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Mechanical and tribological characterization of sol-gel coatings (Interreg TRANSPORT)

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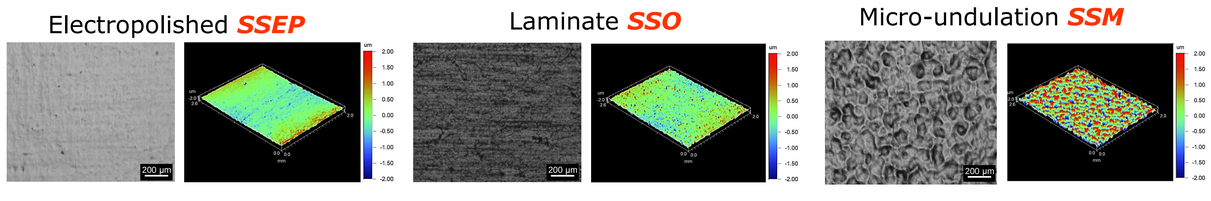
Objective

Determine the effect of different surface treatments of stainless steel substrate on the mechanical properties of an hybrid sol-gel coating obtained by nanoindentation tests and their influence on the tribological behavior.

Materials

Monolayer hybrid sol-gel coating deposited on stainless steel plates with different surface treatments:

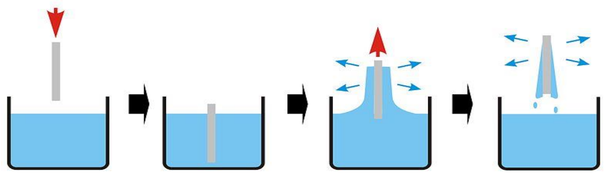
Electropolished ***SSEP*** | Laminate ***SSO*** | Micro-undulation ***SSM***



Principal components in the sol-gel formulation ***M13***: TEOS, MTES, P123 and Ludox HS-40. Thickness of coatings ~ 2 µm.

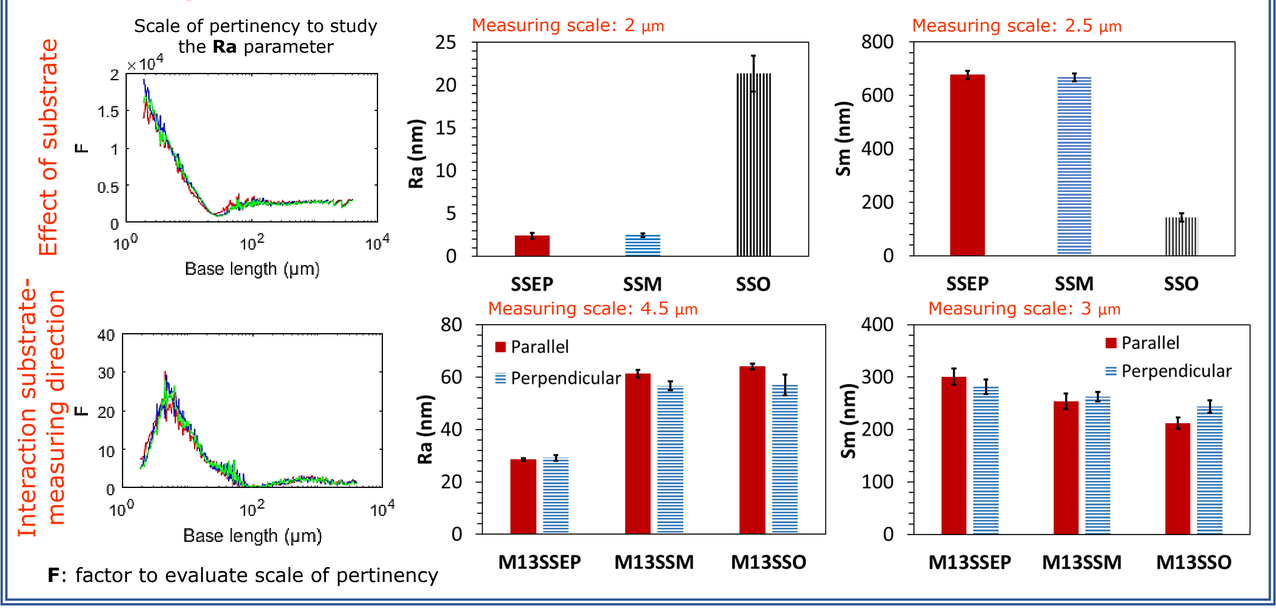
Manufacturing process:

Dip coating + 1 h curing at 170 °C



Morphology evaluation

Data acquisition: contact profilometry, 16 linear profiles of 8 mm length



F: factor to evaluate scale of pertinency

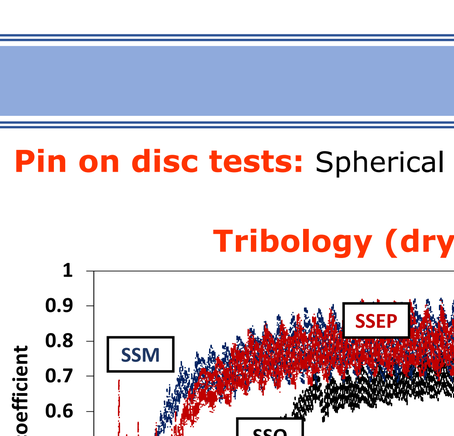
Nanoindentation: multilayer model analysis

Tests: continuous stiffness measurement (CSM) tests up to 2000 nm of penetration depth.

