Corrosion-wear studies on PVD coatings for aeronautical applications.

***R. Bayón*, A.Igartua, U. Ruiz de Gopegui , G. Mendoza**

*Fundación **TEKNIKER** (www.tekniker.es), Avda. Otaola 20, Eibar, Spain*

Introduction

The use of hard chromium as protective coating in several aeronautical applications is nowadays one of the greatest environmental problems due to the presence of **chromium VI** in the plating bath used in the deposition process.

Examples

- ✓ Landing gear
- ✓ Engine components
- ✓ Propeller hubs
- ✓ Actuators *(hydraulic/pneumatic actuators used throughout aircraft)*
- ✓ Helicopter *dynamic components* *(including gearboxes, rotor reads and damper components)*

Objectives of this work

✓**Application**: *aircraft engine components* : turbines

✓ **Material:** Inconel, nickel based superalloy with high resistance to oxidation and corrosion and high strength over a wide range of temperatures.

In the manufacturing of aircraft engine turbines, inconel usually is coated with hard chromium for increasing its wear resistance

PVD coatings are proposed as clean alternatives for replacement hard chromium

Conditions

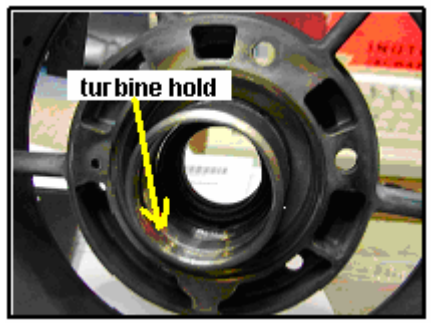
Hard Cr alternatives must to overcome several tests required in the aeronautics protocols:

- ✓ Adhesion to bent
- ✓ Tensile adhesion
- ✓ Electrochemical corrosion resistance
- ✓ Salt fog (3000 hours)
- ✓ Micro-hardness(>600 Kg/mm^2)

- ? Axial fatigue tests
- ? Galvanic corrosion resistance
- ? Coating toughness
- ? Residual Stress ALMEN
- ? Fretting

↓

Tests on real Component - Fretting at 400°C against AMS 6491



- ➥ Monolayer of **CrN** by PVD catodic arc
- ➥ Multilayer of **TiN/CrN** by PVD cathodic arc

} Have passed the first required tests

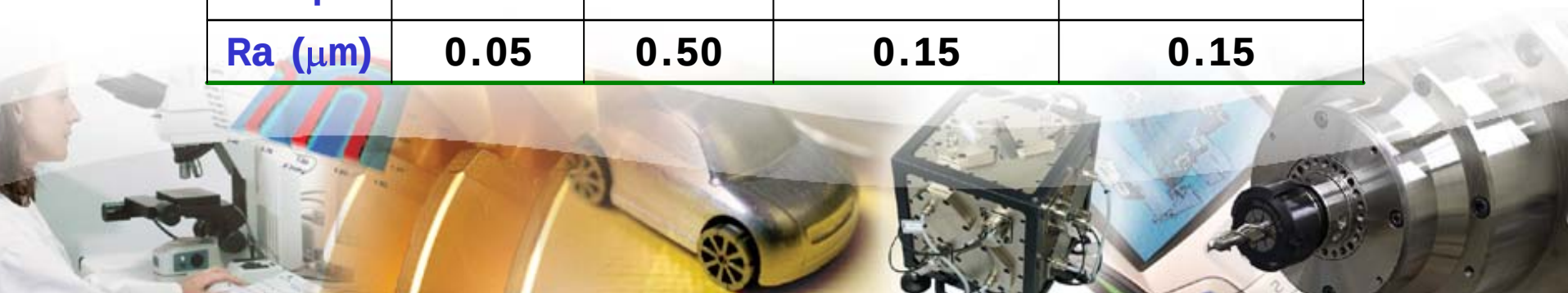
Surfaces Characteristics

Inconel Composition →

element	C	Mn	Si	Cr	Ni	Fe	Al	Ti	Mo	V	Cu	Nb
%	0.05	0.26	0.05	18.50	bal.	17	0.47	1.15	3.11	0.03	0.04	5

	Hardness(Kg/mm^2)	Thickness (μm)
Inconel	**276**	**/**
Inco+Cr	**598**	**120**
Inco+CrN	**1438**	**6.8**
Inco+TiN/CrN	**1211**	**8**

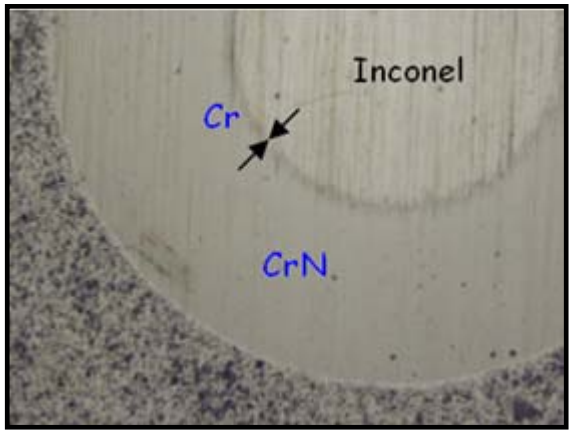
Sample	**Inconel**	**Inco+Cr**	**Inco+CrN**	**Inco+TiN/CrN**
Ra (μm)	**0.05**	**0.50**	**0.15**	**0.15**



