Artificial Lift R&D Council

2021 International Sucker Rod Pumping Virtual Workshop

February 8-12, 2021

Comparison of Corrosion/Wear Resistant Barrel Coatings and Their Failure Behavior Under Acidic Conditions

Dr. Pinar Karpuz-Pickell, Ph.D.
Levins Thompson

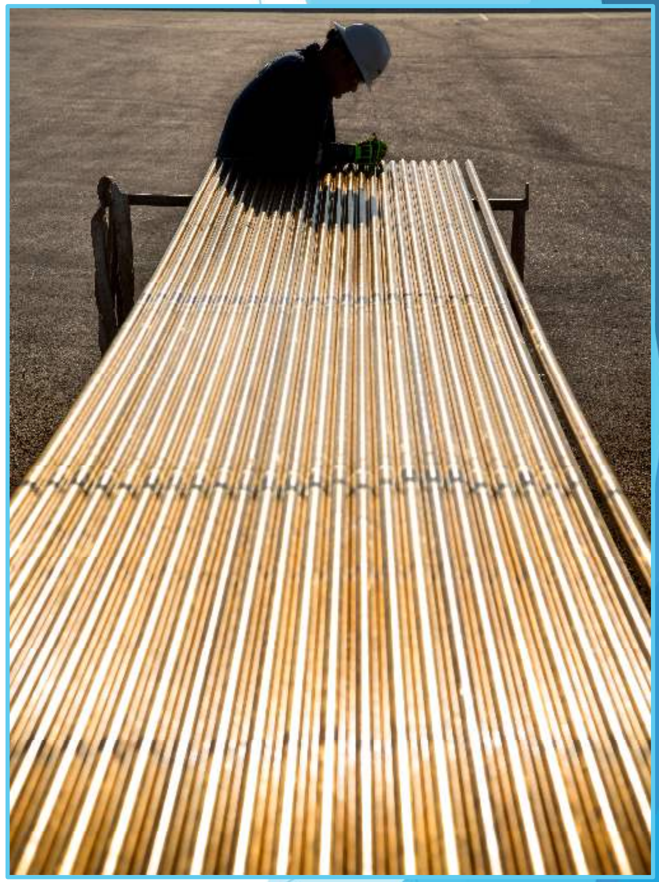
Don-Nan

Introduction

Surface modification in sucker rod pump barrels can be achieved by:

- Methods that involve surface and subsurface modifications without any intentional increase in part dimensions (diffusion and selective hardening) .

- Methods that involve an intentional buildup or addition of a new layer (coatings and hardfacings).

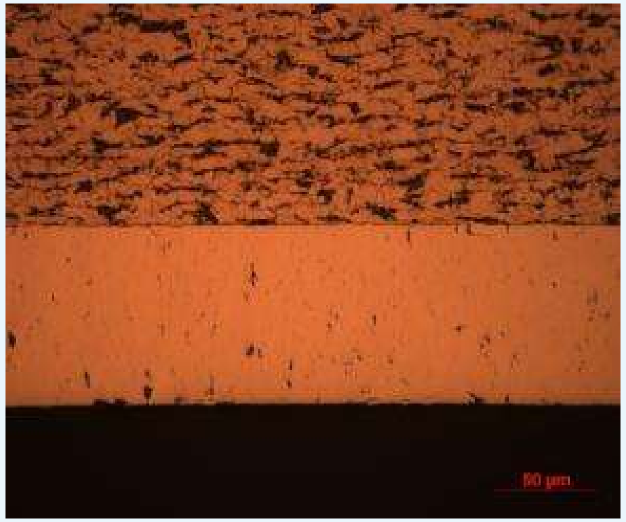
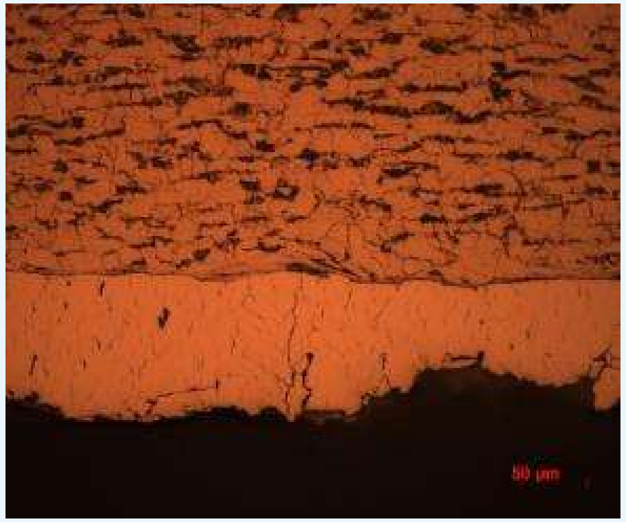


Introduction

- Hydrochloric acid (HCl) is commonly used in the wells for acidizing treatment.
  - While necessary for a well's well-being, the treatment may damage some pump parts, including the coatings on the barrel.
  - Chrome coatings, for example, are known to be very susceptible to HCl attack.
  - Many barrel coatings exist in the market that aim to battle the "harsh well conditions," as well as the acidizing jobs. Some are API standardized; many are not API standardized.
  - API standardized Nickel Carbide composite coating is one of these coatings, along with other specialized and proprietary ones.

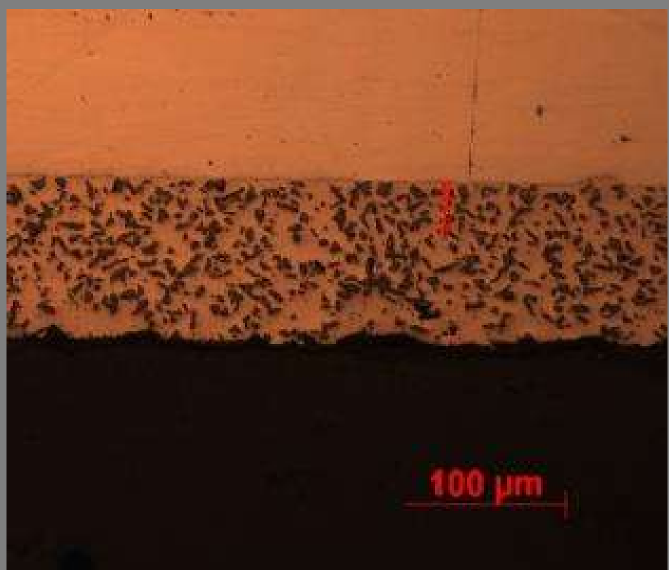
- The barrel coatings that are employed in this study are:
  - Two (2) API standardized Chrome coatings from different manufacturers (Chrome A and Chrome B);
  - One (1) API standardized Nickel Carbide composite coating (Ni-Carb C);
  - And three (3) different specialty coatings (coating X, Y and Z).