Basis of the model

$$H_c = \frac{A_f}{A}H_f + \sum_{k=1}^{n}\frac{A_i}{A}H_i + \frac{A_s}{A}H_s$$

$$\frac{A_i}{A} = 2\frac{C_i t_i}{h} - \frac{2C_i{}^2 t_i{}^2}{h^2} - 2\frac{C_i t_i C_f t_f}{h^2}$$



	E (GPa)	*H* (GPa)
SSEP	194 ± 9	2.3 ± 0.1
SSO	197 ± 13	2.4 ± 0.3
SSM	234 ± 8	5.2 ± 0.3

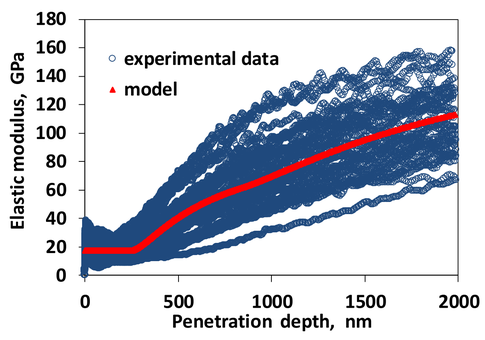
E: elastic modulus by nanoindentation test
H: hardness by nanoindentation test

h: penetration depth
H_c: composite hardness
H_f: film hardness
H_i: *i*-layer hardness
H_s: substrate hardness
A_f, A_i and A_s: areas of top film, *i*-layer and substrate
$A=A_f+A_i+A_s$
C_i: constant related to the deformation mode
t_i: *i*-layer thickness

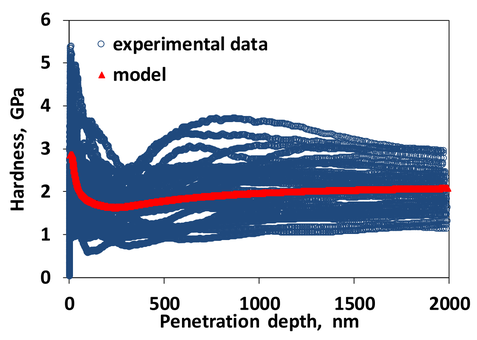
Application to sol-gel coatings

High dispersion of the mechanical properties → Simultaneous treatment of all the curves → Average response of the system coating-substrate

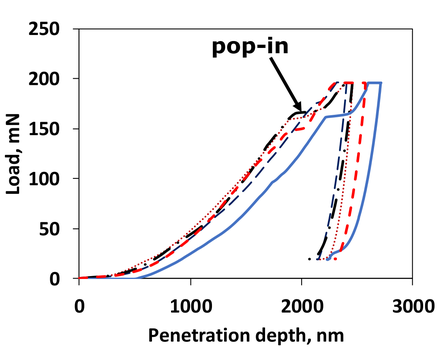
M13SSO



E_1 (GPa)	E_2 (GPa)	SSO (GPa)
17	103	197

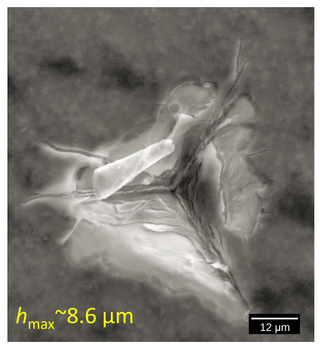


H_1 (GPa)	H_2 (GPa)	SSO (GPa)
2.9	1.5	2.4

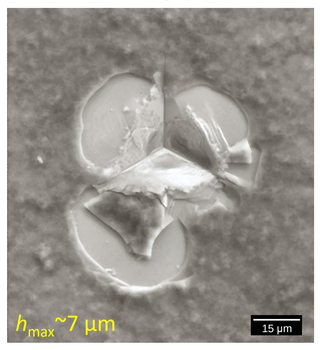


Curves showing pop-in during loading

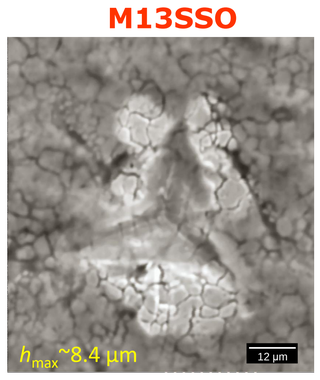
M13SSEP



M13SSM



M13SSO



Indents from tests at higher penetration depths showing chipping due to coating decohesion

