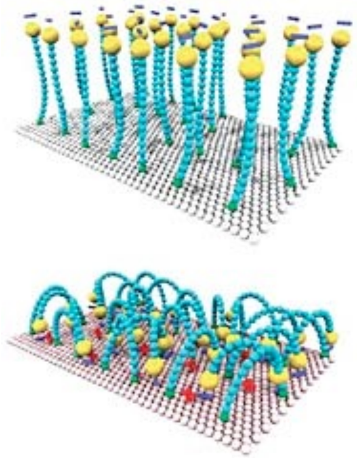


1. Reaction layers
2. Ion implantation
3. PVD-CVD
4. Galvanic layers
5. Thermal projection
6. Thermochemistry
7. Thermal
8. Welding

Reaction and adsorption layers

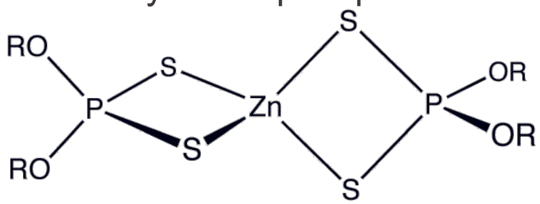
Organic molecules





Organo-metallic film:

Zink-Dialkyl-Dithiophosphate molecules as oil additives



(R = alkyl)

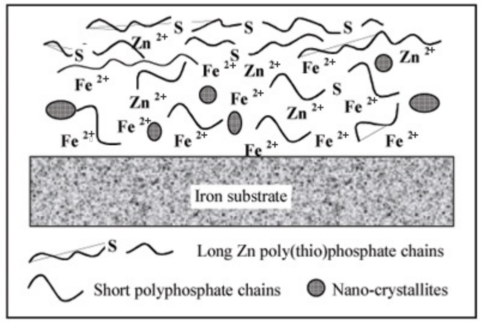
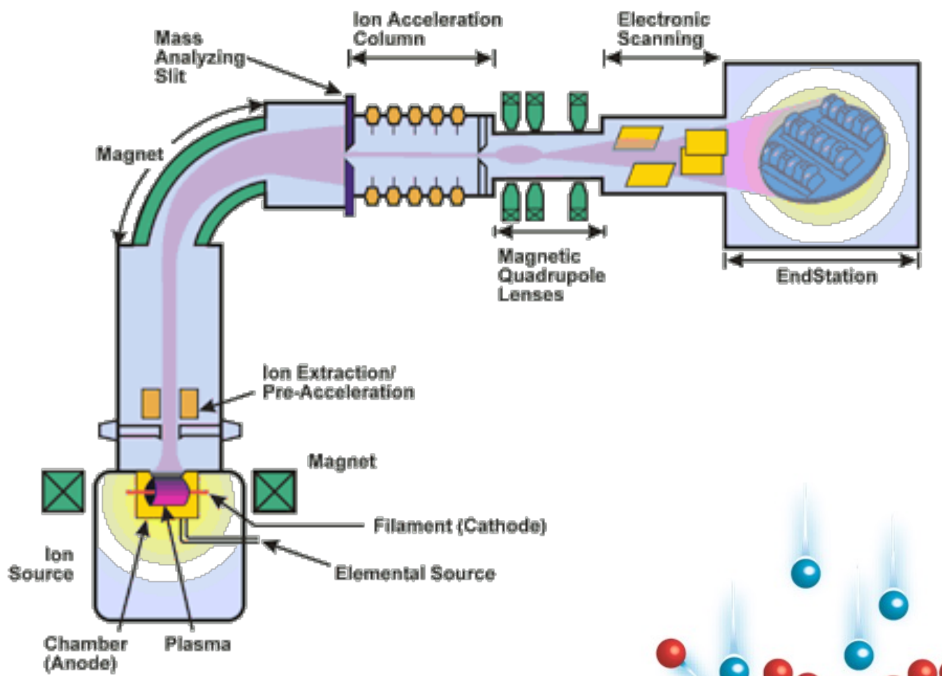
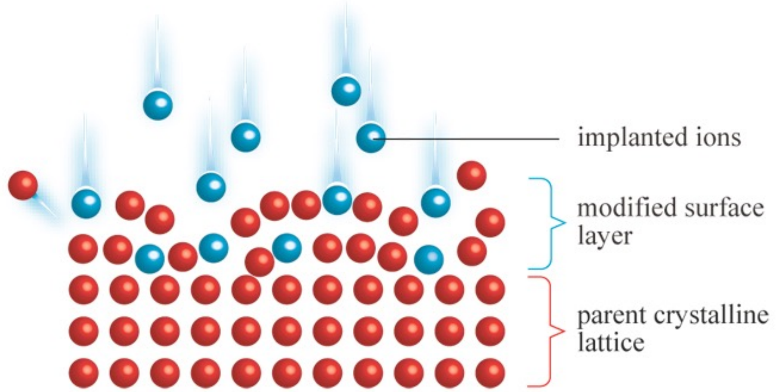


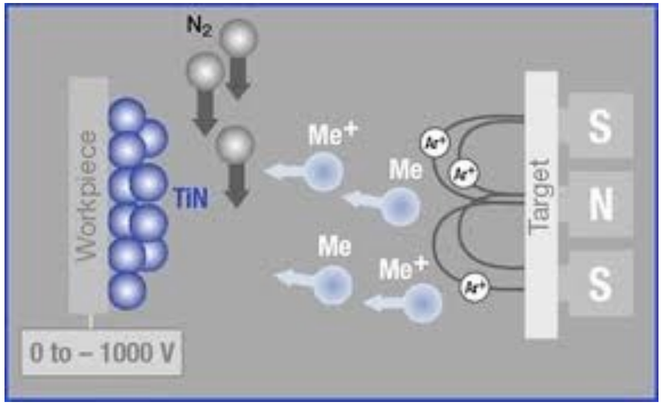
FIG. 6: Schematic structure of the ZDDP tribo-film according to the multi techniques approaches [16]

Ion implantation



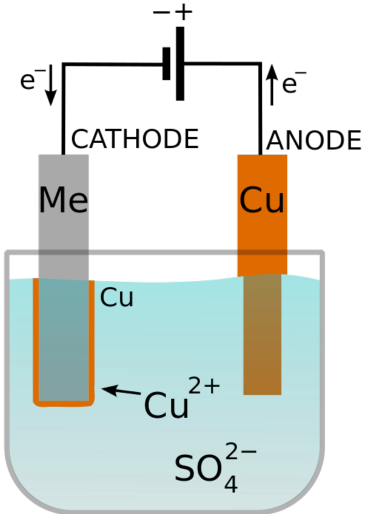


CVD (Chemical Vapor Deposition) and PVD (Physical Vapor Deposition)



