Tribocorrosion in valves

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Swiss Federal Institute of Technology Lausanne

- **Missions: education, research and technology transfer**
- 9500 Students
- 5500 Staff members
- 125 Nationalities
- 5 Faculties
- Basic sciences, Engineering, IT,
- Environment, Life sciences
- 340 Laboratories
- 13 Study programs
- 1 Start-up company/month
- **Turnover: 400 MEUR/year**

Known issues for valves degradation

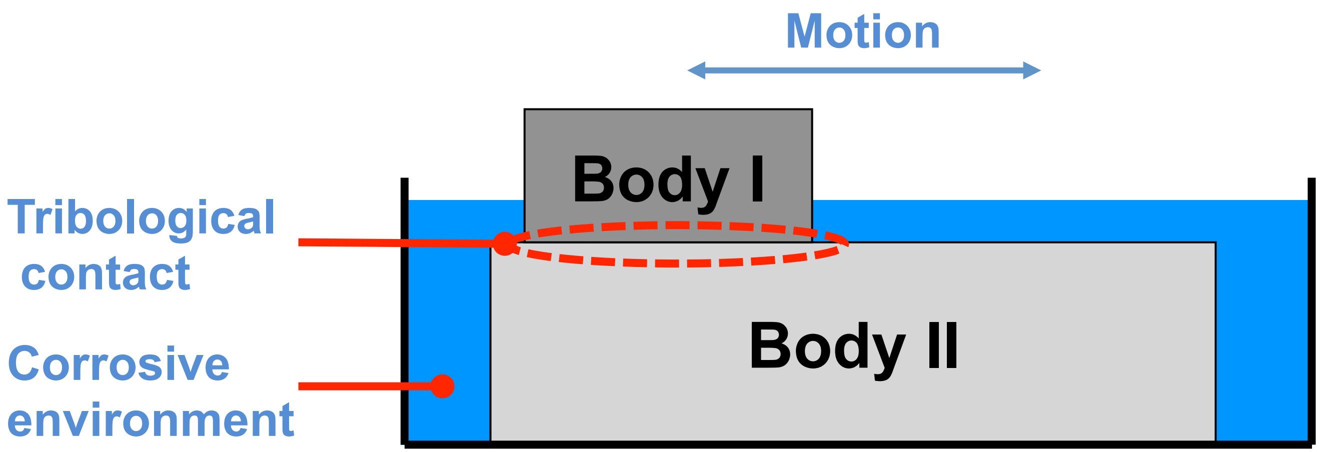
Corrosion: (ASTM) deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment.

Erosion: (ASTM) progressive loss of original material from a solid surface due to mechanical interaction between the surface and a fluid, a multicomponent fluid, or impinging liquid or soil particles .

Cavitation: (ASTM) formation and subsequent collapse within a liquid, of cavities or bubbles that contain vapour or a mixture of vapour and gas.

Tribocorrosion

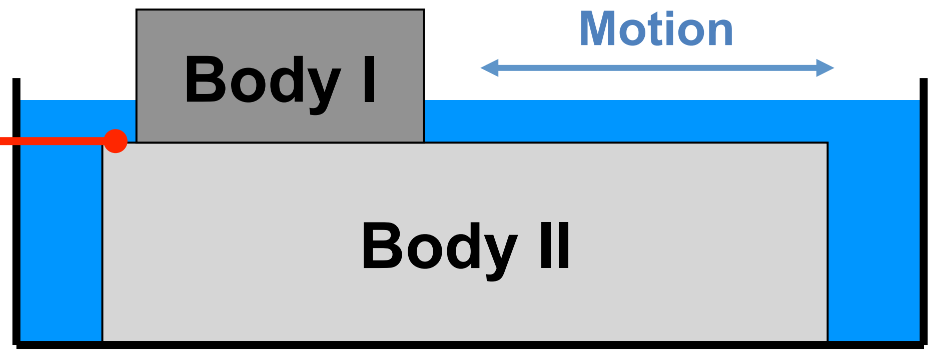
A form of solid surface alteration that involves the joint action of relatively moving mechanical contact with chemical reaction in which the result may be different in effect than either process acting separately. (ASTM)



Tribocorrosion

Reciprocal Sliding

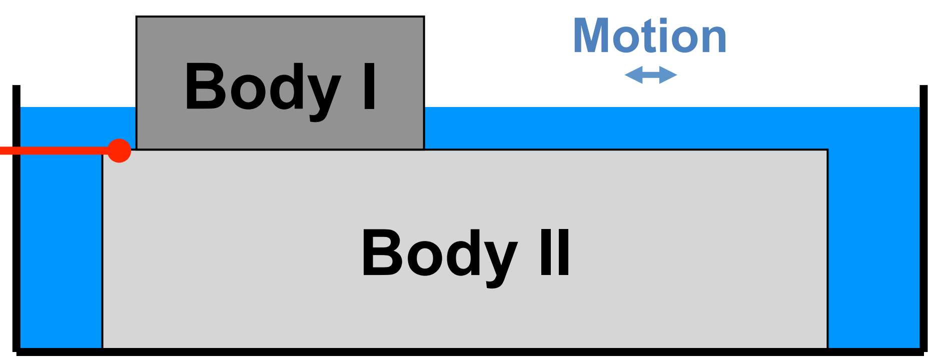
e>1



$$e = \frac{\delta^{*}\ \text{(Displacement amplitude)}}{a\ \text{(Contact radius)}}$$

Fretting

e<1



Complexity of tribocorrosion system

Materials (two bodies in contact)

- Hardness, plasticity
- Microstructure, inclusions
- Surface roughness
- Oxide film properties
- Wear debris, material transfer
- …

Electrochemical

- Applied potential
- Ohmic resistance
- Repassivation kinetics
- Film growth
- Active dissolution valence
- …

Tribocorrosion System*

Mechanical/operational

- Normal force
- Sliding velocity, type of motion
- Shape and size of contacting bodies
- Alignment
- Vibrations
- …

Solution

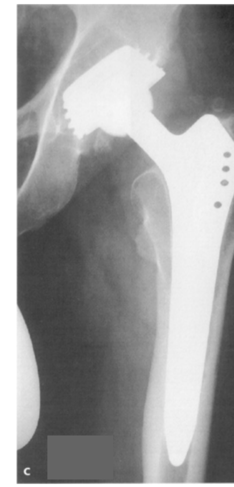
- Viscosity
- Conductivity
- pH
- Corrosivity
- Temperature
- …

*Dieter Landolt, Stefano Mischler. Tribocorrosion of passive metals and coatings. 2011

