Xtalic® Corporation

XPROTECT®

Marlborough, MA

Report Documentation Page

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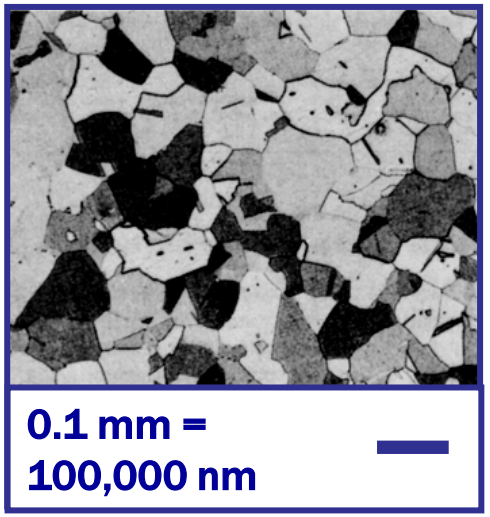
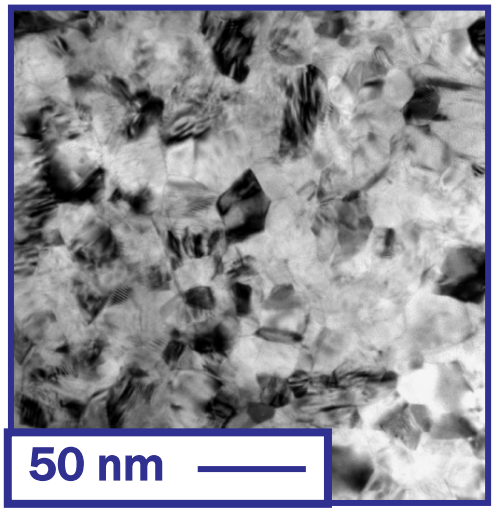
Xtalic Technology

- Crystal (xtal) size and structure strongly influence materials properties
  - Wear
  - Corrosion resistance
  - Appearance
- Xtalic's technology dynamically controls crystal size and structure
  - Proprietary chemistry
  - Patented waveforms
- Xtalic's materials deliver dramatically enhanced performance

Traditional Metals



Xtalic Metals



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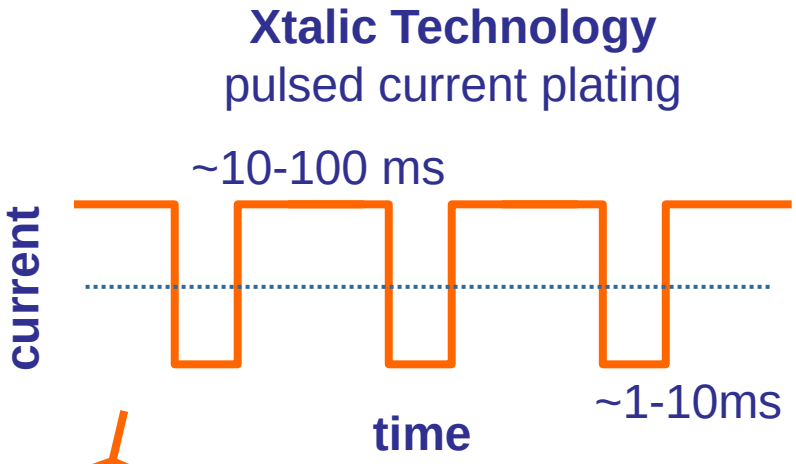
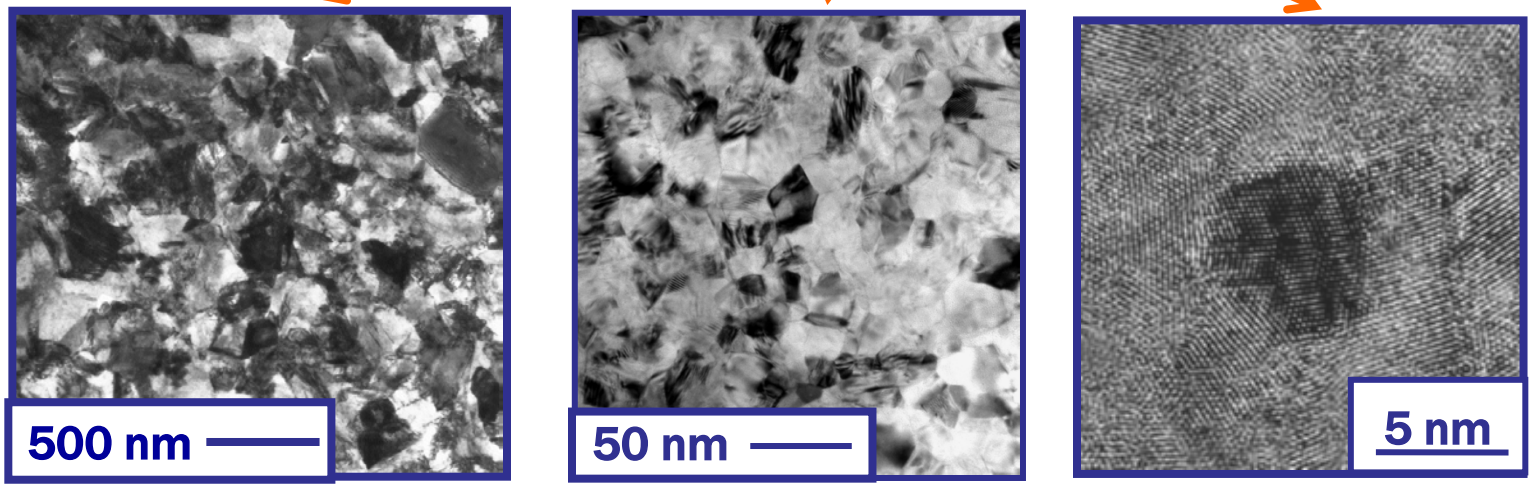
Xtalic Technology