Galvanic (electrochemical) coatings

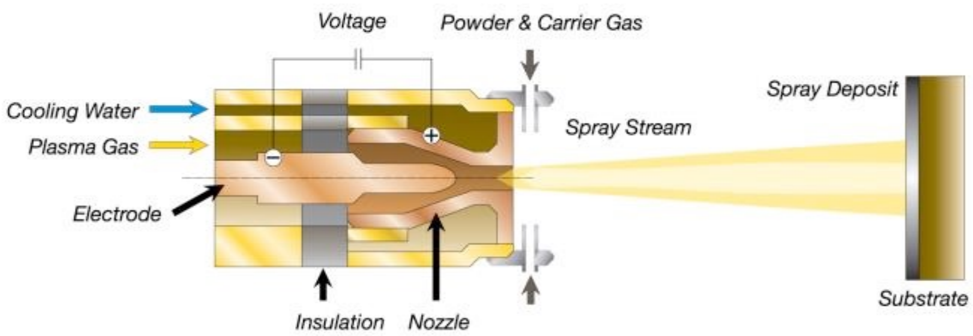
Electrodepositing copper (principle)

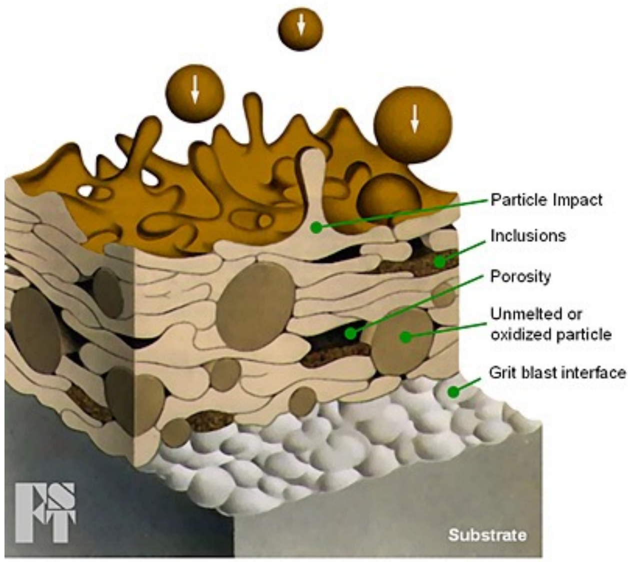


Cathode:
$Cu^{2+} + 2\ e \rightarrow Cu$

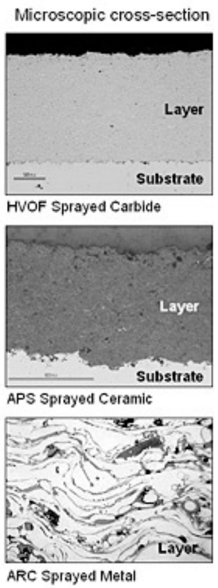
Anode:
$Cu \rightarrow Cu^{2+} + 2\ e$

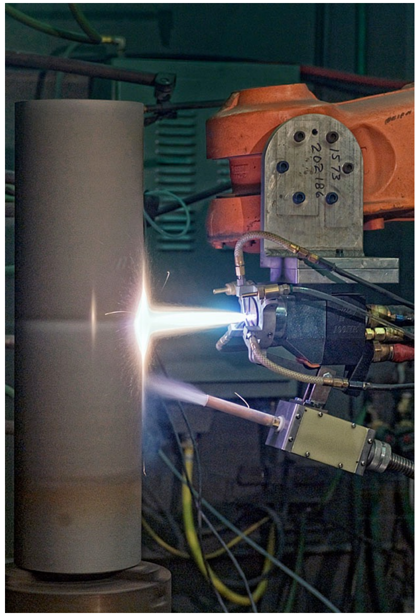
Thermal spray deposition



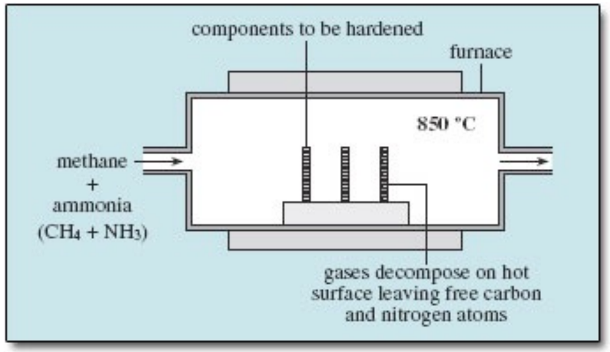


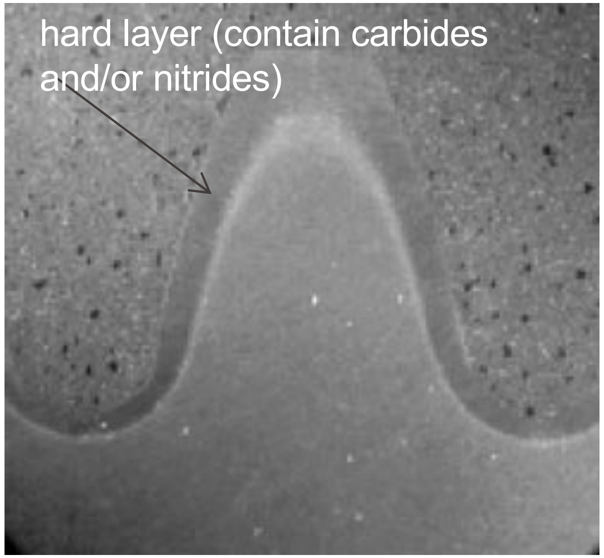
Schematic cross-section of thermally sprayed layer





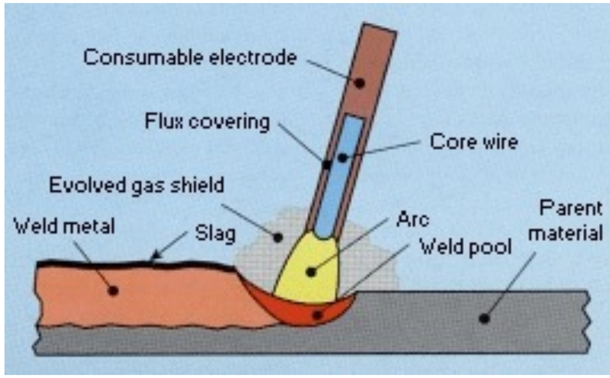
Thermochemical processes (carburizing, nitriding, quenching)



