

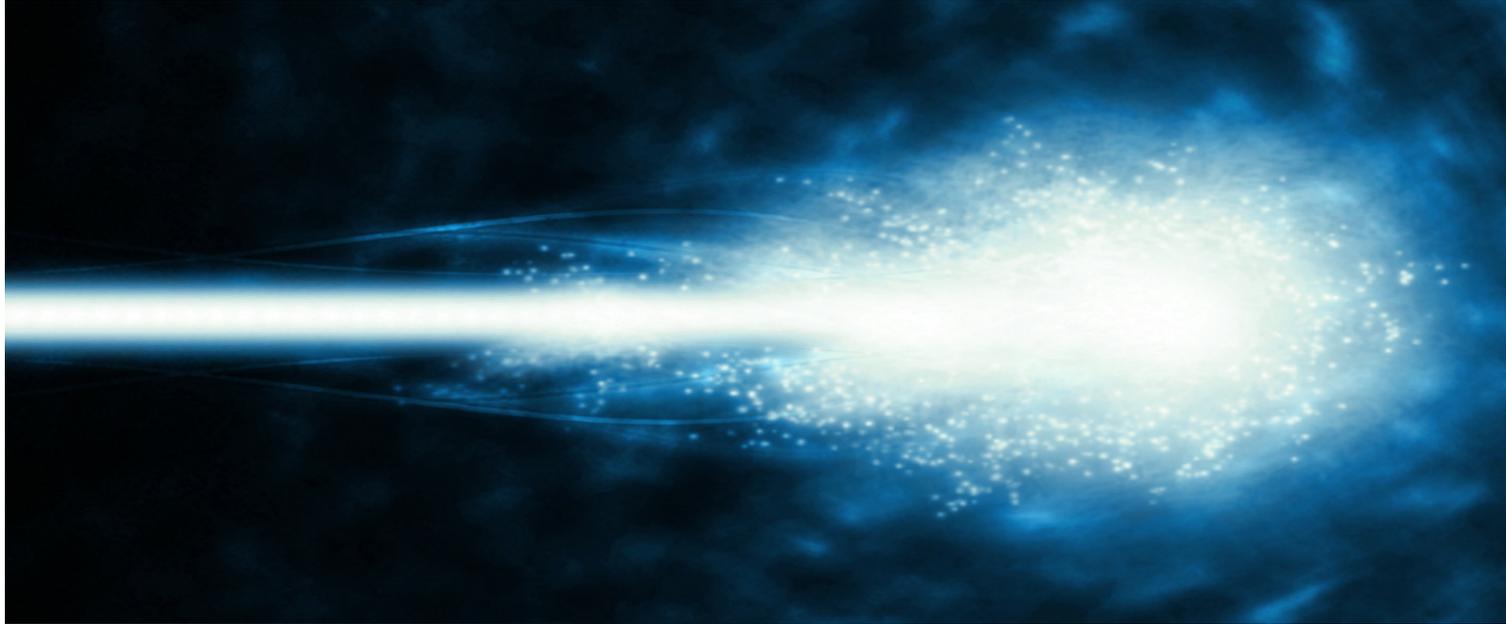


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## **Amorphous Chromium Carbide (a-CrC) Coating Deposited by Low Temperature Chemical Vapor Deposition for Corrosion and Wear Applications**

**Solomon Berman, Roman Motyka, Paul Jarosz, IBC Materials and Technologies, Lebanon, IN**

IBC Materials and Technologies has developed an innovative amorphous chromium carbide (a-CrC) coating, deposited via low-temperature chemical vapor deposition (CVD) technology. Unlike most other commercial CVD coatings that are deposited above 1000° C, a-CrC is applied at less than 450° C. This allows for the coating of most engineering materials without negatively affecting the mechanical properties or dimensional stability. The a-CrC coating bonds directly and tenaciously to a large variety of metals, including alloys of steel, stainless steel, nickel, titanium, molybdenum, tungsten, copper, magnesium, and aluminum, as well as ceramics and composites. With a hardness of over 1500 HV, a-CrC can provide a substantial improvement to wear, abrasion, and galling resistance. The amorphous, chemically inert microstructure of a-CrC is characterized by its complete lack of pores, grain boundaries, cracks, or other defects. The coating process is also non-line-of-sight, which ensures uniform coverage for complex components and tight tolerances. This combination of density and conformity leads to unmatched corrosion performance. Layers as thin as 2 microns can provide complete immunity against salt fog, concentrated acids, and crevice corrosion. Additionally, a-CrC is unaffected by high temperature oxidation up to 750° C. Unlike many metal plating or CVD coatings, the a-CrC process does not use or produce hazardous acidic waste or hexavalent chromium compounds. IBC has demonstrated the performance of this coating technology across several demanding Department of Defense (DoD) and commercial applications to date, including cadmium replacement, hard chrome replacement, liquid gallium corrosion resistance, and molten sodium corrosion resistance.



