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Plasma nitriding plus oxidizing as a protective treatment for AISI 4140 steel

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Motivation

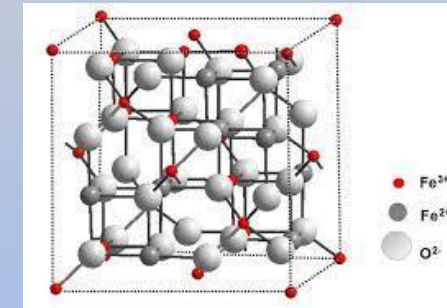
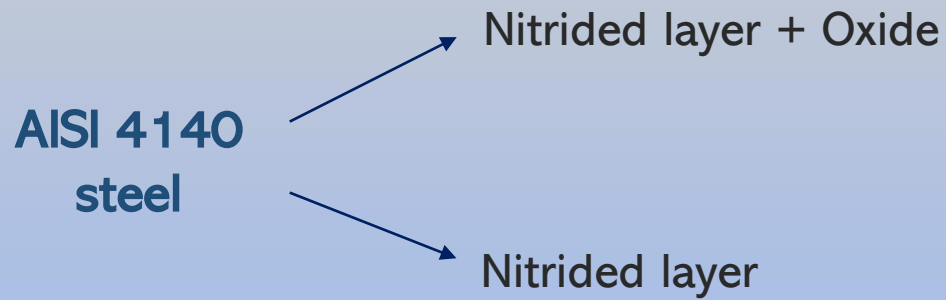
Steels

Nitrided layer

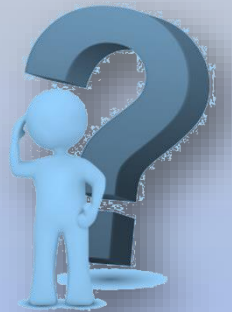
Hardness and good wear resistance, sometimes poor corrosion resistance

Oxide layer

Good corrosion resistance and also low friction coefficient



Magnetite



Main Goals

1. To study of the microstructure and surface properties of the nitrided and oxidized layer.
2. To evaluate the wear behaviour under different conditions such as rotational- reciprocating sliding, and fretting.
3. To analyze the corrosion resistance using Salt Spray Fog Test and potentiodynamic polarization.



Experimental

1. **Samples:** Heat treated AISI 4140 steel discs

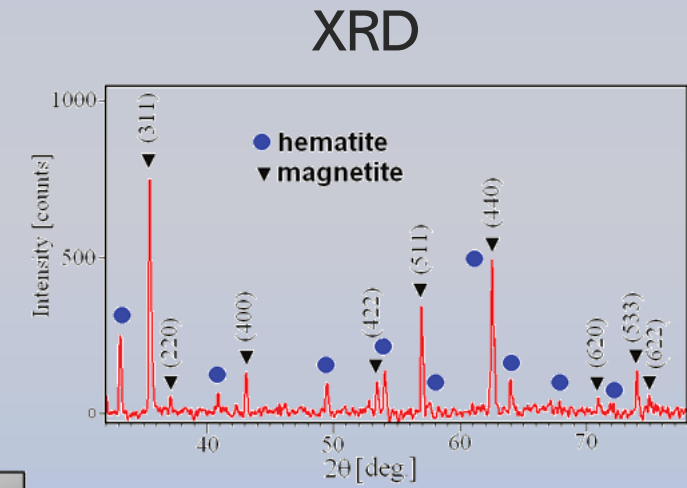
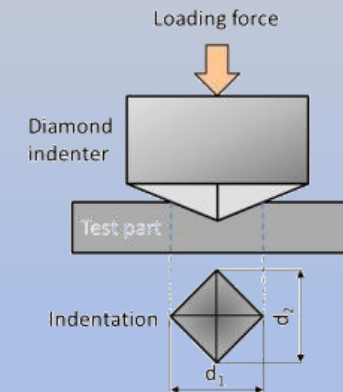
Fe (%)	C (%)	Si (%)	Mn (%)	Mo (%)	Cu(%)	Cr (%)
96.9	0.398	0.304	0.789	0.23	0.142	1.05

2. **Nitriding:** IONAR S.A. (Arg), DC pulsed plasma nitriding
20% N₂ – H₂, 500 °C, 15 h

3. **Oxidizing:** water steam, 400 °C, 1 h

4. **Characterization:**

Optical Microscopy, SEM, XRD



Vickers Hardness

Experimental

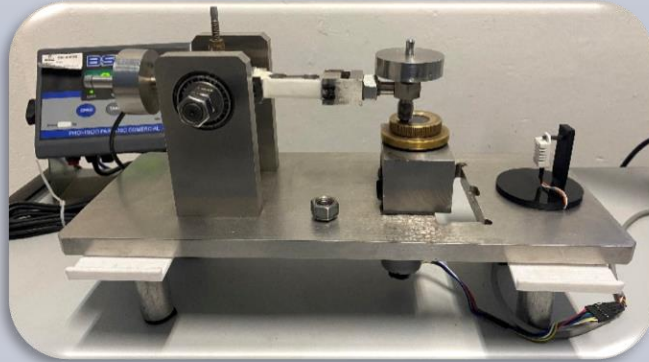


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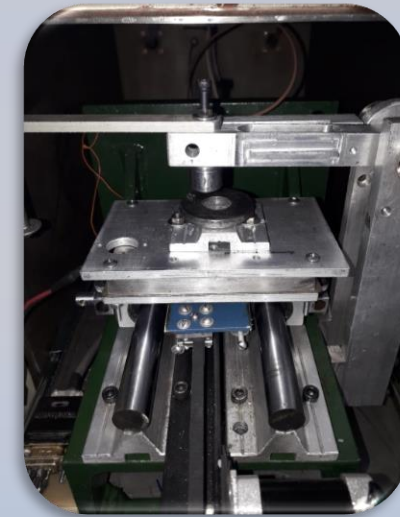
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Wear