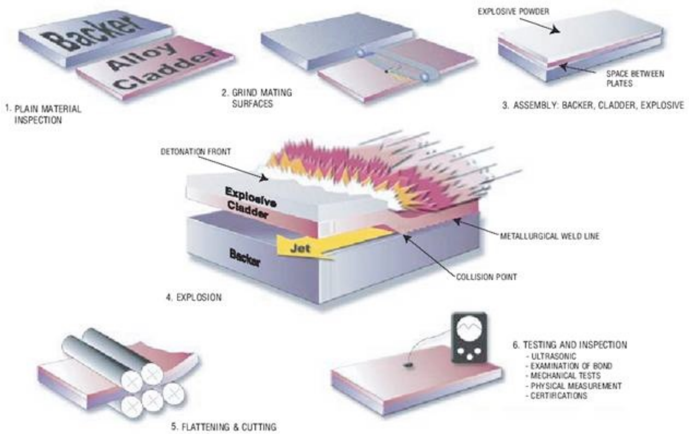


Weld and explosive cladding

Weld cladding



Explosive cladding



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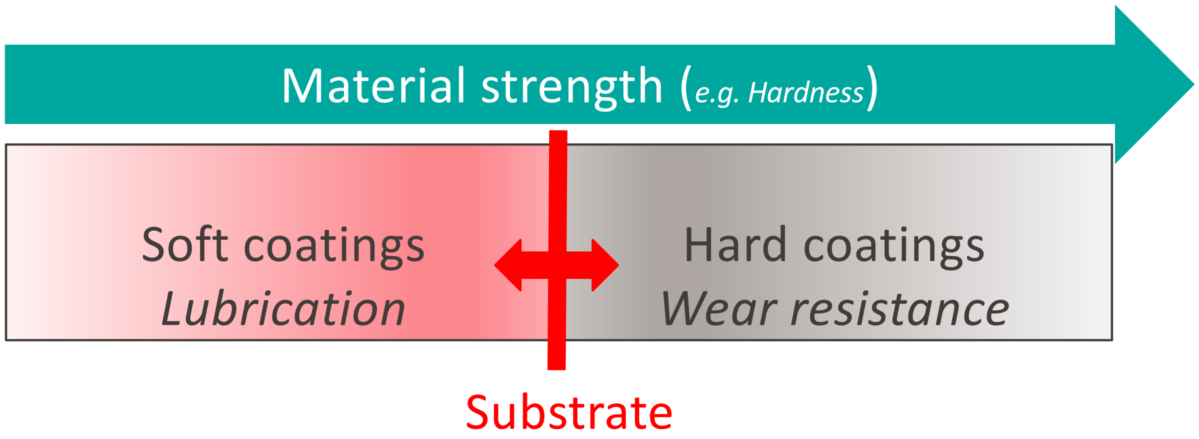
3. MoS2 self-lubricating coating

Zambelli & Vincent Ch. 19 à 21, Hutchings Ch. 8

Soft and Hard Coatings

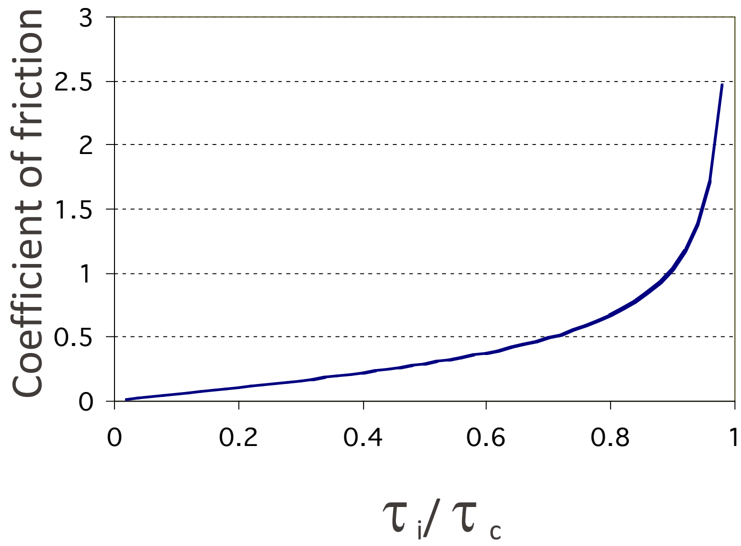


- Soft coating: coating exhibiting less strength than the substrate; acts as lubricant to reduce stress field on the substrate.

- Hard coating: coating exhibiting larger strength than the substrate; acts as stress shield for the substrate.

Friction reduction in soft coatings

- **Principle:** the coating generate a soft (easy to shear) interfacial layer that reduces friction. The friction reducing effect depends on both the mechanical properties of the coating and of the substrate.



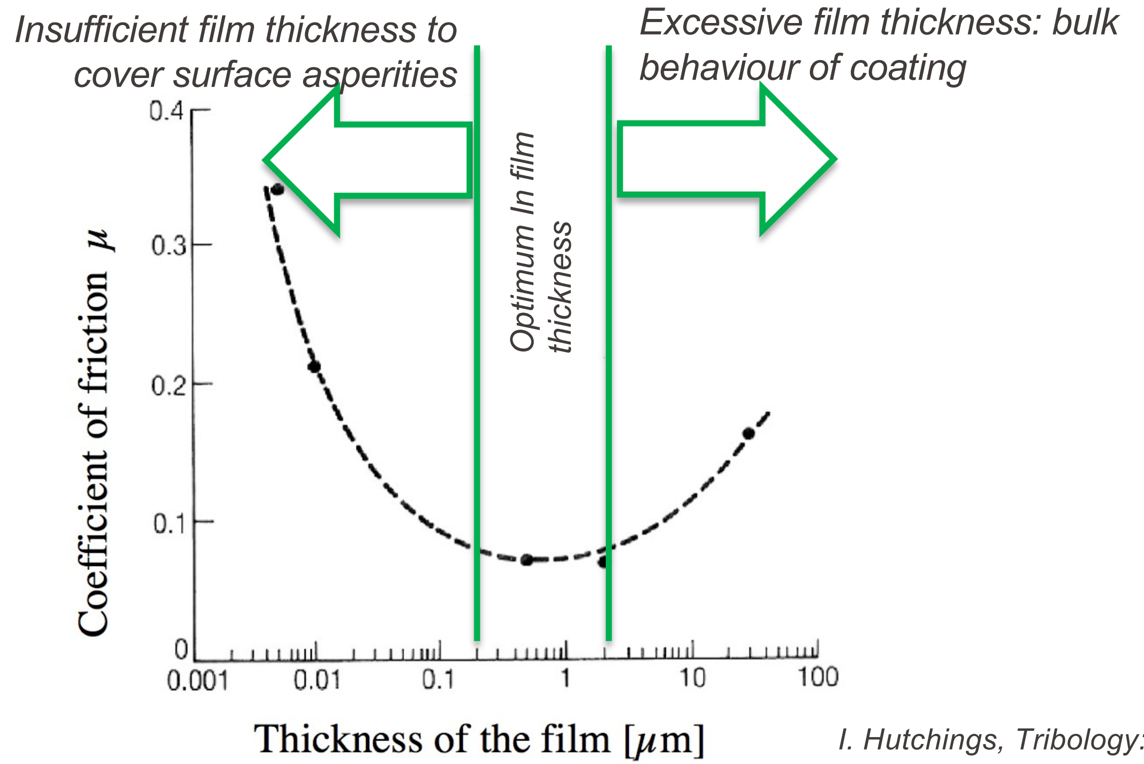
τ_i : shear stress of the interface layer

τ_c : critical shear stress of the substrate

- **Consequence:** the choice of the soft coating must be tuned to the substrate: a soft gold coating can efficiently lubricate hard steel contacts but not softer polymer contacts.

Coating thickness and friction

- Coefficient of friction of steel rubbing against Indium coated tool steel

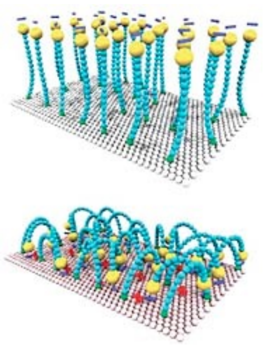


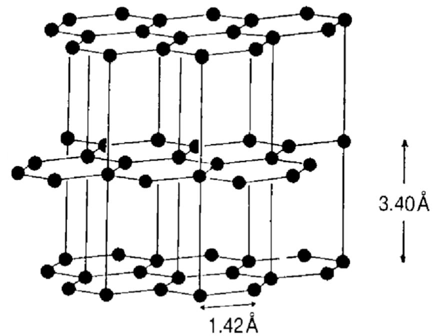
I. Hutchings, Tribology: Friction and Wear of Engineering Materials, Arnold 1992

Lubricating coatings: more does not mean more lubrication!