05.2023



## Amorphous Chromium Carbide (a-CrC) Coating Deposited by Low Temperature Chemical Vapor Deposition for Corrosion and Wear Applications

Presented by : Dr. Solomon Berman

IBC Materials & Technologies, LLC | 825 Hendricks Drive, Lebanon, IN 46052 | [www.ibcmaterials.com](http://www.ibcmaterials.com)



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# IBC's Background



- Privately-owned surface engineering company
- Established in 1996 and located in Lebanon, Indiana
- 100+ employees and 100,000+ sq. feet
- Specialized in the development of surface treatments to improve wear, corrosion, fatigue and lubricity properties
- Industrial-scale application of PVD, CVD, TD, and other coating processes

- Aerospace,
- Oil and Gas,
- Automotive,
- Metal Forming,
- Die Casting,
- Forging,
- Medical,
- and many more



# Ceratough™ 0801 CVD Amorphous Chromium Carbide Coating Capability



Horizontal barrel coater (optional rotation)  
Dia. 10" x L 18"



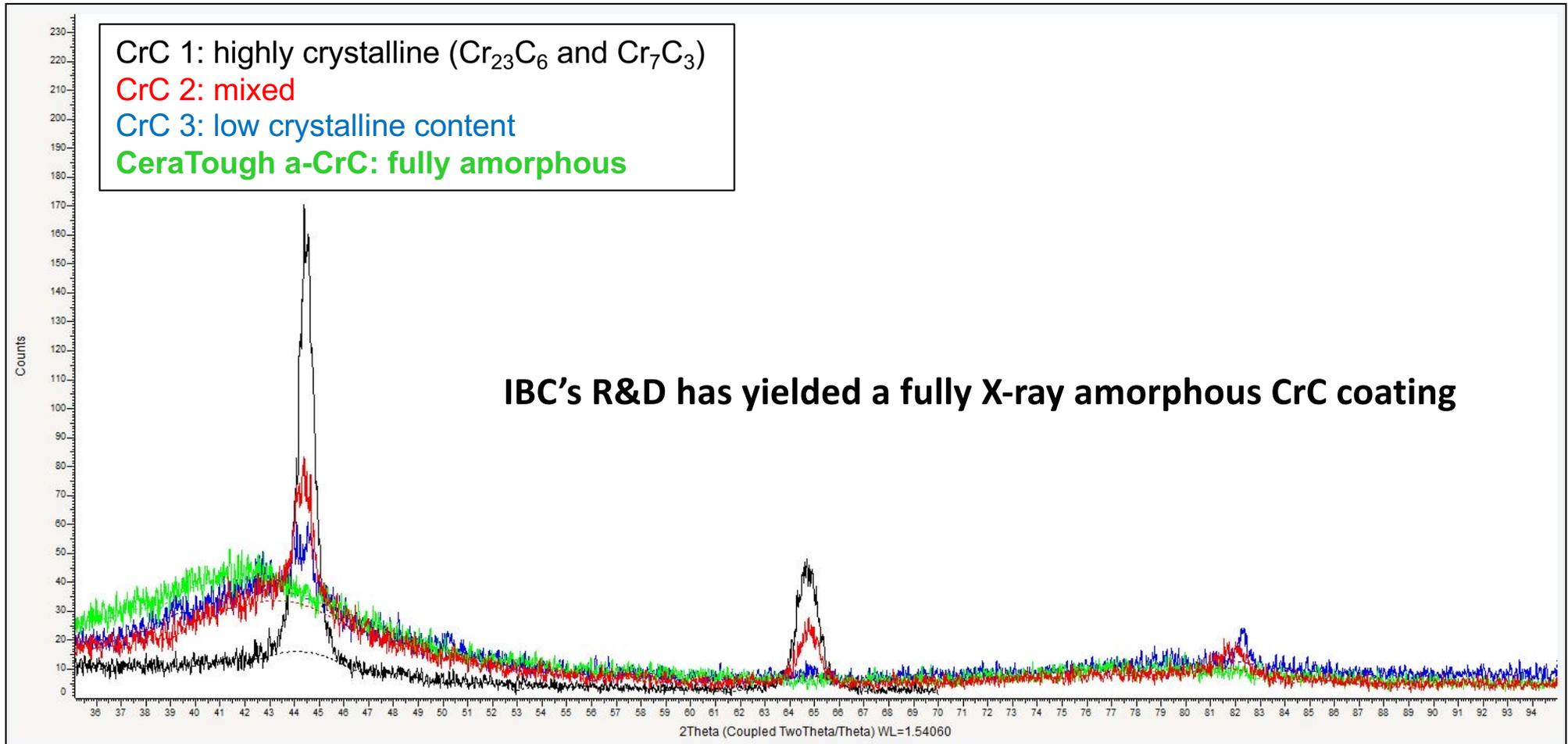
Vertical fixed chamber  
Dia. 40" x H 72"

# Ceratough™ 0801 Low temperature CVD Amorphous Chromium Carbide Coating



Property	Value and Benefit
Low temperature CVD (390-500°C)	Minimal effect on heat treatment or dimensional stability
Non-line-of-sight	Uniform coating of complex shapes
Available in-process rotation	Total coating coverage without fixture marks
Amorphous microstructure	High density and corrosion resistance
High hardness (>1400 HV)	1500-2000 HV Good for wear and abrasion resistance
Thickness	0.5-50 µm
Coefficient of Friction Dry/Lubricated against steel	0.5/0.1
Substrate material	Metals , Ceramics, Fibers and more
Color	Silver
Thermal Stability	750 °C