PVD coatings properties

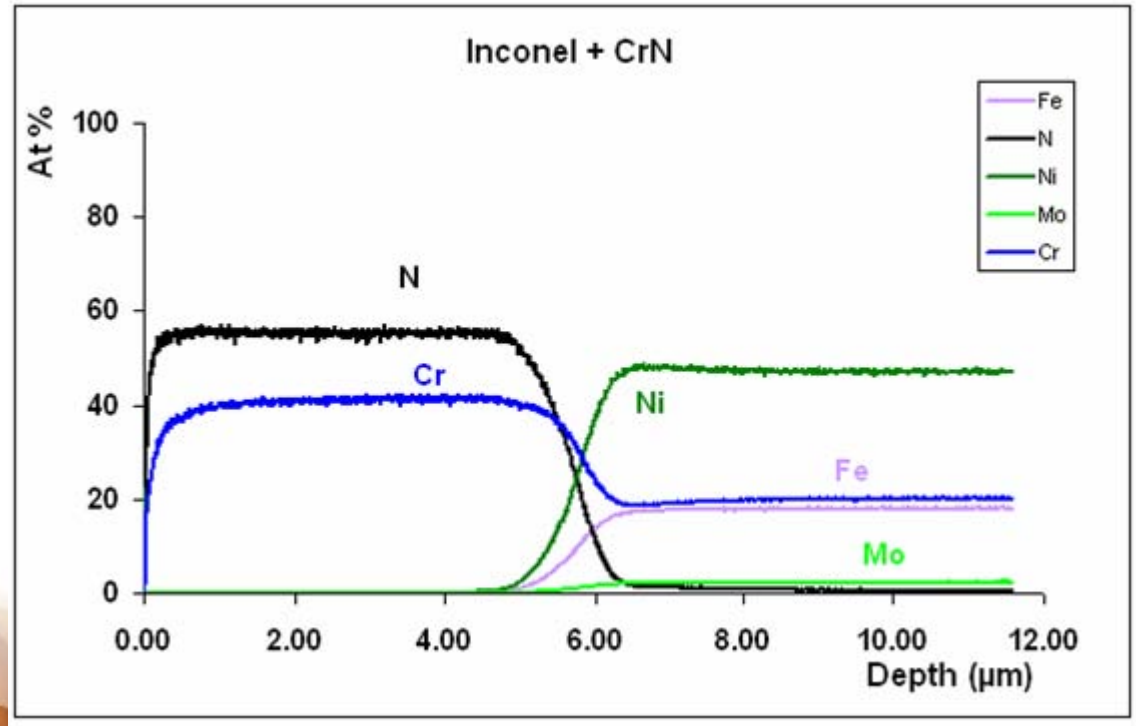
- Inconel+ CrN monolayer

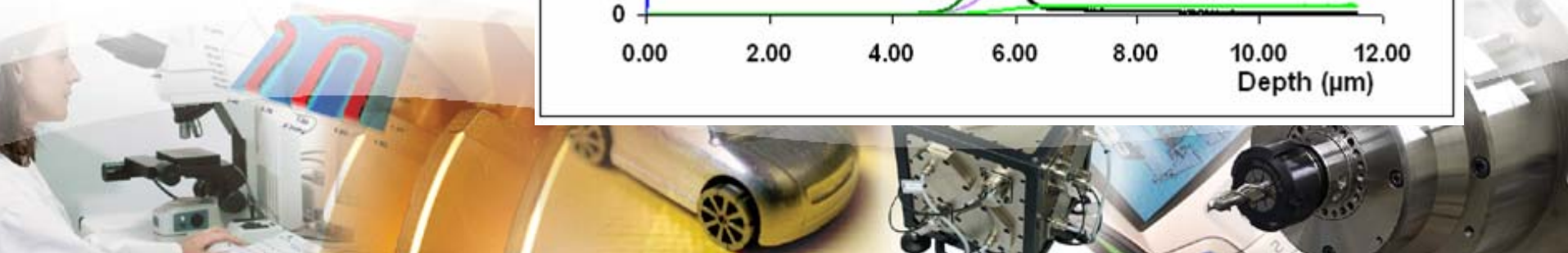
Calotest



6.8 μm

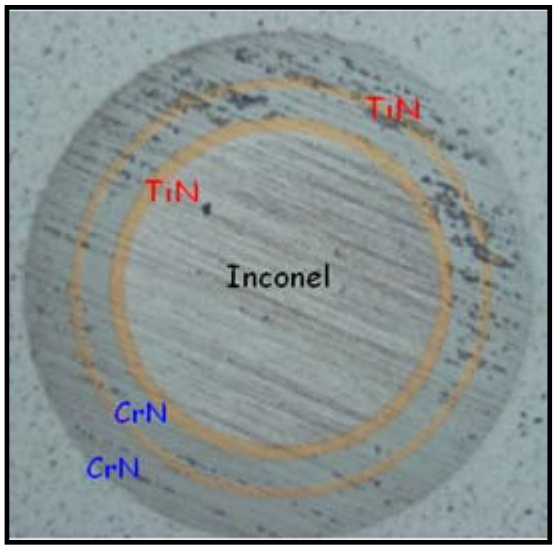
GD-OES





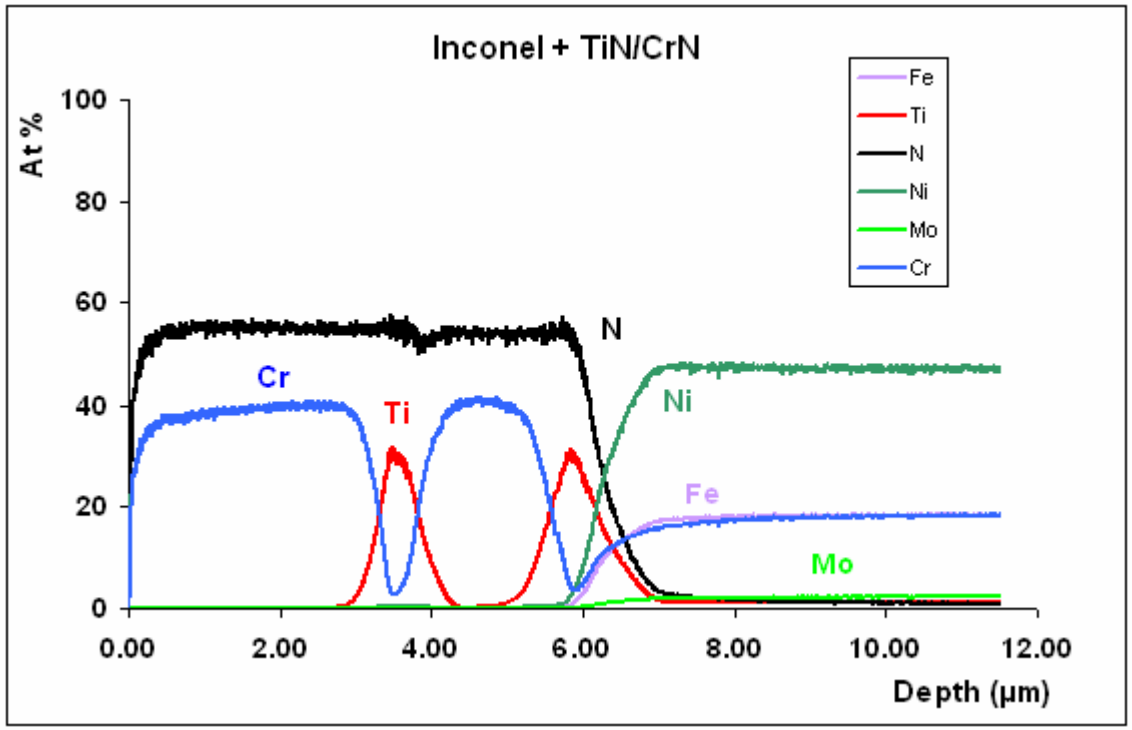
- Inconel+ TiN/CrN multilayer

Calotest



~8 μm

GD-OES

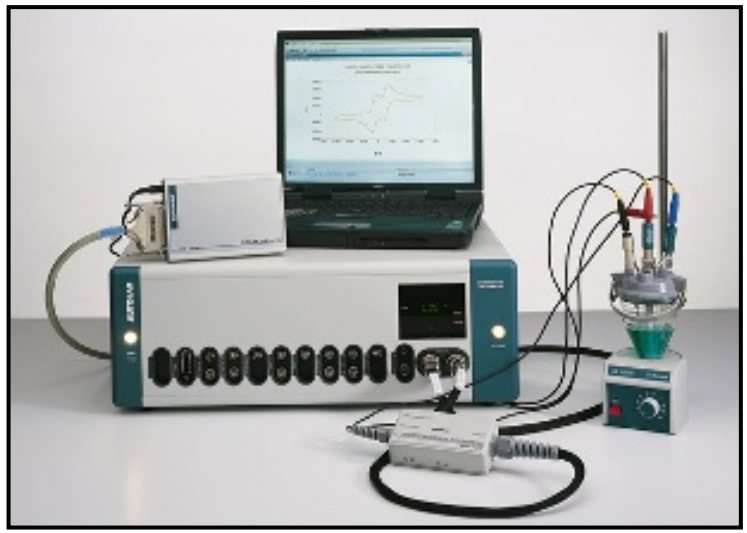


Surfaces corrosion behaviour

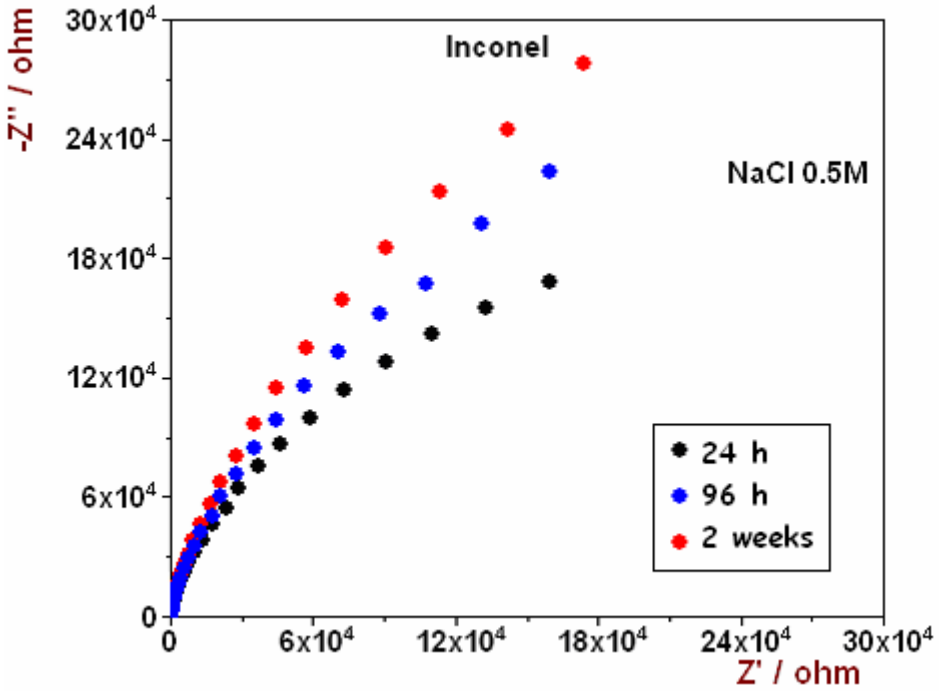
✓ Electrochemical impedance measurements (EIS) periodically
24h,96h,2 weeks