Adhesive
Pin-on-Disk
ASTM G99
3 N, 500 m



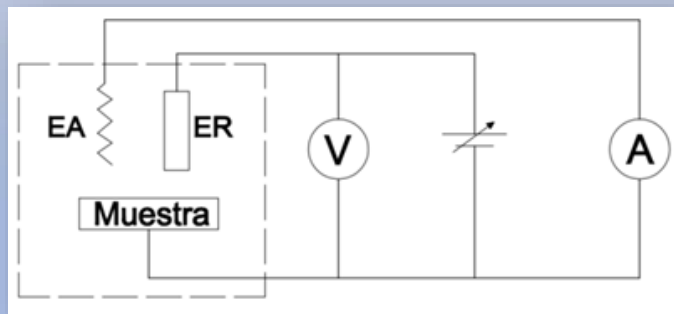
Reciprocating
sliding tests
5 mm length
354 Mpa



PAO 6 Oil

Corrosion

Potentiodynamic polarization / NaCl



Salt Spray
Fog tests
following
ASTM B117
100 h

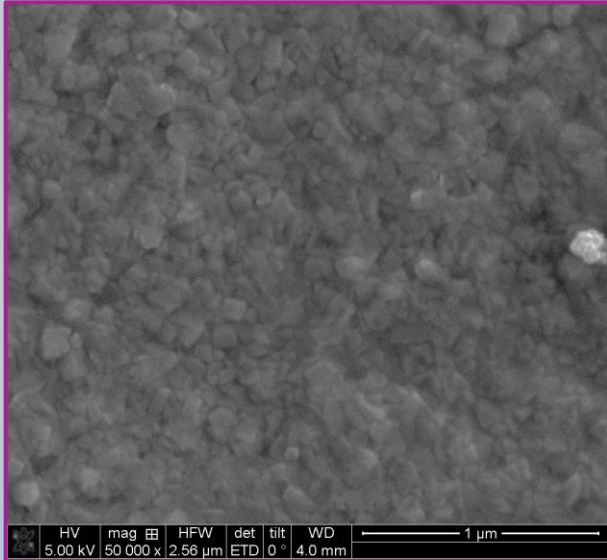


Fretting tests
A: 80 μ m
Load 2.1 N
17 Hz, 15 min

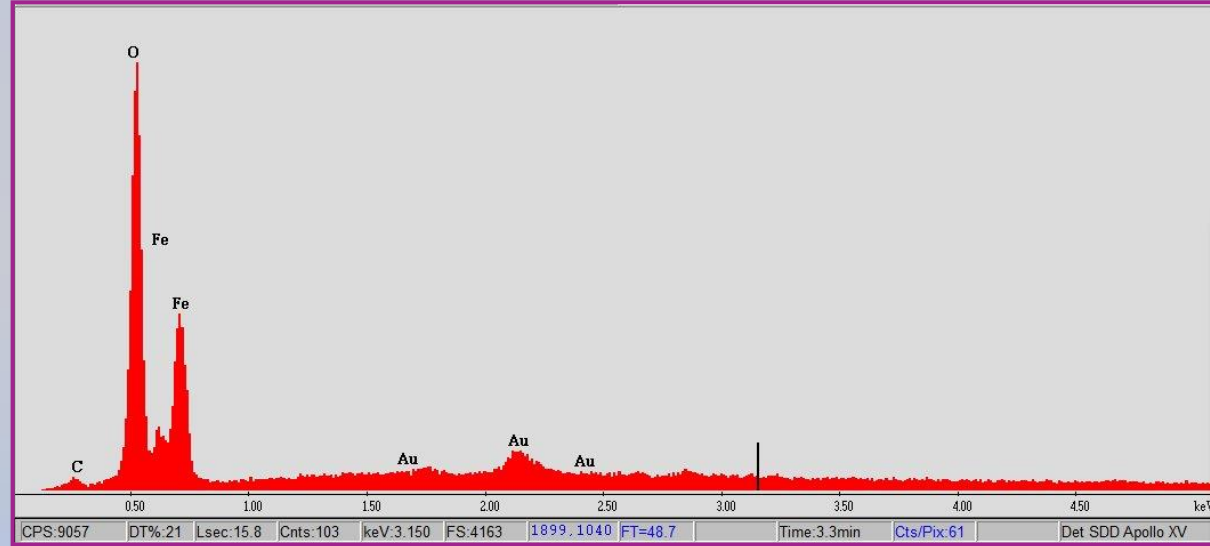


Results

Composition



SEM image on the surface



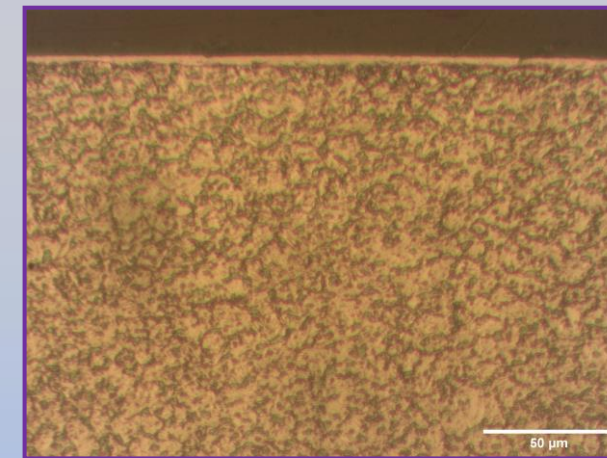
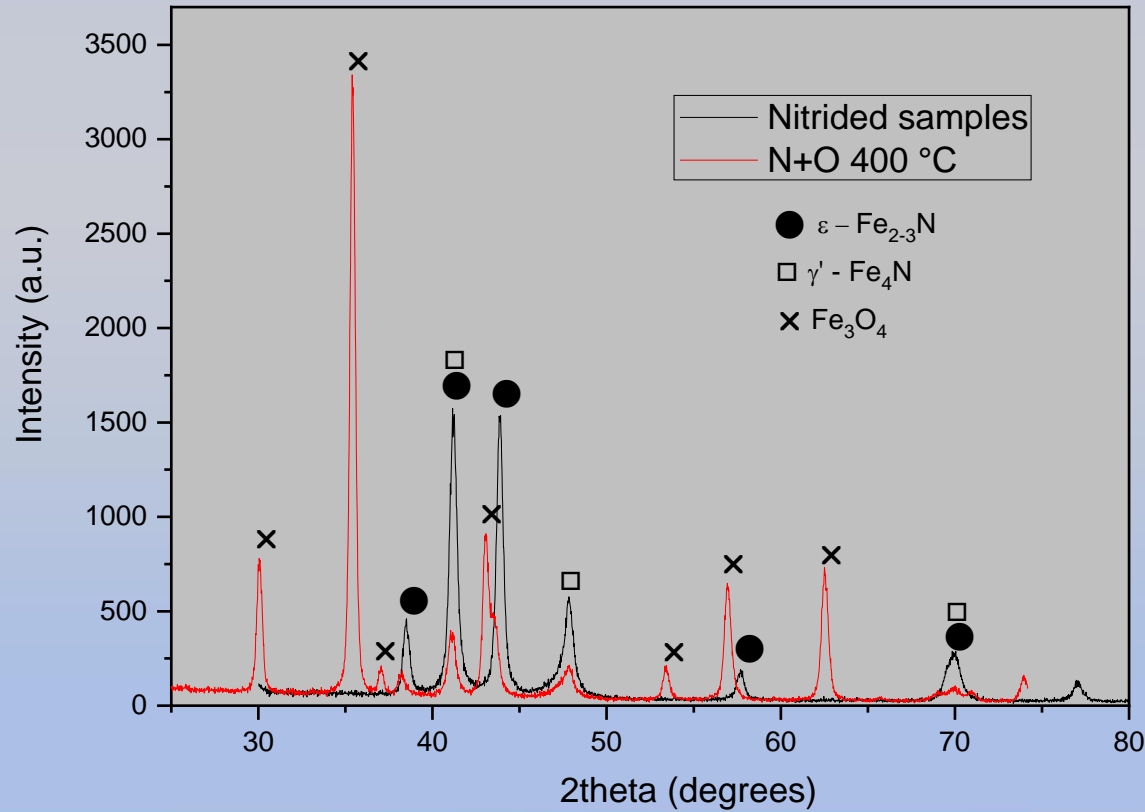
EDS measurement

