Potential Use of Cold Sprayed Nanostructured Aluminum for Corrosion and Wear Protection

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OVERVIEW

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introduction

- Perpetual Technologies
- nanostructured materials
- ONR program
- cold spray
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- corrosion & nanostructured metals

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Perpetual Technologies

"offers consulting services relating to conventional and nanostructured coatings"

ACTIVITIES

- provide technical solutions to production problems
- support and/or coordinate R&D projects
- conceive and carry out in-house R&D
- match clients' unique technology/product with applications

CURRENT R&D

- nanostructured oxide coatings
- nanostructured MCrAlY and YPSZ for TBCs
- cold spray application of nanostructured Al, its alloys, and its composites
- nanostructured WC-base coatings for mining and other severe wear applications

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ACCOMPLISHMENTS

- development of first non-military application of thermal sprayed nanostructured coating - over 10 mines using nanostructured TiO2 coatings
- 3 patents relating to thermal spray nanostructured coatings
- co-development of economical processing of nanostructured metal powders

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Perpetual Technologies

CLIENTS (★) & COLLABORATORS (↻)

- GE-Global Research Center ★ ↻
- ExxonMobil ★ ↻
- Praxair Surface Technologies ★
- ONR ★
- NSWCCD ★ ↻
- USNA ↻
- ARL ↻
- SAIC ★ ↻
- Syncrude Canada ↻
- Hydro-Quebec ★ ↻
- Rice University ★
- McGill University ★ ↻
- Univ. of California, Irvine & Davis ★ ↻
- Rutgers University ★ ↻
- University of Pittsburgh ↻
- FW Gartner ★ ↻
- Mogas Industries ★ ↻
- Scientific Valve and Seal ↻
- Metal Processing Systems (U.S.) ↻
- n-WERKZ, Inc. ↻
- McCarthy Tetrault ★
- Xebec ★

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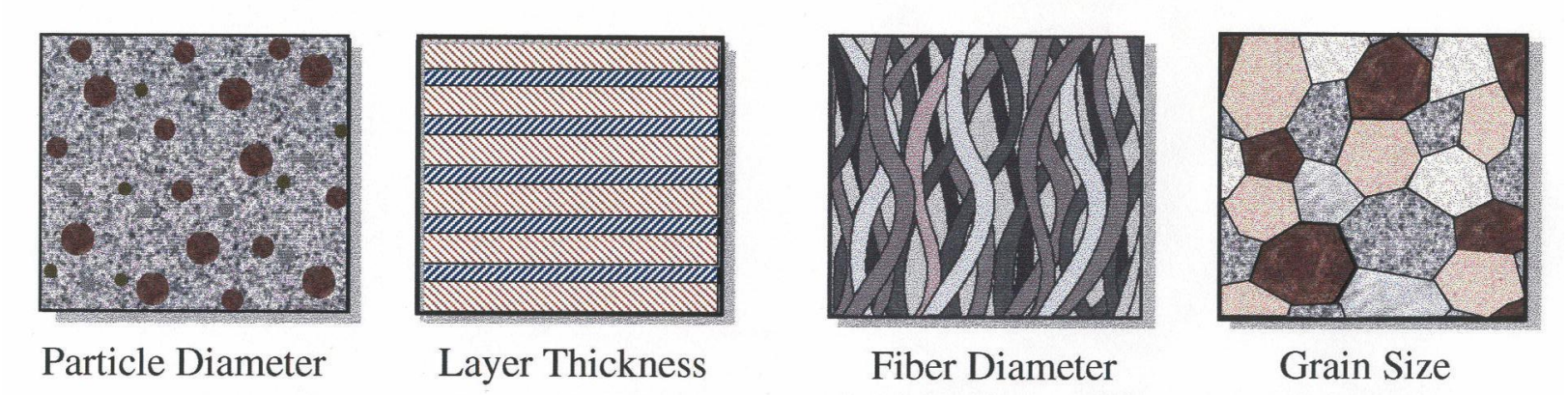
nanostructured materials

"The term nanostructured is used to describe any material which has some physical feature less than 100 nm in size"