API Standardized Chrome Coating

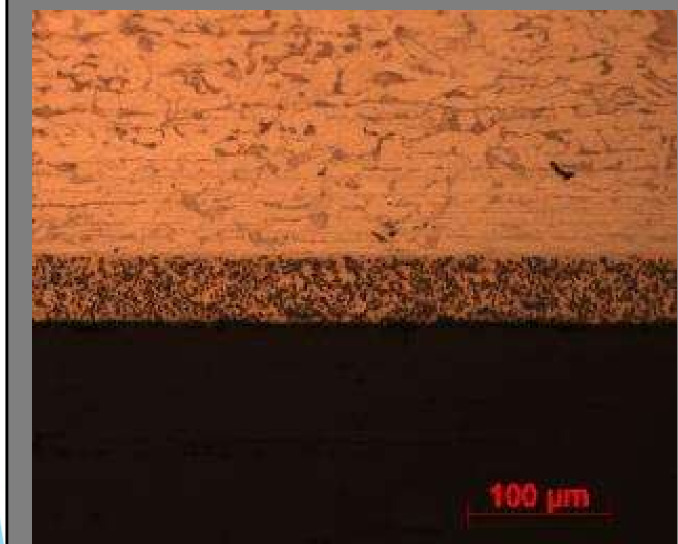
	Chrome A	Chrome B	API 11AX Specification
Coating Thickness	101.4 microns	64.4 microns	76.0 microns
Coating Hardness (HV100)	1046.7	926.0	900-1160
Structure	Electroplated hard Chrome only on ID	Electroplated hard Chrome only on ID, nodular surface, macrocracks	N/A
Surface Condition			N/A

API Standardized Nickel Carbide Composite Coating

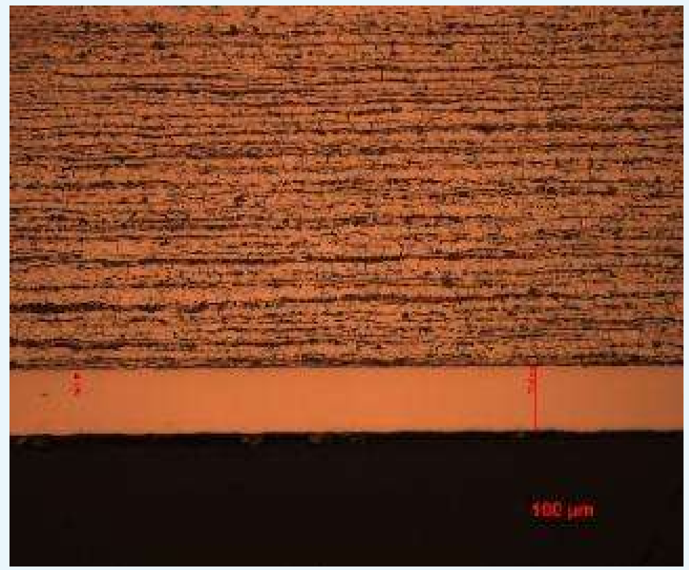
	Ni-Carb C		API 11AX Specification
Coating Thickness	95.5 microns		33.0 or 76.0 microns
Coating Hardness (HV100)	N/A		N/A
Structure	Electroless Ni-P deposit with SiC particles, both on OD and ID		N/A
Structure	Matrix	11.0%P 89.0%Ni	N/A
	Particles	18.1%C 81.9%Si	
	Particle Density (%)	35	



Specialty Barrel 1 (Coating X)

	Coating X		Manufacturer Claim
Coating Thickness	44.9 microns		N/A
Coating Hardness (HV100)	N/A		1128
Structure	Electroless Ni-P deposit with SiC particles, only on ID		Comparable to Chrome coating, more uniform
Structure 	Matrix	10.6%P 89.4%Ni	N/A
	Particles	19.6%C 80.4%Si	
	Particle Density (%)	47	

Specialty Barrels 2 &3 (Coating Y and Z)

	Coating Y Tests and Measurements	Coating Z Tests and Measurements		Manufacturer Claim
		ID	OD	
Coating Thickness	71.9 microns	75.7 microns	98.2 microns	0.003 in minimum
Coating Hardness (HV100)	846.4	886.3	858.7	Meets API hardness requirement
Structure	Electroless Ni-P deposit 7.9%P, 92.1%Ni 	Electroless Ni-P deposit 		Comparable to Chrome coating, more uniform

Specialty Barrels 2 &3 (Coating Y and Z)

	Coating Y Tests and Measurements	Coating Z Tests and Measurements		Manufacturer Claim
		ID	OD	
Coating Thickness	71.9 microns	75.7 microns	98.2 microns	0.003 in minimum
Coating Hardness (HV100)	846.4	886.3	858.7	Meets API hardness requirement
Structure	Electroless Ni-P deposit 7.9%P, 92.1%Ni	Electroless Ni-P deposit		Comparable to Chrome coating, more uniform

CHEMICALS	PLATING	HARD CHROME PLATING
Hydrochloric Acid 7.5%	Resistant – no failure @ 48hrs.	Failure @ 8hr – Exposed base metal
Hydrochloric Acid 10%	Resistant – no failure @ 48hrs.	Failure @ 1hr - Exposed base metal
Hydrochloric Acid 15%	Resistant – no failure @ 48hrs.	Failure @ 1hr - Exposed base metal

Test Setup and Procedure

- The barrels of coatings to be tested are:
  - Sectioned at and near the central area;
  - Test pieces are masked so that only a square inch of the coated region is exposed on the ID;
  - And each experiment is performed three (3) times, to ensure consistency & reliability of results.

	Chrome A			Chrome B			Ni-Carb C			Coating X			Coating Y			Coating Z		
HCl Test Solution	2.5%		5%	2.5%		5%	15%			15%			15%			15%		
Test Time (hrs)	4	8	12	4	8	12	12	24	48	12	24	48	12	24	48	12	24	48

Test Setup and Procedure

- The exposed surfaces are documented.
  - Metallographic samples are sectioned from the exposed specimens.
  - Mounted in epoxy and phenolic molds, and ground and polished according to ASTM E-3 Standard.
  - Most of the samples are etched in 2% Nital solution to reveal the base metal microstructure.
  - Axiovision software is used for quantitative measurements.

Observations

Degradation of "Coating Y" and "Coating Z" when exposed to HCl:

- HCl solution turns yellow (Fe contamination, base metal is exposed)
- Surface cracks become visible and ribbons form/flake.

Degradation of Chrome when exposed to HCl:

- Severe bubbling on the specimen surface starts,
- Specimen surface turns dull
- HCl solution turns blue

Degradation of "Ni-Carb C" and "Coating X" when exposed to HCl:

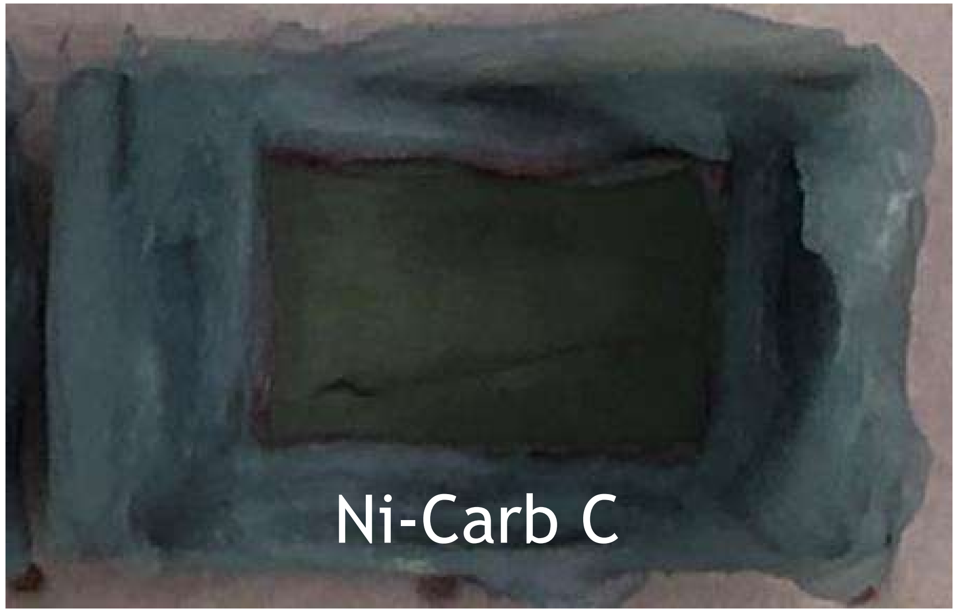
- There is no visual hint of degradation