Sample	% At. O	% At. Fe
Nitrided and oxidized steel	38,8	56,8

Results

Microstructure

XRD grazing incidence 3 degrees



Nitrided layer
≈ 3 μm

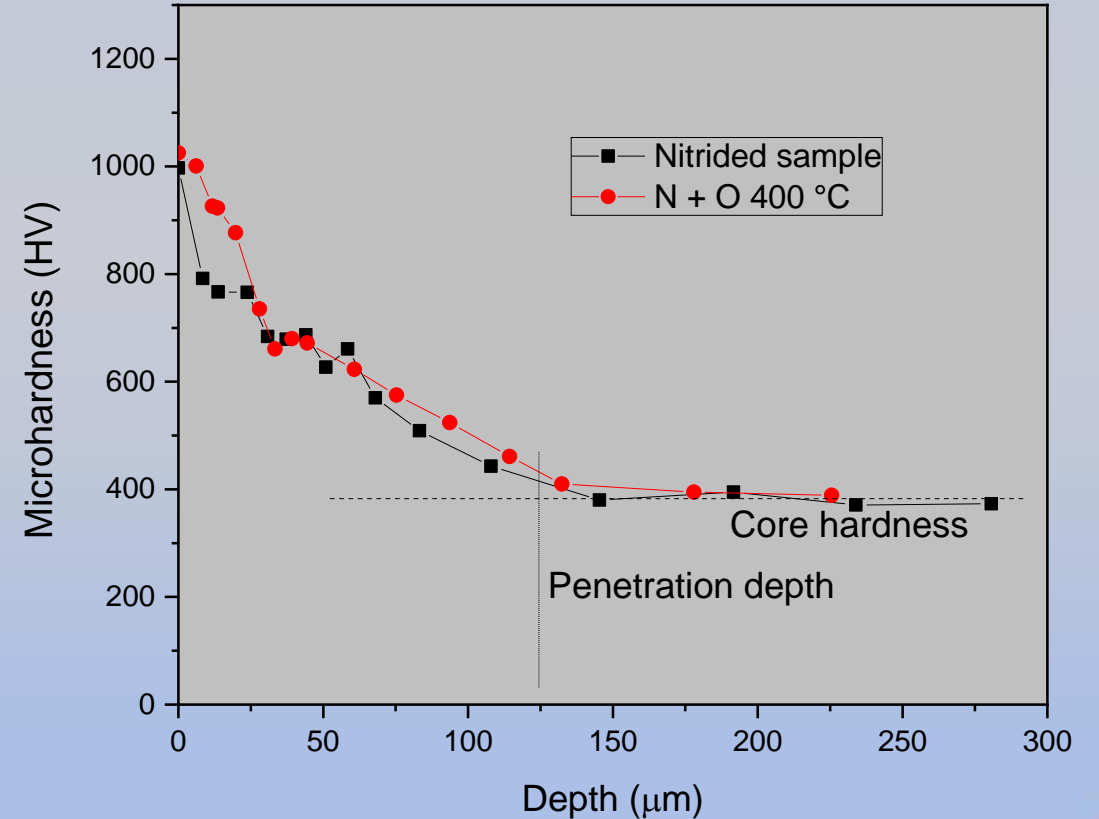
Optical micrograph
cross section N + Ox

Results

Surface Hardness and depth profile

Vickers microindenter

Samples	Hardness HV 0.05
Nitrided + oxidized steel	1020 ± 50
Nitrided steel	1000 ± 50
Heat treated steel	390 ± 10

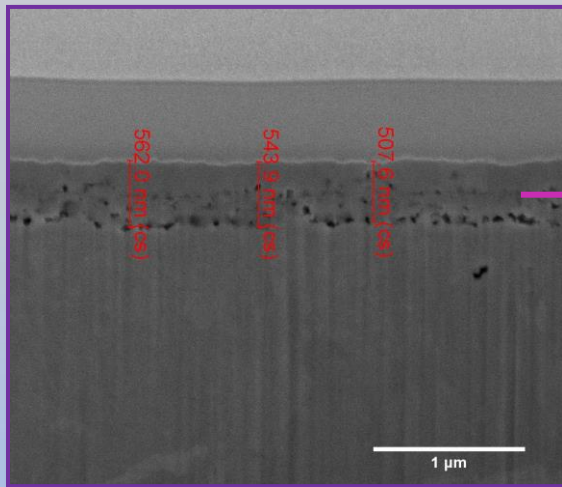


Results

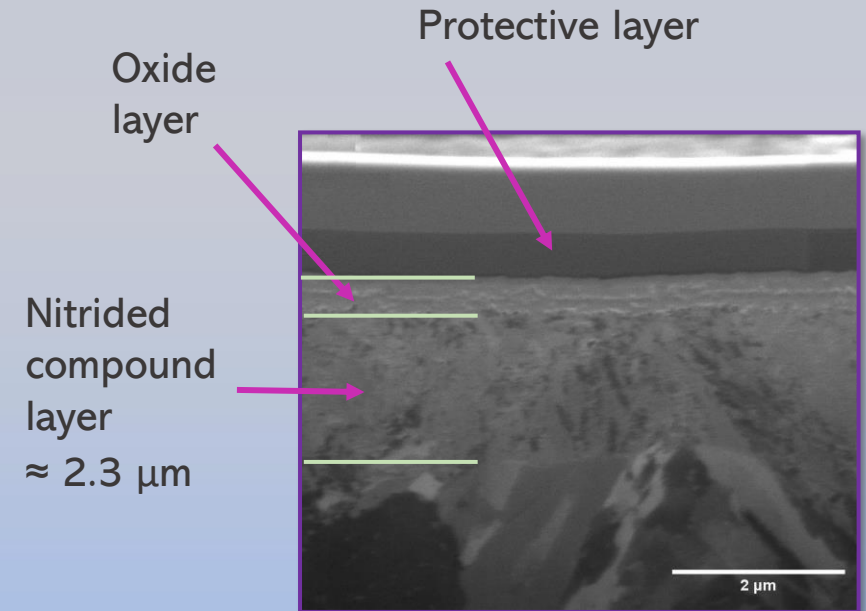
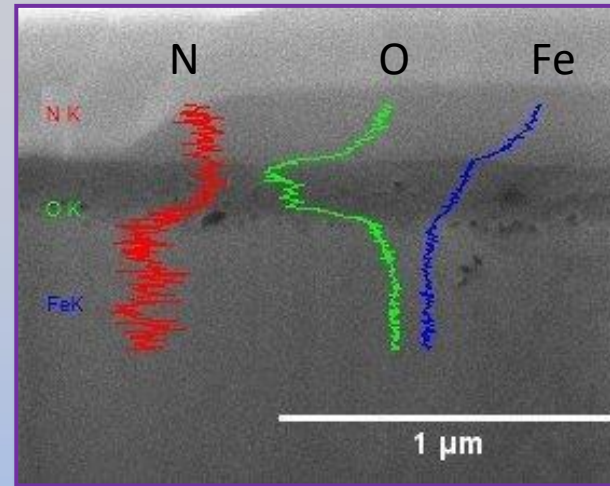
Layers thickness