# Ceratough™ 0801 Low Temperature CVD Amorphous Chromium Carbide Coating - X-Ray Diffraction



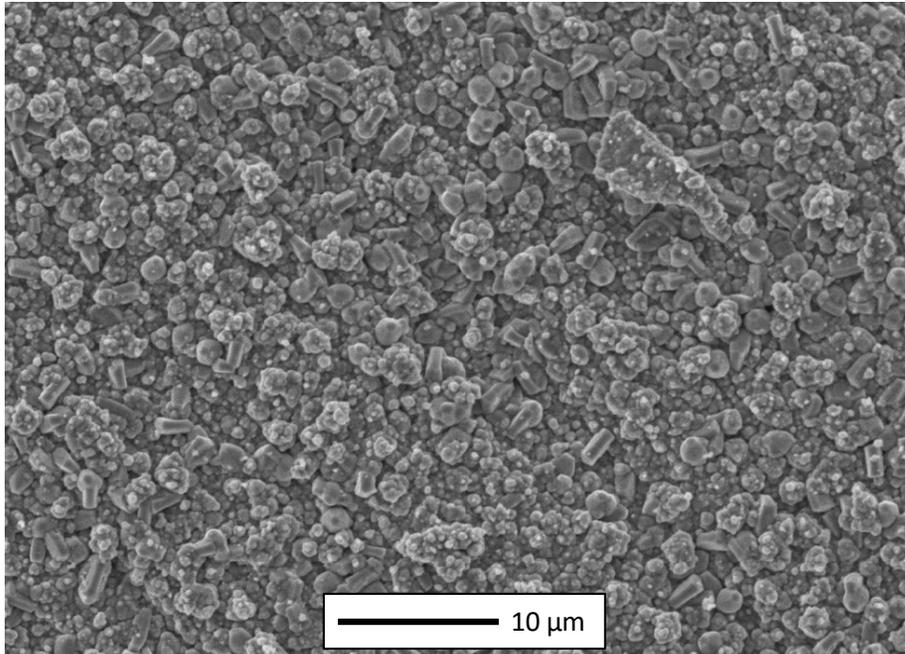
# Ceratough™ 0801

## CVD Amorphous Chromium Carbide

- Surface morphology

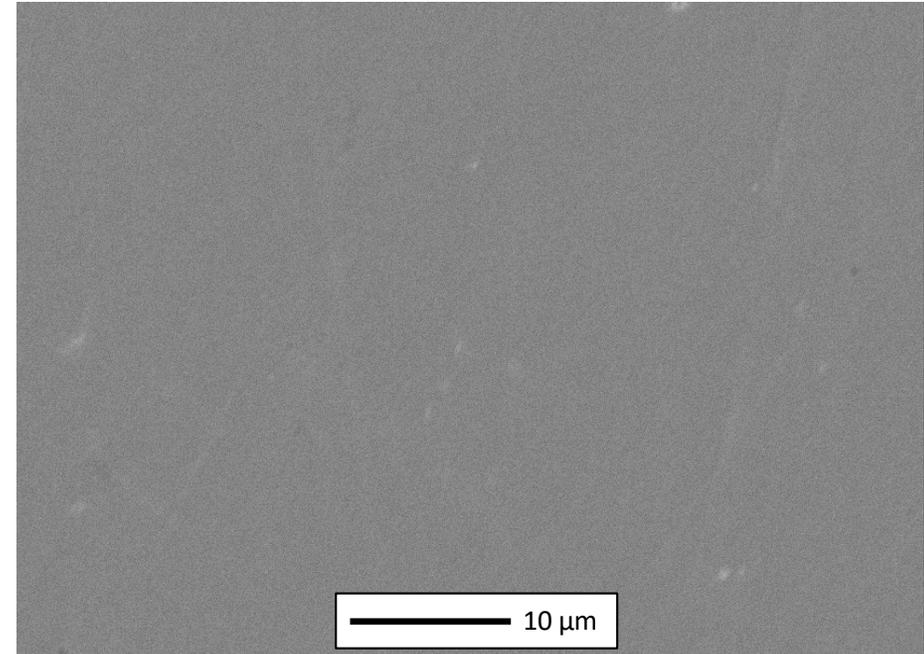


Crystalline CrC growth results in pores and grain boundaries that allow access to the substrate and lead to **poor corrosion resistance**.



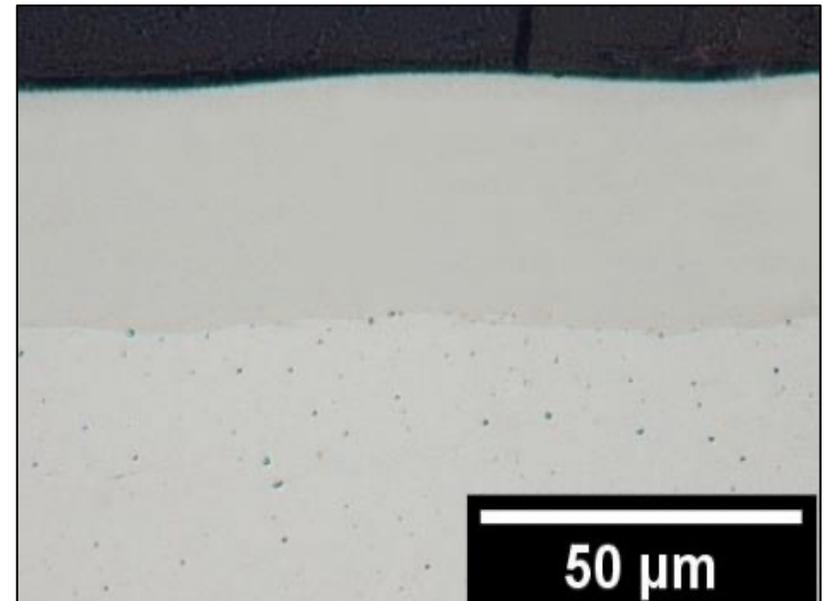
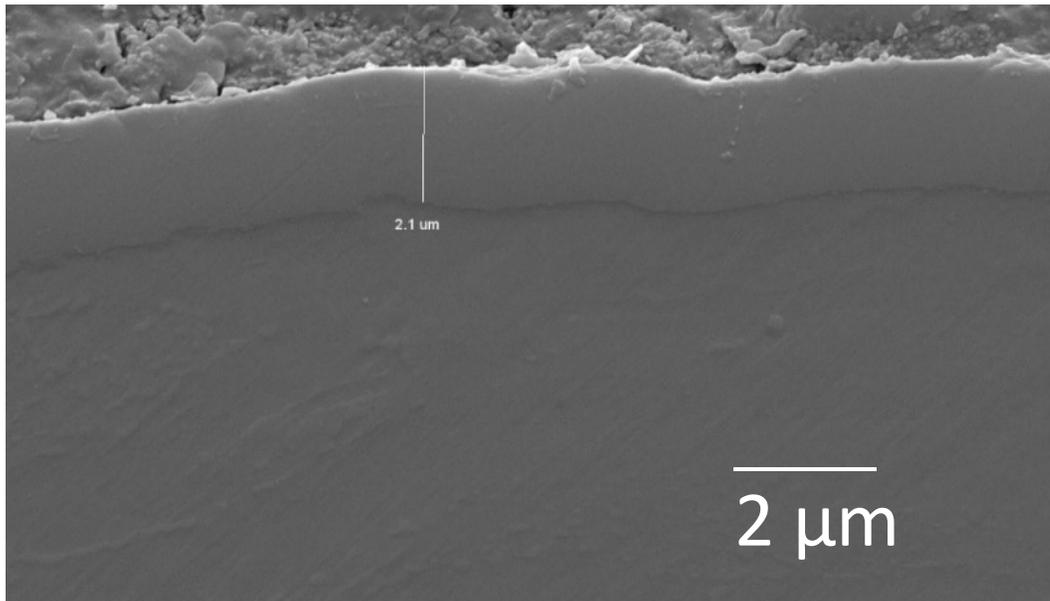
Crystalline CrC surface (SEM 2000x)