Typical soft tribological coatings

- Soft metals: Pb, Sn, Au, Ag, Cu, In
- Polymers : PE, PTFE, PA, PET , …
- Self assembled monolayers
- Diamond like carbon (DLC)
- Lamellar mineral solids : MoS2, Graphite





Structure of graphite
Inter-lamellae bonds are weak and easy to shear. They offer little resistance (friction) to sliding.

Hard coatings

- **Principle:** the coating forms a thin hard barrier for stress shielding the substrate and reducing wear.

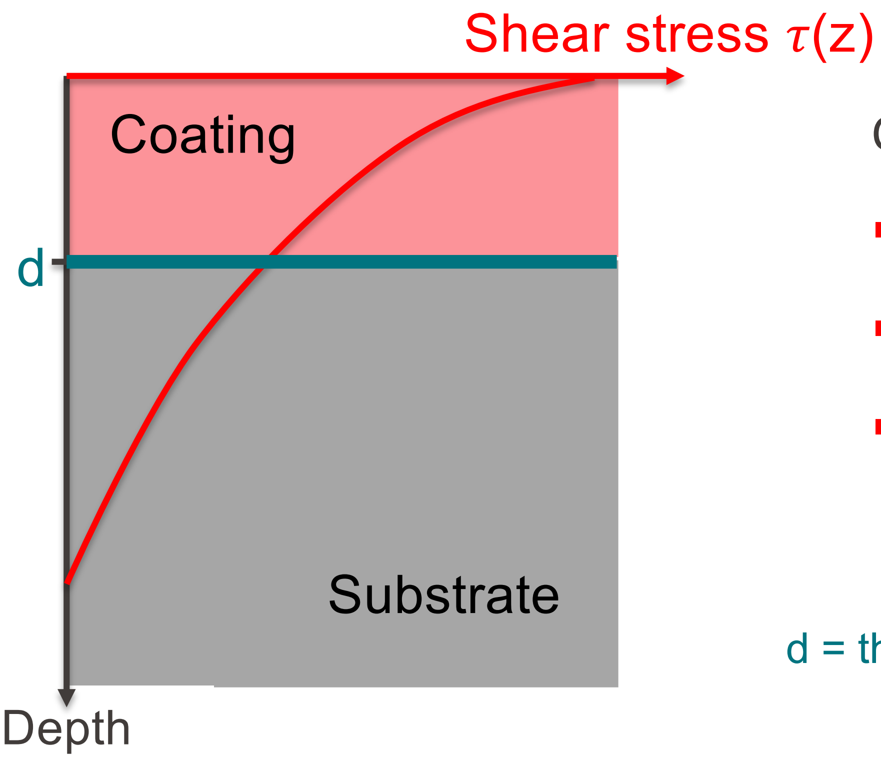
- **Requirements:**

  - Corrosion resistance (i.e. ceramic coatings such as nitrides, carbides, oxides and hard metallic coatings such as Cr)

  - Stress shielding properties (strength, adherence, elasticity, roughness)

Mechanical aspects

- The mechanical and tribological efficiency of a coatings does not only depend on the properties of the layer but also of the substrate and of the interface.



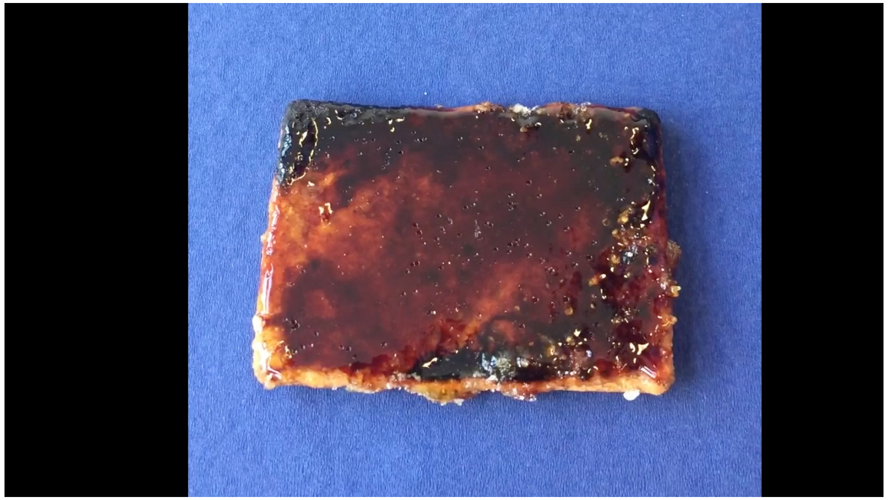
Conditions for stability:

- Strength of the coating > τ_{max}
- Strength of the interface > τ (d)
- Strength of the substrate > τ (d)

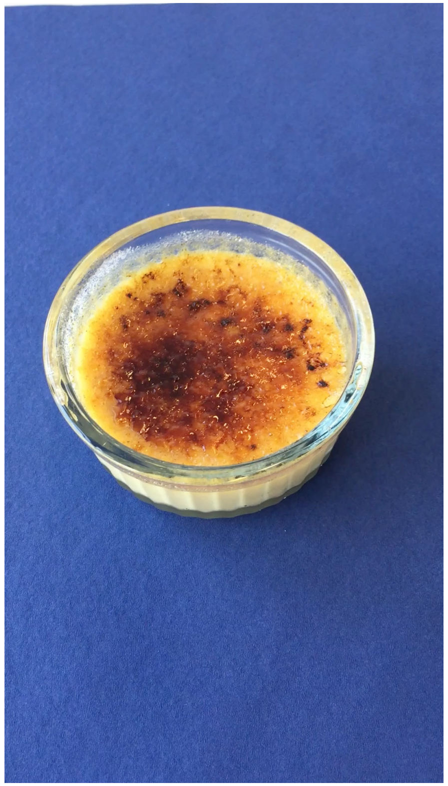
d = thickness of the coating

The role of substrate on coating performance

Hard coating on hard substrate (biscuit)



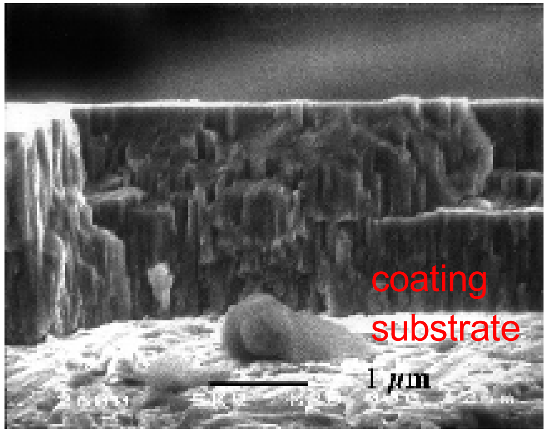
Hard coating on soft substrate (cream)



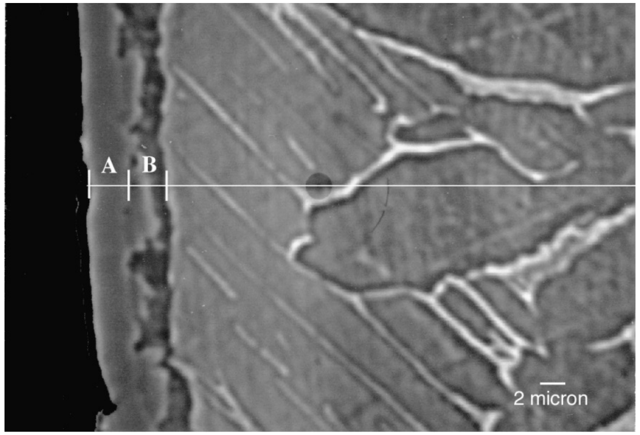
Hard coatings need a sufficiently strong substrate!