FIB-SEM images on different samples

Elem. Chemical profile



Oxide layer
 $\approx 0,5 \mu\text{m}$

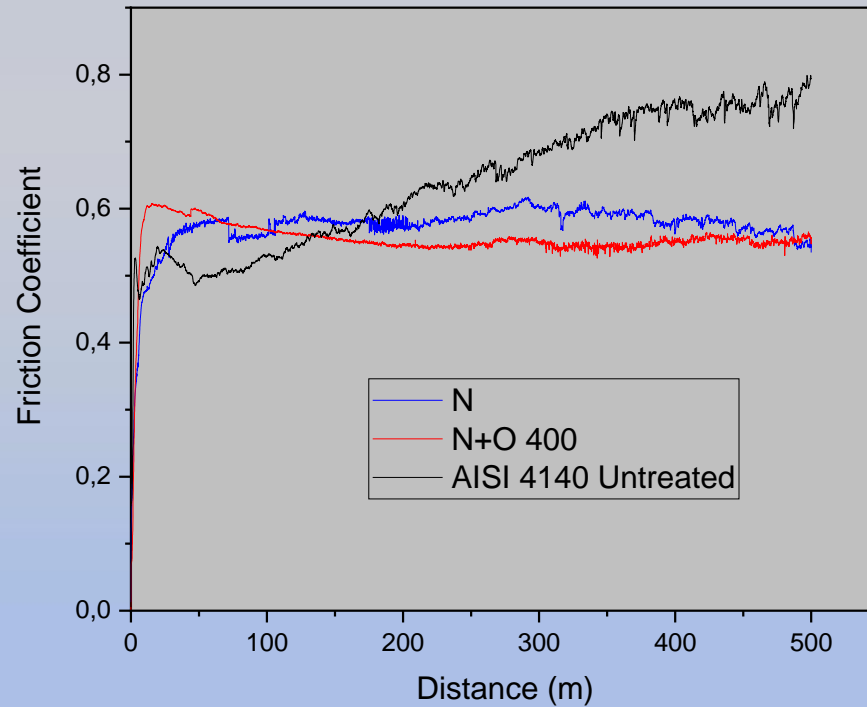


Results

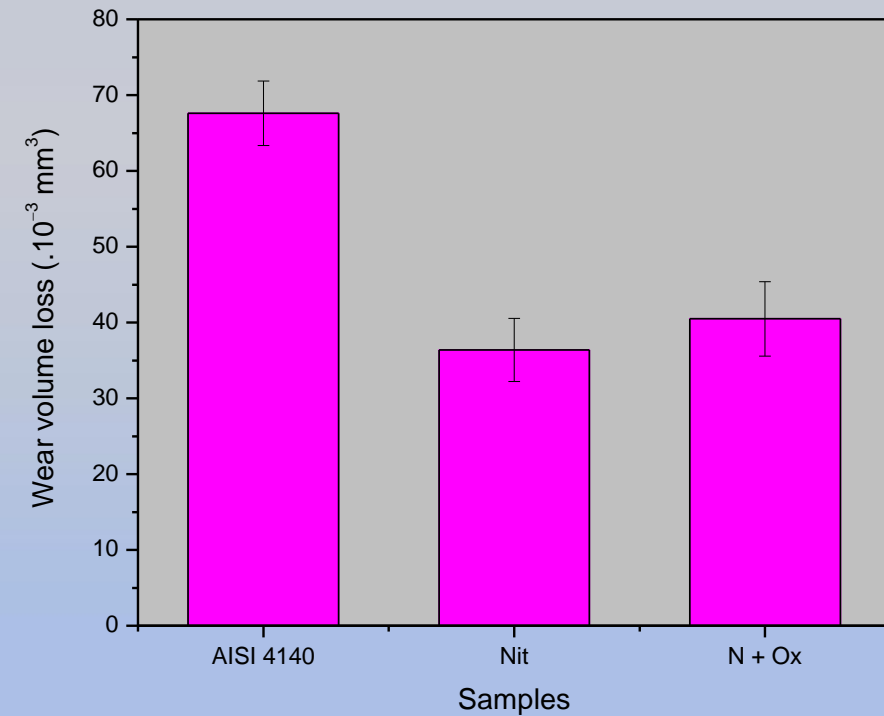
Wear and Friction

Pin on disk results

Friction coefficient



Wear volume loss



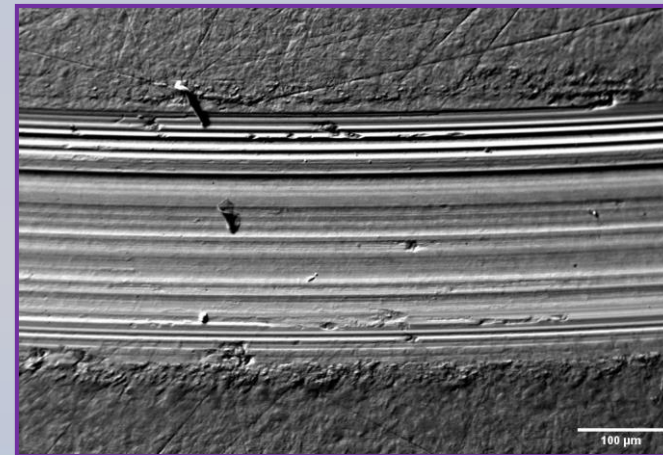
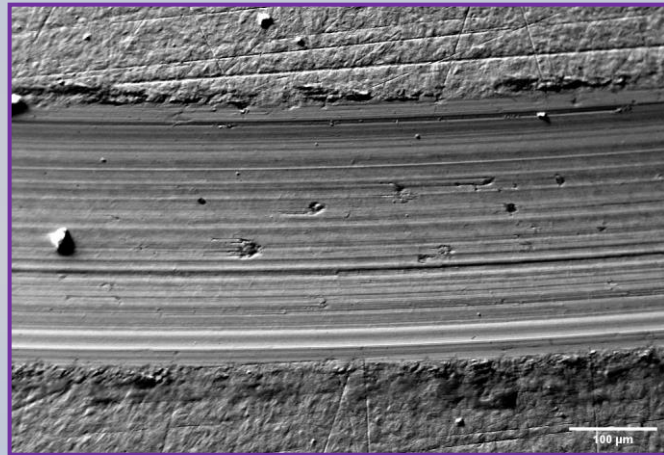
Results