Waveform control makes it possible to create tailored, nanocrystalline structures chosen to optimize performance





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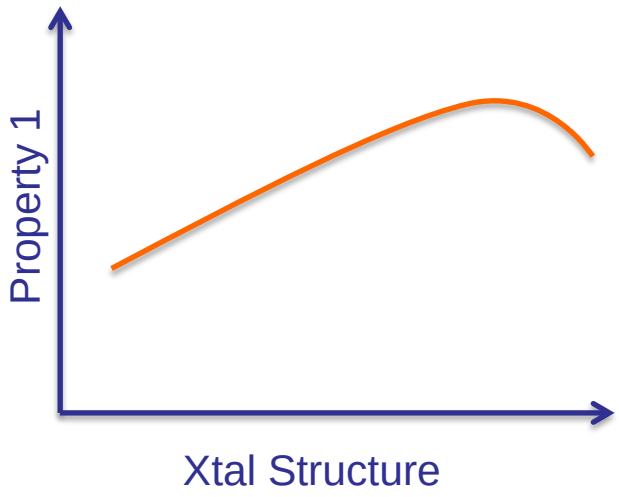
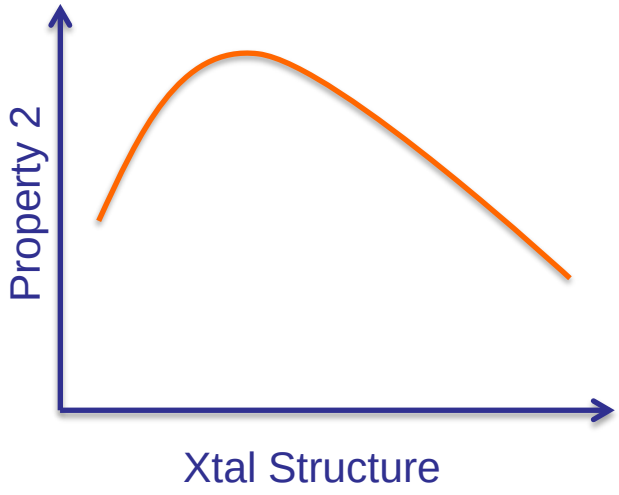
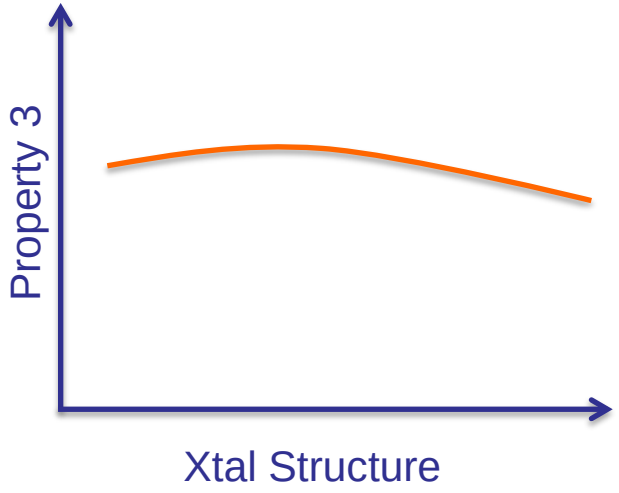
Engineering the Optimum



- Xtalic tunes the crystal structure to optimize properties
  - Wear
  - Corrosion protection
- A crystal structure can be selected that creates optimal properties within a single layer