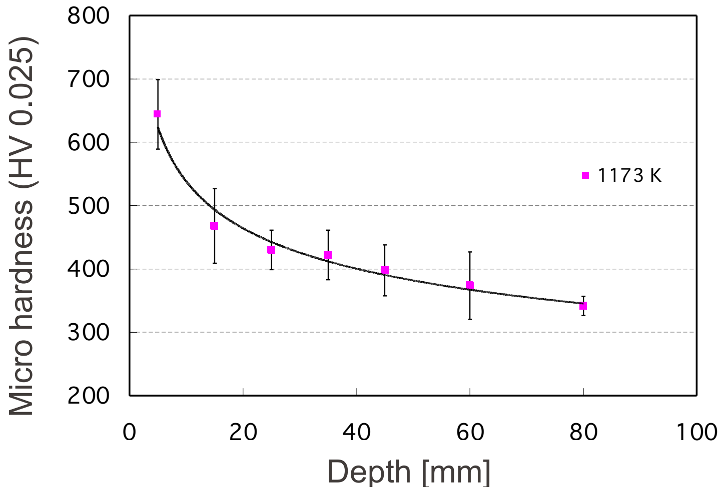
Interfaces examples

Abrupt interface : TiN PVD coating on a steel substrate.



Graded interface : 900°C plasma nitridation of a Ti_6Al_4V alloy.





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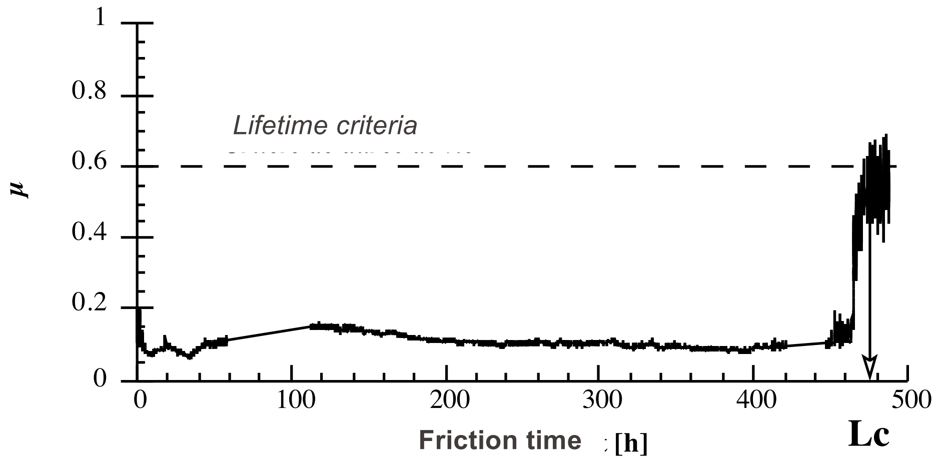
Self-lubricating MoS_2 PVD-deposited coatings

- Thin MoS_2 (lamellar solid lubricant) films (thickness typically inferior to 1μ) reduce friction and/or wear without adding oil. They are used to lubricate some ball bearings used in aerospace applications.

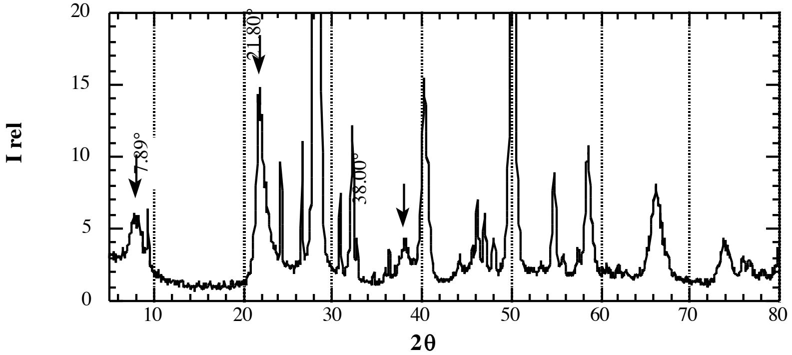
- The functionality of the coating is limited by its deterioration during use. The lifetime L_c of a self-lubricating coating if often defined as the friction time during which the coefficient of friction stays inferior to the value measured without self-lubricating film.



Self-lubricating MoS_2 PVD-deposited coatings

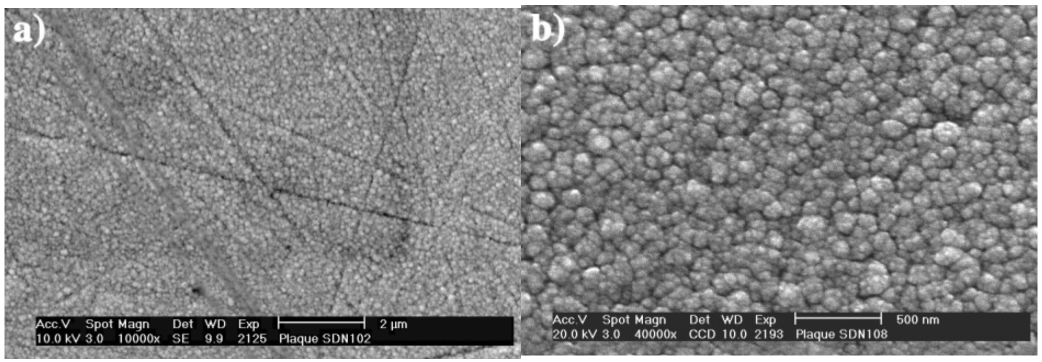
- **Physico-chemical characterization of MoS_2 coatings**

Structure



X-ray diffraction spectrum of the AISI 440C steel substrate + MoS_2.