Amorphous CrC growth results in a dense, featureless coating with **excellent corrosion resistance**.



Amorphous-CrC surface (SEM 2000x)

# Ceratough™ 0801 CVD Amorphous Chromium Carbide Coating



Completely dense, defect-free microstructure

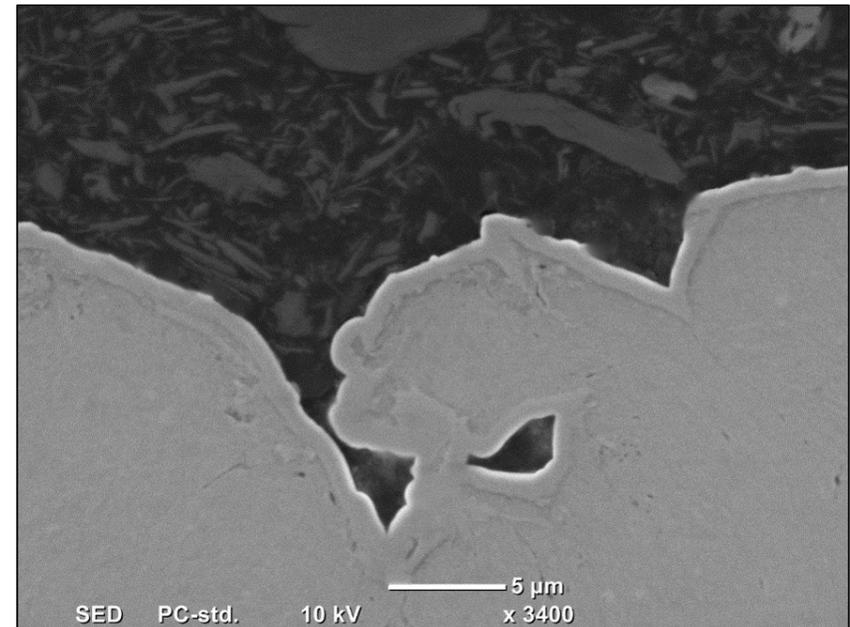
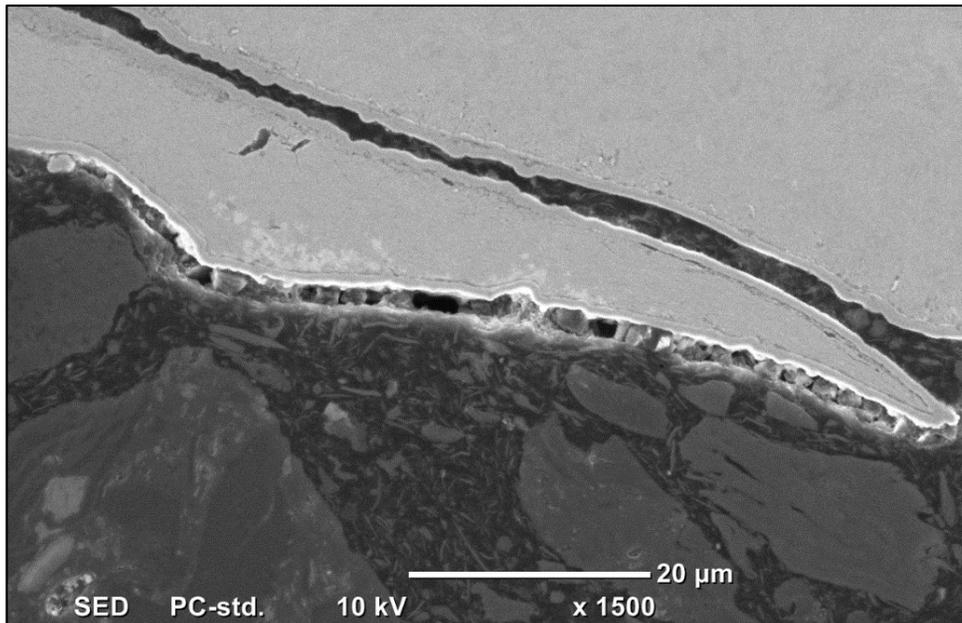
# Ceratough™ 0801