Engineering tribocorrosion systems

Marine installations

Pressurized Water Reactors

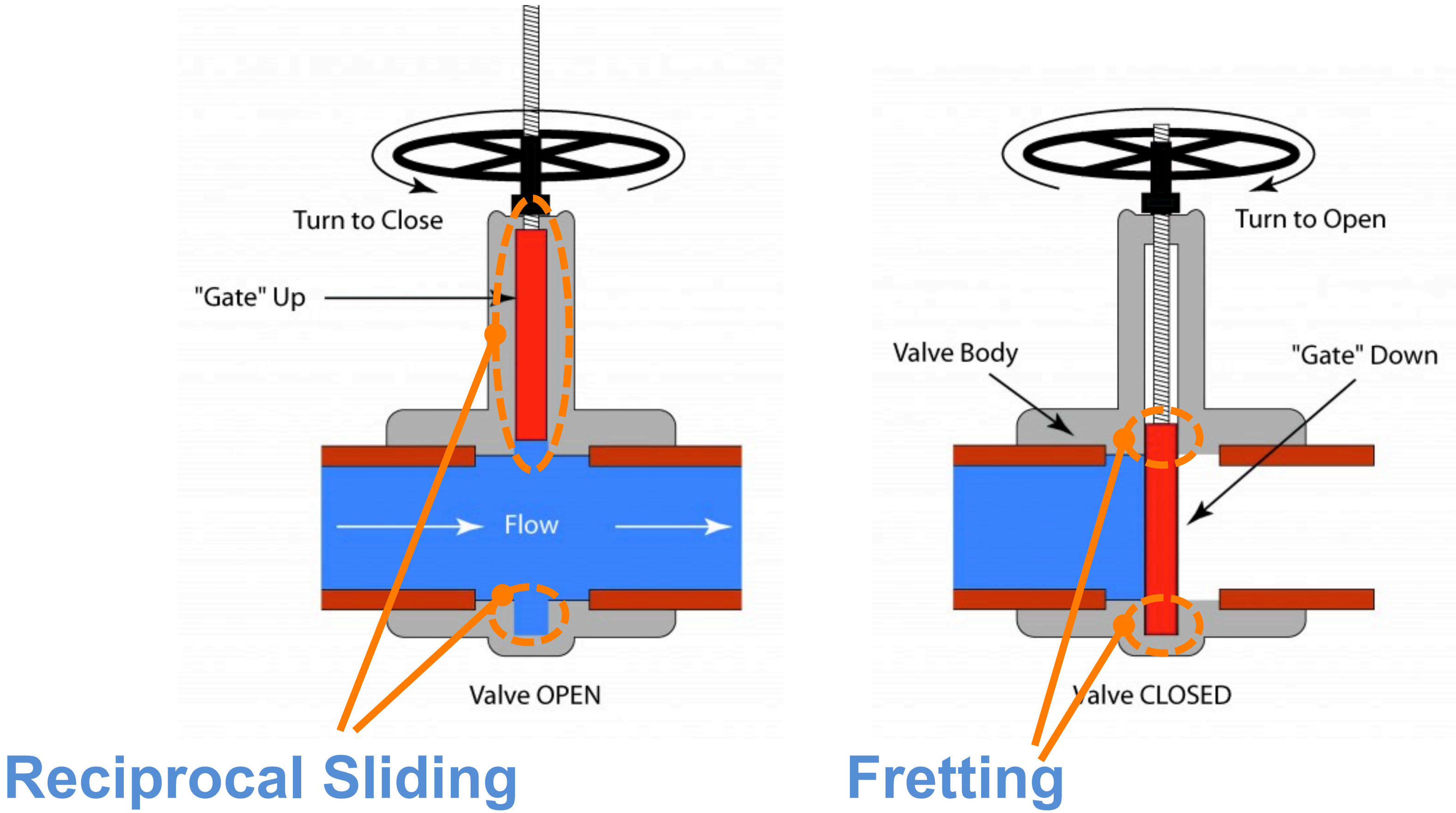


Biomedical implants

Machining, forming

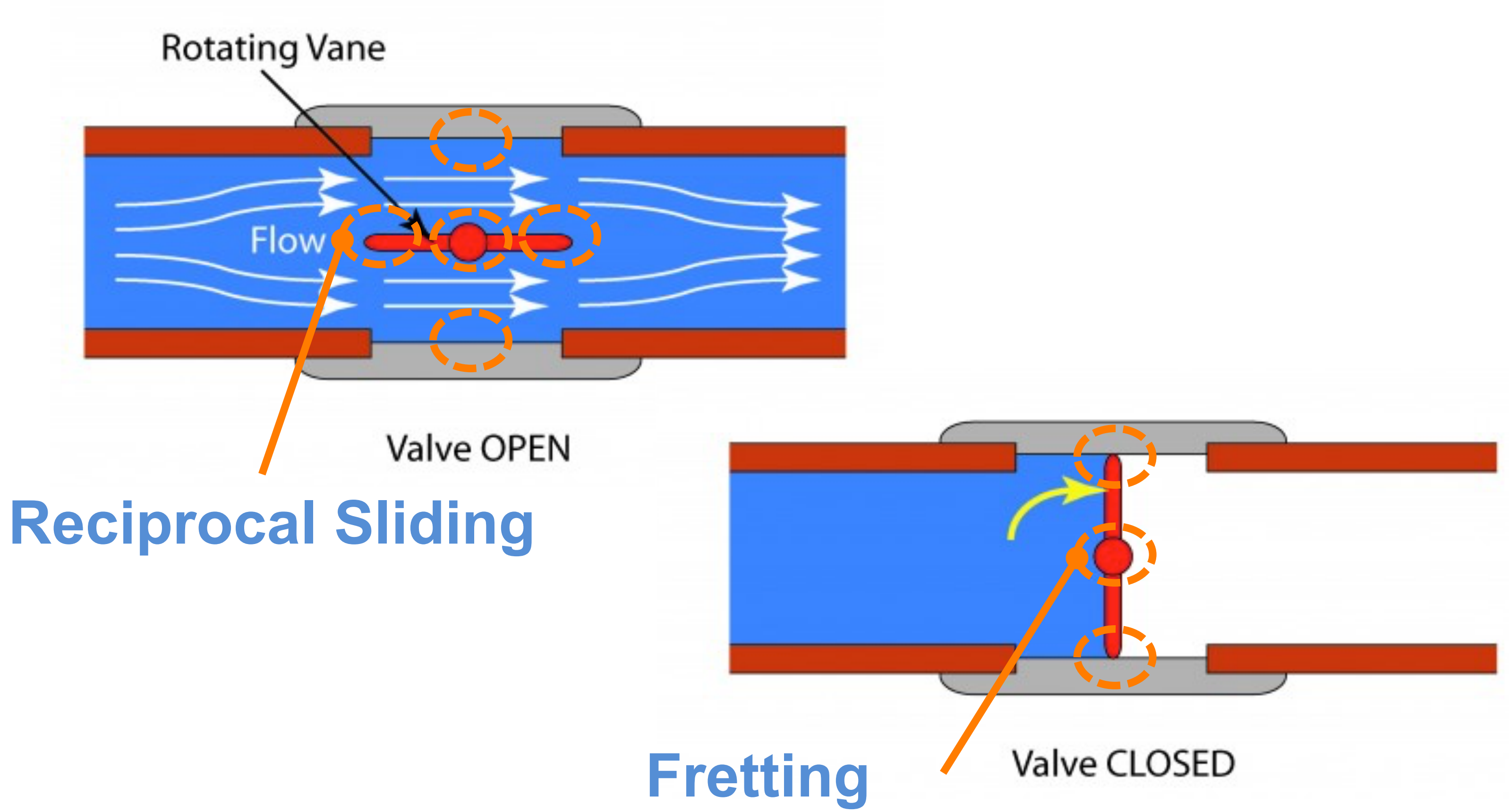
Valves

Sliding phenomena in gate valves



http://www.ctgclean.com

Sliding phenomena in butterfly valves



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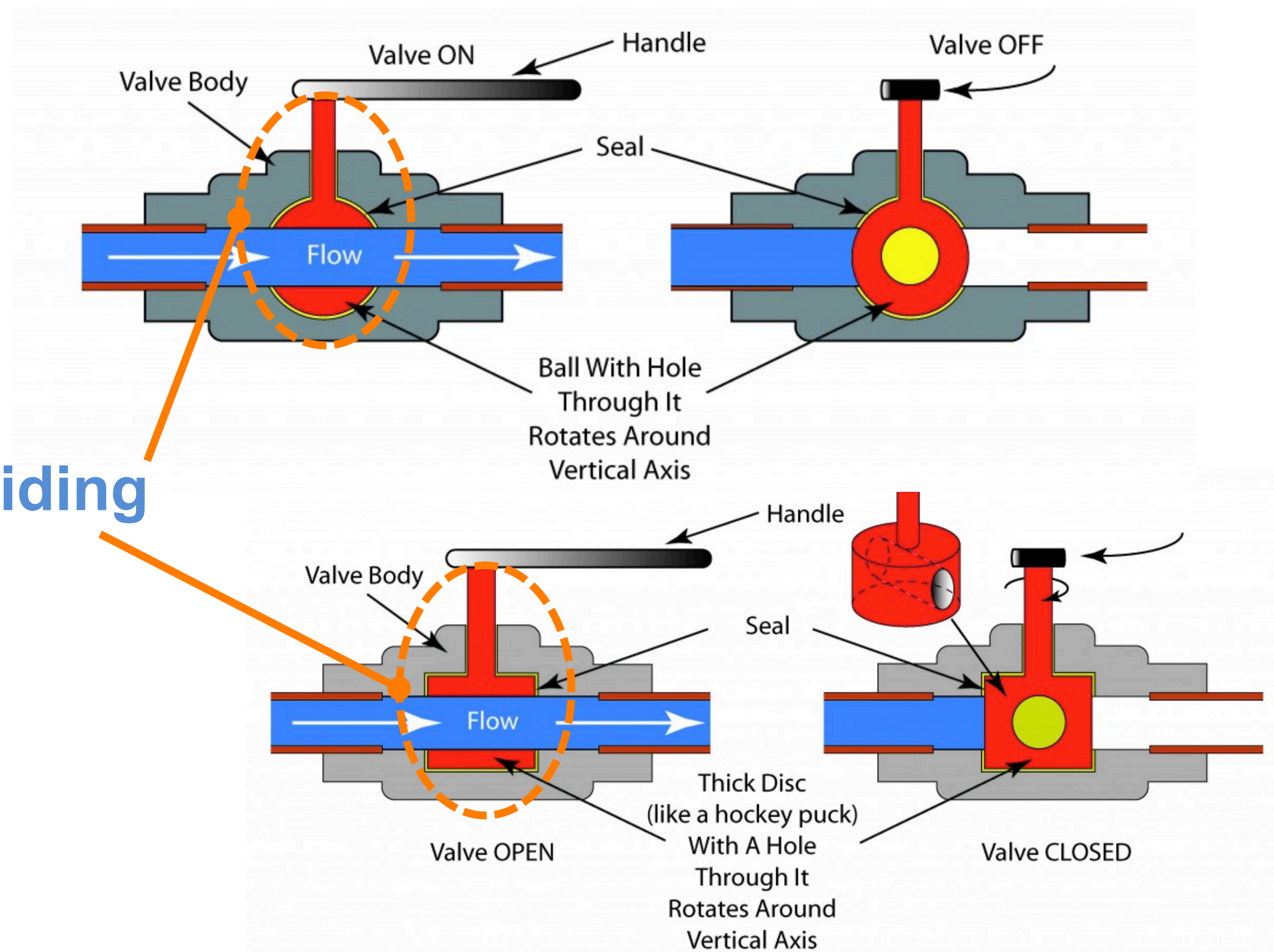
Sliding phenomena in ball and rotary valves.