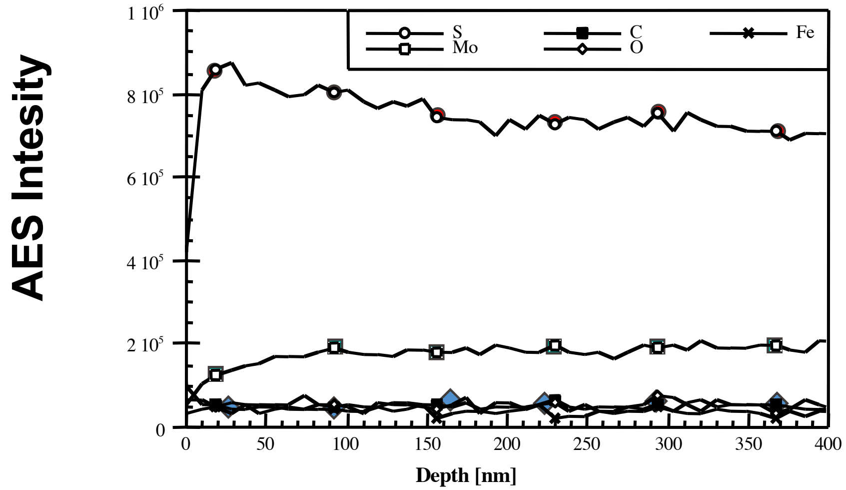
Surface morphology

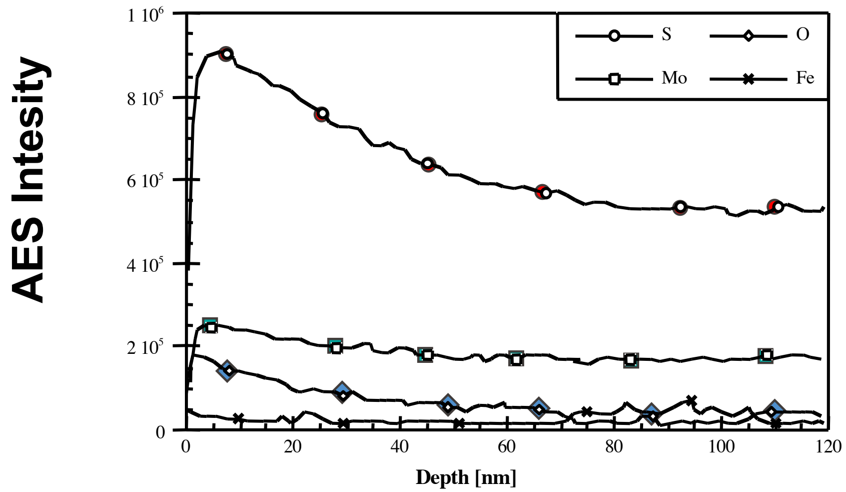


SEM images (Scanning Electron Microscope) of the surface of the MoS_2 depot . a) Magnification 10000x, 10 KV and b) 40000x, 20KV.

Composition (stoechiometry, contaminations)

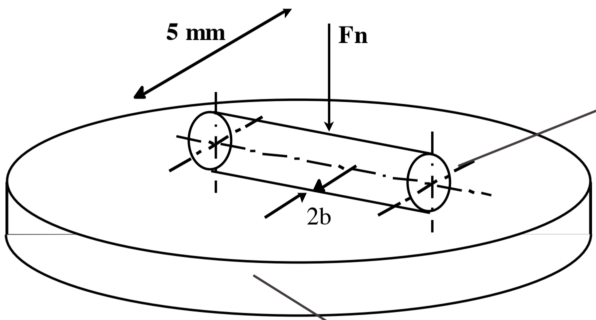
- AES depth profiles of two commercial MoS_2 depots.





Tribological characterization example

EPFL thesis 2188 S. Debaud

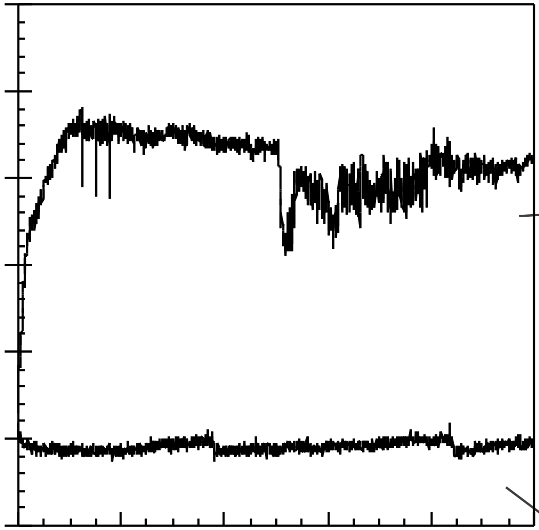


$100Cr_6$ quenched steel cylinder (pin). For some tests, pins coated with a thin (< 0.5 µm) Ti or Au layer are used to estimate the effect of surface chemistry.

Quenched steel disc covered with a 0.7 µm PVD-deposited MoS_2 layer.

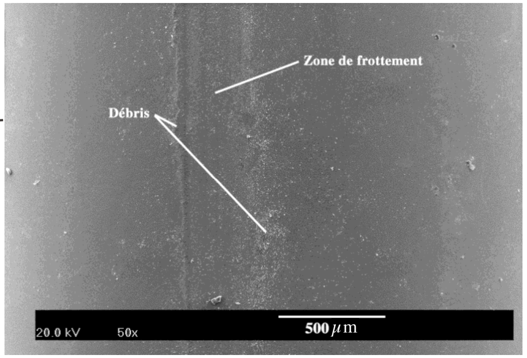
Lubricating effect

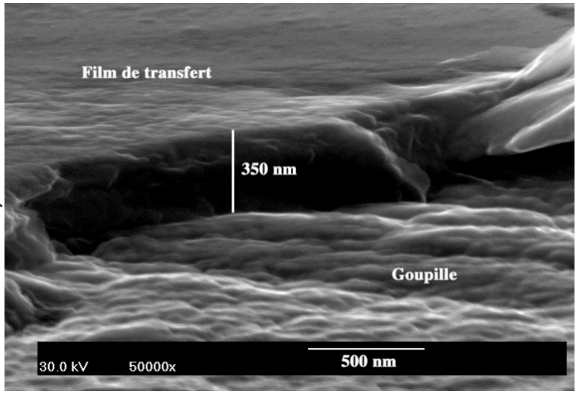
- The lubricating effect is linked to the formation of a transfer film.



Evolution of the coefficient of friction over time during two different tests, run under identical conditions.
(Contact AISI440C + MoS_2/100Cr_6; atmosphere : nitrogen 100%)