Observations

Ni-Carb C and Coating X

Degradation of Ni-Carb C and Coating X when exposed to HCl

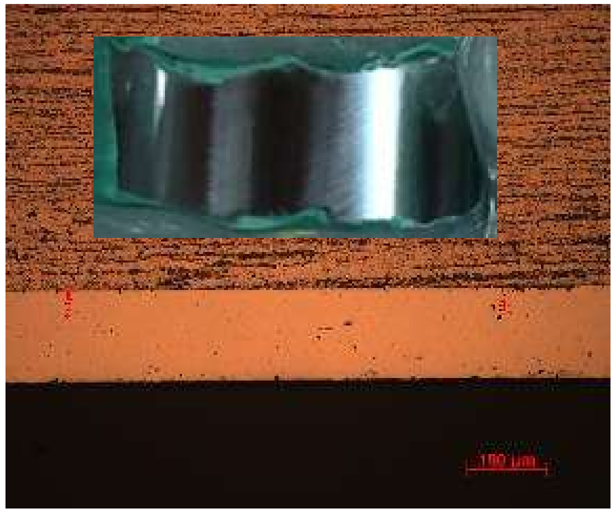
- There is no visual hint of degradation on surface.

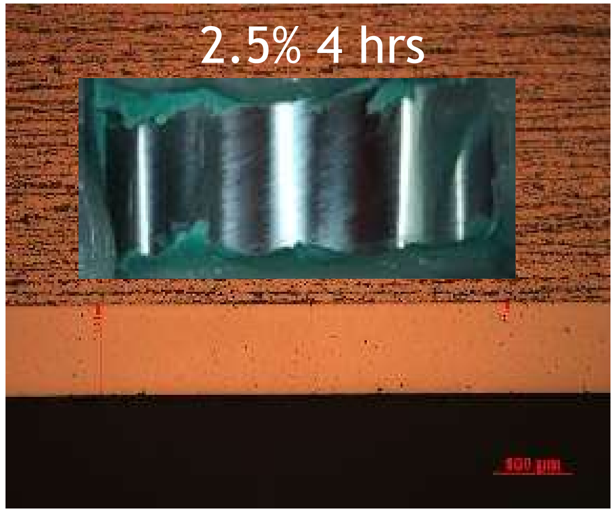


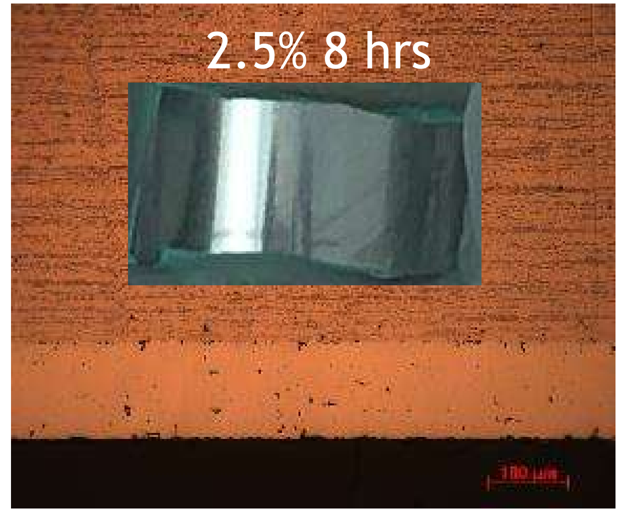
Results

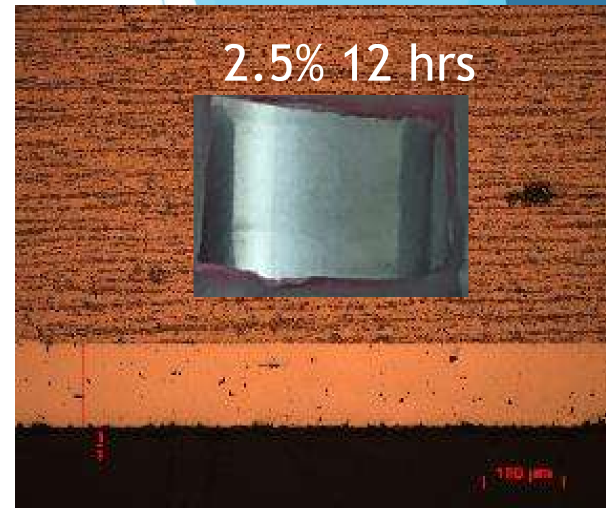