Schematic from ONR

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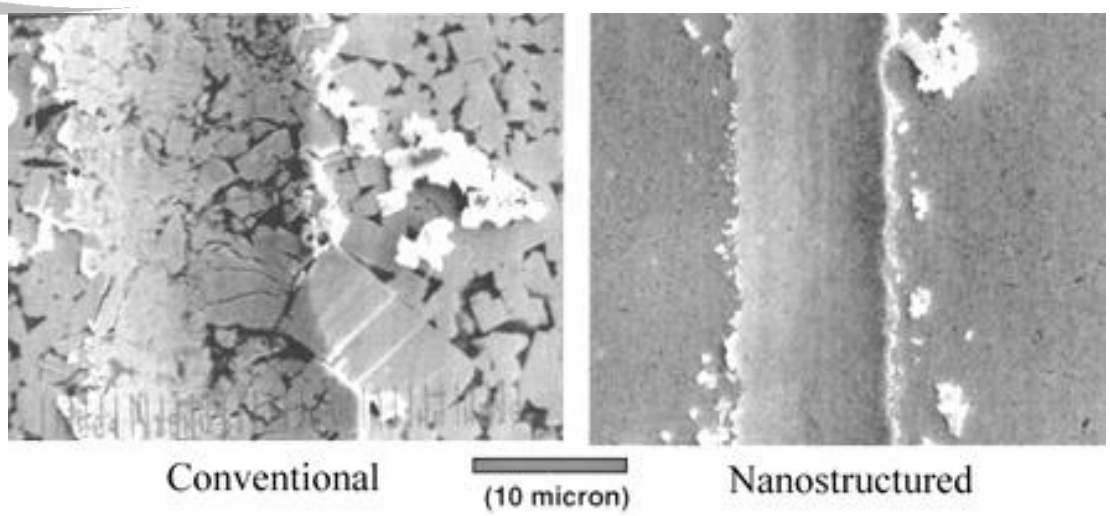
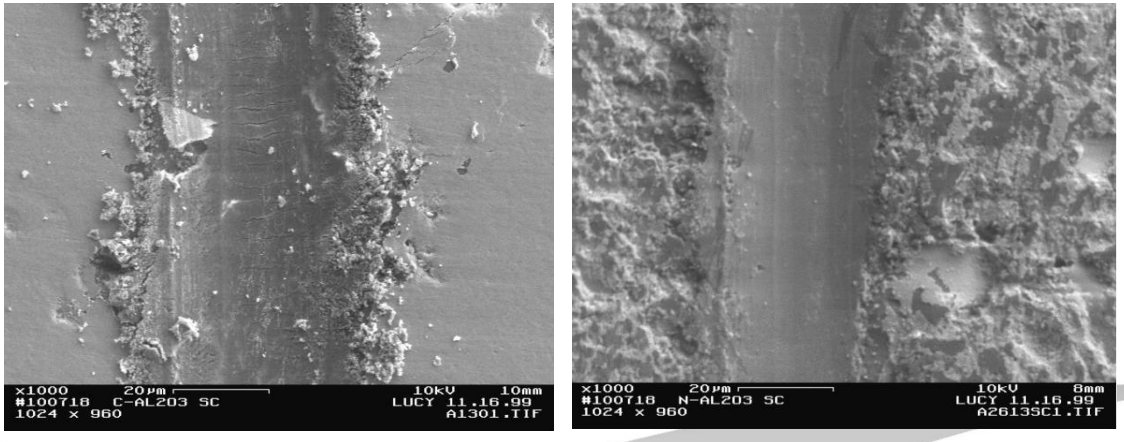
nanostructured bulk materials