No transfer film

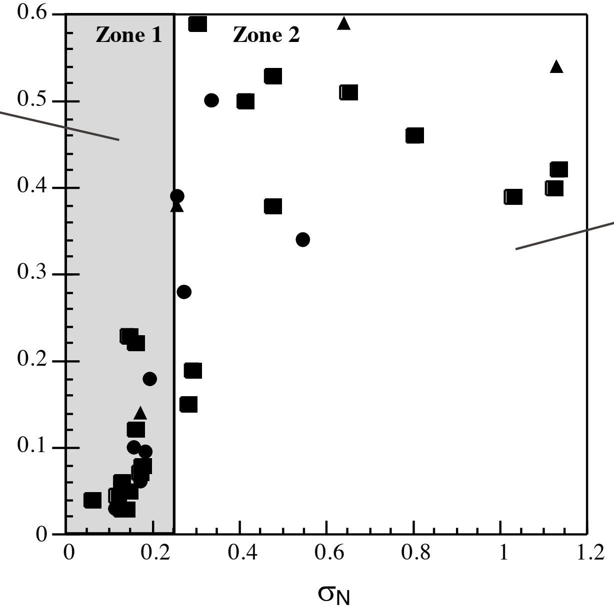




Transfer film

Effect of vibrations on the formation of a transfert film

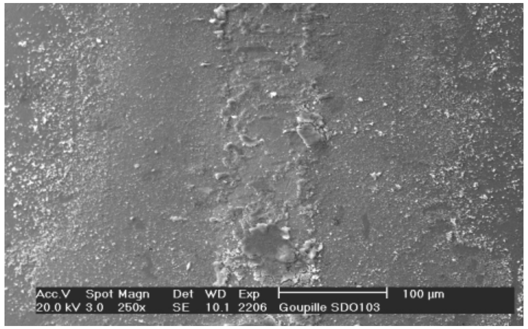
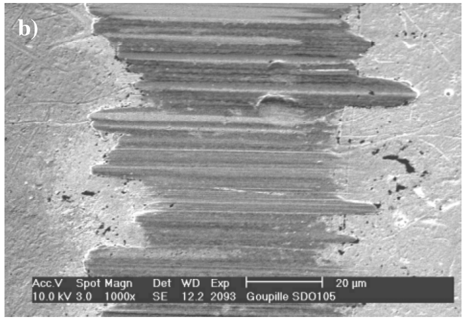
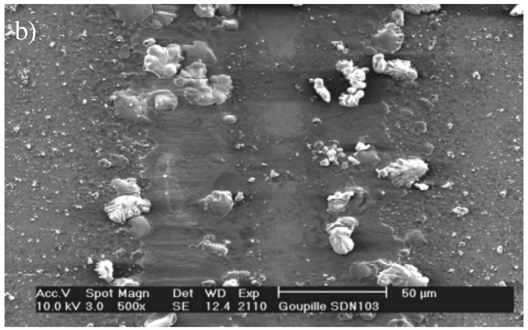
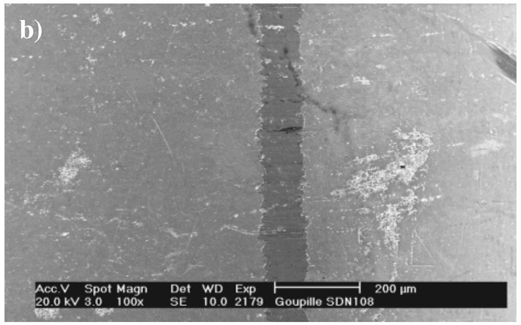
Transfer film



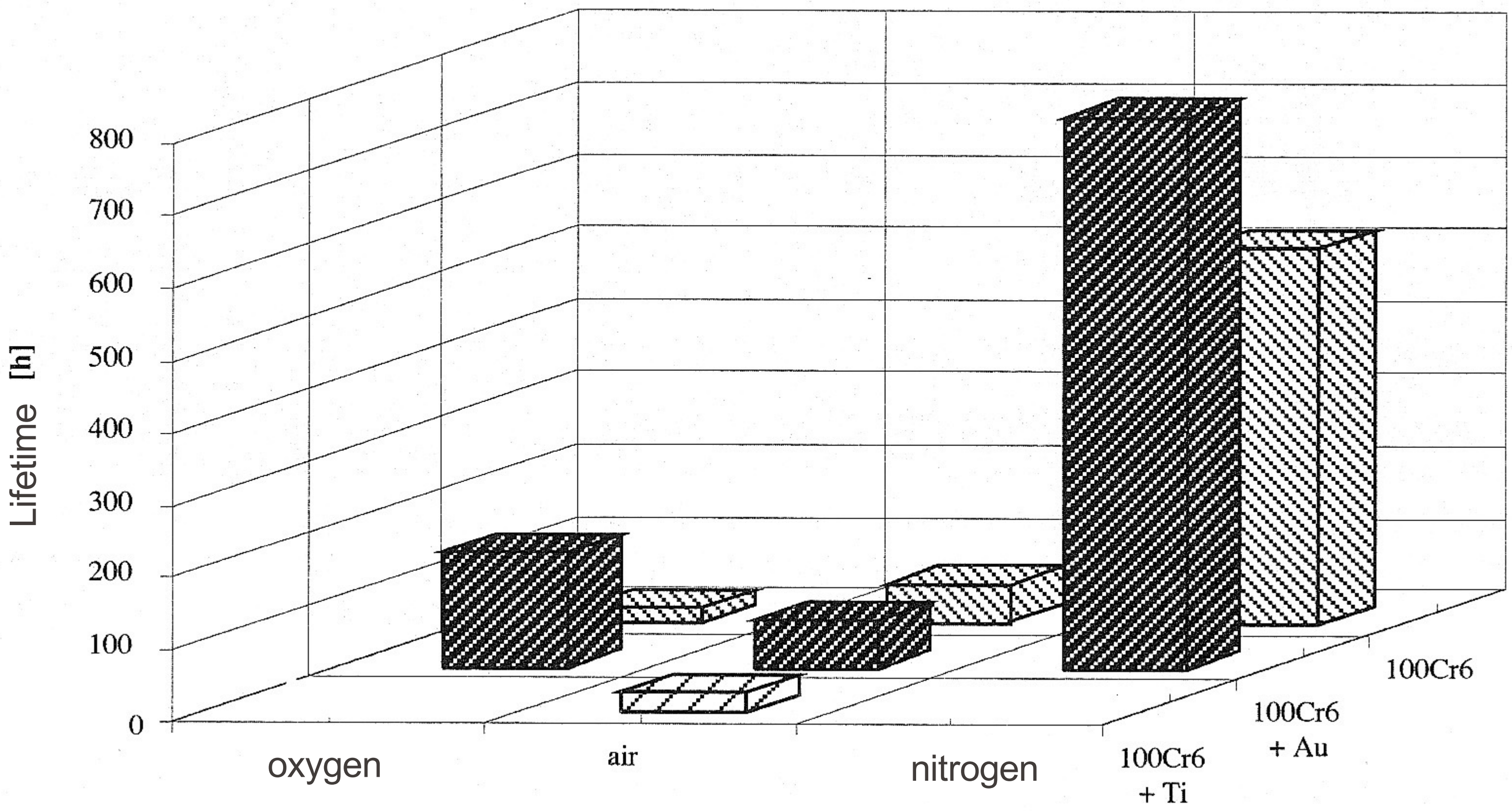
No transfer film

Mean coefficient of friction against normalized standard deviation of the normal stress (σN), all test conditions mixed up. Zone 1 : SEM and EDAX observations show that a transfer film is present on the pin. Zone 2 : SEM and EDAX observation show absence of such a film on the pin.