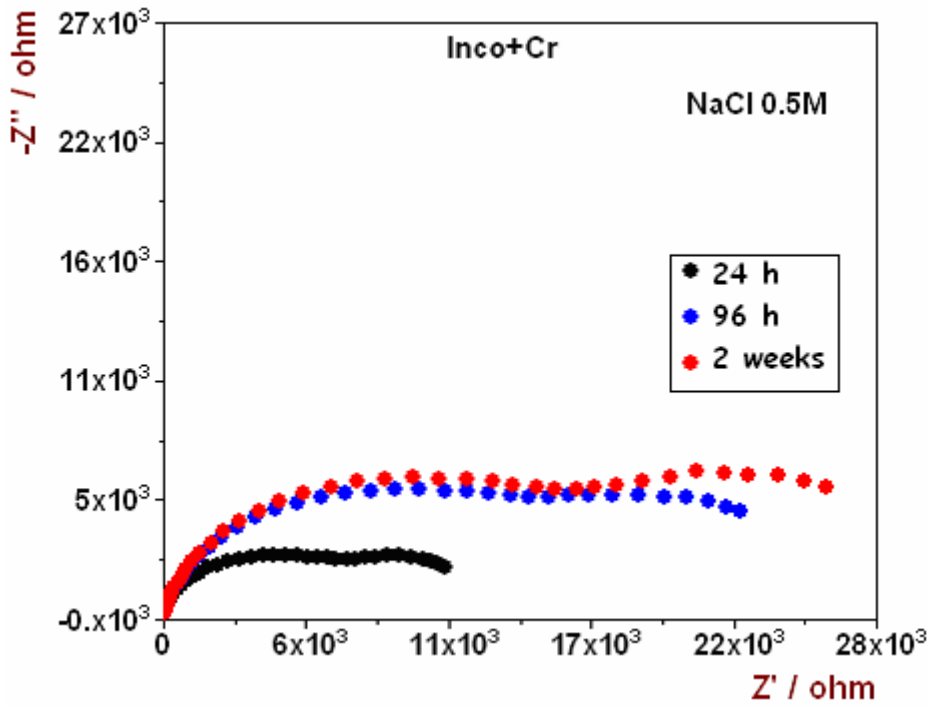
✓ Cyclic polarizations after two weeks

✓ NaCl 0.5M, room Tª, aerated



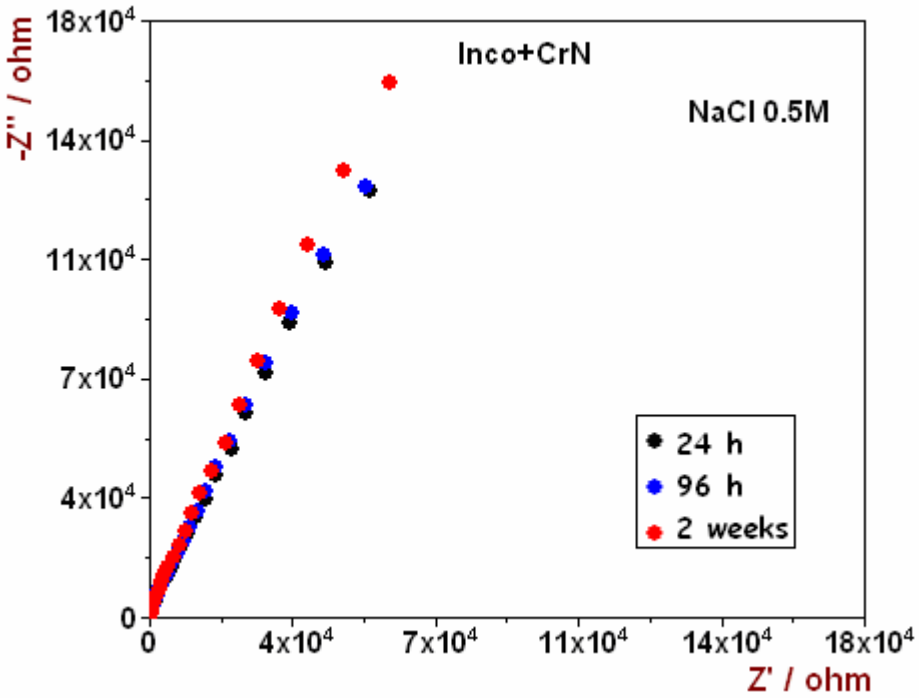
Corrosion Results: EIS measurements

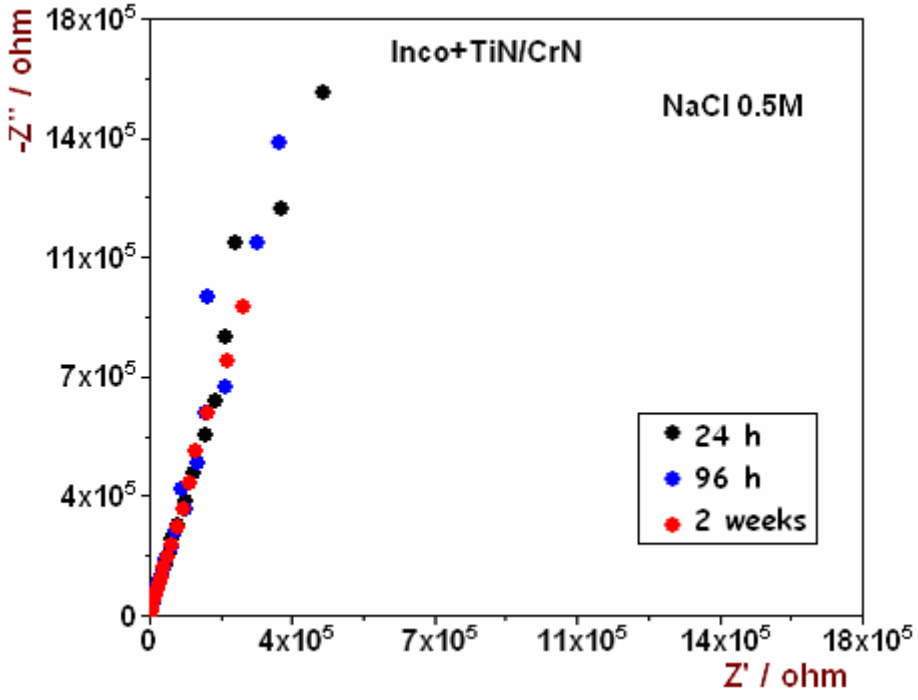




- ✓ Improvement of surfaces electrochemical resistance with immersion time
- ✓ Good corrosion behaviour of both surfaces (~ 4MΩ and 50 kΩ respectively)

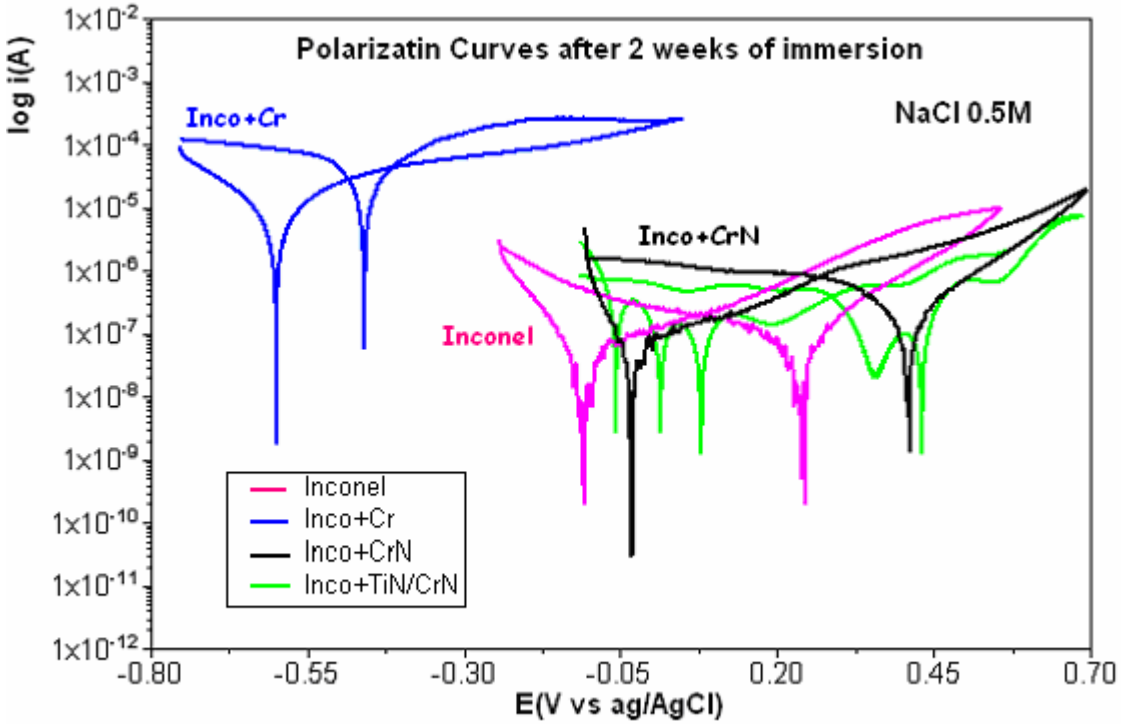
EIS measurements on PVD coatings





- ✓ Similar behaviour during the total exposure to the aggressive media
- ✓ Capacitive behaviour, *corrosion resistance* of the order of **10MΩ**
- ✓ No coatings porosity is detected

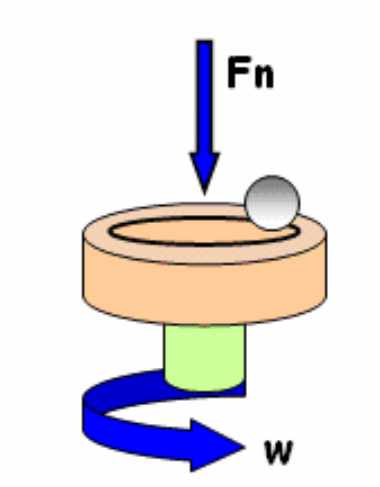
Polarization curves



	Ecorr (V)	Icorr (nA/cm²)
Inconel	-0.11	4.55
Inco+Cr	-0.60	4346
Inco+CrN	-0.03	5.53
Inco+TiN/CrN	-0.06	25.88

- ✓ Low corrosion currents ~ **10^{-9}** A/cm²
- ✓ Passive behaviour

Surfaces Tribocorrosion behaviour



⇨Electrochemical cell + Tribometer. (ball on disc configuration).

⇨ Ag/AgCl reference electrode (+0.207 vs SHE).

⇨ Pt counter electrode.

⇨ Potentiostat/Galvanostat.

⇨Counter bodies: polished Si_3N_4 balls (4mm ϕ).

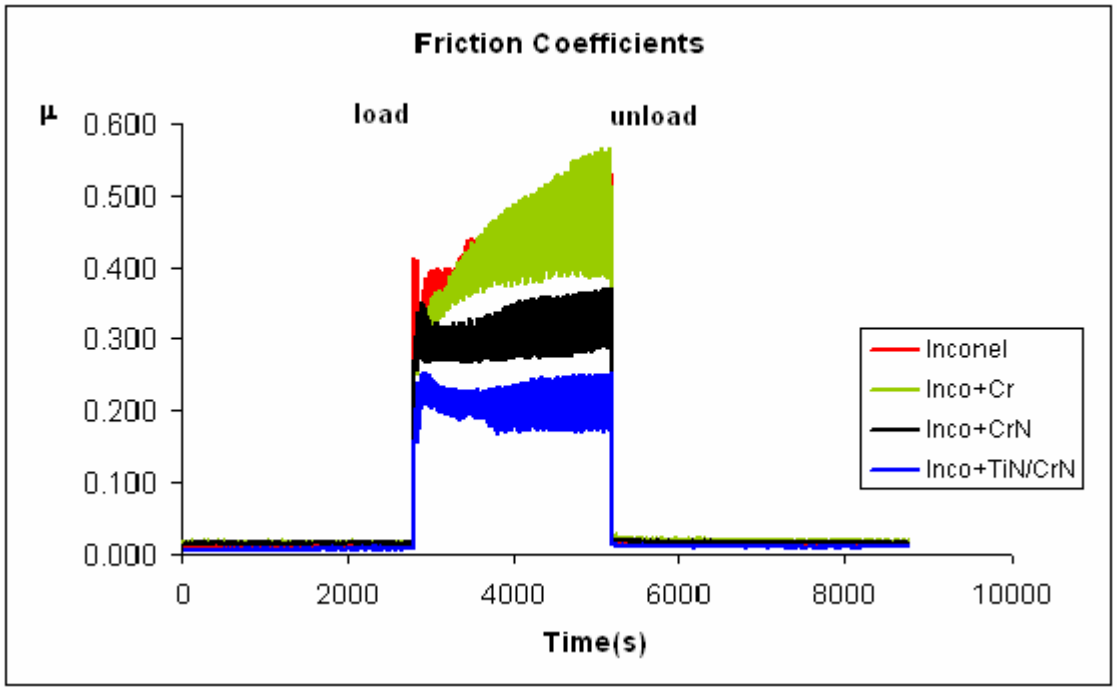
⇨ NaCl 0.5M

10N, 25 rpm, 6 mm of track diameter

→ Friction coefficients and potentials measurements before, during and after wear process