Wear tracks

Pin on disk
wear tracks

Nitrided sample

N + Ox



Counterpart



SEM
Images

OM
Images



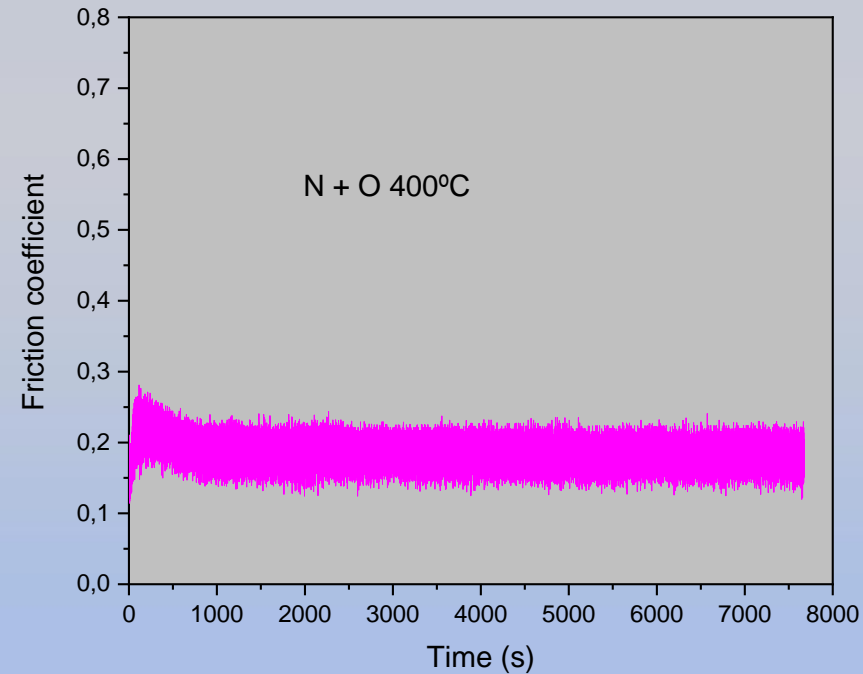
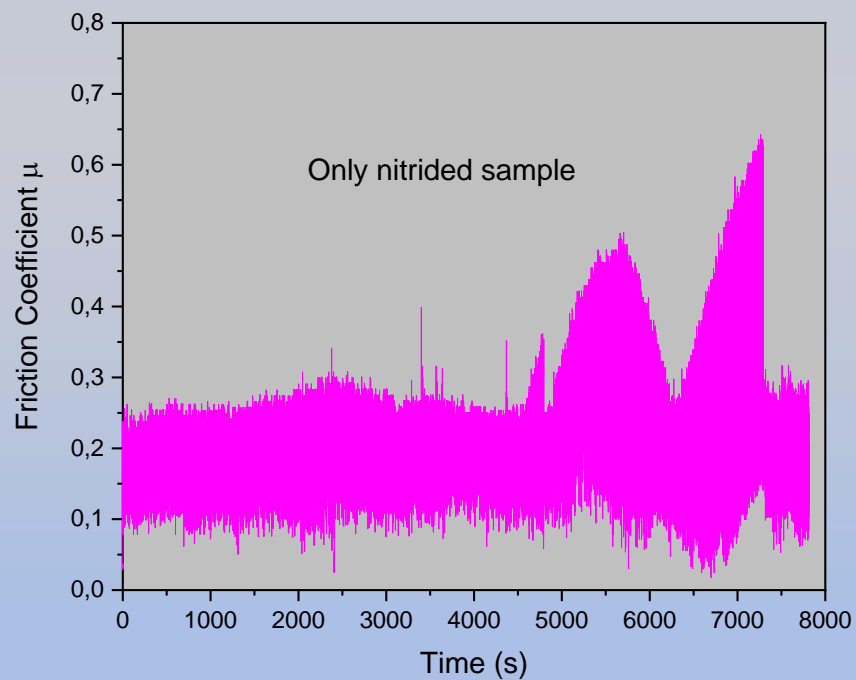
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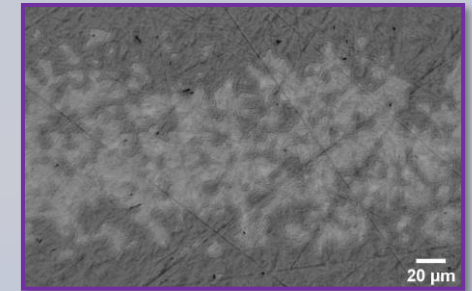
Results