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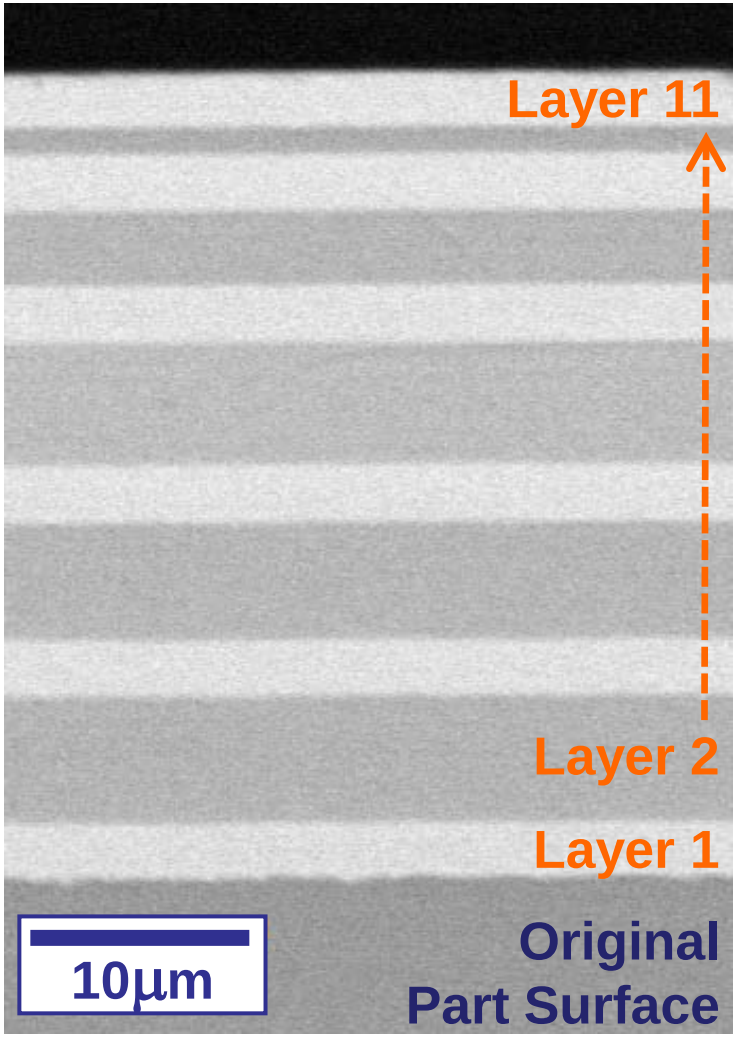
Xtalic Technology

- Multiple layers with tailored properties are created in a single process step
- Dynamic control of crystal size and structure: crystal size, structure and alloy composition are variably controlled
- Superior composite performance is achieved

Dynamic Nanostructure Control™



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Xtalic Delivers

- Enhanced performance
  - Wear, Corrosion, Appearance
- Multiple properties in a single step
  - Potential for reduced thickness and material usage
  - Fewer steps required, less energy required
- Low environmental and worker heath and safety impact
  - Replaces Hexavalent Chromium in a range of applications
  - In some cases, only workable alternative to Chromium
- Easily implemented production solution

Xtalic Application Areas

- Decorative – XBRIGHT®
  - Distinctive, high performance, environmentally friendly decorative coating
- Electronics – XTRONIC®
  - Very low porosity, slow diffusing barrier layer coating for electronics applications
- **Functional – XPROTECT®**
  - **Engineering coating for functional wear + corrosion applications *(typically replacing hexavalent chrome or electroless Ni)***

XPROTECT ®

- Excellent corrosion protection
- Superior wear performance
- Improved properties under heat
- Replicates substrate R_a
- Good coating uniformity
- Chromium free

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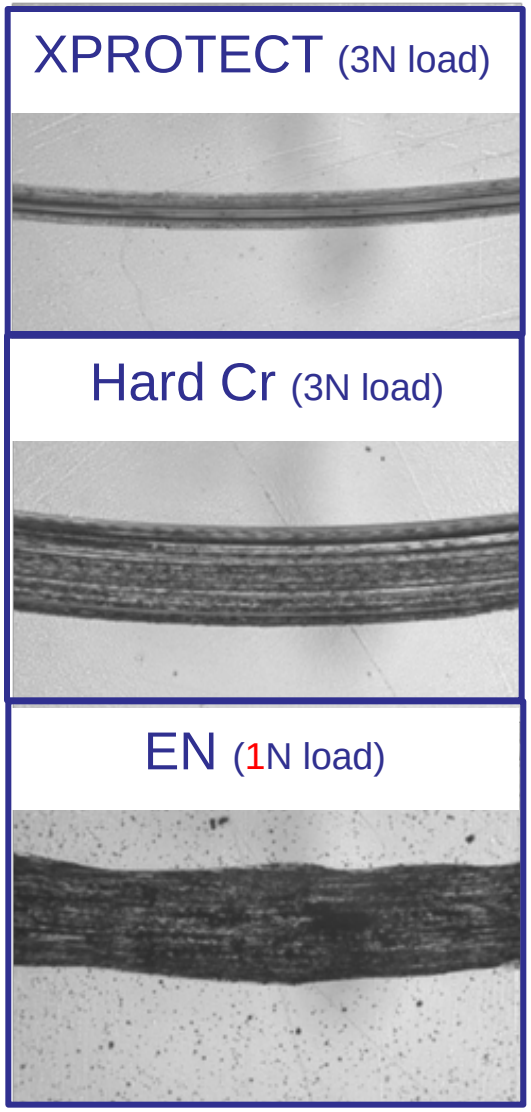
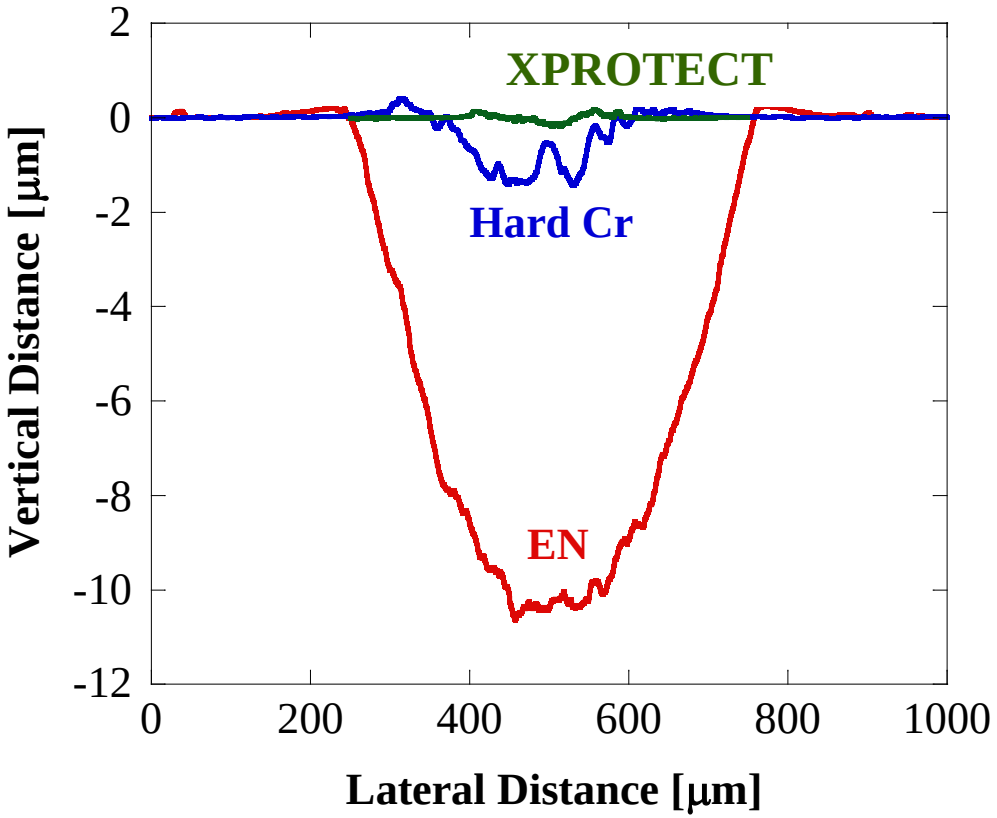
XPROTECT ® : Superior Wear