→ EIS measurements before and after the wear process

Tribocorrosion - Results

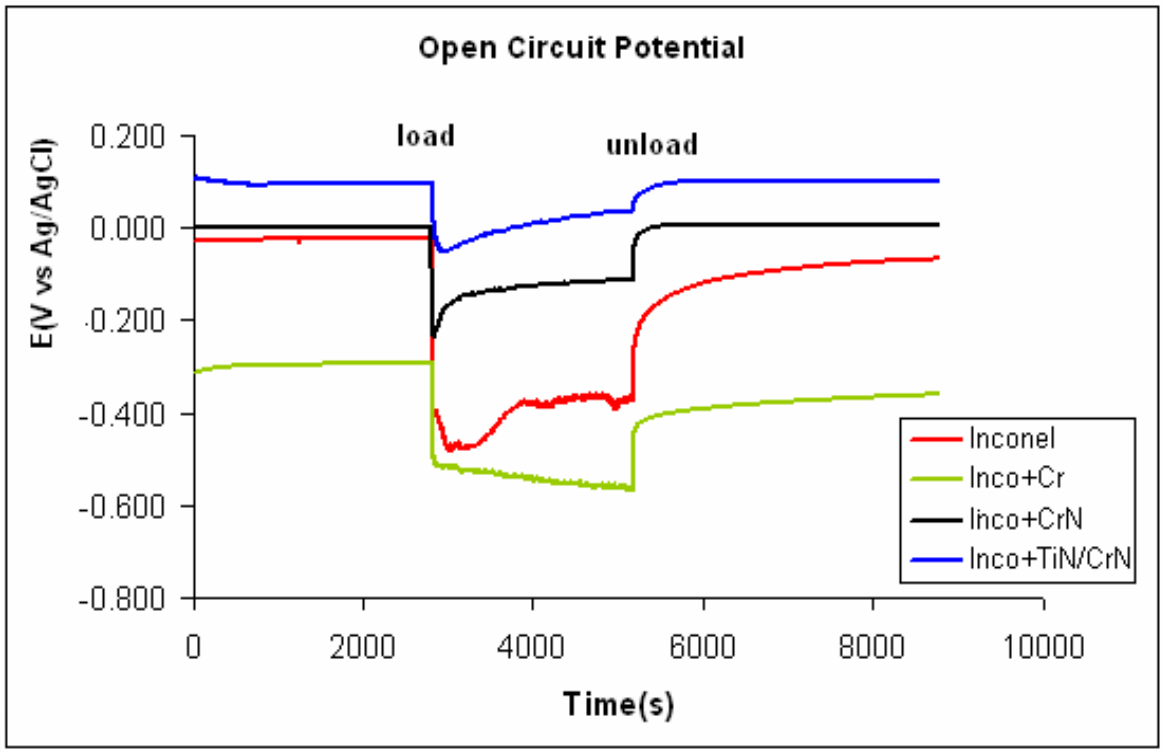


	Mean μ
Inco	0.439
Inco+Cr	0.460
Inco+CrN	0.322
Inco+TiN/CrN	0.213

✓High friction coefficients due to the non lubricated contact

✓ PVD layers reduce friction specially **TiN/CrN** multilayer

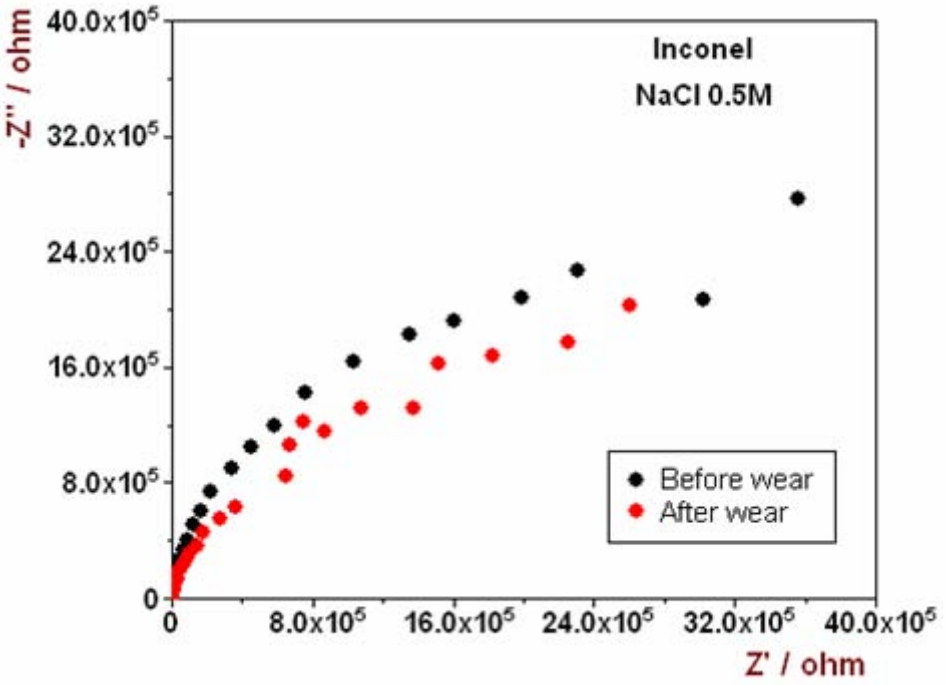
Potential measurements during wear process

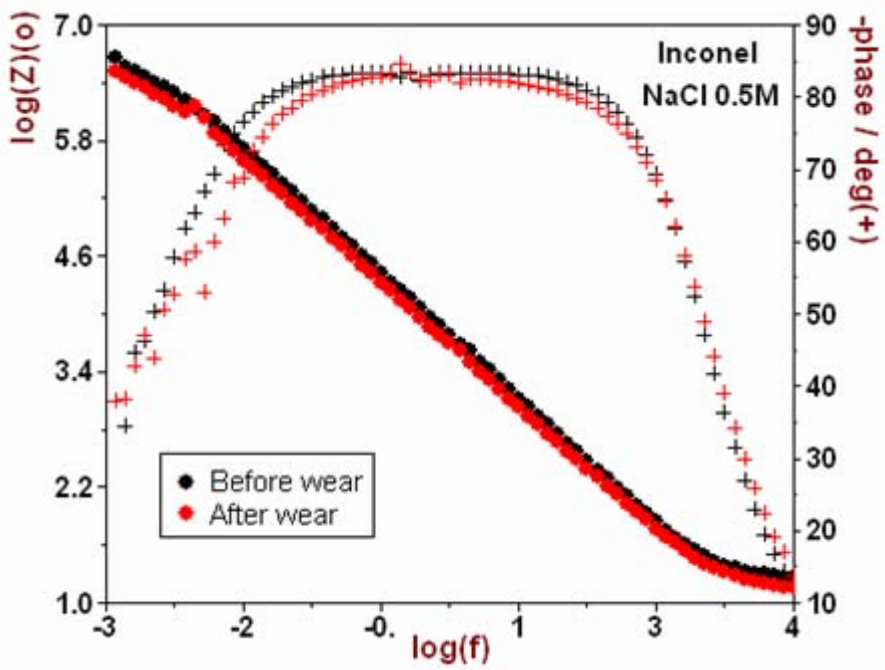


Inconel suffer the most significative potential drop from -0.024 V to -0.479 V

3600s after stop rubbing, the potential in Inconel and Inco+Cr surfaces has not reached yet its initial values

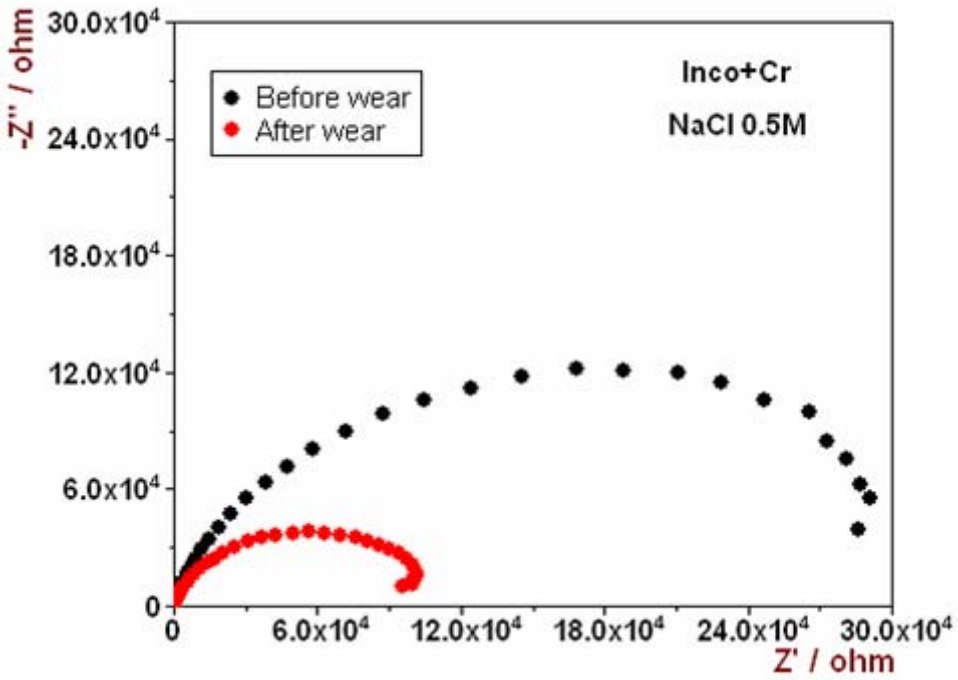
EIS measurements before and after the wear

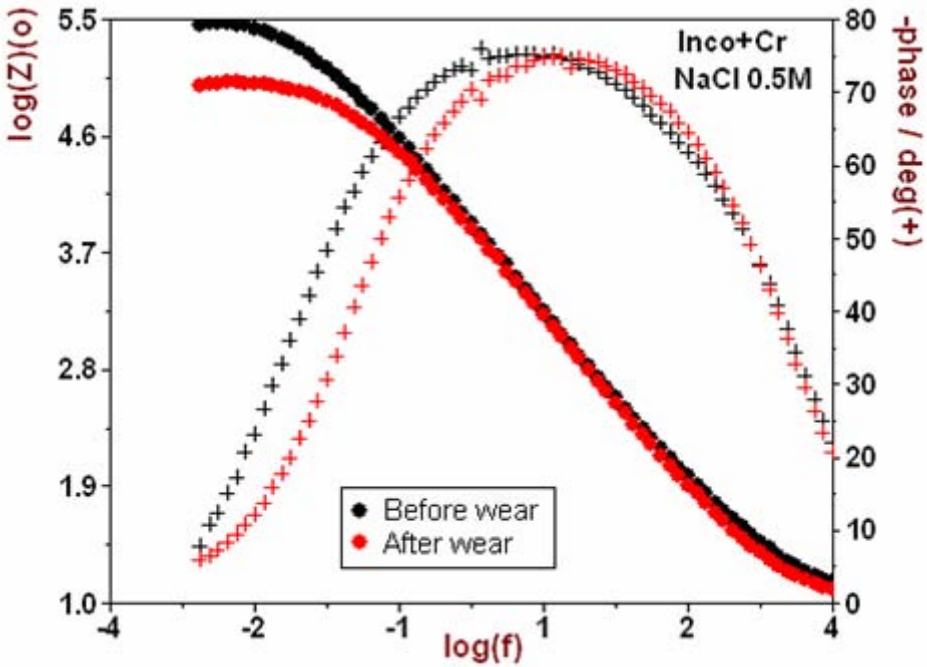




✓Corrosion resistance decreases slightly after wear due to the depassivation process on the worn surface area