Reciprocating sliding tests with lubrication

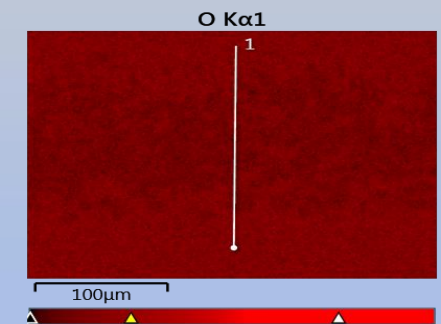
Friction coefficient



N + Ox



SEM image of the track



EDS map

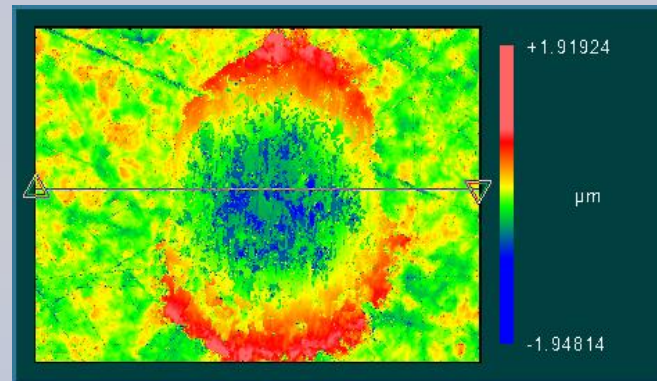
Thanks to W. Tuckart and G. Prieto, UNS-CONICET, Ba. Bca. Arg

Results

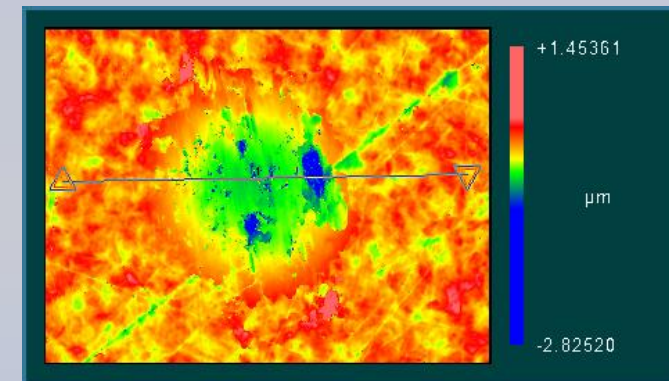
Fretting wear tracks

WLI images

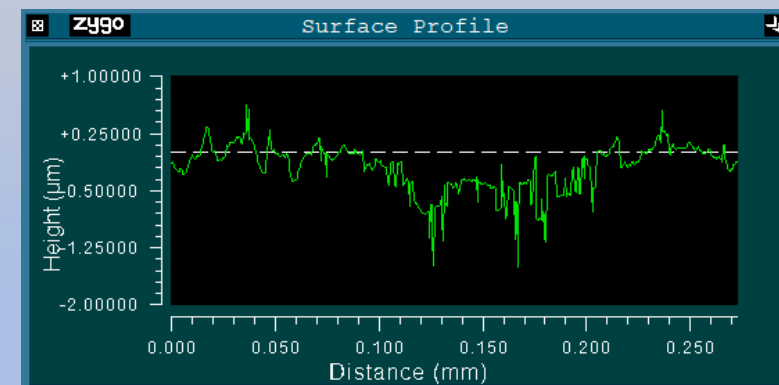
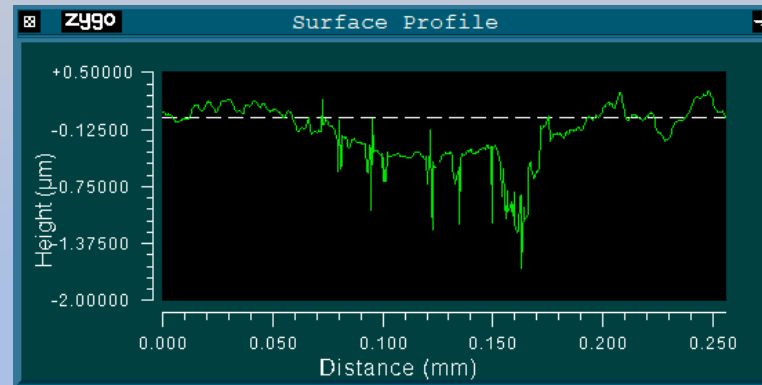
Nitrided