Light-optical micrographs of the pin-on-disc wear tracks



Profilometer measurements of wear tracks



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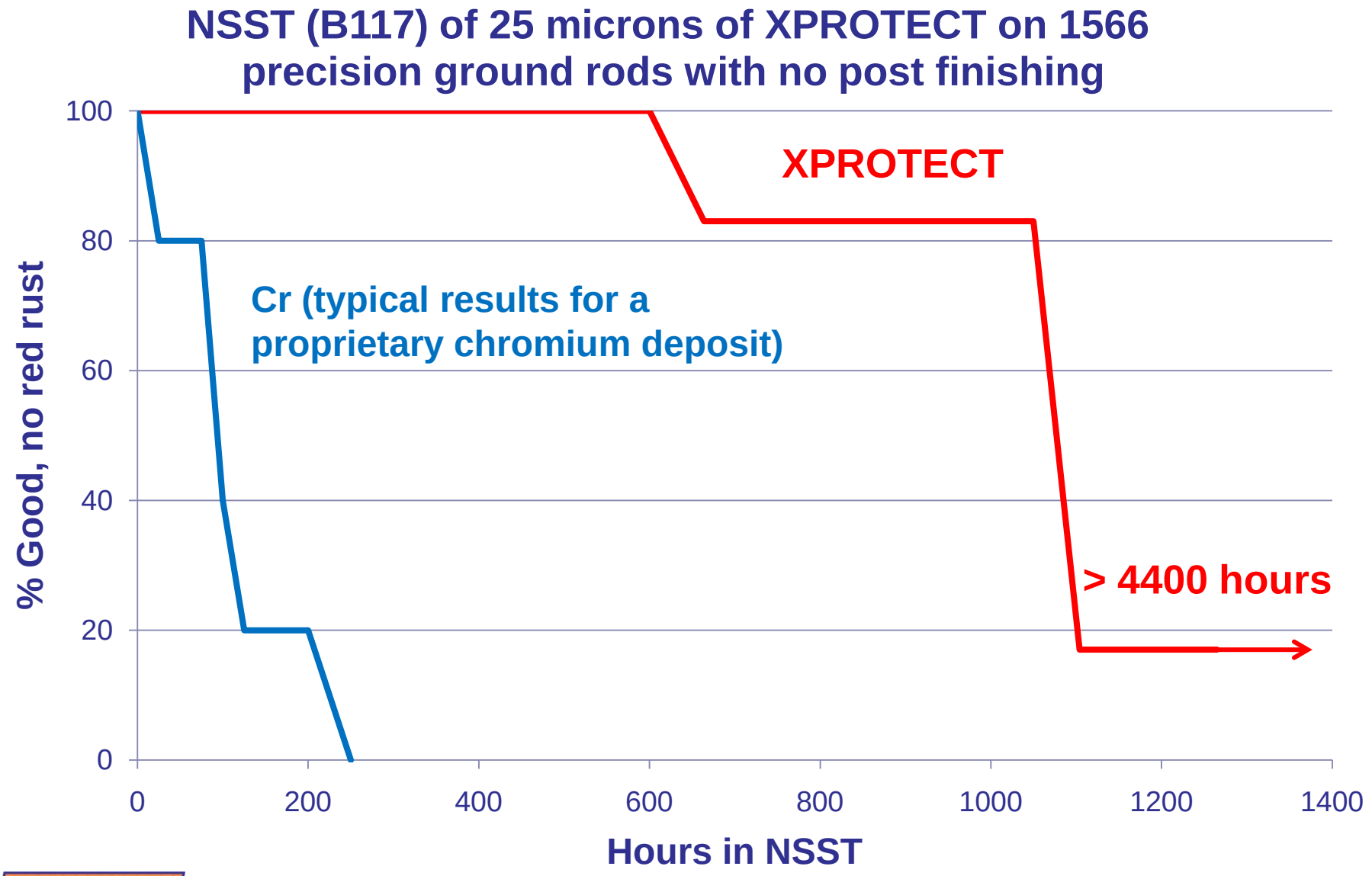
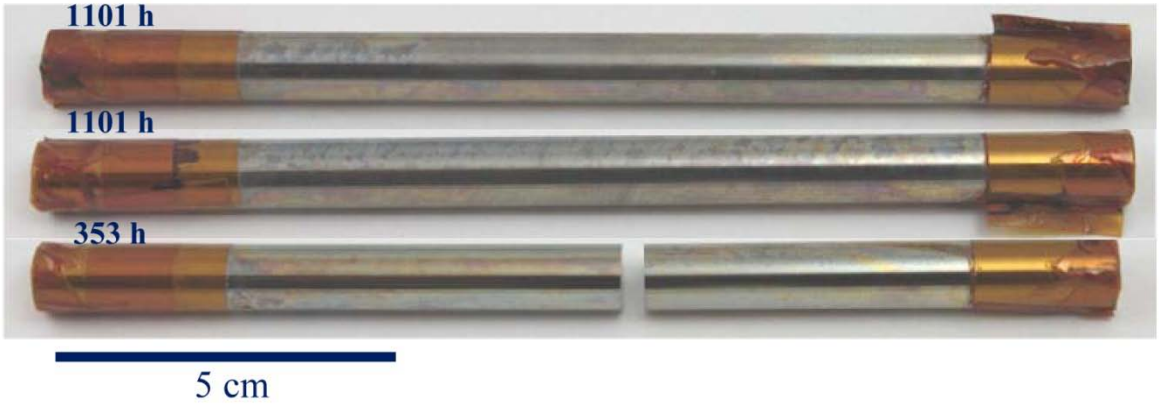
XPROTECT ® : Corrosion Protection