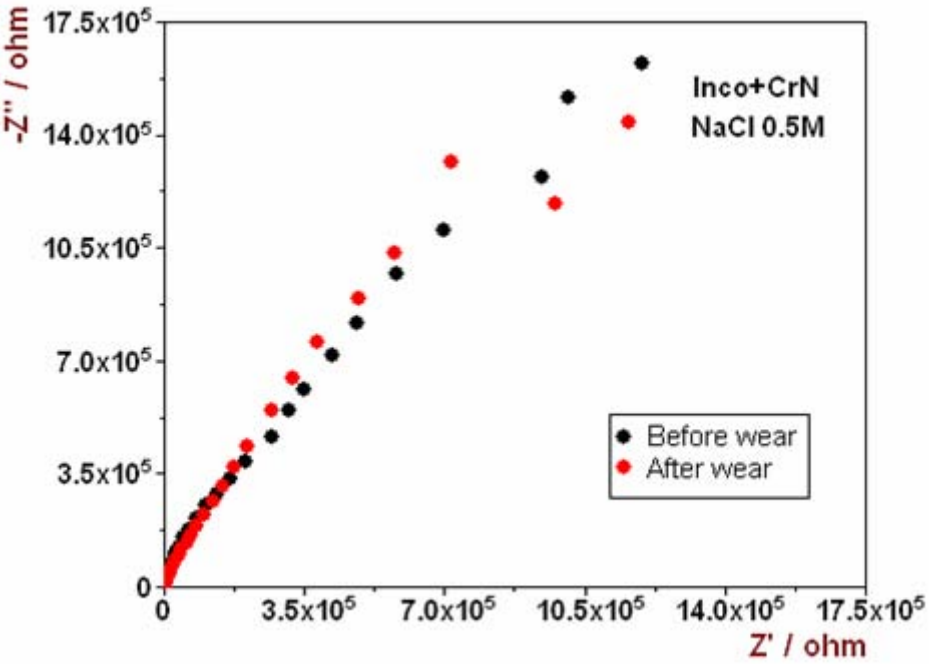
✓Mechanical effects influence on the Inconel corrosion behaviour

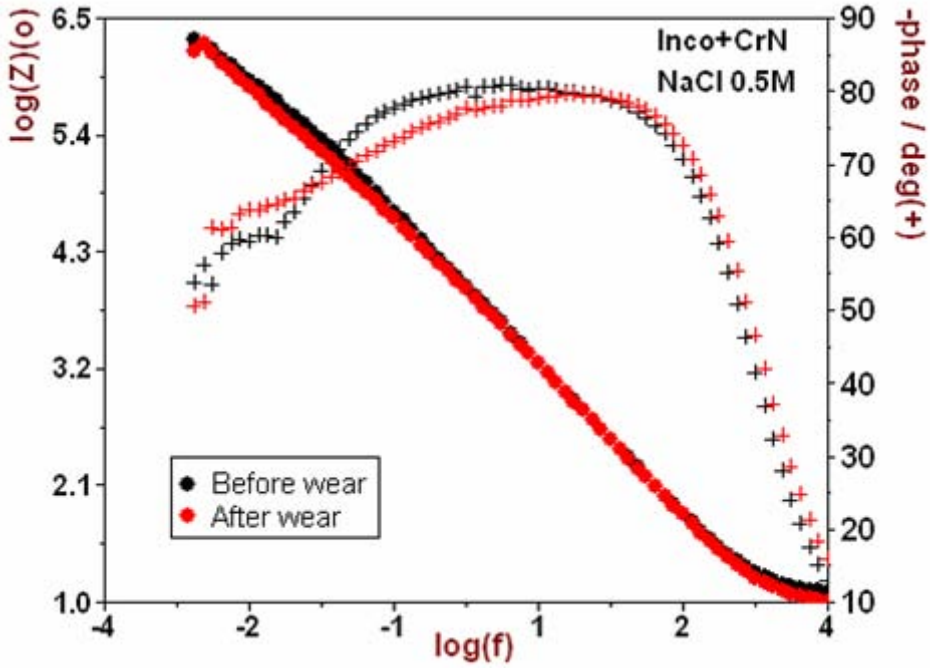




✓ Electrochemical surface state of hard chromium coating differs notably before and after wear

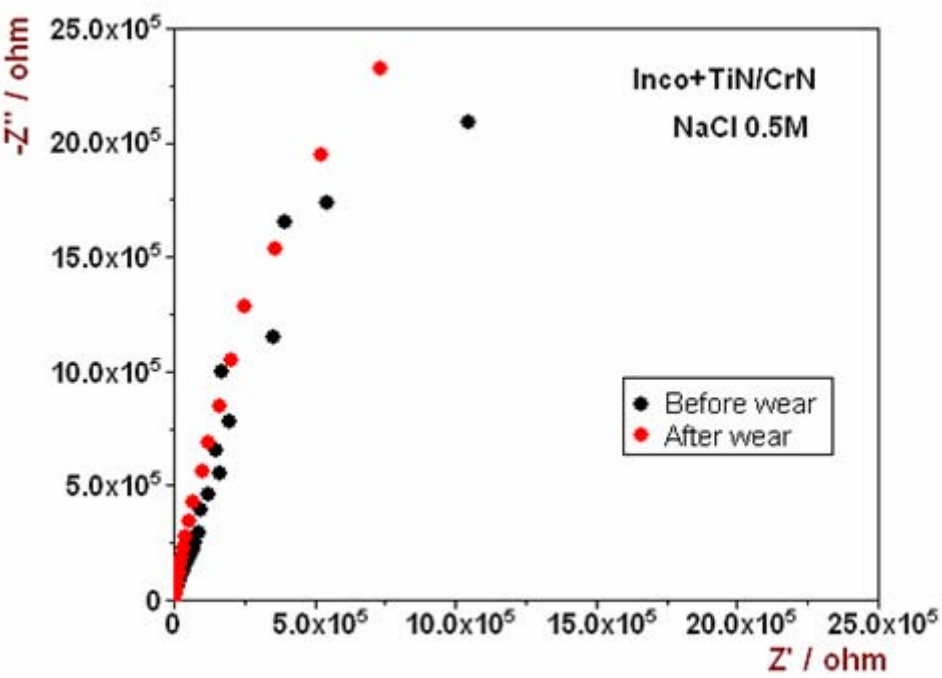
✓ Mechanical effects reduce its corrosion resistance by altering the formation the protective oxide film on the surface

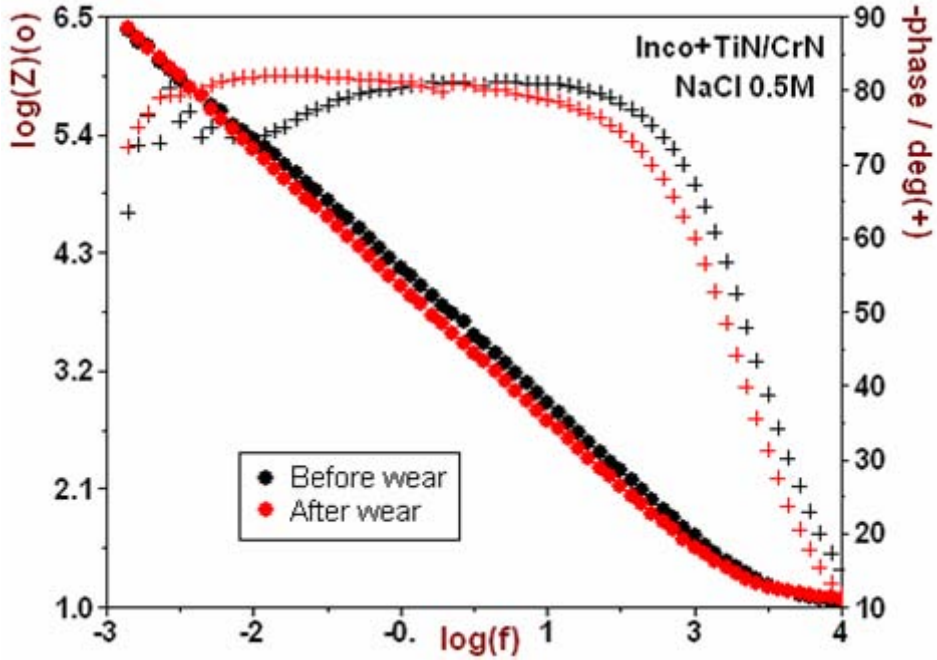




✓ Electrochemical surface state of CrN is similar before and after wear

✓ Mechanical effects have not affected the corrosion behaviour of the coated surface. Worn area repassivates quickly after rubbing process

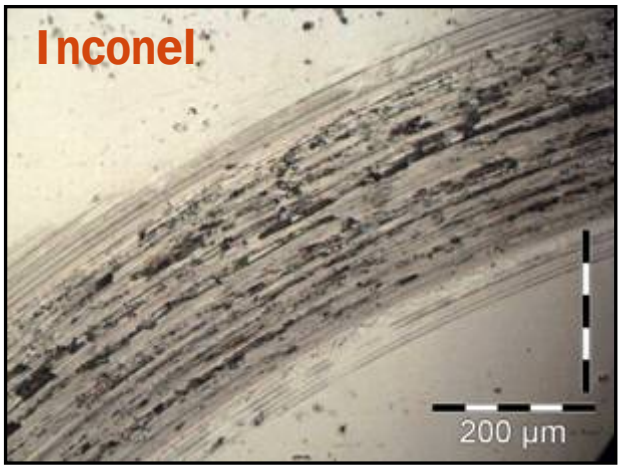


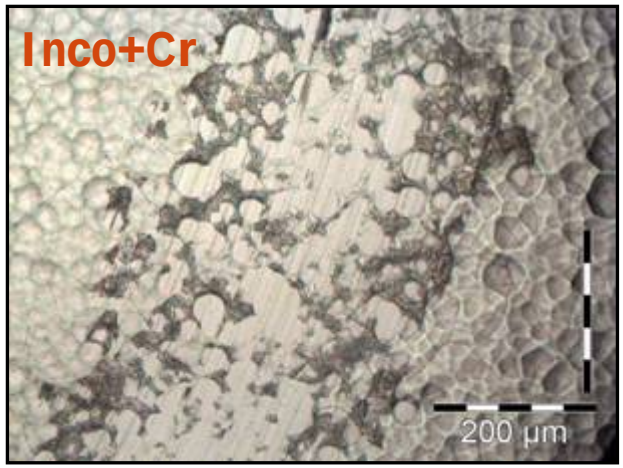


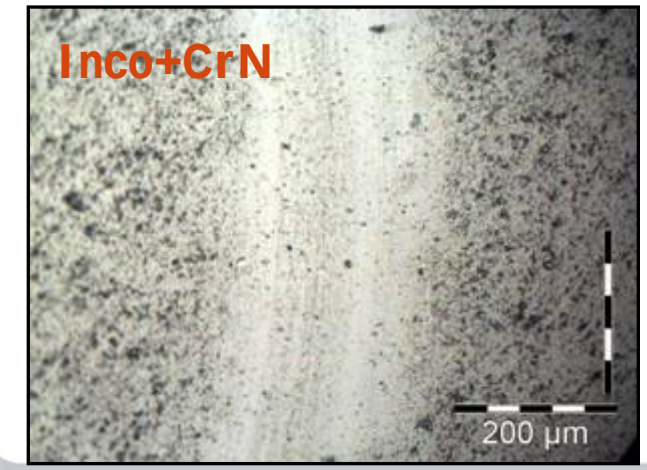
✓ Electrochemical surface state of multilayer **TiN/CrN** is also similar before and after wear showing the highest corrosion resistance under wear conditions