Reciprocal Sliding



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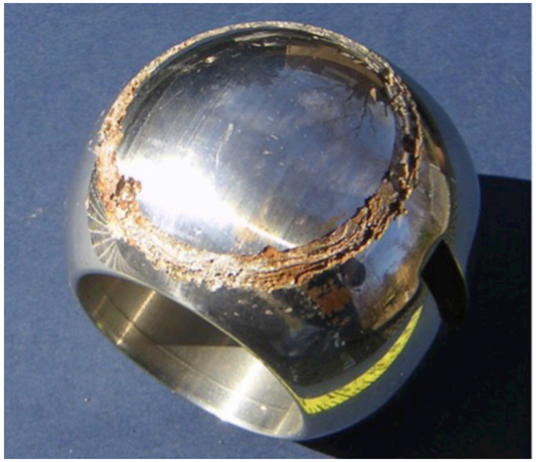
Damaged valves.



Possible contribution of Tribocorrosion

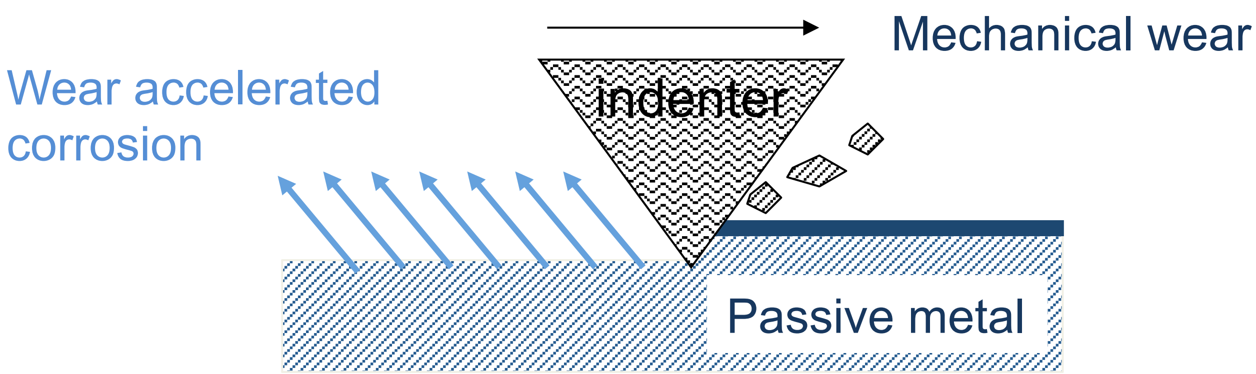
?

Basic aspects and tribocorrosion testing

Mechanistic tribocorrosion model for passive metal

Two distinct but coupled degradation mechanisms:

- Wear accelerated corrosion (release of ions)
- Mechanical wear (release of metal particles)

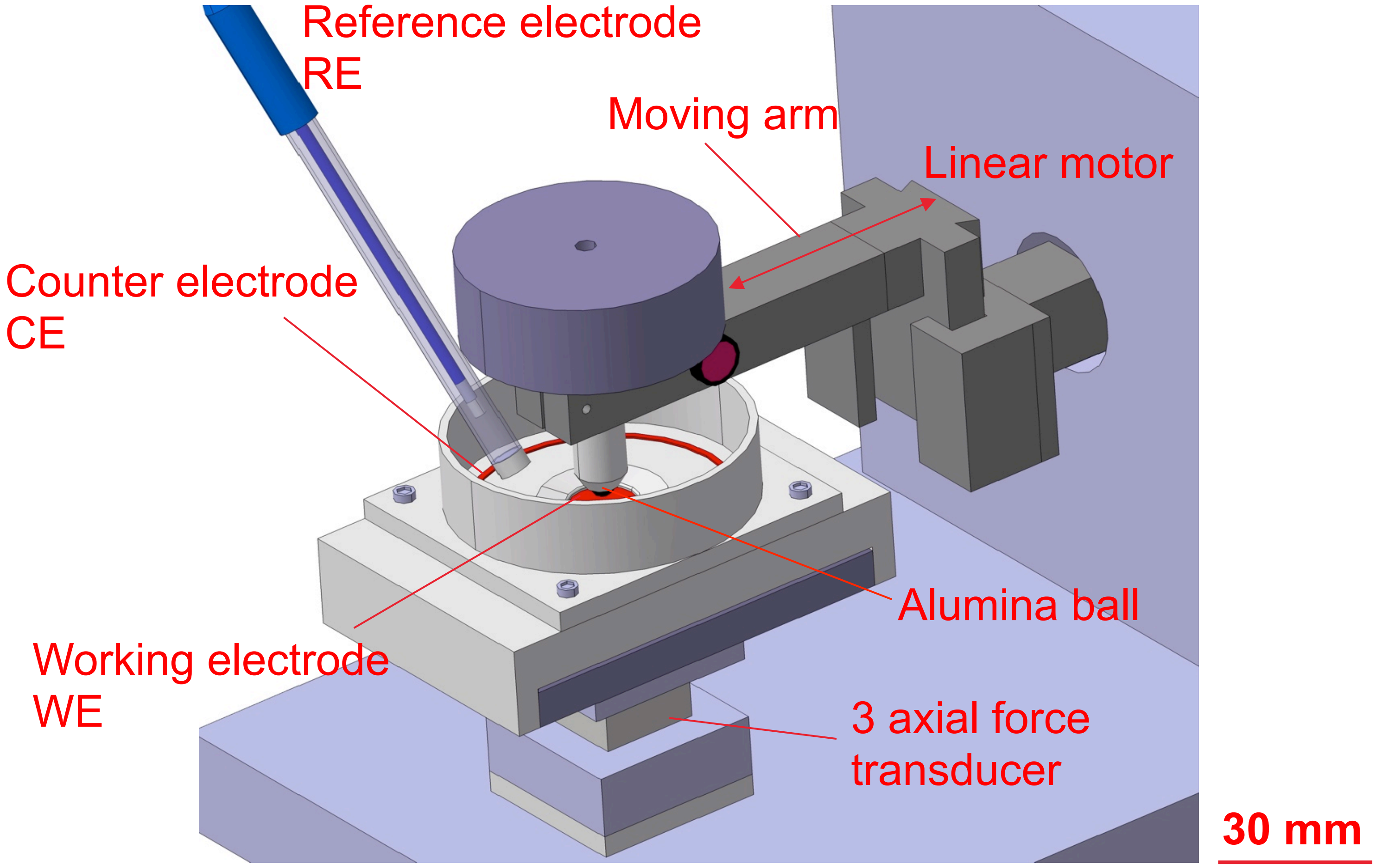


Total material loss:

$$V_{total} = V_{wac} + V_{mech}$$

*Uhlig. 1954

Tribo-electrochemical test rig



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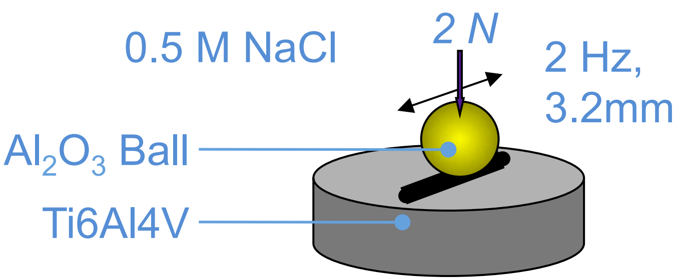
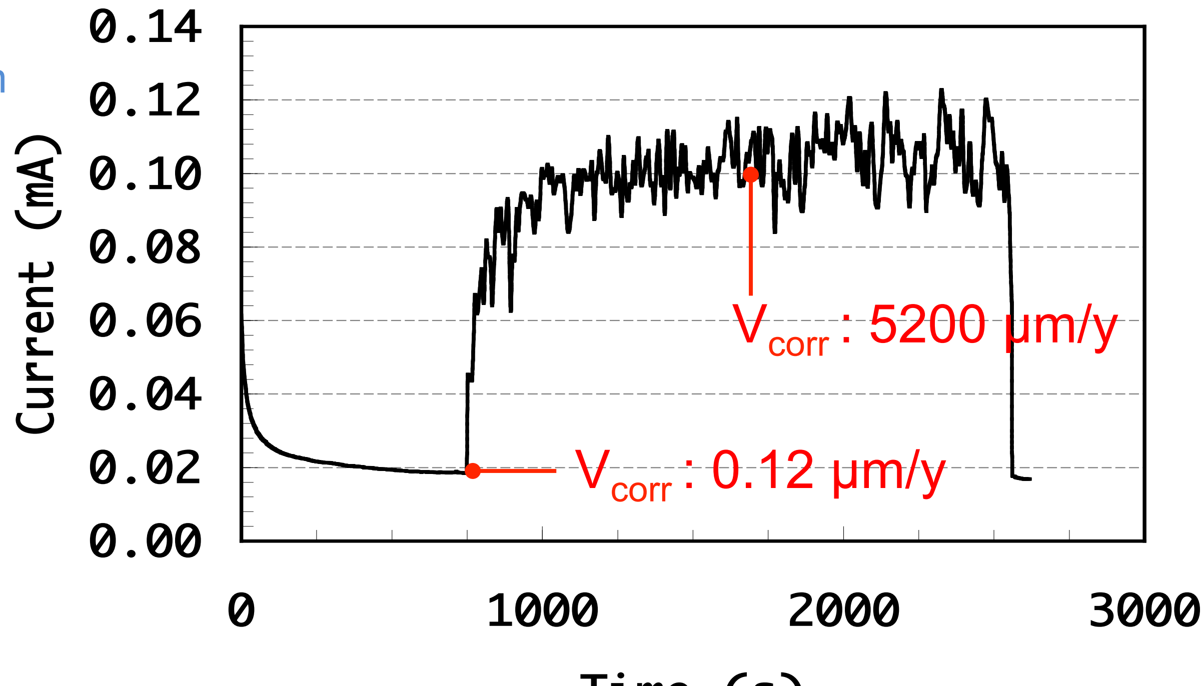
Potentiostatic test

Measure the corrosion rate of a metal while simulating chemical and electrochemical conditions of real environment.