Chrome A

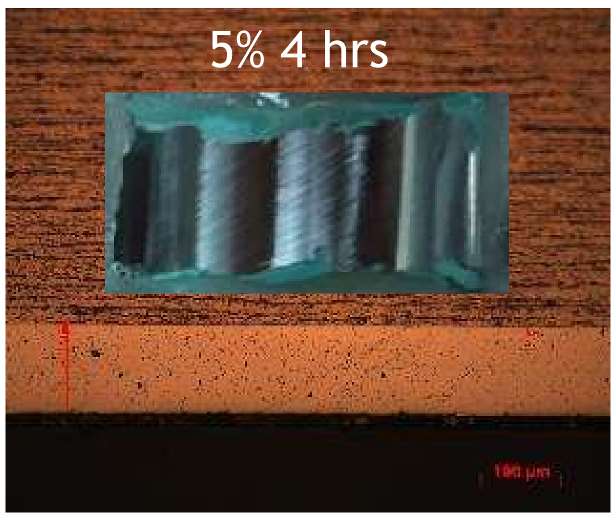
4 hours | 8 hours | 12 hours





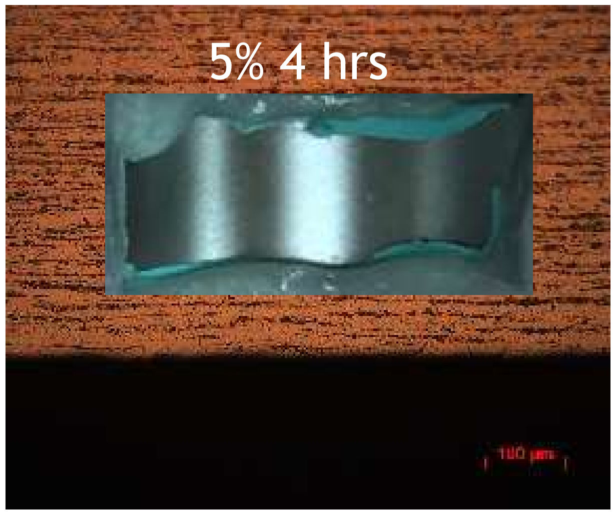






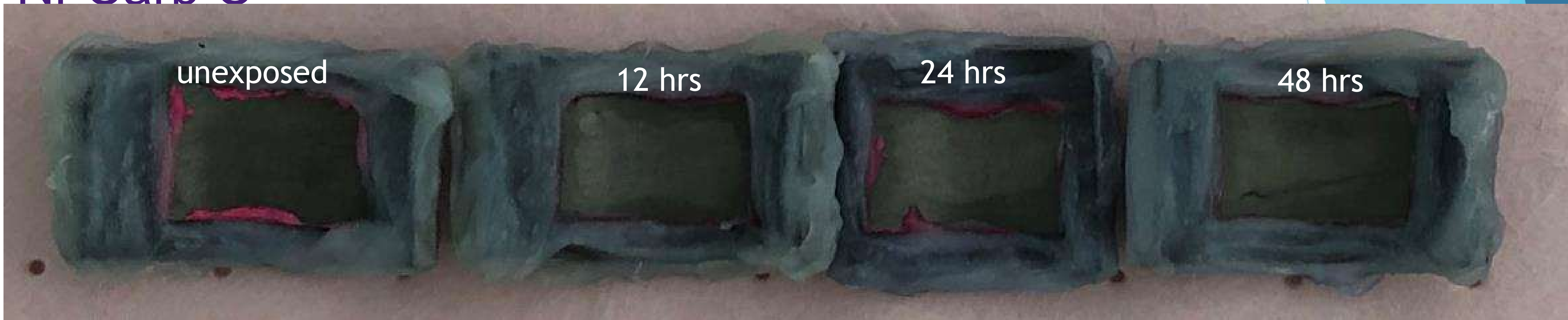
Results

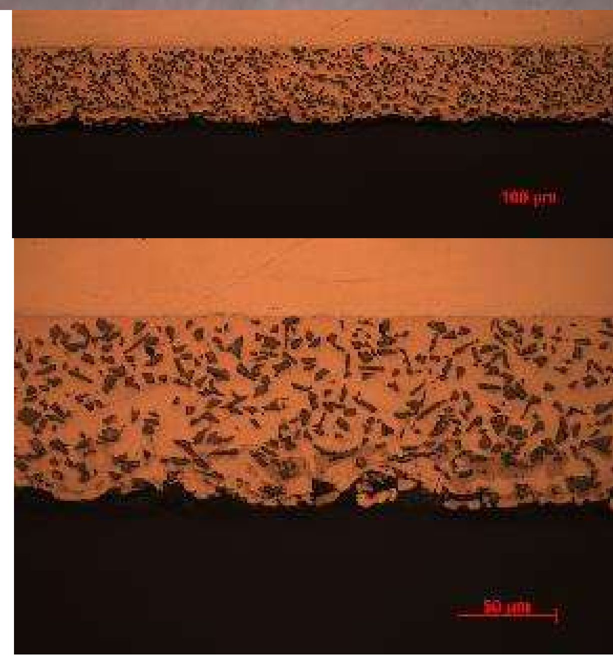
Chrome B

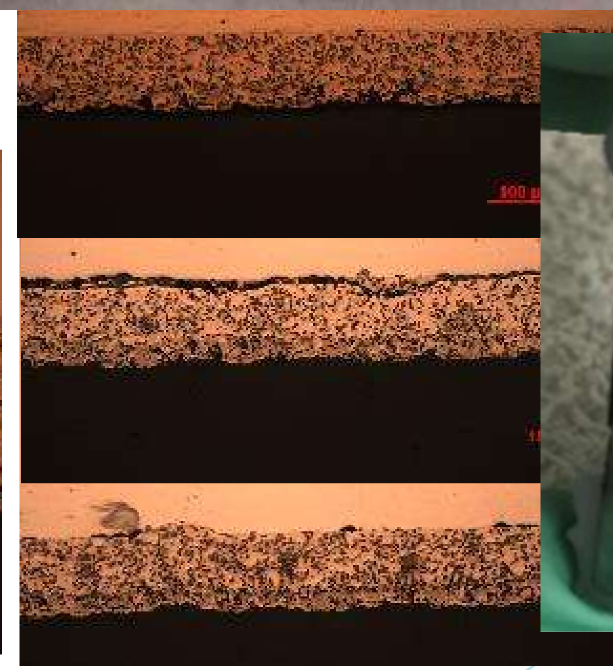
	4 hours	8 hours	12 hours
		N/A	N/A
		N/A	N/A