WC - Co



Al_2O_3- 13TiO_2

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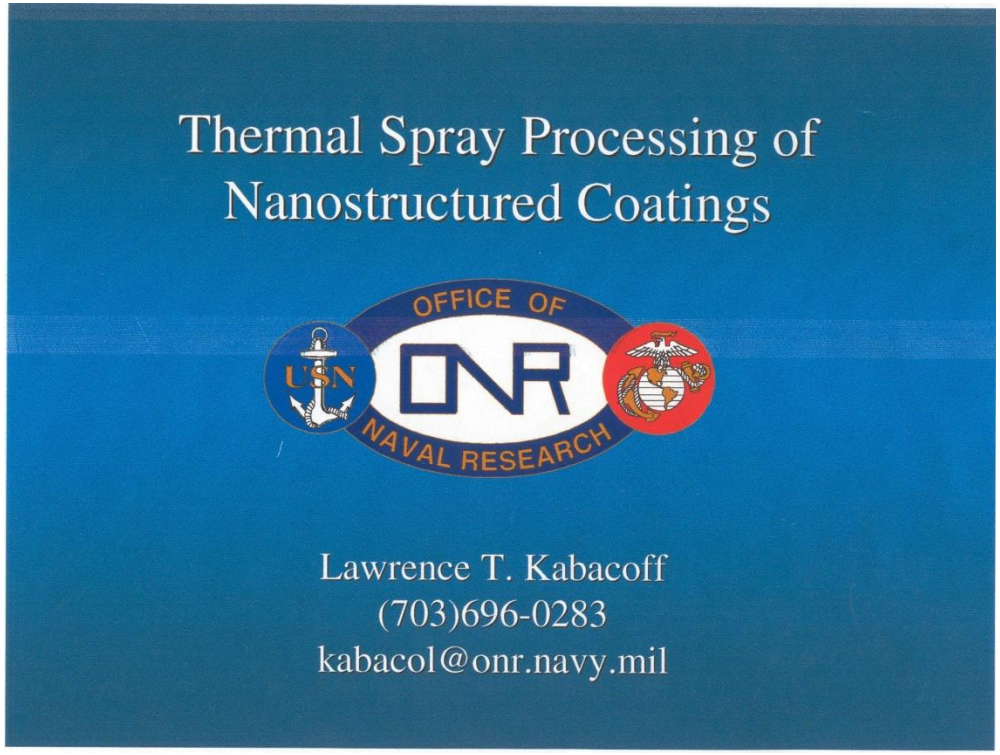
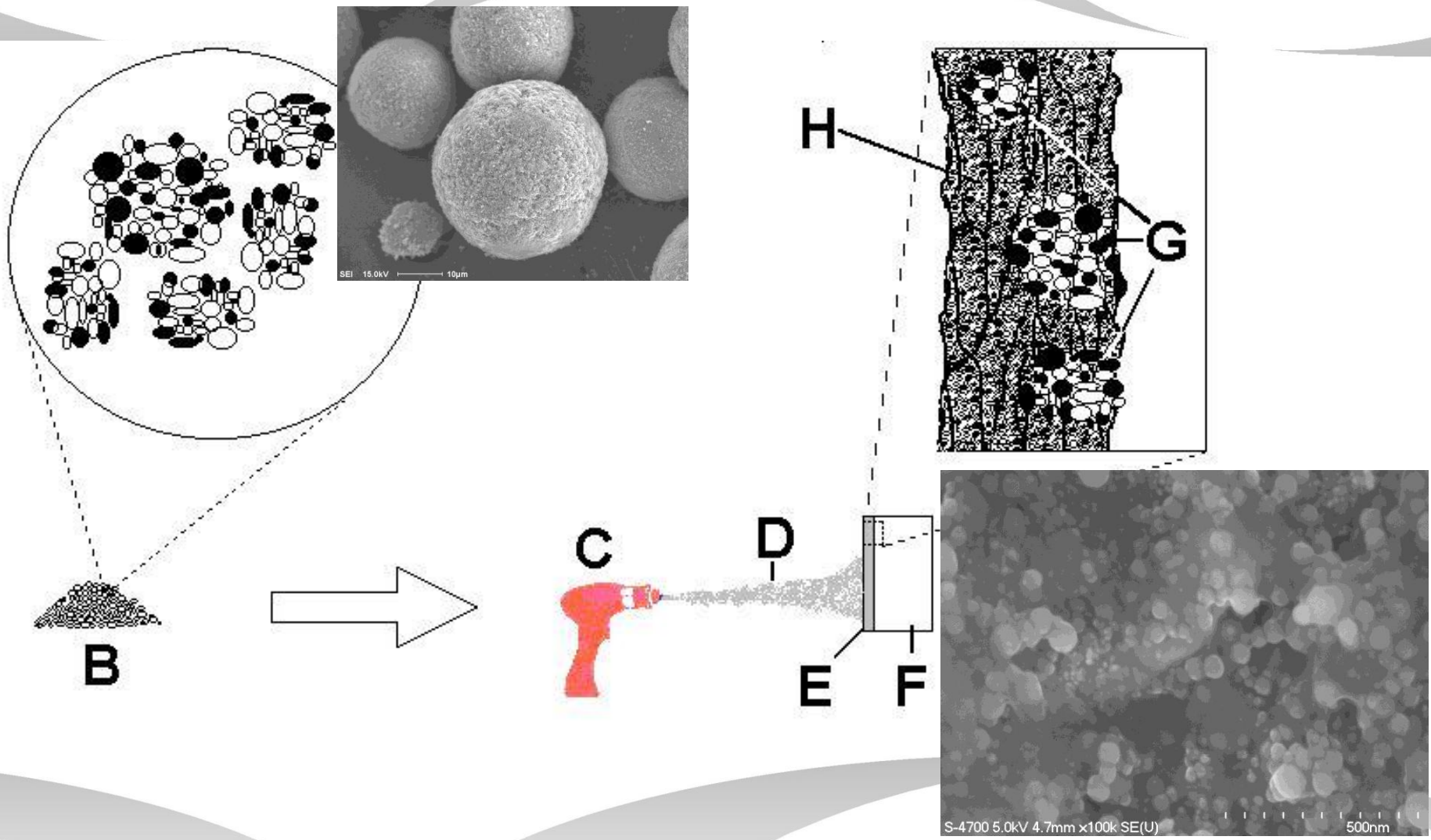
ONR program