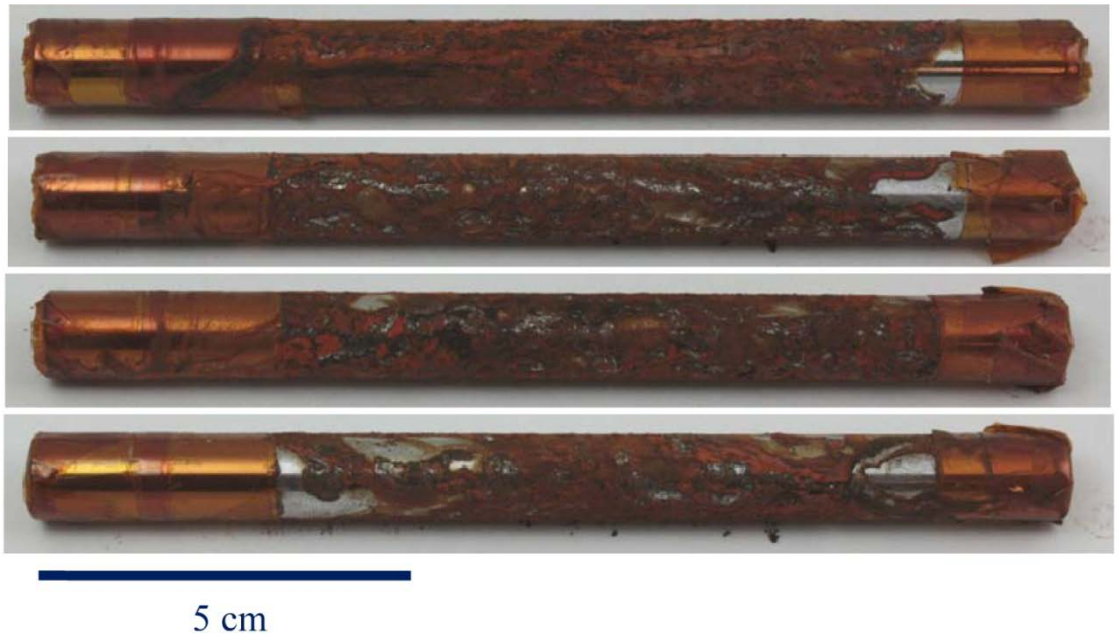


XPROTECT: Corrosion Protection

12 µm XPROTECT coated steel shafts after NSST, with exposure times as shown.