N + Ox



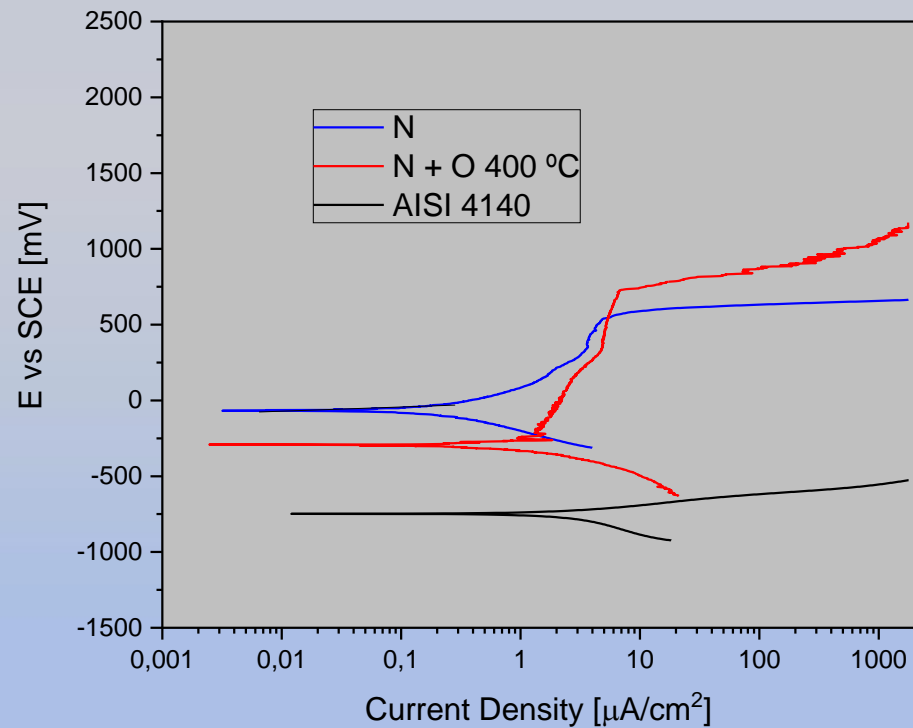
WLI Profiles



Results

Corrosion behaviour

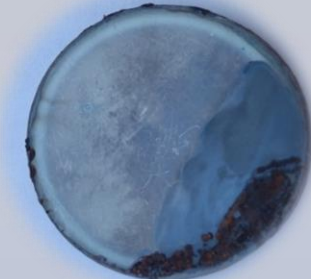
Potentiodynamic polarization in NaCl 3.5 %



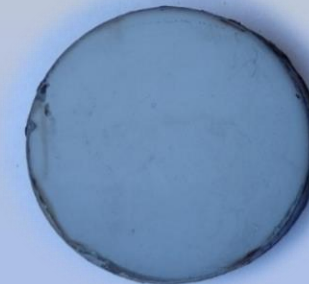
Salt Spray Fog Test results



AISI 4140



Nitrided sample



N + Ox sample

Results

Corrosion morphology

Optical micrographs

Crevice + pitting

SEM micrographs

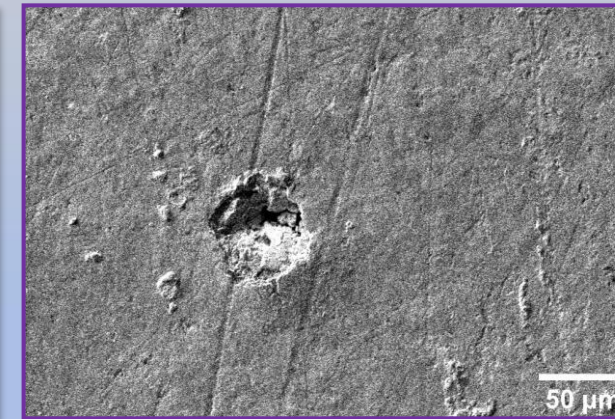
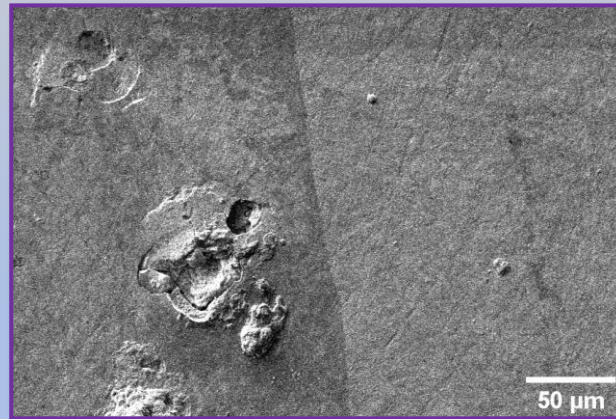
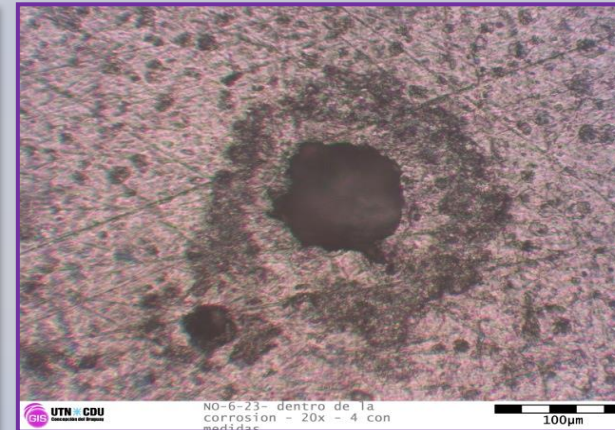
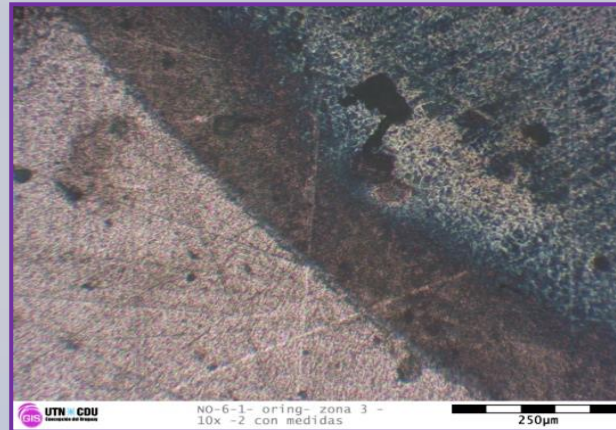


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Nitrided

N + Ox



Pitting

Conclusions

1. A duplex plasma treatment, nitriding + oxidizing, was applied successfully in the same process work chamber over AISI 4140 steel.
2. An oxide layer of 0.5 μm thick was formed after the oxidizing treatment, consisting in pure magnetite.
3. This layer did not improve the tribological behaviour under dry conditions (pin on disk and fretting) in comparison with the nitrided layer. However, it reduced the friction coefficient in reciprocating sliding tests under lubricated conditions and low hertzian pressure.
4. The oxidized layer, provided good corrosion protection in saline environments as revealed in the salt spray and potentiodynamic tests.



Thank you!



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¡Muchas Gracias!