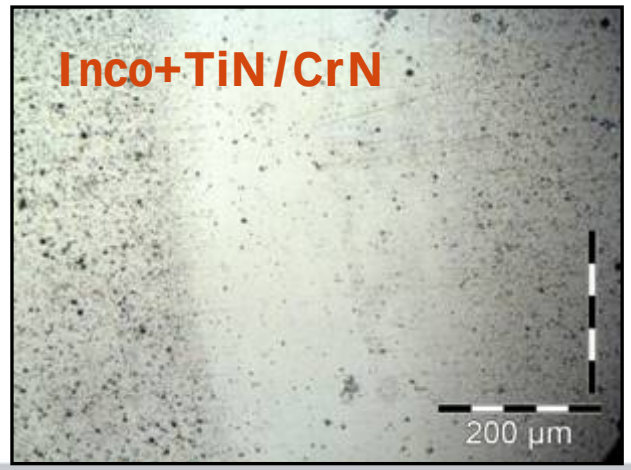
✓ The worn area repassivates quickly after rubbing

Surfaces state after tribocorrosion tests





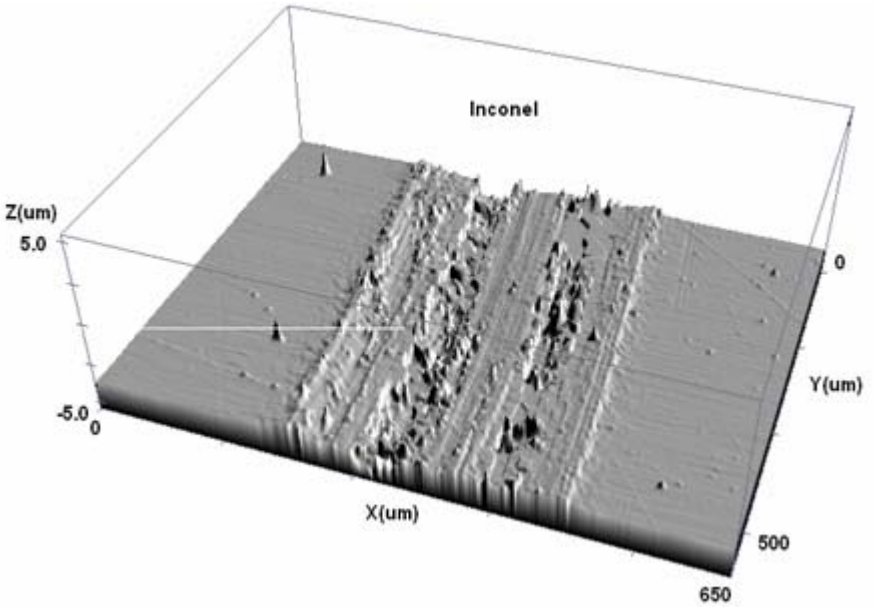


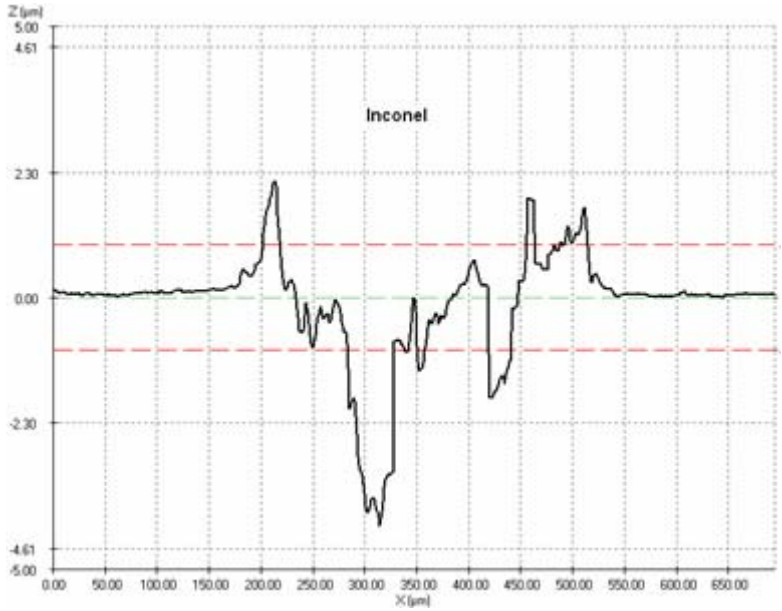


- ✓ Significative differences on surfaces worn areas
- ✓ Uncoated inconel exhibit important damage inside the wear track
- ✓ PVD coatings show a smoothed effect

Wear tracks topographies

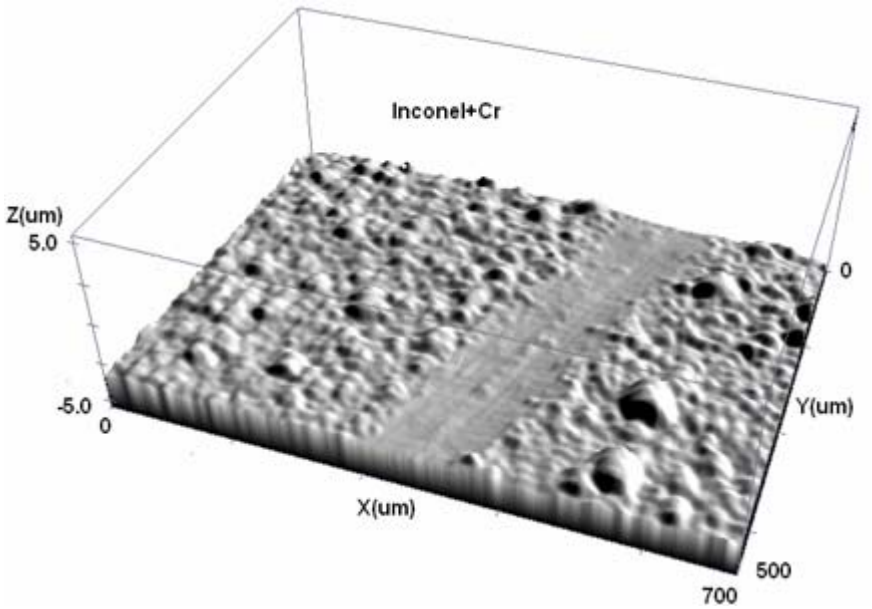
Inconel wear track

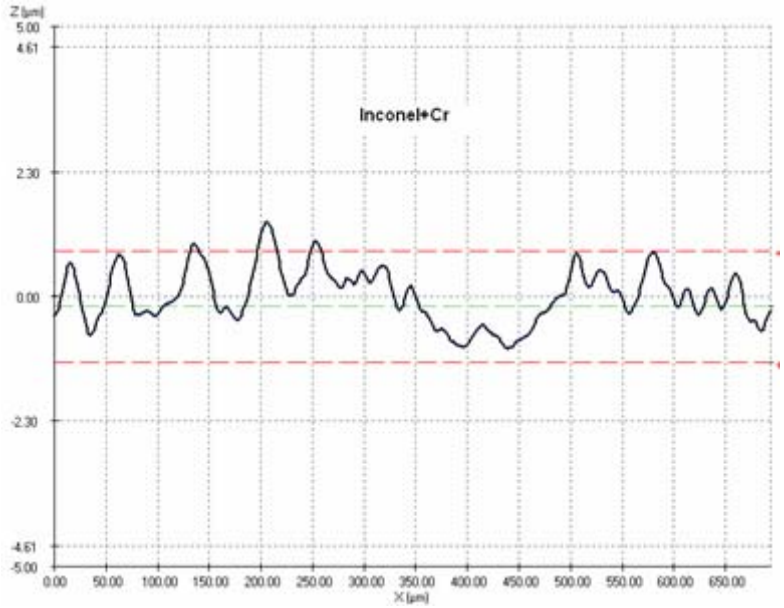




- ✓ Inconel wear track shows strong abrasion and cracks.
- ✓ Track depth reach 4 μm