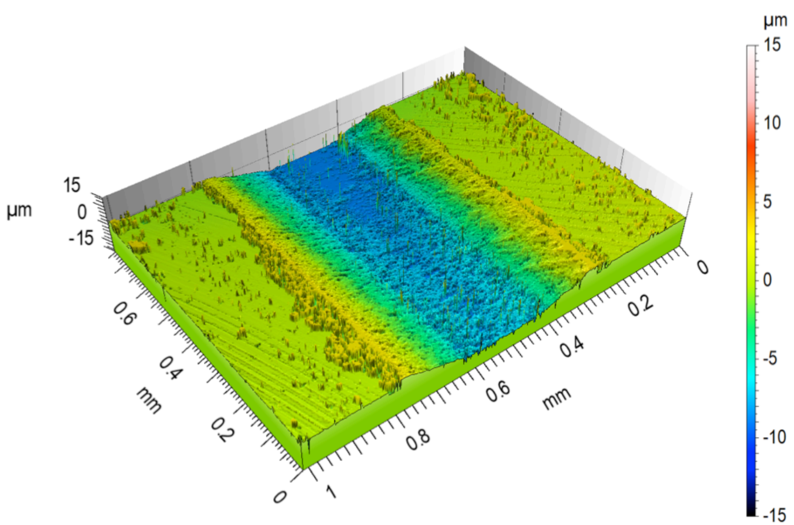


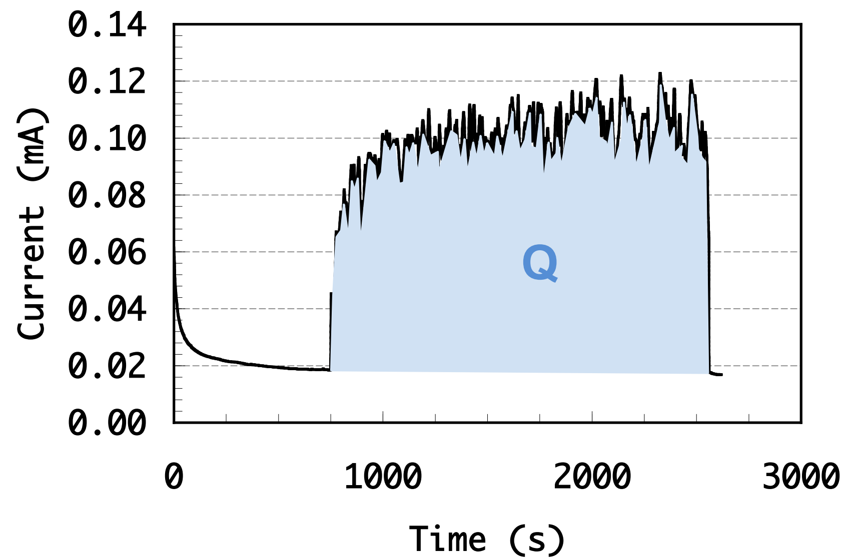
E (0.3V vs SSE)

F. Galliano, et al, Surf. and Coatings Techn. 145 (2001)



Quantification of material loss components





V_{tot}: Total material loss

V_{mec}: V_{tot} - V_{wac}

V_{wac}: Integration of the current during rubbing and use of the Faraday's law

$V_{wac} = QM/nF\rho$

Valves materials

Passive metals are commonly used in extreme conditions (corrosive stream and high temperature)

*Trim Materials	Applications
13% Cr, Type 410 SS	Oil and Oil vapors and general services with heat treated seats and wedges
13% Cr, Type 410 plus Hardfacing	General service requiring long service life up to 593°C
Type 316 SS	Liquids and gases which are corrosive to 410 SS up to 537°C
Monel	Corrosive service (acids, alkalies, salt solutions, etc.) up to 450°C
Alloy 20	Corrosive service (hot acids) temperature range -45°C – 320°C
Full Stellite	Abrasive and severe service up to 650°C

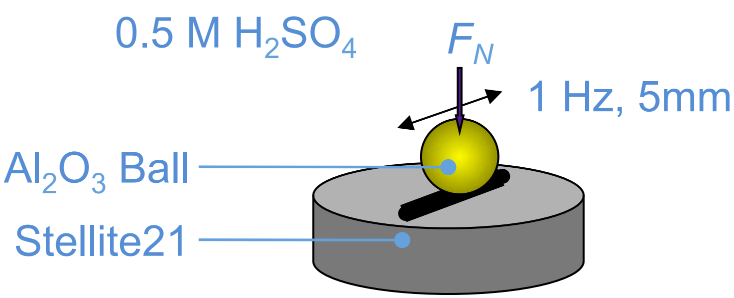
*Global supply line

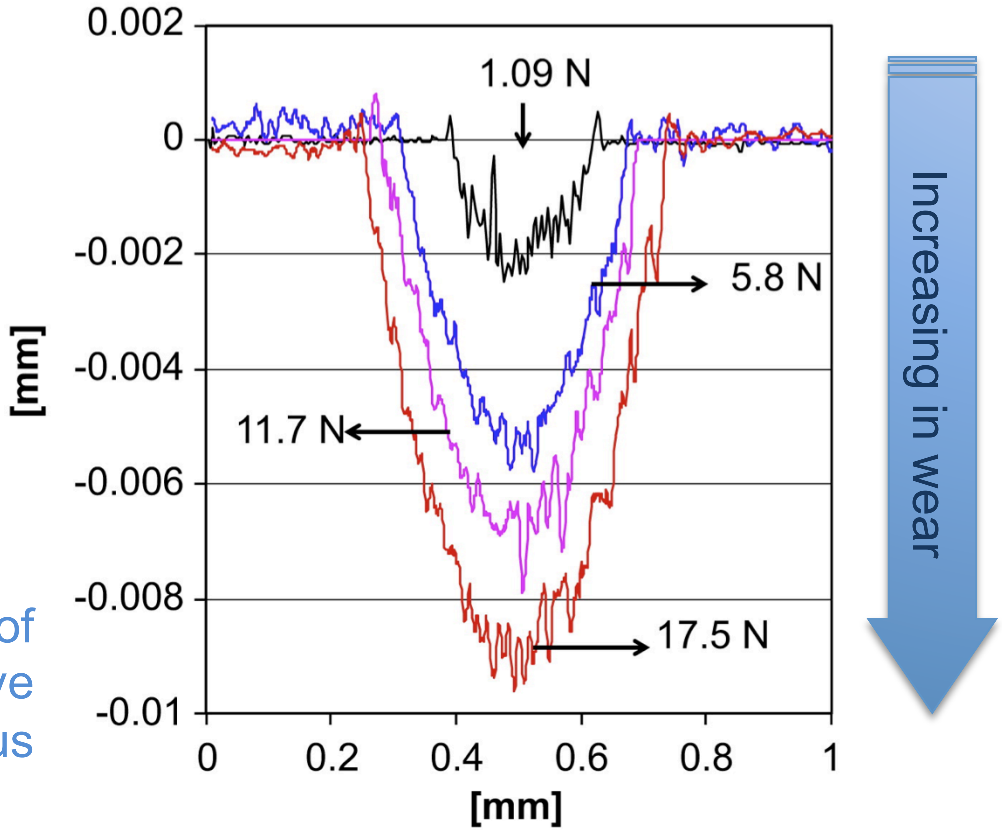
Tribocorrosion of Stellite alloy

Case Study

S.G. Maldonado, S. Mischler, M. Cantoni, W.J. Chitty, C Falcand, D Hertz. Mechanical and chemical mechanism in the tribocorrosion of a Stellite type alloy. Wear. 2013; 308: pp. 213-221.