Effect of the metal and of the atmosphere on the structure of the transfer film

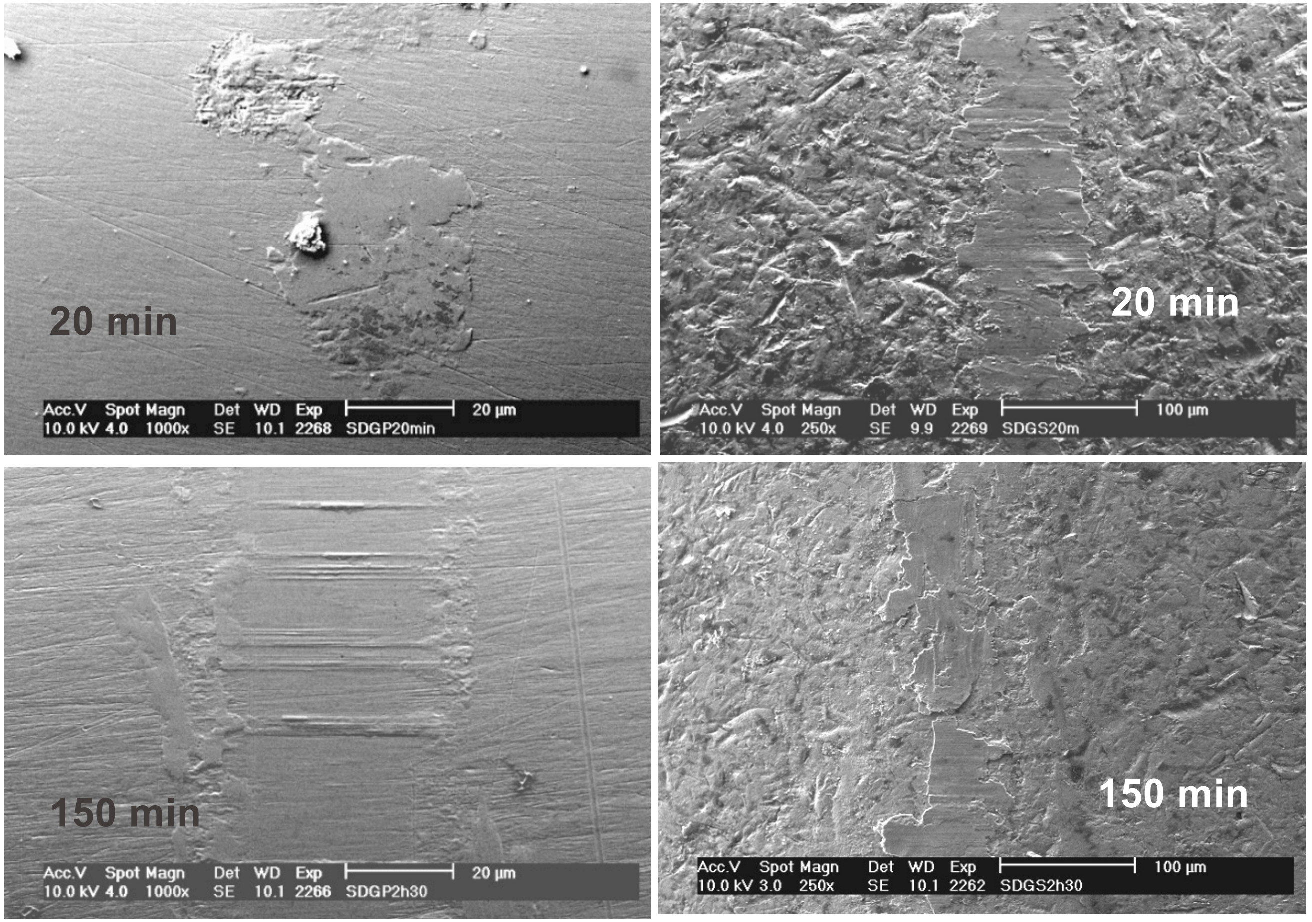
	Steel pin	Au-coated steel pin
Test in air		
Test in a nitrogen atmosphere (45 ppm O_2 and 10 ppm H_2O)		
	Fragile transfer film with Fe-Cr (nitrogen) and Fe-Cr-Mo (air) oxides debris.	Homogeneous transfer film, with few very fine debris.

Effect of metal and atmosphere on the lifetime of the coating



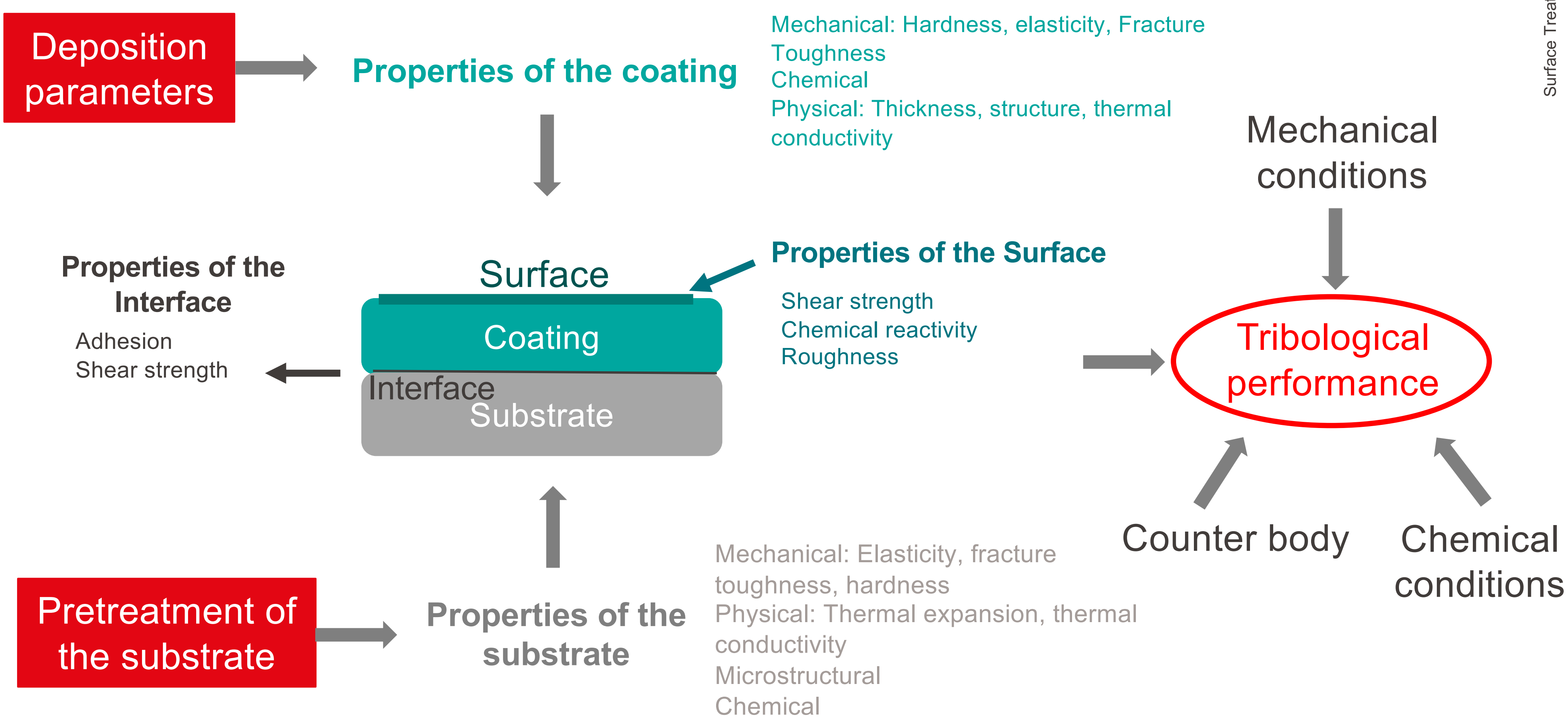
Effect of roughness and friction time on the structure of the transfert film

Smooth pin (R_a 0.07 µm) | Rough pin (R_a 1.01 µm)



Nitrogen atmosphere

System approach to coatings tribology



Adapted from Holmberg and Matthews Coatings Tribology, 1994