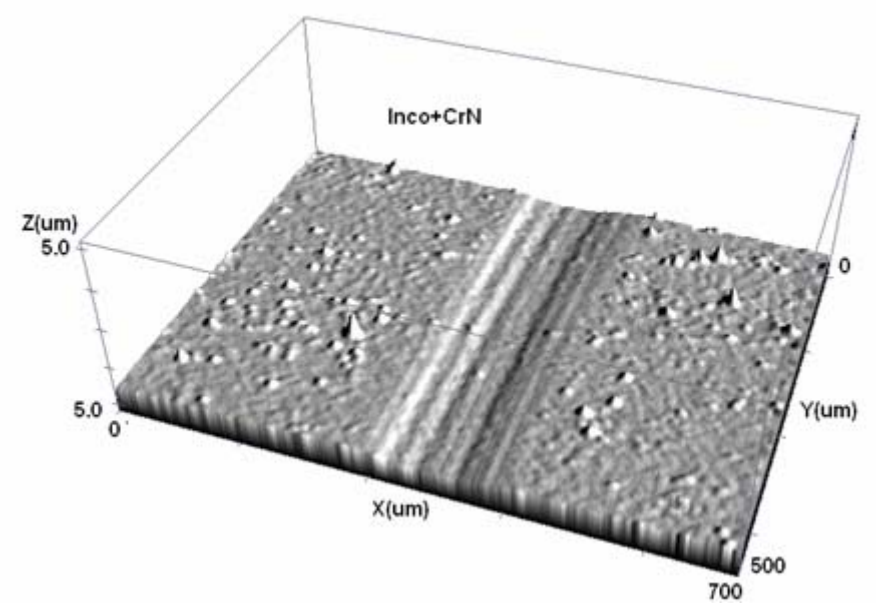
Inco+Cr wear track

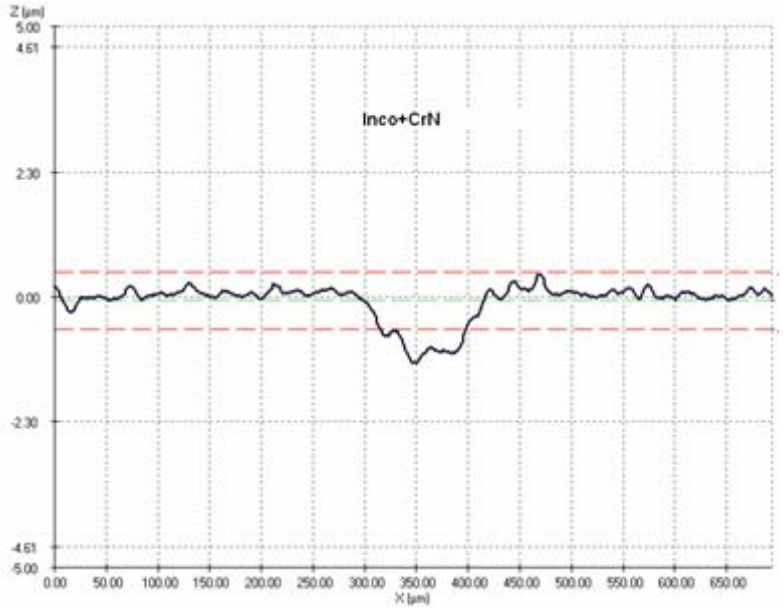




- ✓ Chromium coating topography reveals low wear (small loss of volume)
- ✓ Track depth is around 1 μm

Inco+CrN wear track

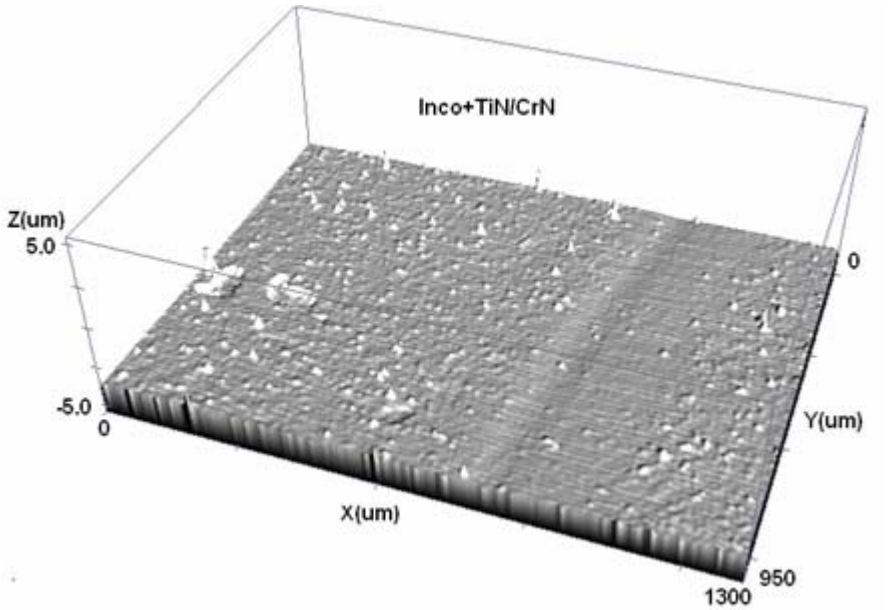


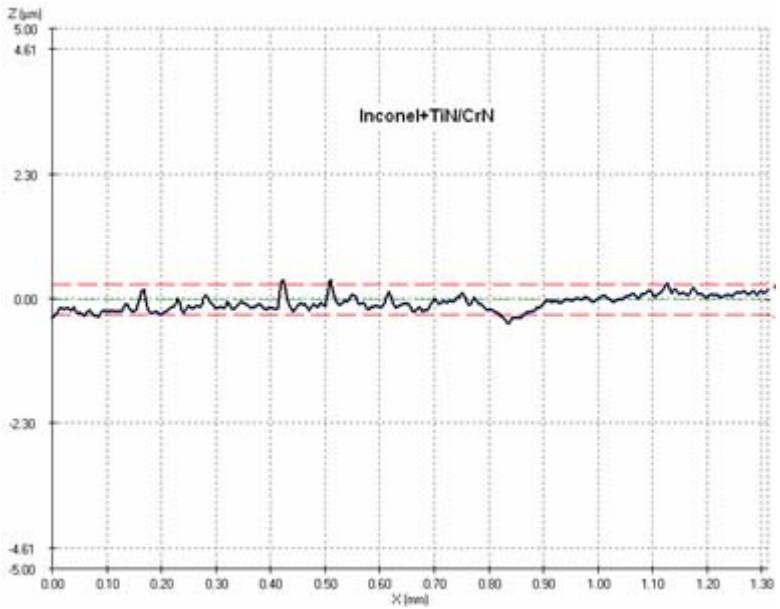


✓ CrN coating topography reveals low wear and abrasion marks

✓Track depth is similar to the obtained in chromium coated surface, around 1 µm, the substrate have been protected during rubbing by the coating

Inco+TiN/CrN wear track

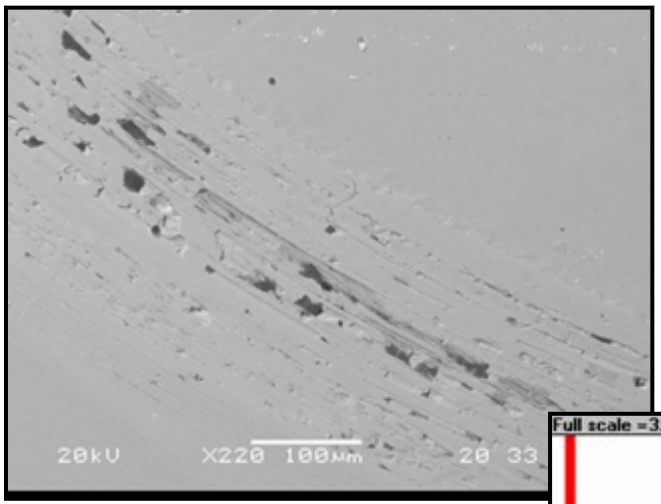




- ✓ TiN/CrN coating topography reveals insignificant wear
- ✓Track depth is less than 0.5 μm,