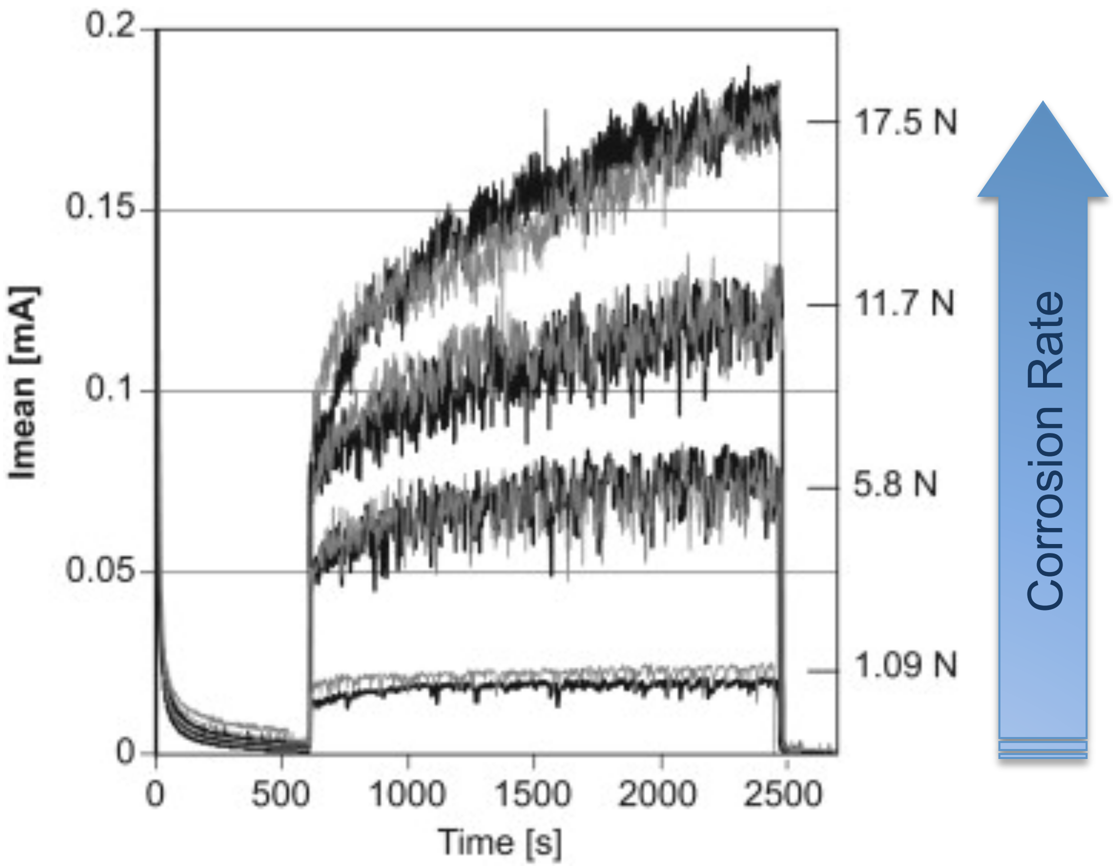
The load applied during tribocorrosion test affect the total volume loss.





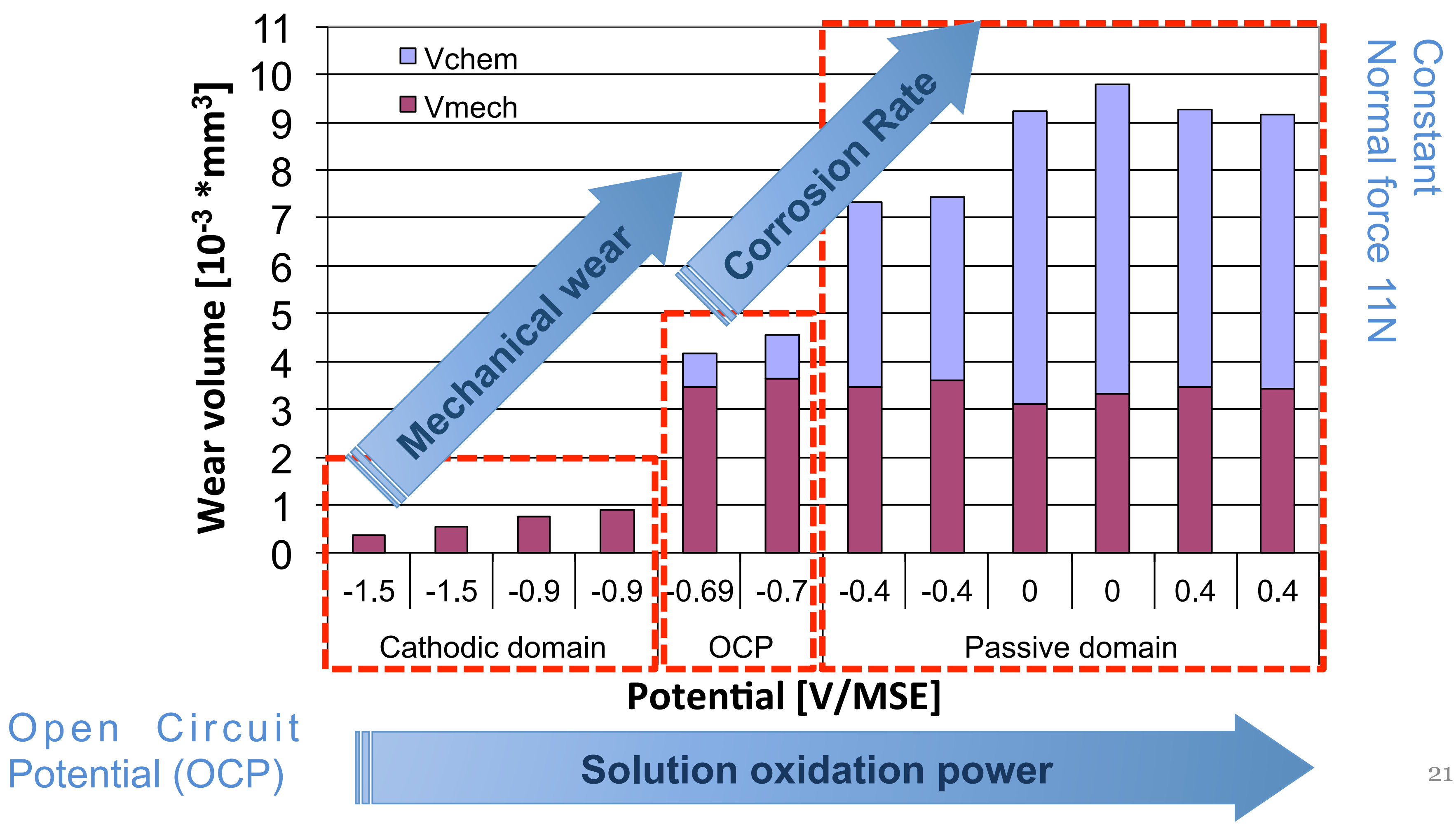
Profilometer cross section scans of wear tracks formed under passive potential. (0 V vs. Mercury-mercurous Sulfate Electrode)

The load applied during tribocorrosion test affect the corrosion rate.



Evolution of the current with time during an experiment at passive potential. (0 V vs. MSE)

The corrosion conditions affect both, mechanical and chemical wear.



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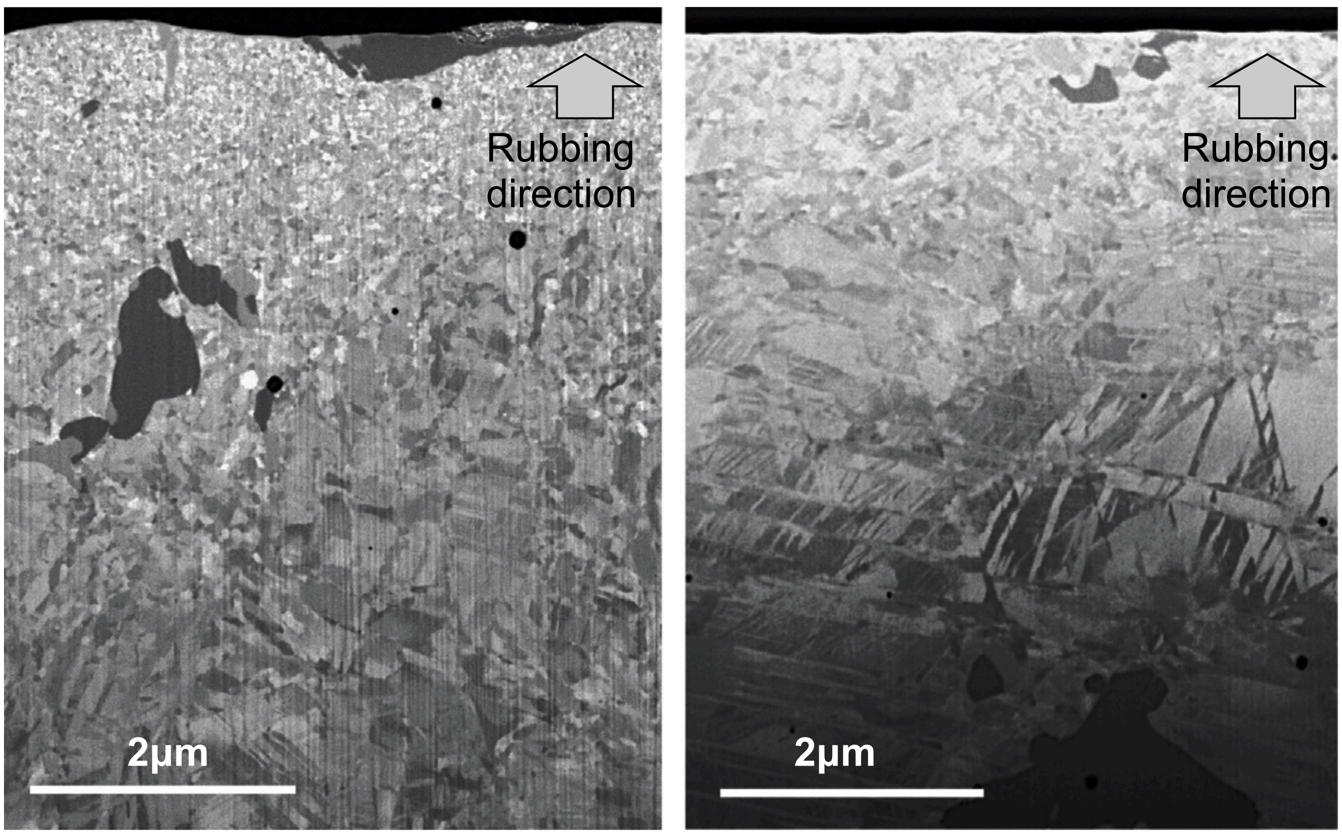
The corrosion conditions affect the mechanical response of the material under tribocorrosion.