12 µm hard Cr coated commercial steel shafts after 48 hours of NSST



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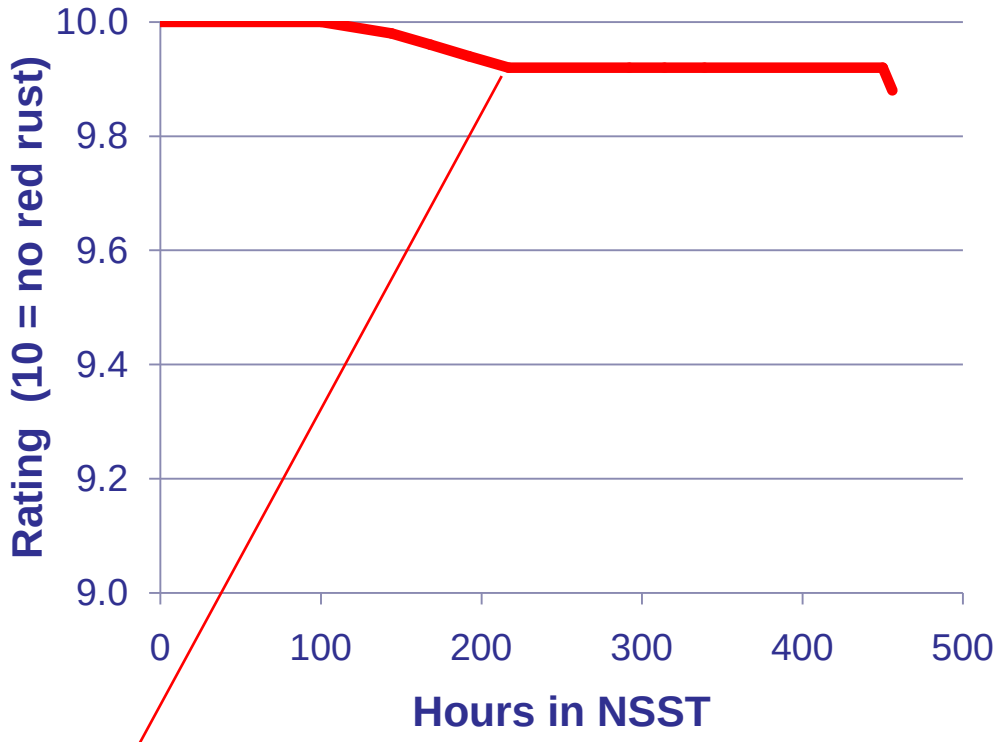
XPROTECT – Hydraulic Shaft Example

- 12 µm XPROTECT™ coated hydraulic shaft
- 500 hours of exposure to NSST
- No corrosion sites; rating = 10
- Sample size: 2”x12”

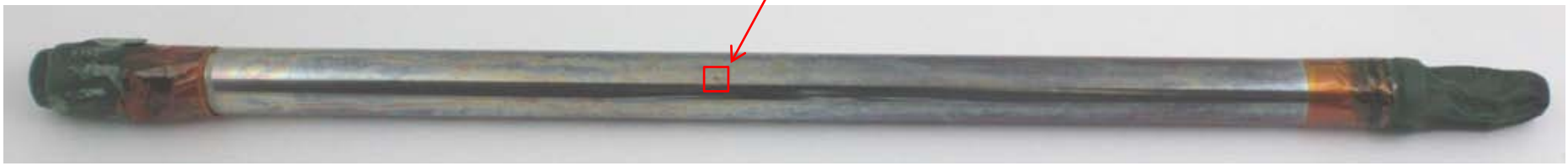
4 inches

XPROTECT ® – Shock Absorber Example

- 25 µm XPROTECT coated shock absorber
- 500 hours of exposure to NSST
- Sample size: 0.62”x12”
- Significant defects from transport of unplated substrates led to isolated corrosion spots.



4 inches



XPROTECT ® – Shock Absorber Example

Head to Head with Hard Chromium

- Compression adhesion test
  - Equivalent to Chromium
- NSST Corrosion test
  - XPROTECT > 744 hours
  - Chromium < 250 hours
- Russian Mud Test
  - XPROTECT pass
- Coefficient of friction with 300N Load

$$\left(\begin{array}{c}\text{XPROTECT with}\\ \underline{\text{no}}\text{ post-finishing}\end{array}\right) > 0.5 \left(\begin{array}{c}\text{Hard Chromium with}\\ \text{post-finishing}\end{array}\right)$$