## CVD Amorphous Chromium Carbide Coating

- Uniformity on Complex Shapes



- The process applies coating with excellent coverage and uniformity
- Even surface micro-defects (dents, burrs, etc.) are **fully coated**, which is critical for corrosion performance

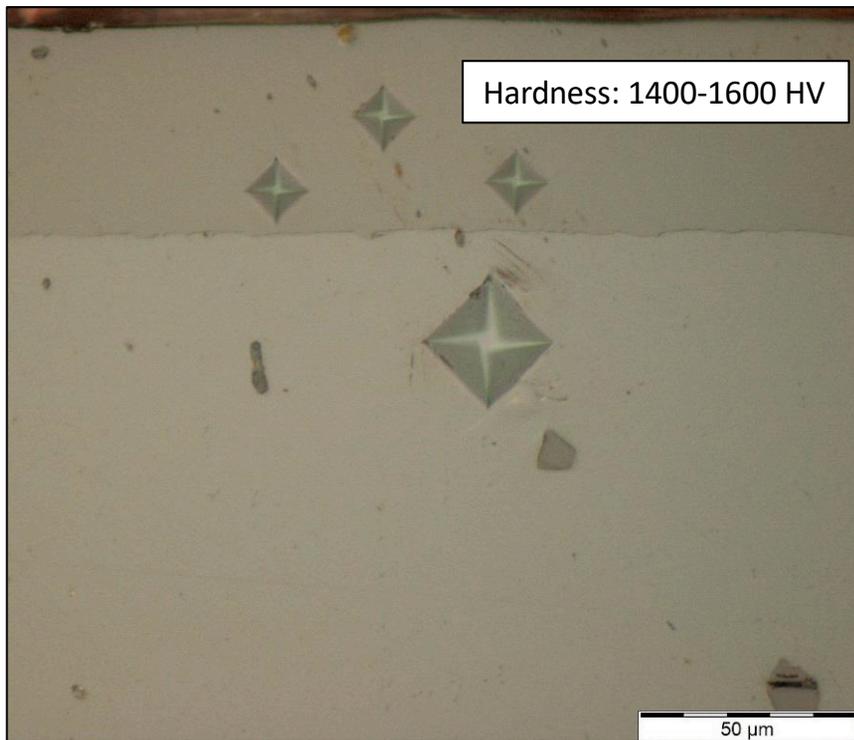


Fastener burrs show CrC is uniformly applied even inside <math><5 \mu\text{m}</math> gaps.

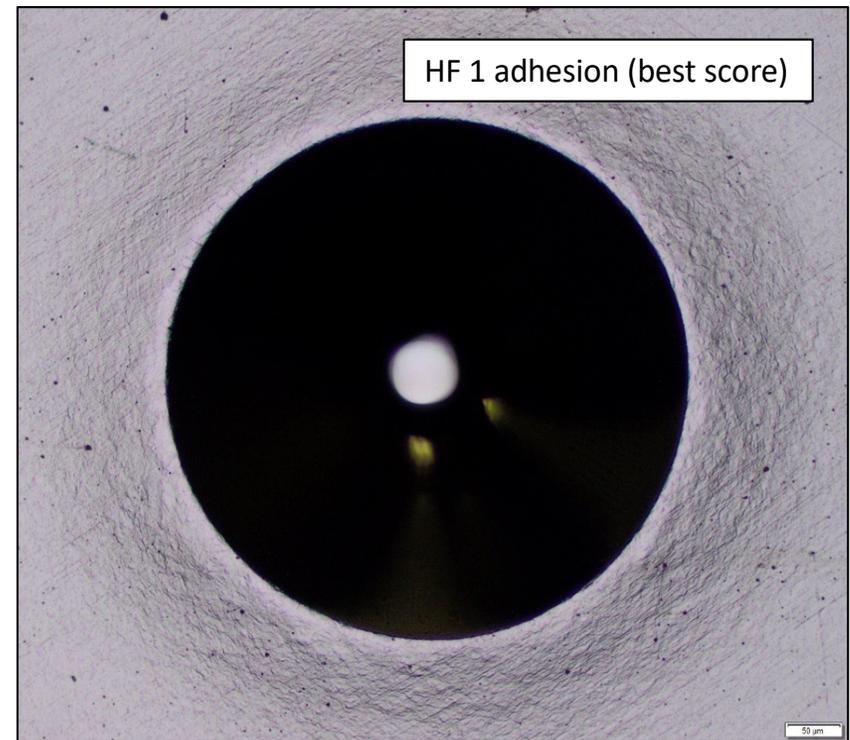
# Ceratough™ 0801 CVD Amorphous Chromium Carbide Coating Hardness, Adhesion and Ductility



The coating is much harder than steel, yet ductile enough to resist cracking or delamination.



50 μm of a-CrC on A286 SS



HRC indent adhesion test (VDI 3198)

# Corrosion Testing of Ceratough™ 0801 CVD Amorphous Chromium Carbide Coating



## ASTM G85 Annex 4 (Salt Spray with SO<sub>2</sub>): Coatings applied to A286 stainless steel



**1 µm of a-CrC showed no evidence of corrosion after 423 hours of exposure.**



**8 µm of cadmium plating corroded after <336 hrs of exposure.**



**Uncoated A286 rusted in <24 hrs.**

## ASTM G31 Acid Immersion Corrosion:

CeraTough™ a-CrC is impervious to concentrated hydrochloric and sulfuric acids, which aggressively attack most materials.