Focused Ion beam Cross Sections of the wear track

Passive potential 0V vs. MSE

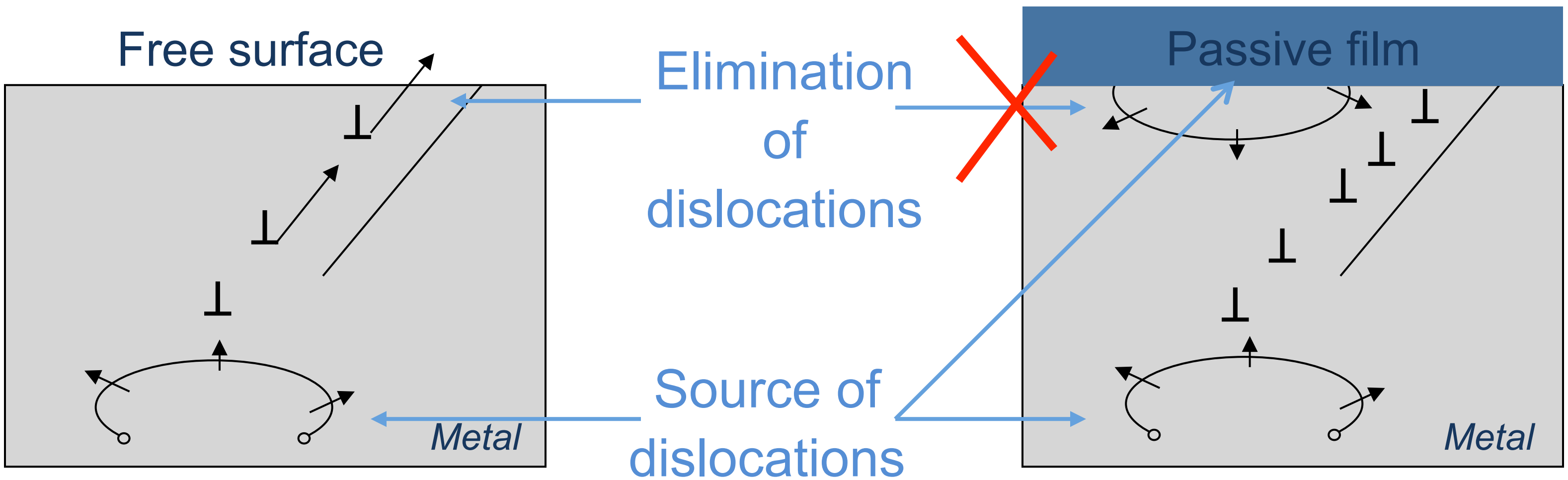


Cathodic potential -1.5V vs. MSE

Normal force 5.8N

Mechanism

Cathodic potential **Passive potential**



Equilibrium between generation and elimination of dislocations:
limited strain accumulation

Passive film blocks the surface, act as source of dislocations and inhibits their elimination:
strain accumulation

Outcomes

- Passive alloys are very sensitive to tribocorrosion because:
  - ✓ Mechanical removal of the passive film leads to very high corrosion rate.
  - ✓ The passive film can mechanically weaken the metal.

Tribocorrosion of plasma nitrided CoCrMo alloy

Case Study

A Bazzoni, S. Mischler, N. Espallargas. Tribocorrosion of pulsed plasma nitrided CoCrMo implant alloy. Tribological letters. 2013; 49: pp. 157-167.

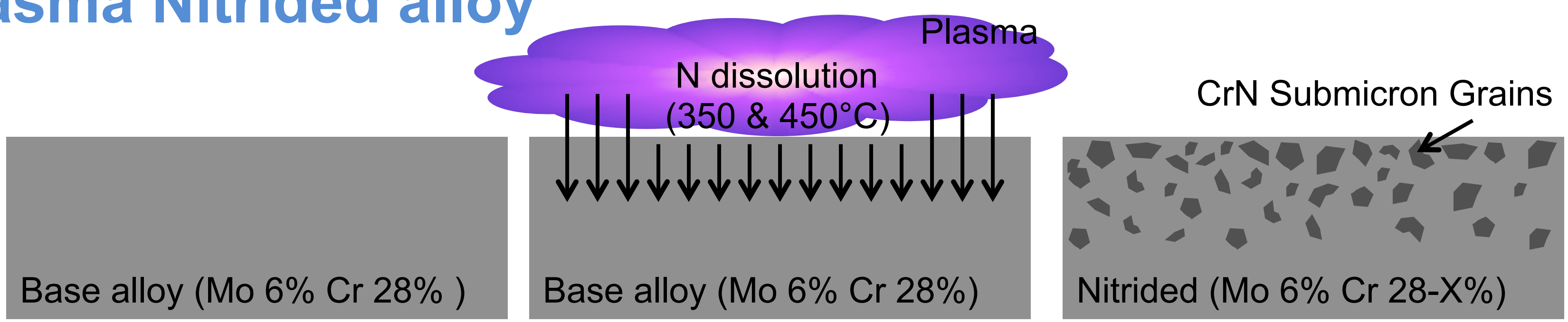
Tribocorrosion of CoCrMo alloy

Base alloy

Forged Co28Cr6Mo alloy (ISO 5832-12). wt%: Co Balance, Mo 5.7%, Cr 27.7%, Fe 0.17%, Mn 0.8%, Si 0.4%, C 0.04%, Ni 0.3%, N 0.16%.

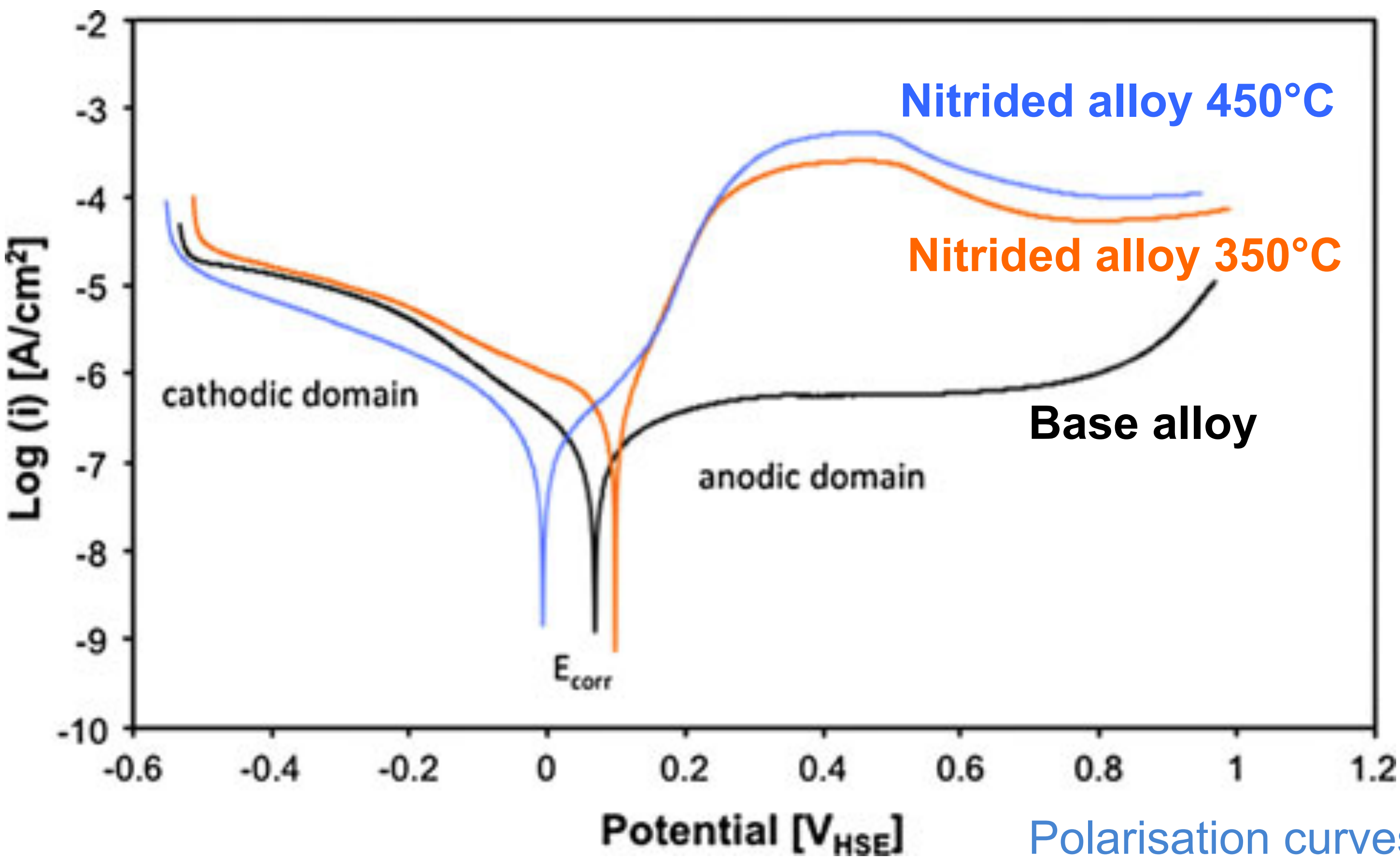
Surface Hardness: **400 $HV_{0.1}$**
Dry wear (40-60% RH laboratory atmosphere): **4.10 10^{-2} mm^3**