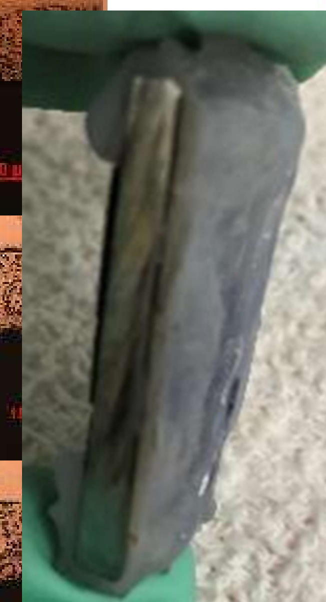
Results

Ni-Carb C



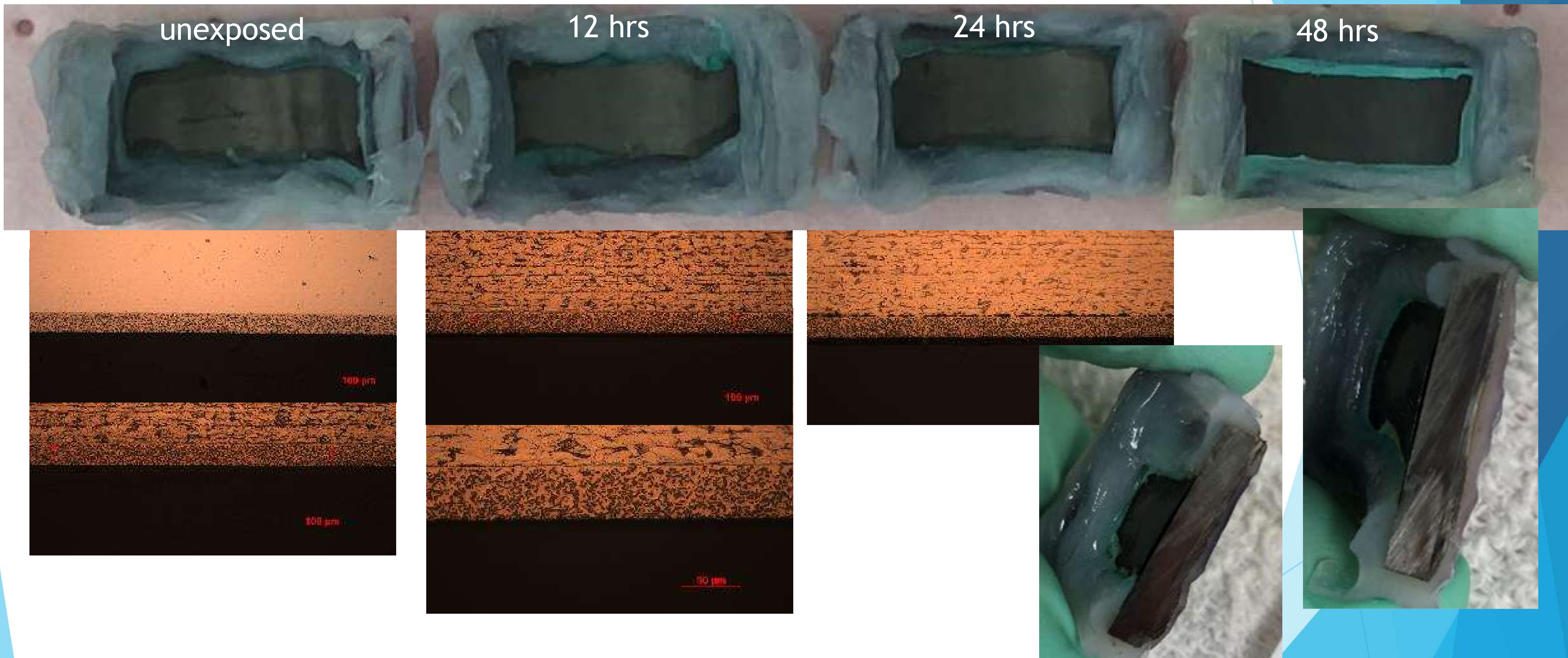






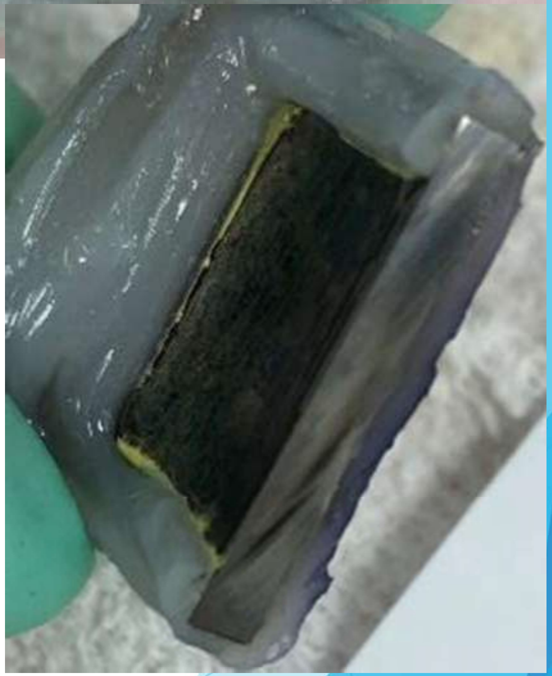
Results

Coating X



Results

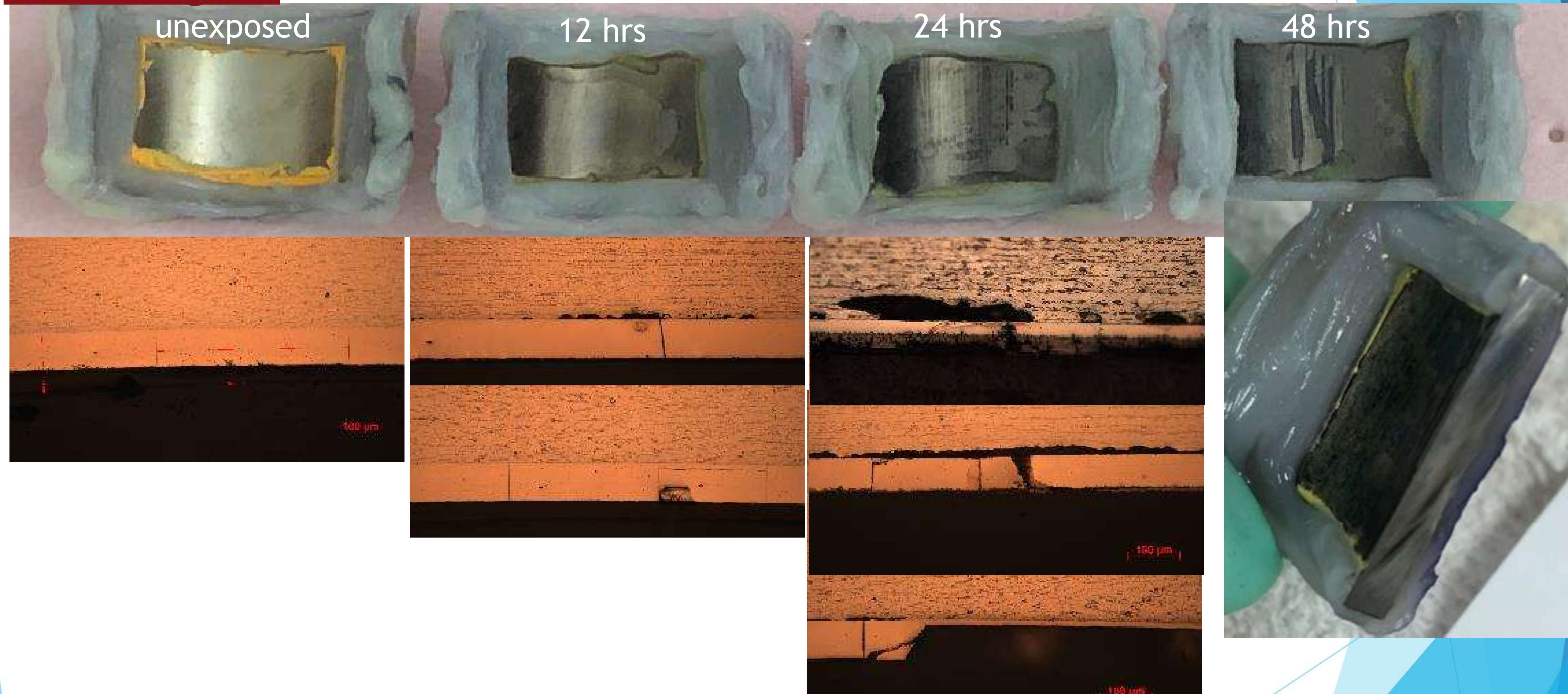
Coating Y



CHEMICALS	[redacted] PLATING	HARD CHROME PLATING
Hydrochloric Acid 7.5%	Resistant – no failure @ 48hrs.	Failure @ 8hr – Exposed base metal
Hydrochloric Acid 10%	Resistant – no failure @ 48hrs.	Failure @ 1hr - Exposed base metal
Hydrochloric Acid 15%	Resistant – no failure @ 48hrs.	Failure @ 1hr - Exposed base metal

Results

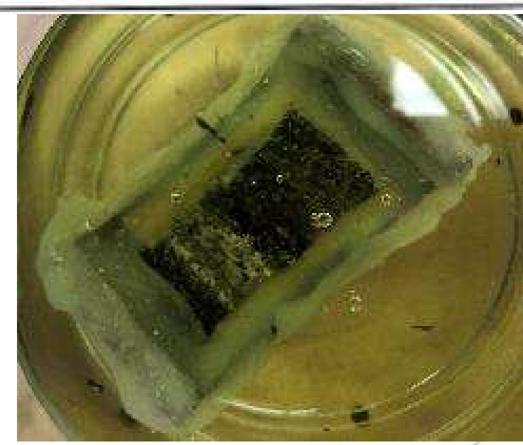
“Coating Y”