Uncoated: HCl turns yellow-green from dissolved Fe and Cr



a-CrC: HCl remains clear after testing

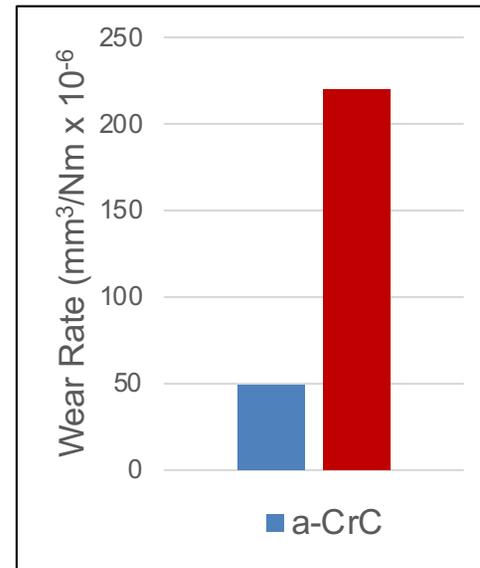
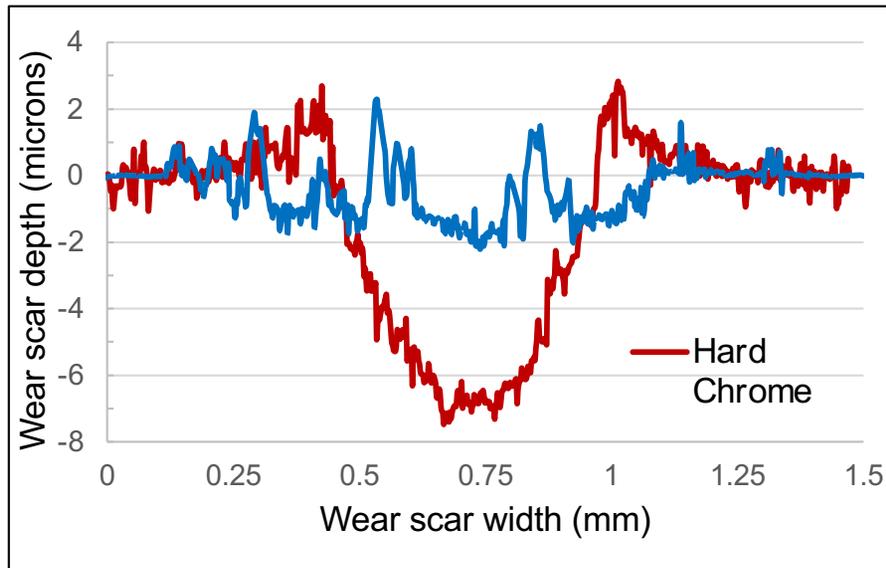
A286 SS with 5 µm a-CrC		
Acid	Mass Loss (mg)	
	Uncoated (24 hrs)	a-CrC (500 hrs)
20% HCl	8	0
60% H <sub>2</sub> SO <sub>4</sub>	17	0

# Wear Resistance



**ASTM G133 dry sliding wear at 400°C against aluminum oxide.**  
Wear scars (left) and wear rates (right)

CeraTough™ a-CrC demonstrated **4.5X better wear resistance** than hard chrome plating

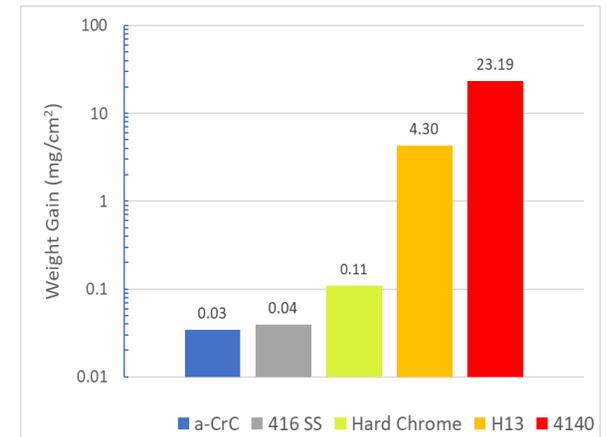
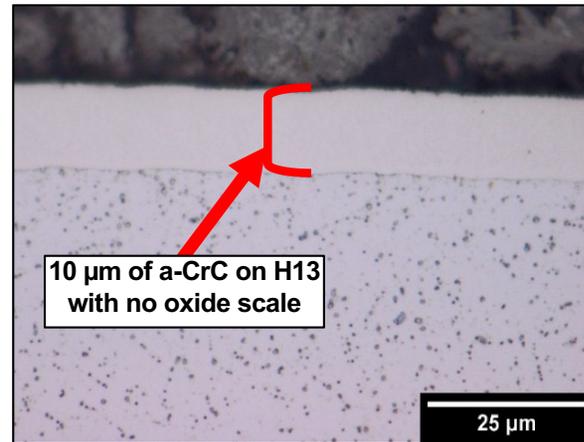
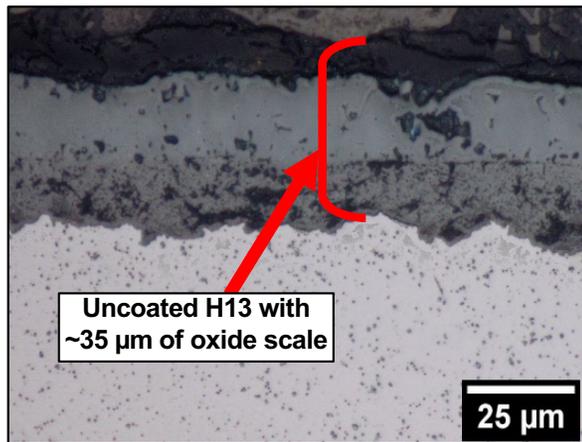


# High Temperature Oxidation Resistance



After open air oxidation at **750°C for 24 hrs**, a-CrC showed negligible weight gain and no visible scale.