Plasma Nitrided alloy



Surface Hardness: **800 $HV_{0.1}$**
Dry wear (40-60% RH laboratory atmosphere): **0.41 10^{-2} mm^3**

Corrosion behaviour of CoCrMo alloy

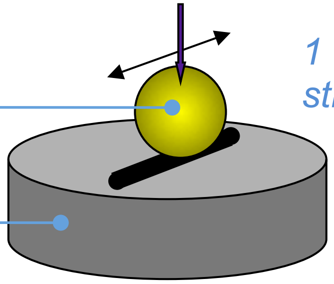


Polarisation curves in 0.9 wt.% NaCl

Tribocorrosion of CoCrMo alloy

Environnent & Contact configuration

0.9 wt.% NaCl under imposed electrode potential (3 electrode set-up).



	Base alloy			Plasma Nitrided alloy		
Conditions	V_{mech}	V_{wac}	V_{corr}	V_{mech}	V_{wac}	V_{corr}
Passive	2.36	1.54	0.003	0.65	0	1.262
Non passive	0.33	0	0	0.33	0	0

Wear volume (10^{-2} mm^3)

Outcomes

- Hardening by means pulse plasma nitriding is a good solution for reducing the dry wear of CoCrMo alloy. However corrosion resistance is reduced.

- By suppressing passivity plasma pulse nitriding can reduces tribocorrosion of CoCrMo alloy. However corrosion rate increases.

Tribocorrosion of Ni-Cr alloy (Inconel 625)

Case Study

N. Espallargas, S. Mischler. Dry wear and tribocorrosion mechanisms of pulsed plasma nitrided Ni–Cr alloy. Wear. 2011; 270: pp. 464-471.

Tribocorrosion of Inconel 625 in sulphuric acid

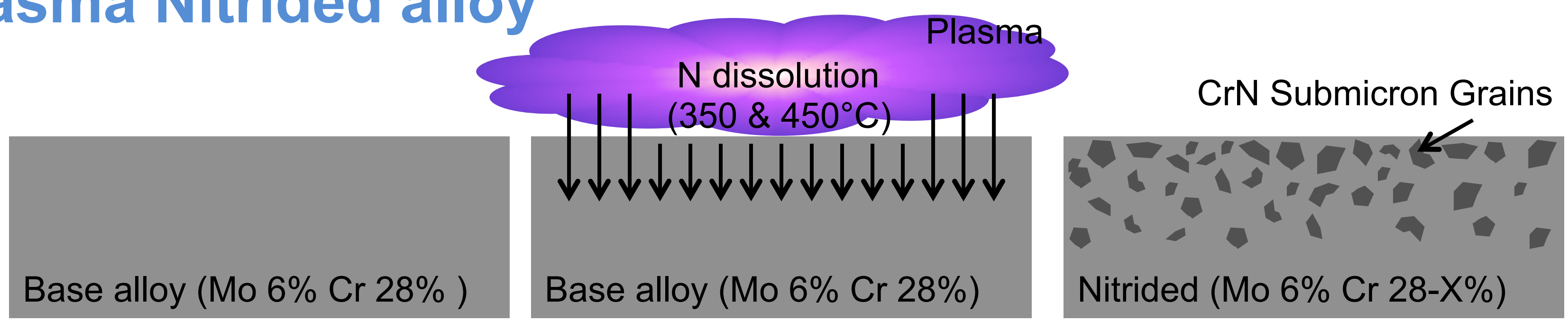
Base alloy

overlay welded Inconel 625 coating deposited onto carbon steel (EN 10113-3). Composition wt%: Ni 59%, Cr 20%, Fe 15%, Mo 6%.