Results

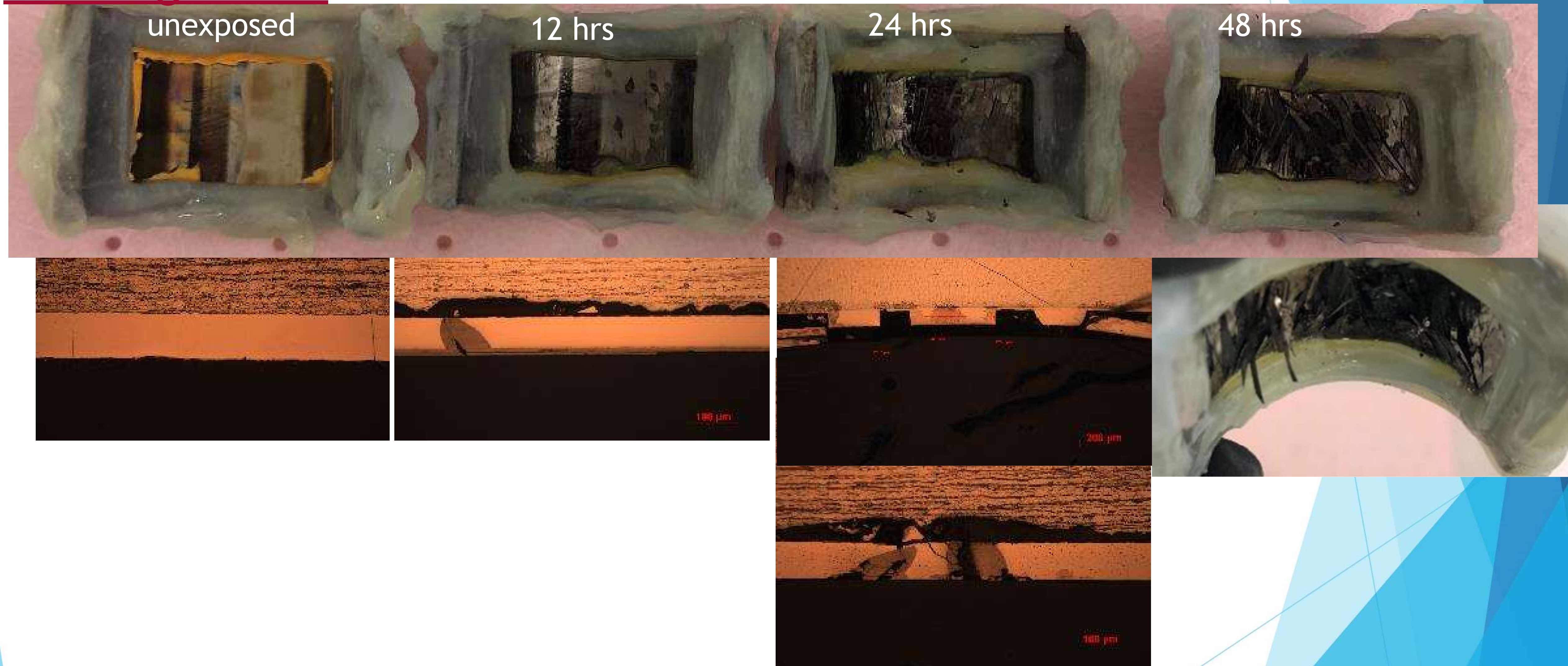
Coating Z - ID

CHEMICALS	[redacted] PLATING	HARD CHROME PLATING
Hydrochloric Acid 7.5%	Resistant – no failure @ 48hrs.	Failure @ 8hr – Exposed base metal
Hydrochloric Acid 10%	Resistant – no failure @ 48hrs.	Failure @ 1hr - Exposed base metal
Hydrochloric Acid 15%	Resistant – no failure @ 48hrs.	Failure @ 1hr - Exposed base metal



Results

Coating Z - ID



Discussion

HEAT TREATMENT

Coating Y and Coating Z

Hardening heat treatment results in 3 main changes:

- Once Ni_3P phase starts forming, it reduces the P content of the surrounding material
- The particles create active/passive corrosion cells
- Deposit shrinks as it hardens, causing the coating to crack and exposing the substrate to attack.

Corrosion resistance significantly decreases

Heat treated at 360C (Ni_3P+α region), cooled to an equilibrium phase of 100% Ni_3P+α, with a fully crystalline structure.

Discussion

Coating Y and Coating Z

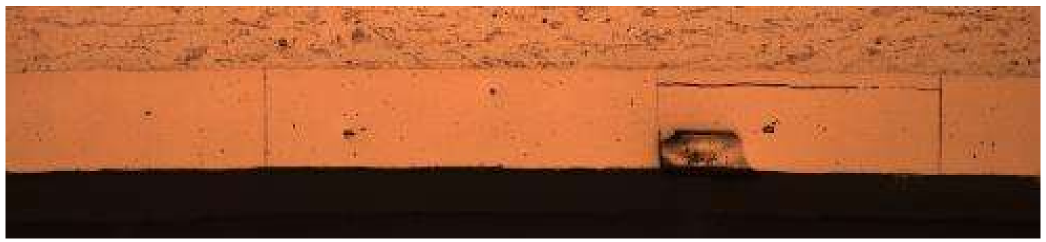
The structural changes during heat treatment at temperatures above 250°C can cause EN coatings to shrink. This shrinkage can also increase tensile stress or reduce compressive stress in the coatings. This stress and shrinkage cause the cracks often present in electroless nickel coatings after heat treatment.

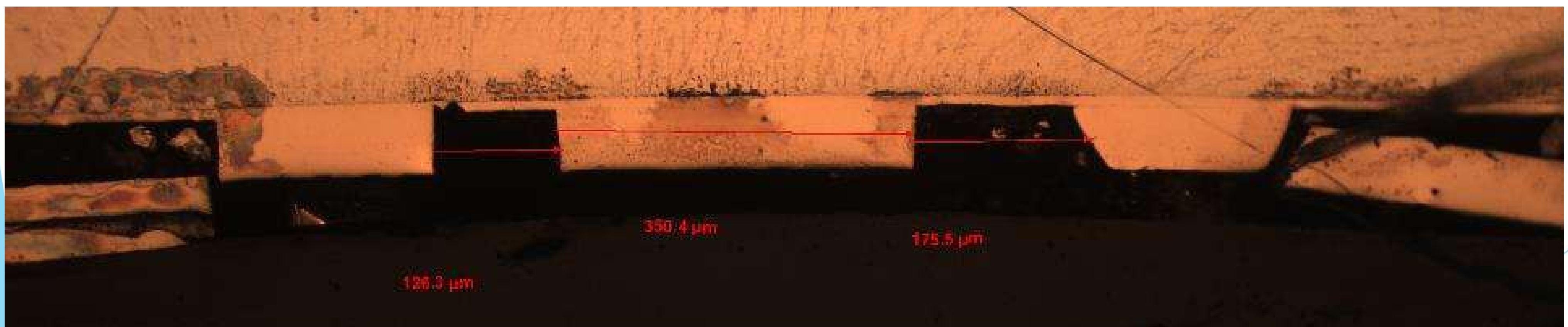
The cracks that form during the hardening heat treatment causes two main detrimental failure characteristics.

Discussion

Coating Y and Coating Z

1. The cracks that do not reach the base metal are observed to join and form "ribbons" that end up loose . These ribbons can cause spalling.