The a-CrC coating provided a stainless-level of oxidation protection to a non-stainless steel.

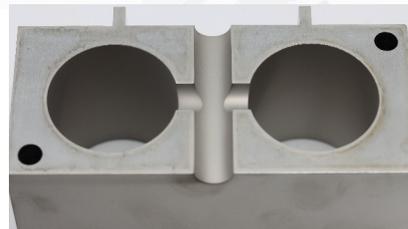
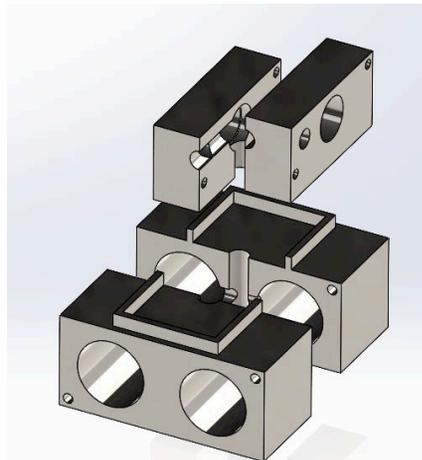


Weight gain after oxidation at 750°C for 24 hrs.

# Application to Protect from High Temperature Erosion/Corrosion Inside Complicated Channels



- IBC designed and manufactured a modular mock-up to simulate the complex shape.
- The mock-up was coated and analyzed to measure uniformity.
- The a-CrC process was able to coat all surfaces with 5-10  $\mu\text{m}$ .
- Real testing showed zero damage to the coating, compared to heavy erosion and corrosion on the baseline



Mock-up after coating and disassembly.

Component coated with a-CrC.



Baseline interior showing erosion/corrosion

# Fasteners & Housings



Thousands of tight tolerance fasteners coated with 1-2  $\mu\text{m}$  of a-CrC.



Small ID (0.06") housings coated entirely with 5-6  $\mu\text{m}$  a-CrC.

# ASTM G31 HCl Immersion Corrosion Testing of Ceratough™ 0801 CVD Amorphous Chromium Carbide Coating



**Immersion corrosion testing per ASTM G31**  
The images below show results after 18 hrs.



Uncoated: dark  
corroded surface



a-CrC (2 μm): No visible  
pits, very low mass loss

8740 Steel Fastener Weight Loss After HCl (15%) Submersion		
Sample	Weight Loss (mg)	
	30 min	18 hrs
Uncoated	3	47
Ceratough™ 0801 coating (2 μm thickness)	0	1

The a-CrC coating provides significant corrosion resistance despite a complex shape and very low thickness.

# Cd+SFL Replacement



**Problem:** Aircraft component suffering from excessive wear and corrosion damage. In addition, cadmium (Cd) plating is highly hazardous to apply and dispose of.

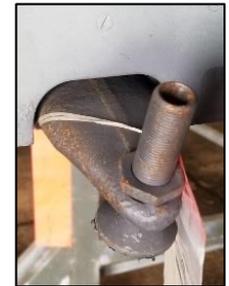
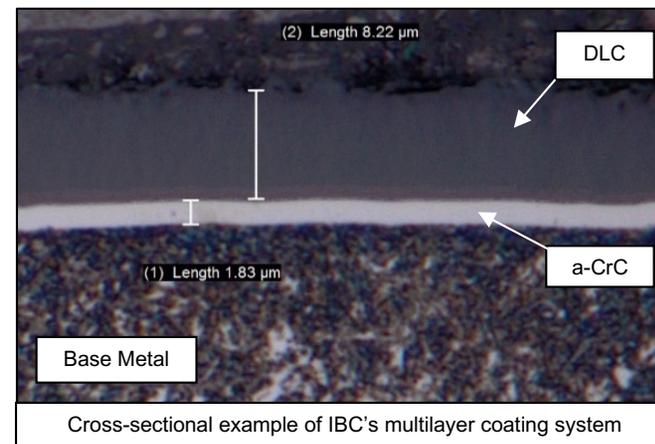
## **Solution:**

Innovative multilayer system composed of a-CrC and DLC coatings.

- a-CrC: serves as an impermeable, corrosion resistant base layer
- DLC: creates a self-lubricating, low friction surface for wear resistance

## **Timeline:**

- Durability Testing: Complete, >3X improvement
- Corrosion Testing: Complete, >2X improvement
- Production Scale Up: In Progress