OFFICE OF NAVAL RESEARCH (ONR) FUNDED PROGRAM (FY1996 - FY2001)



TS n-ceramic coating

developed at UCONN



Nanostructured regions

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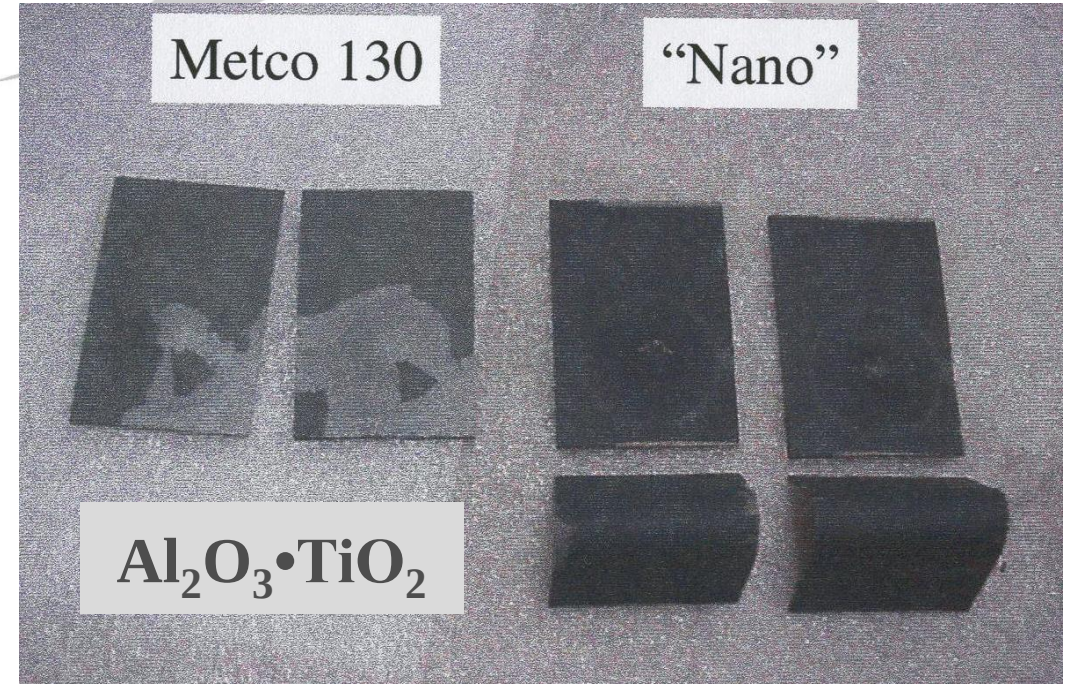
ONR program - flagship result



from ONR

Advantages of n-coating

- 2x bond strength
- 4x wear resistance
- remarkable toughness
- qualified under MIL STD 1687A "Thermal Spray Coatings for Shipboard Machinery"