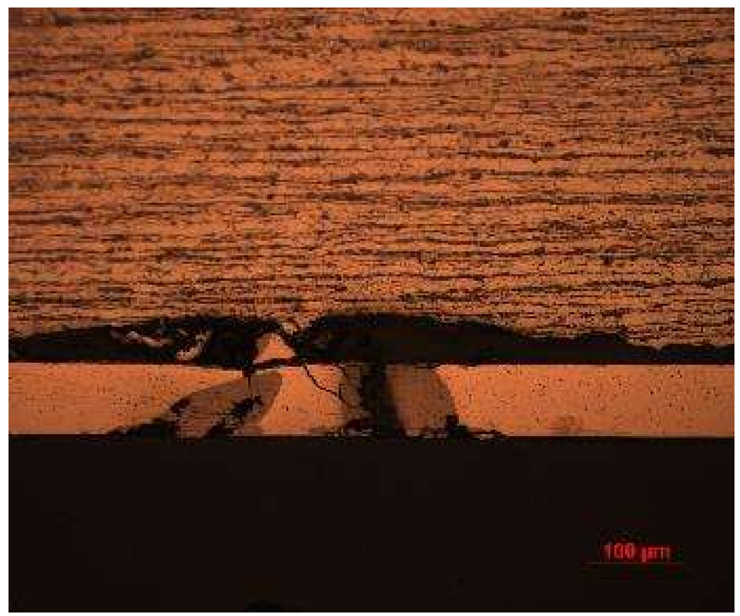


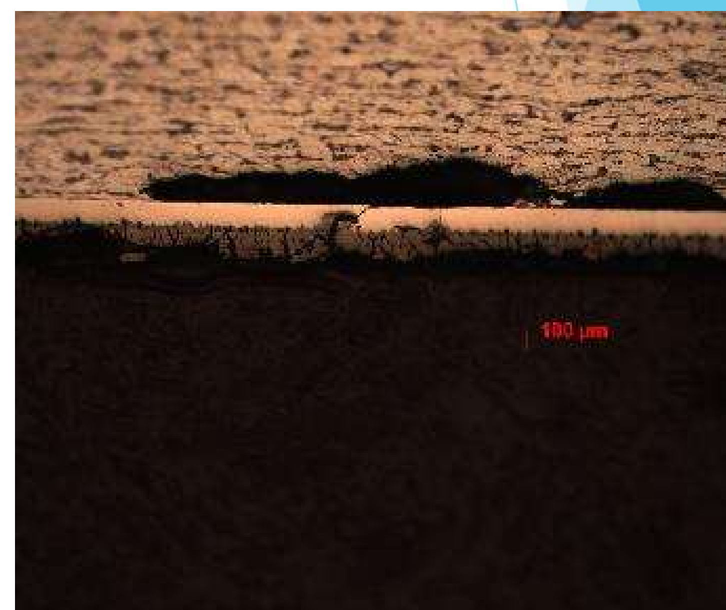


Discussion

Coating Y and Coating Z

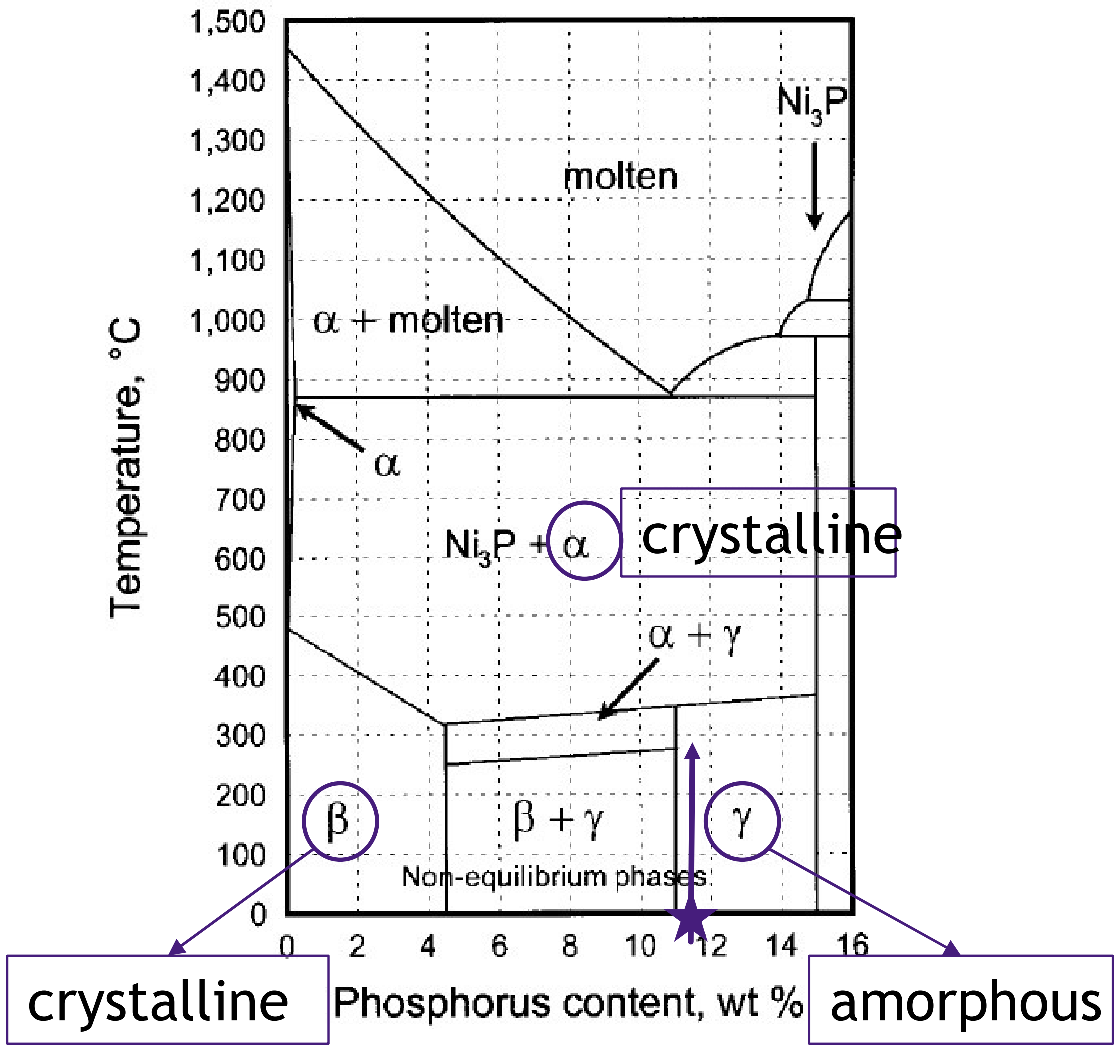
2. The cracks that do reach the base metal form a direct path for corrosion and cannot be a barrier anymore. The coating may look intact but material loss from base metal results in decrease in wall thickness.





Discussion

Ni-Carb C and Coating X



Does not need extreme hardness since wear resistance is significantly improved by addition of the very hard SiC particles to the matrix.

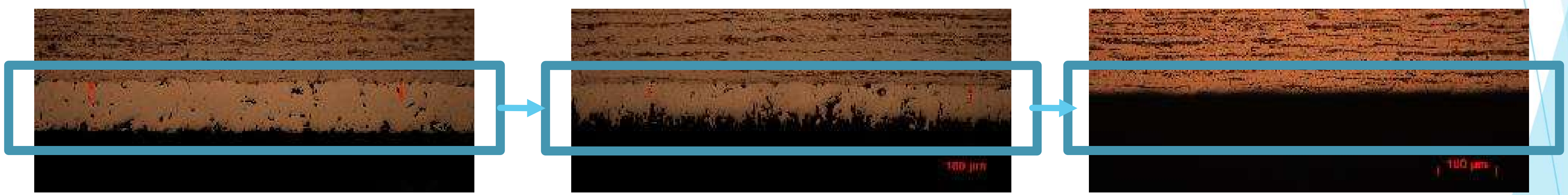
Heat treated at ≈200C, stays in the fully amorphous γ region.