	E_1 (GPa)	E_2 (GPa)
M13SSEP	14	97
M13SSM	15	84

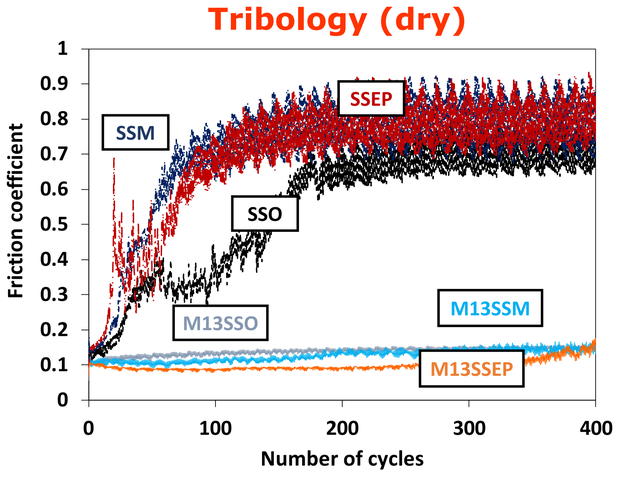
	H_1 (GPa)	H_2 (GPa)
M13SSEP	2	1
M13SSM	3	1

- Bilayer behavior
- Some loading curves exhibit pop-in
- Similar mechanical properties of coating independent of the substrate surface treatment

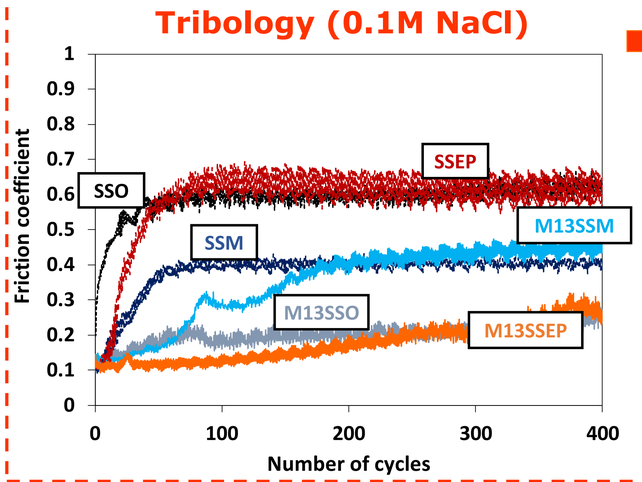
Tribology characterization

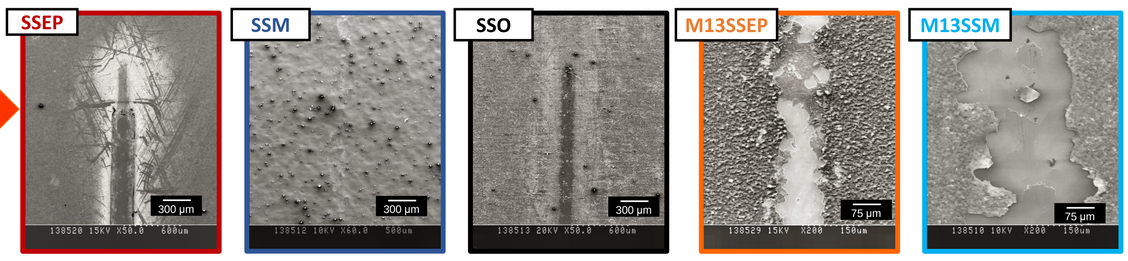
Pin on disc tests: Spherical pin of alumina (ø 10 mm). Oscillating movement. 1 N load.

Tribology (dry)



Tribology (0.1M NaCl)





- Substrate is reached during wear tests in NaCl solution for M13SSEP and M13SSM samples. For M13SSO sample, after 400 cycles no visible wear track
- Smaller wear tracks while testing in NaCl solution compare with those in air
- M13SSO and M13SSEP similar mechanical properties and friction coefficients, but different wear behavior - related to the coating adhesion due to substrate surface treatment (?)

Conclusions and outlooks

- ✓ C1. Roughness of M13SSEP is significantly different from M13SSO and M13SSM at a measuring scale of 4.5 µm
- ✓ C2. Sol-gel coatings behave mechanically like a bilayer system
- ✓ C3. Tribological behavior of sol-gel coatings depends on substrate surface treatment
- ➢ O1. Model mechanical properties by a continuous gradient approach
- ➢ O2. Determination of coating toughness through pop-in in nanoindentation tests
- ➢ O3. Scratch tests to qualify the adhesion of coatings

Acknowledgments

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TRANSPORT

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