- Endurance wear testing
  - In Progress

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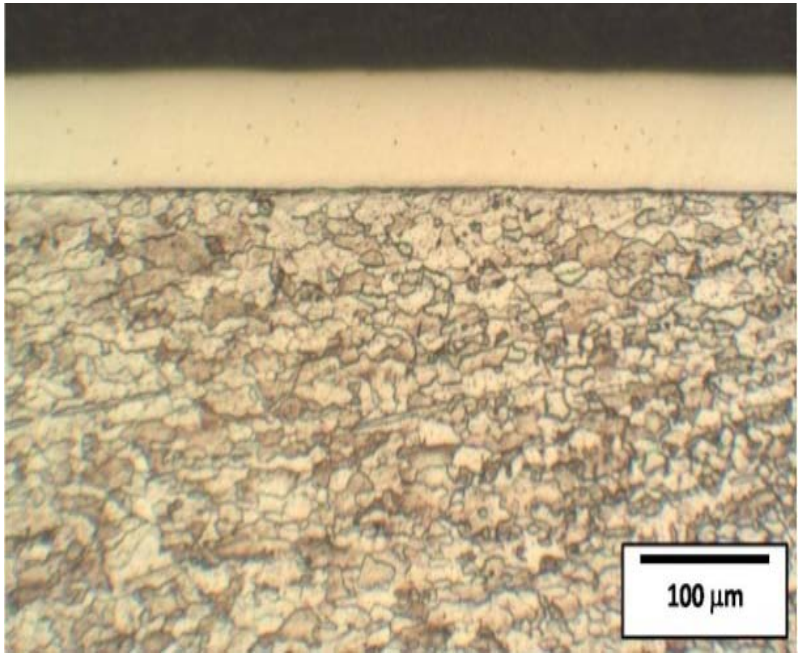
XPROTECT ® : Strengthens Under Heat

- Simple heat treat
  - Six hours at 191º C (375º F)
- Increased hardness
  - HV_{100g} = 900 - 950
  - 15% increase
- Stable structure
  - Key properties maintained or enhanced



Customer-Reported Sample Hardness Data

Sample #	Temperature	Time	Hardness, HVN100
1	none	N/A	679
2	375º F (191º C)	3	758
3	375º F (191º C)	8	840
4	375º F (191º C)	24	862
5	500º C	2	1040
6	500º C	5	1078
7	500º C	98	888

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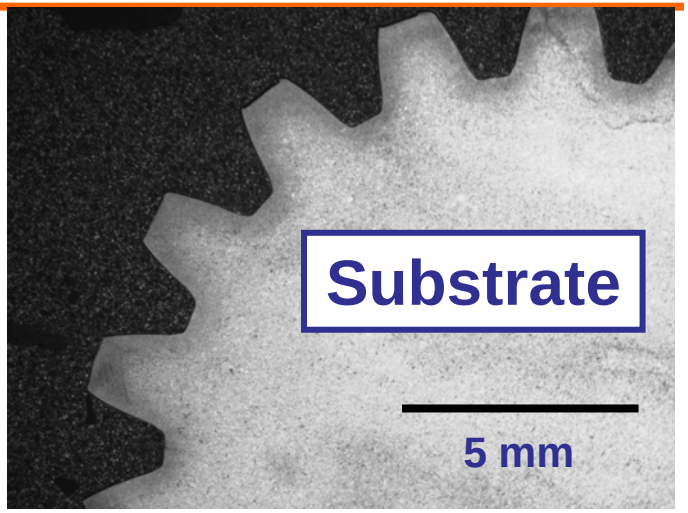
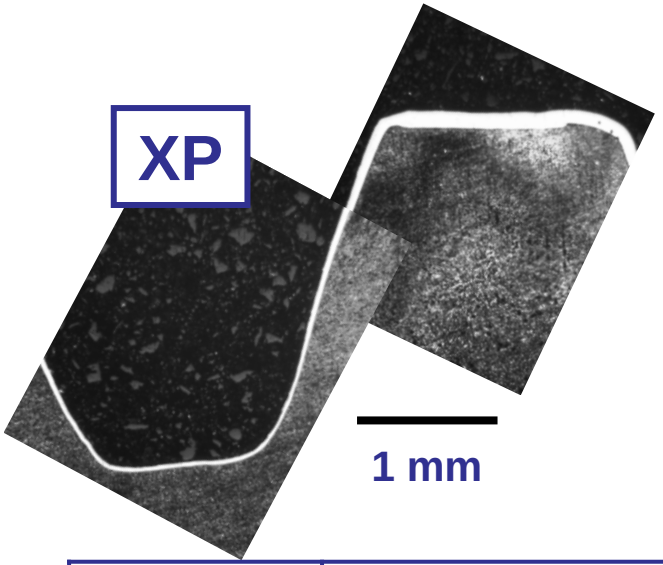
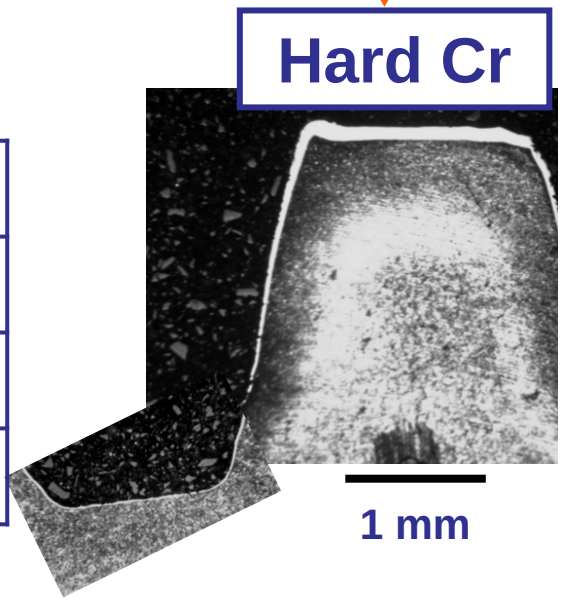
Plating Uniformity, Complex Geometry