Phosphorus content stays the same in the bulk of the deposit and the cracks due to heat treatment do not form.

Summary

Chrome A and Chrome B

- As expected, Chrome coatings have the lowest resistance to acidic conditions.
- The coating "dissolves" upon exposure to HCl, losing the barrier effect for corrosion protection.

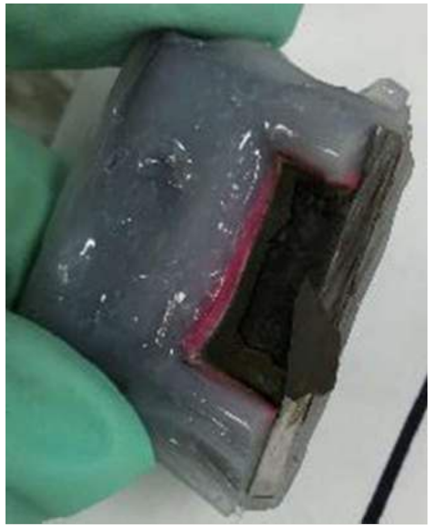
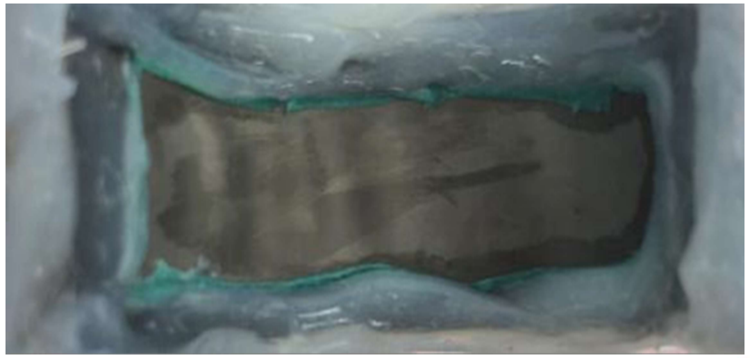


- But not all Chrome coatings in the industry are the same! There are many parameters that may result in increased service life. Ask your pump vendor about their Chrome!

Summary

Ni-Carb C and Coating X:

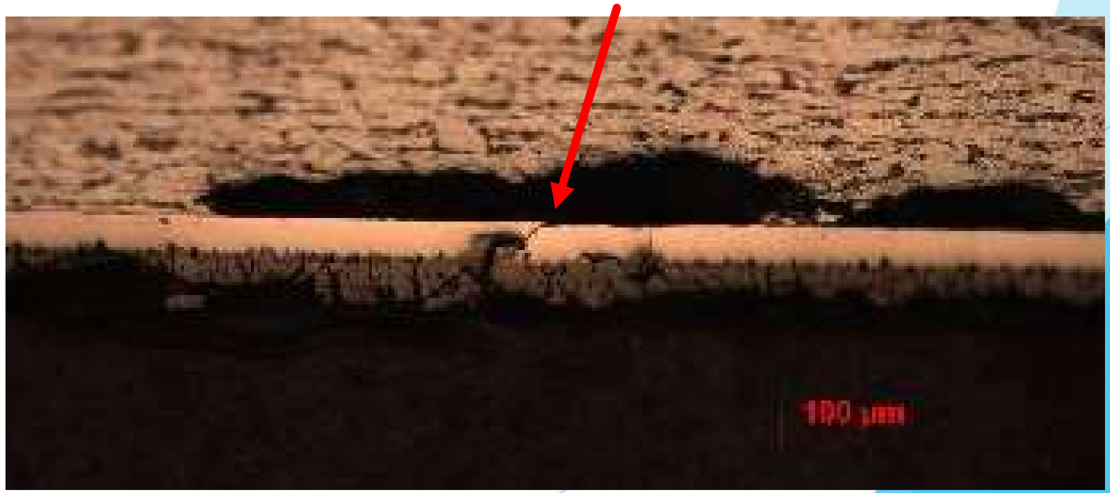
- These are very similar except Ni-Carb is coated both on ID and OD, while Coating X is only coated on ID. Coating X has higher particle percentage but be careful, this may be not as advantageous. One possibility is a difference in heat treatment, which would result in difference in matrix hardness but since both Ni-Carb C and Coating X are composite structures, microhardness measurements are not representative of the matrix only.
- Neither coating revealed any visual sign of degradation after long exposure times at high HCl concentrations; except they both “flaked off” during specimen preparation. Coating X also revealed a sign of a crack. This can be due to a different heat treatment of the EN matrix that would result in cracking –as discussed for Coating Y and Z.


Summary

Coating Y and Coating Z

- These are the same coating; except Coating Y is only coated on the ID, while Coating Z is coated on the ID and OD.
- The failure mode of the coatings are intriguing as they formed "ribbons" that became loose and can cause unwanted wear and spalling in the assembly
- Due to the heat treatment they underwent to achieve high hardness, the coating cracked in multiple locations, forming a direct path for corroding agents.
- Both coatings showed much less resistance to acidic conditions than they claimed. These specialty coatings are not as "special" as they claim! Despite fancy names, these are simply electroless Nickel coatings.



Recommendations

- Users should be knowledgeable of performance of coatings and platings in different wellbore environments to prevent premature failures
- Users should be aware that vendor branding can mask performance ability in practicality
- No coating or plating is suitable for all applications however, chrome or nickel composite with carbide particles are currently the industry's best conventional options for most well hazards
- Users should still rely on chemically treating wells in order to avoid corrosion damages

Thank You!

Questions?

You can email your questions to pkarpuz@don-nan.net

Copyright

Disclaimer

Artificial Lift R&D Council

The following disclaimer shall be included as the last page of a Technical Presentation or Continuing Education Course. A similar disclaimer is included on the front page of the International Sucker Rod Pumping Workshop Web Site.

The Artificial Lift Research and Development Council and its officers and trustees, and the International Sucker Rod Pumping Workshop Workshop Steering Committee members, and their supporting organizations and companies (here-in-after referred to as the Sponsoring Organizations), and the author(s) of this Technical Presentation or Continuing Education Training Course and their company(ies), provide this presentation and/or training material at the International Sucker Rod Pumping Workshop "as is" without any warranty of any kind, express or implied, as to the accuracy of the information or the products or services referred to by any presenter (in so far as such warranties may be excluded under any relevant law) and these members and their companies will not be liable for unlawful actions and any losses or damage that may result from use of any presentation as a consequence of any inaccuracies in, or any omission from, the information which therein may be contained.

The views, opinions, and conclusions expressed in these presentations and/or training materials are those of the author and not necessarily those of the Sponsoring Organizations. The author is solely responsible for the content of the materials.

The Sponsoring Organizations cannot and do not warrant the accuracy of these documents beyond the source documents, although we do make every attempt to work from authoritative sources. The Sponsoring Organizations provide these presentations and/or training materials as a service. The Sponsoring Organizations make no representations or warranties, express or implied, with respect to the presentations and/or training materials, or any part thereof, including any warrantees of title, non-infringement of copyright or patent rights of others, merchantability, or fitness or suitability for any purpose.