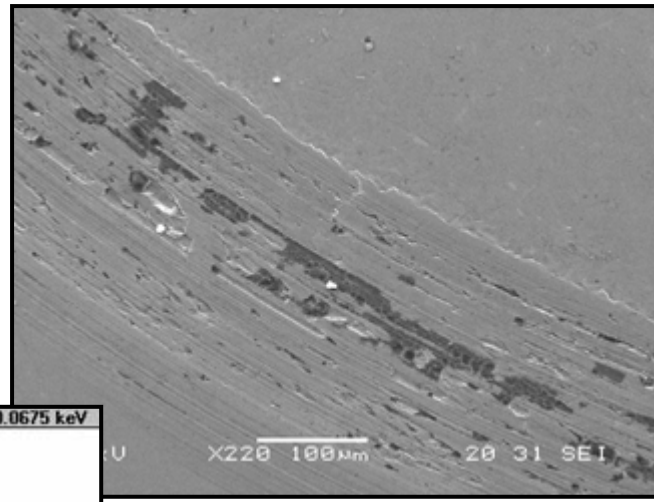
SEM-EDS wear track analysis

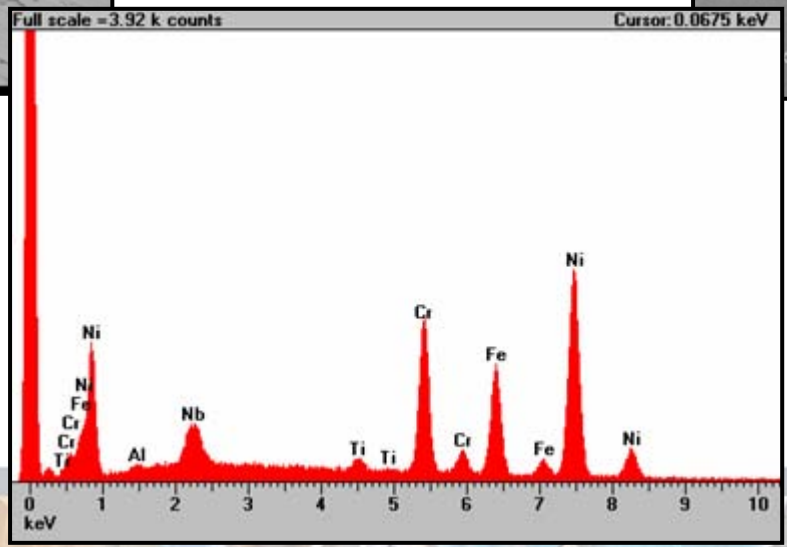
Inconel wear track



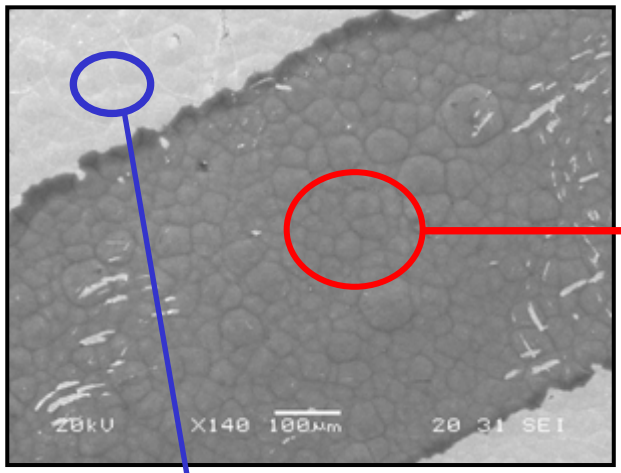
Abrasive wear

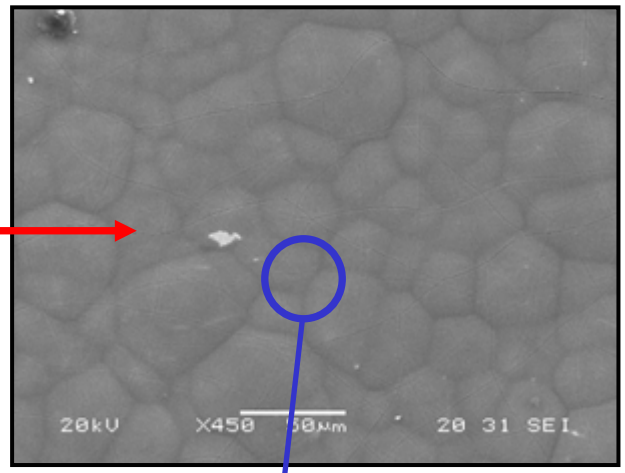
Micro-cracks inside the track

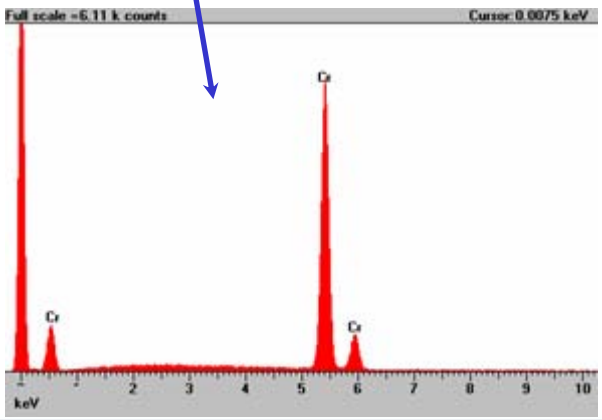


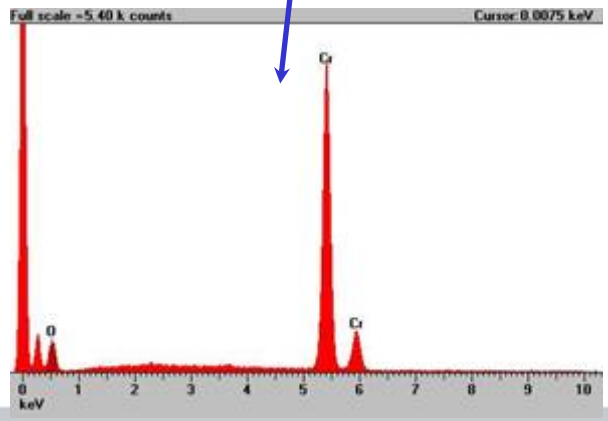


Inco+Cr wear track



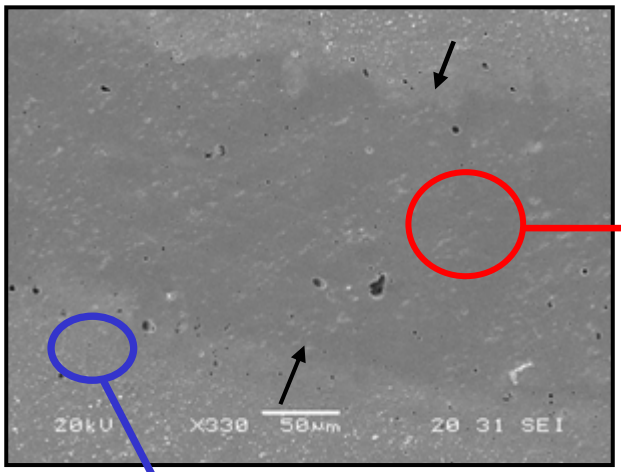


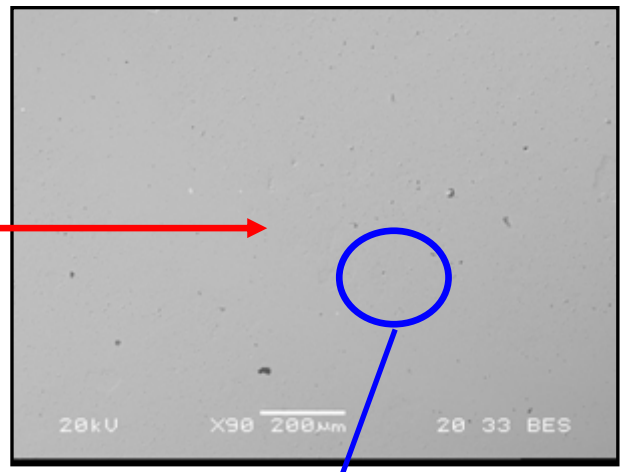


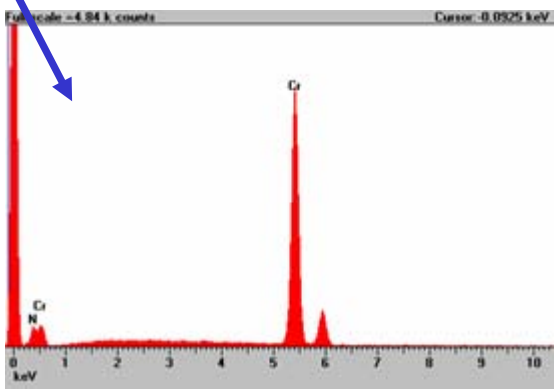


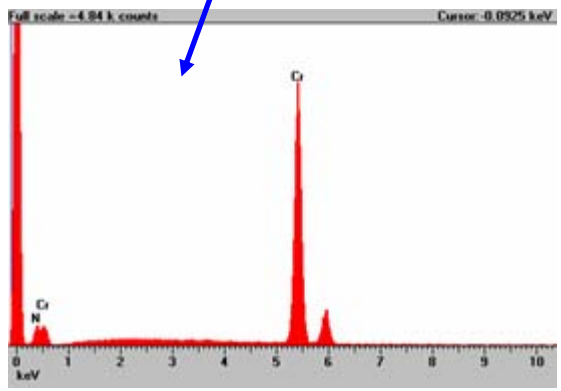
Hard Cr coating reduces inconel wear

Inco+CrN wear track





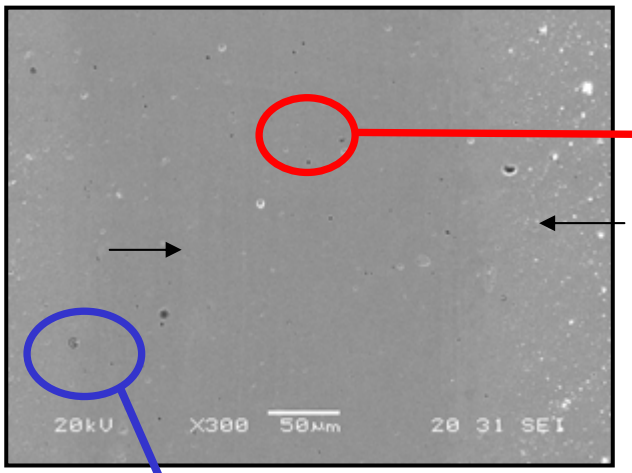


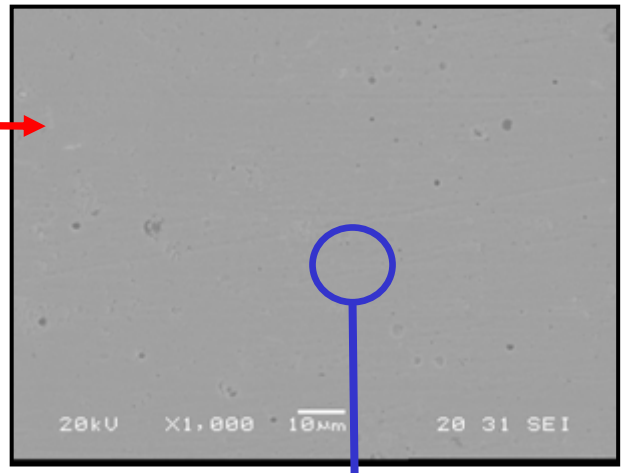


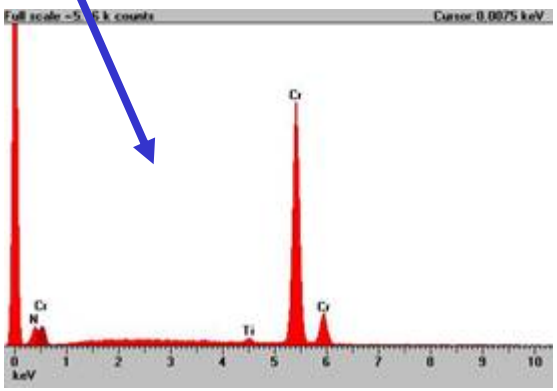
Same composition outside and inside the track

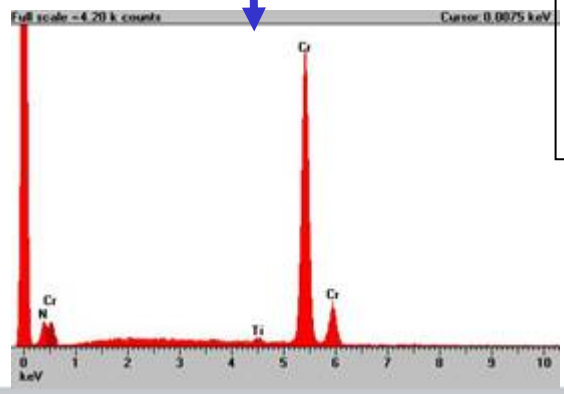
Negligible wear, smoothed effect

Inco+TiN/CrN wear track









Same composition outside and inside the track

Negligible wear, smoothed effect

Wear takes place on the outer CrN layer

Conclusions

▶ Two PVD coatings have been proposed as clean alternatives for replacement hard chromium coatings of the aeronautical industry

▶ CrN and TiN/CrN layers pass successfully the preliminary protocol tests for be employed as aircraft turbine coatings.

▶ Corrosion tests in saline media reveal excellent corrosion behaviour of coatings specially the multilayer structure proposed

▶ When corrosion and wear are studied simultaneously, **TiN/CrN** offers the best friction and wear resistance, improving the properties of hard chromium coating. Mechanical effects do not affect the electrochemical resistance of this film

Next steps

Inconel+TiN/CrN

→ **Finish protocol Tests**

→ **Study Fretting behaviour under real conditions**

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Thank you!