Direct comparison, XP to hard Cr

Gear with aspect ratio 1.2:1







XP		Hard Cr
76	Avg peak thickness, µm	66
21	Avg valley thickness, µm	7.2
3.6	Peak to valley ratio	**9.2**

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Hydrogen Embrittlement Resistance

- Notch tensile specimens plated with 50 µm of XPROTECT ®
  - no post-bake
- Five samples tested per ASTM F519 (standard specimen, 1a.1)
- All samples passed loading requirement of 200 hours at 75% of ultimate tensile strength
- Samples *do not* require baking to pass the test

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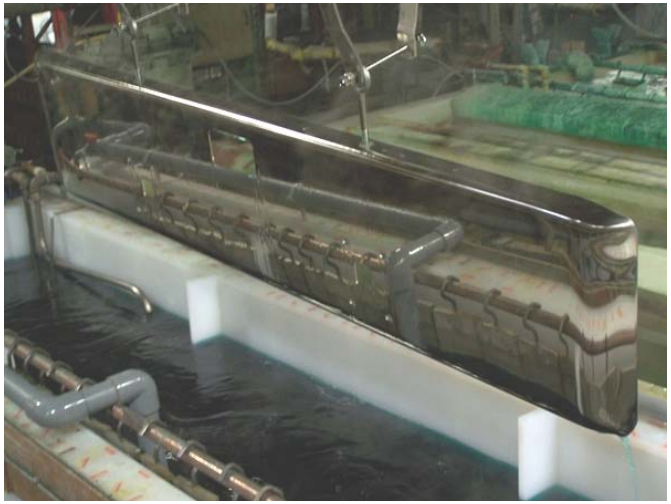
Plating at Scale: Evaluation Process

Xtalic pilot line in Marlborough, MA

- *375 liter (100 gallon) capacity*
- *Maximum part dimension up to ~50 cm (20 in)*
- *Part weights up to ½ ton*

Xtalic partner shops

- *Up to 1500 gal (6000 l) capacity*
- *Maximum part dimension up to ~4 m (12 ft)*
- *Part weights up to 1 ton*



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Xtalic: A Platform Technology

- Dynamically controlled structure allows tailored materials properties
- Multiple alloy systems maximize the accessible property sets
- Enhanced performance can be achieved across many markets
  - Aerospace
  - Automotive
  - Security
  - Medical Device
  - Home Appliances
  - Consumer Goods
  - Sports Equipment
  - Electronics
  - Communications
  - Industrial Equipment

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Conclusions

Performance properties are summarized in the table below:

Coating	Sliding Wear Resistance	NSST Corrosion Resistance	Surface Texture	Coating Distrib.
XPROTECT ®	++	+++	+	+
XPROTECT®,HT	++	+++		
Cr	+	0	-	-
EN-P↑	-	++	0	+++
EN-P↑, HT		+		

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XPROTECT ® : Superior Wear

Non-lubricated Pin-on-Disc Apparatus with a Tungsten Carbide Pin

Coating	Load [N]	COF	Penetration depth [µm]	Wear rate [mm^3/hr]	Relative Wear rate
XP	3	0.5	0.2	$1.0x10^{-3}$	1
XP, 400ºC/4hr	3	-	0.1	$4.0x10^{-4}$	0.25
Hard Cr	3	0.85	1.5	$2.3x10^{-2}$	23
EN (high P)	1	0.62	10.5	$2.9x10^{-1}$	290

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XPROTECT ® Corrosion Protection

Hard Chromium

- Failures were rapid at 12 µm **< 4 hours**
- Functional chromium deposits with a thickness of 25 µm (1 mil) will last in NSST for between *(Jones)* **10 and 500 hours** depending upon pre-finishing, plating and post finishing.

XP Coating

- XP coatings with between 12 and 25 µm (0.5 to 1.0 mils) lasted in NSST for between
  - **350 and > 4400 hours**
- When the coatings did corrode, the corrosion sites were typically very small and did not expand rapidly.

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XPROTECT ® Corrosion: Acid Data

Performance properties XPROTECT ® vs. Cr

Coating	Corrosion Rates, mm/year		
Acid 10% (v/v)	HCl	H2SO4	HNO3
Temp, C	22	58	58
XPROTECT (Immersion)	0.0030	0.35	TBD
XPROTECT (EC) (minimum)	0.054[1]	0.017[1]	0.071[1]
Cr[2]	rapid	250	0.3

[1]Room Temp - 5 day test
[2]Corrosion data from Uhlig

XPROTECT ® : Corrosion Protection

Corrosion Panels after 1000 hrs B-117 Exposure
(Note: Panel 1 was exposed for only 24 hrs)

Sample #	Hours Exposed	Observation
1	24	Red rust
2	>1000	No red rust
3	>1000	10 isolated spots (small)
4	>1000	No red rust
5	>1000	4 isolated spots (small)
6	>1000	No red rust

Plating Uniformity, Shaft/Rod

- Sample dimensions: 25 mm diameter and 300 mm length
- Tank anodes used on each side of part; no conforming anodes
- 300 mm anode to cathode separation
- Plating time: 1 hour

Location around rod (degrees)	Thickness (µm)
0	41.9
90	40.9
180	39.9
270	40.6
Average	40.9

- Uniformity around the circumference (eddy current): ±2.4%

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