Surface Hardness: **170 HV**

Dry wear (40-60% RH laboratory atmosphere): **16 10^{-2} mm^3**

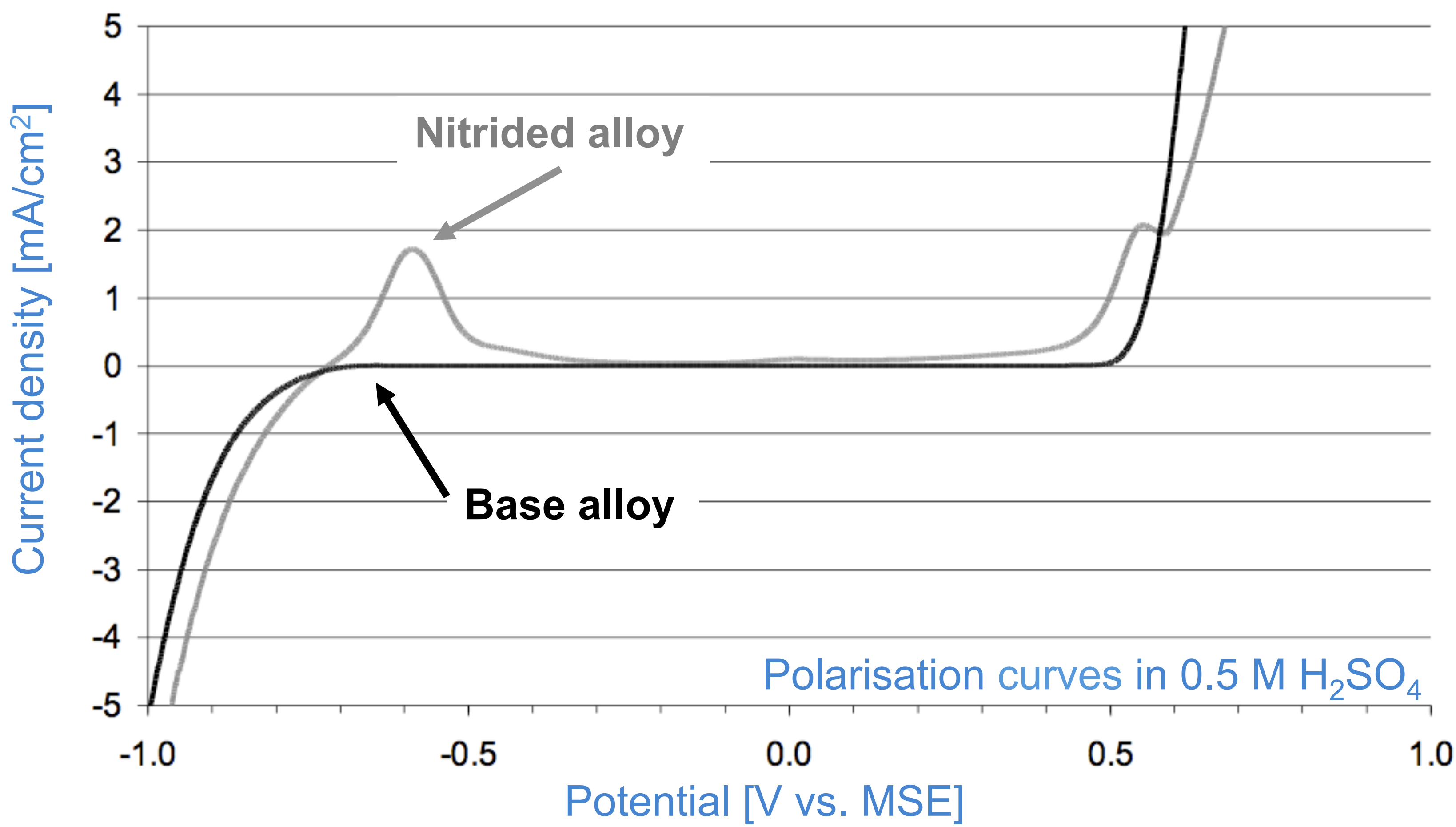
Plasma Nitrided alloy



Surface Hardness: **600 HV**

Dry wear (40-60% RH laboratory atmosphere): **1.6 10^{-2} mm^3**

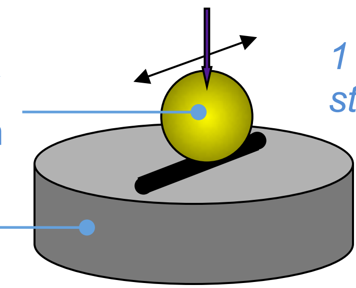
Corrosion behaviour of Inconel 625

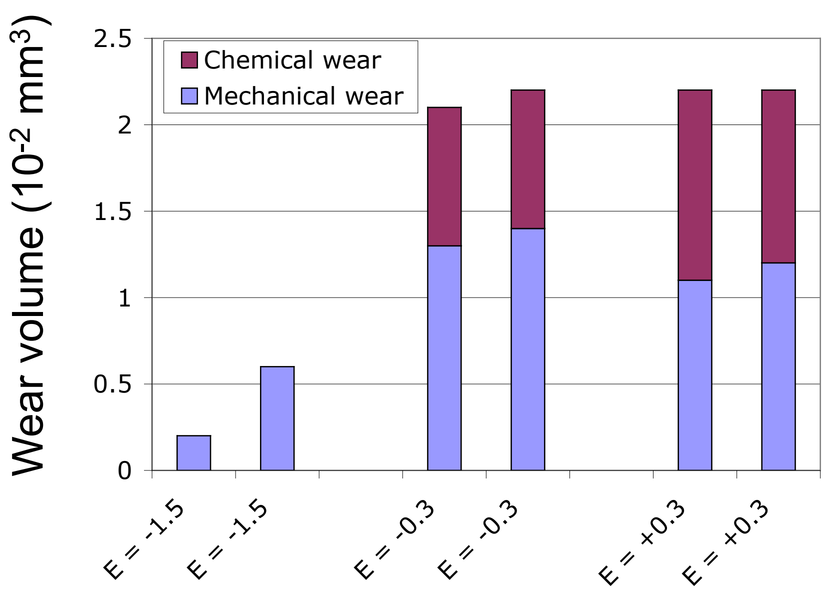


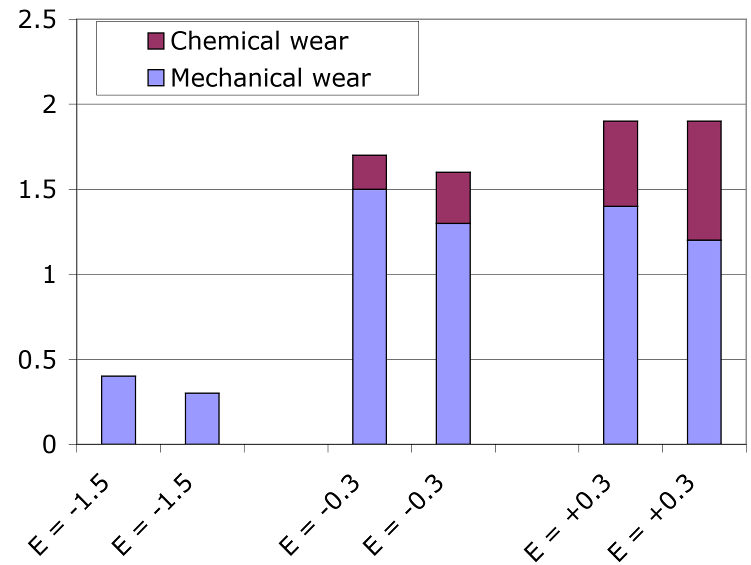
Tribocorrosion of Inconel 625 in sulphuric acid

Environnent & Contact configuration

0.5 M H_2SO_4 under imposed electrode potential (3 electrode set-up).

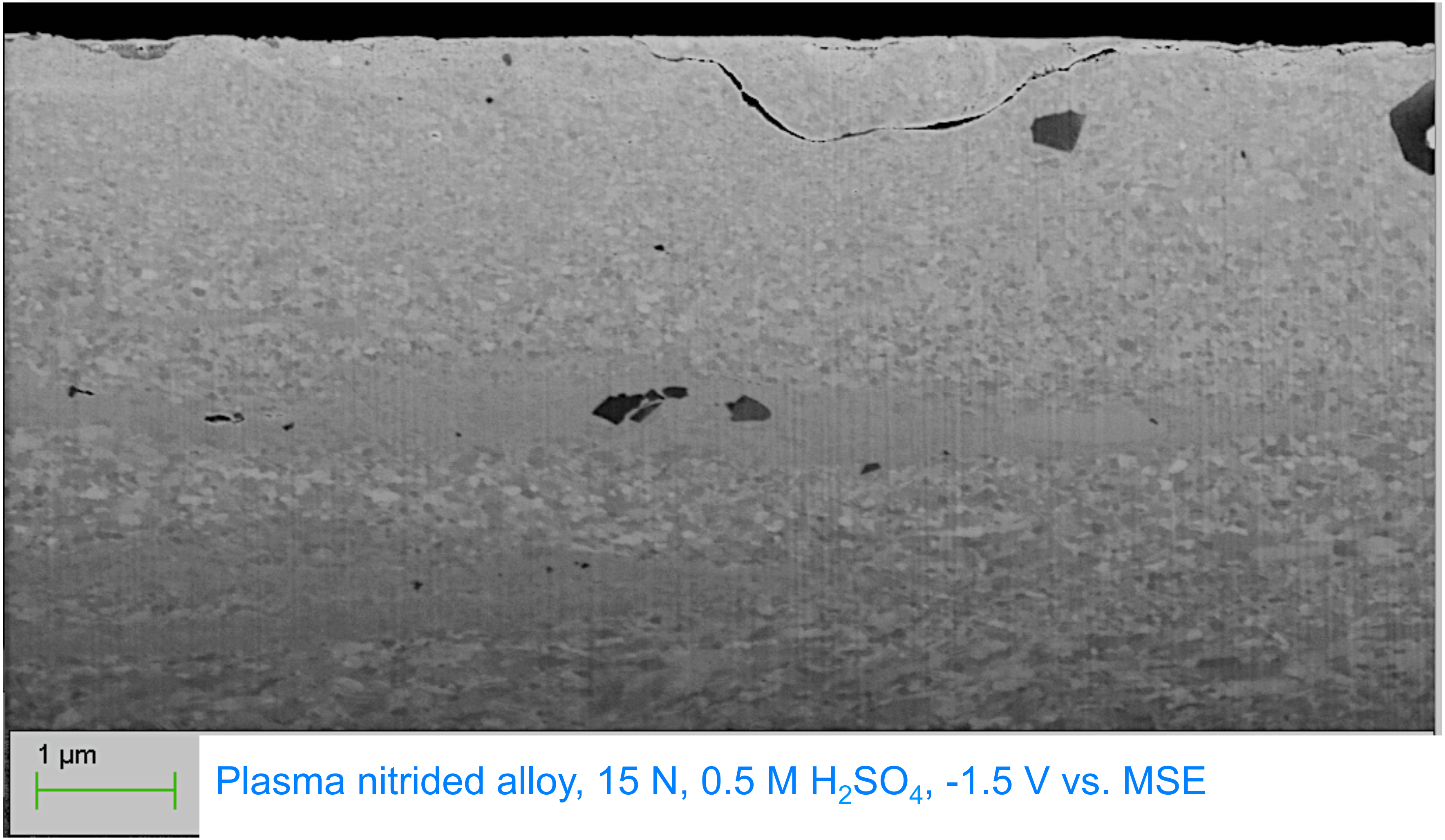






(E V vs. MSE)

Nitrides suspended in the Nano crystalline layer do not provide reinforcement for tribocorrosion



Plasma nitrided alloy, 15 N, 0.5 M H_2SO_4, -1.5 V vs. MSE

Outcomes

- Hardening by means pulse plasma nitriding is a good solution for reducing the dry wear of Inconel 625.
- Under tribocorrosion conditions, Inconel 625 hardened by means pulsed plasma nitriding has nearly the same behaviour of the base alloy.
- This is due to microstructural transformations occurring under tribocorrosion conditions.

Take home message

- In certain fluids, tribocorrosion can occur in valves and can significantly affect the reliability and service life.
- Tribocorrosion has the potential to undetermine the value that is normally gained from traditional material selection for enhanced corrosion resistance and to provide wear protection.
- Fundamental concepts and experimental setup are now available for efficiently addressing industrial tribocorrosion issues.

Acknowledgments

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Program
on Materials

KTI/CTI

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Good Food, Good Life

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