An exposed component with heavy corrosion



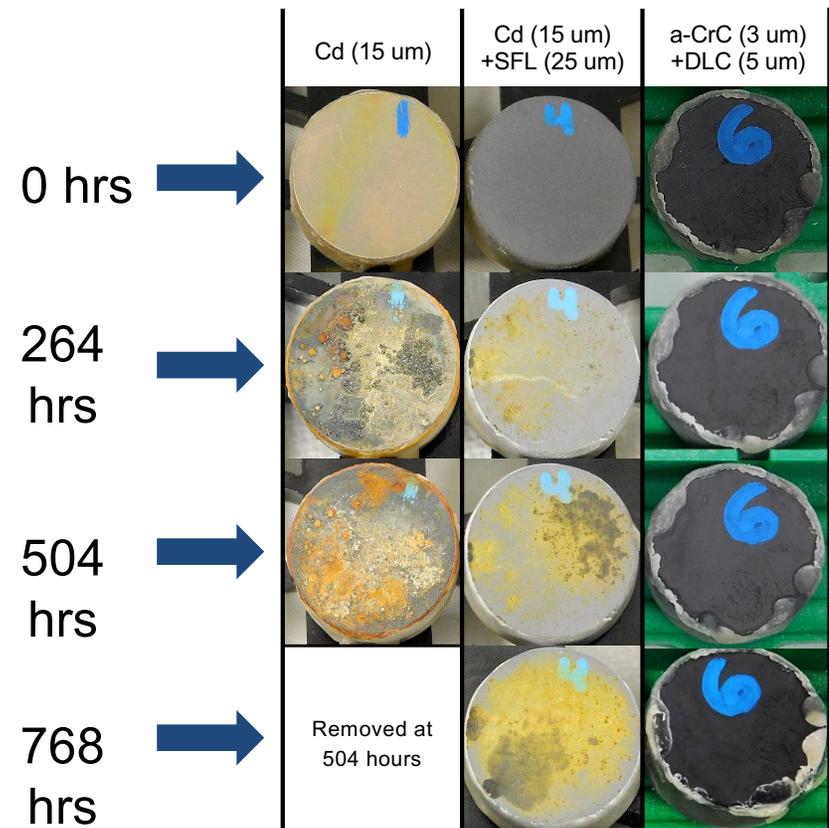
Component showing heavy wear

# a-CrC + DLC: Corrosion Testing Results



## ASTM G85 Annex 4 (Salt Spray with SO<sub>2</sub>): Coatings applied to 4140 steel

- The Cd and Cd+SFL began corroding by 264 hrs.
- IBC's multilayer coating, despite being much thinner than the baselines, showed no corrosion after 768 hrs, demonstrating a **2-3X improvement**.

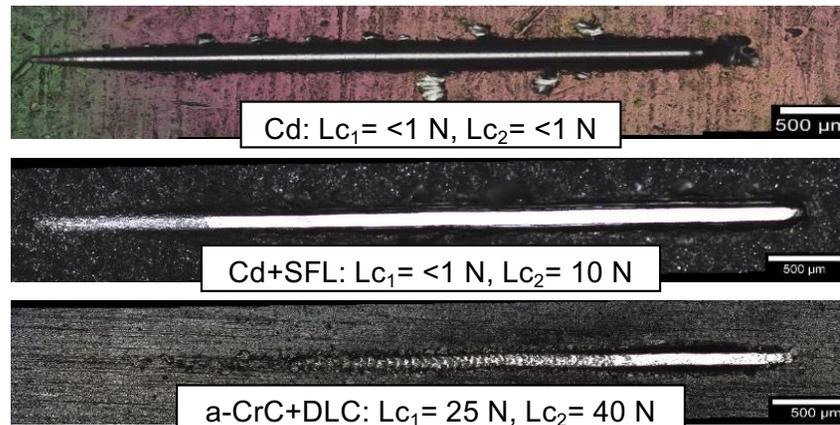


# a-CrC + DLC: Durability Test Results

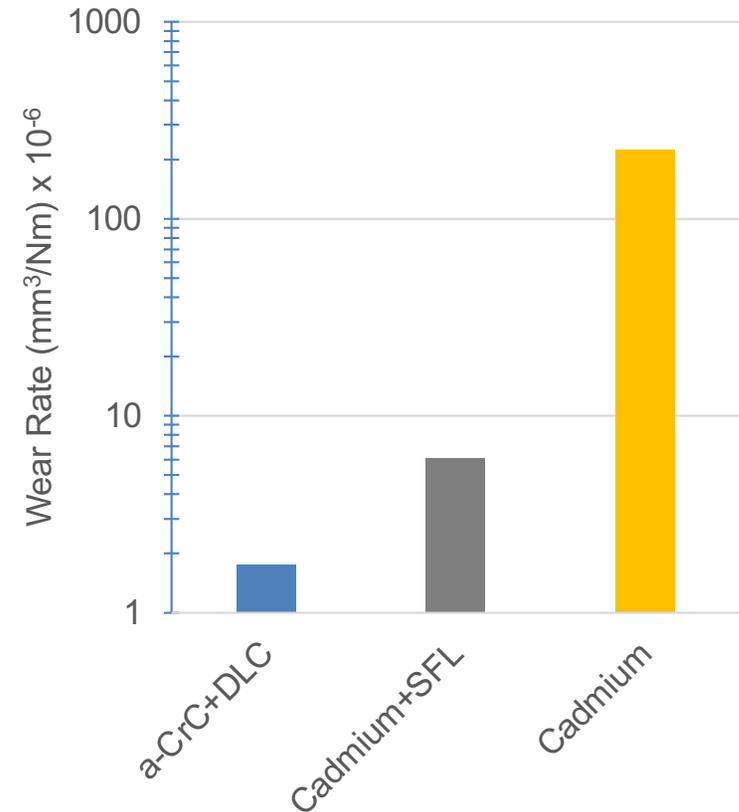


- In ASTM G133 sliding wear, IBC's multilayer coating outperformed Cd+SFL by >3X, and pure Cd by >100X.
- In ASTM C1624 scratch testing, both Cd and Cd+SFL are compromised immediately. Cd+SFL maintains partial coverage up to 10 N of load.
- IBC's multilayer was not compromised until 25 N, and was not removed until 40 N.

## ASTM C1624 Diamond Scratch Testing



## ASTM G133 Coating Wear



# a-CrC + DLC: Coated Components



a-CrC



a-CrC + DLC



# IBC Contact Information



- Dr. Solomon Berman
- Phone: (765) 481-2900 Ext 113
- Website: [www.ibcmaterials.com](http://www.ibcmaterials.com)
- Address:  
825 Hendricks Drive  
Lebanon, IN 46052