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WHAT WE KNOW…

n-Al_2O_3/TiO_2 ON PROPULSION SHAFTING – STERN TUBE & STRUT BEARINGS

Courtesy of Ken Scandell - NSWCCD

WHAT WE KNOW…IN-SERVICE T&E

n-Al_2O_3/TiO_2 ON PROPULSION SHAFTING – STERN TUBE & STRUT BEARINGS

Old Method: $280,000
OEM Weld Repair

ROI COST AVOIDANCE = $36,500,000

Plasma Thermal Spray n-Alumina Titania Ceramic

Surface Grinding & Finishing

New Method: $75,000
Coating Repair

Courtesy of Ken Scandell - NSWCCD

"Nanostructured Coatings Development Team Wins Cheapskate Prize"

- Lawrence T. Kabacoff, A.K. Vasudevan, Robert McCaw and Kenneth Scandell were members of this team
- annual savings are estimated to approach $100 million

ONR's Cheapskate Award for Affordability celebrates technological improvements that have had the greatest impact on the future availability of affordable technologies for Naval forces.

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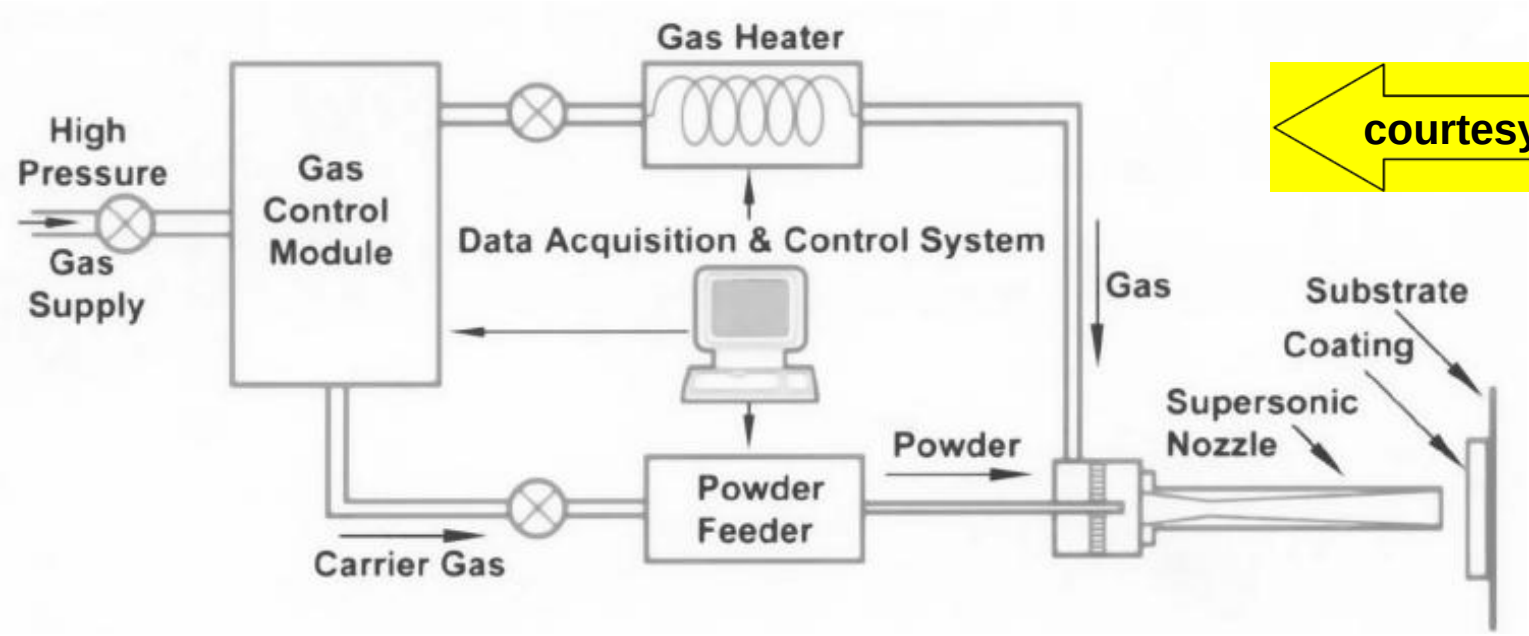
cold spray process (CSP)



courtesy of ARL

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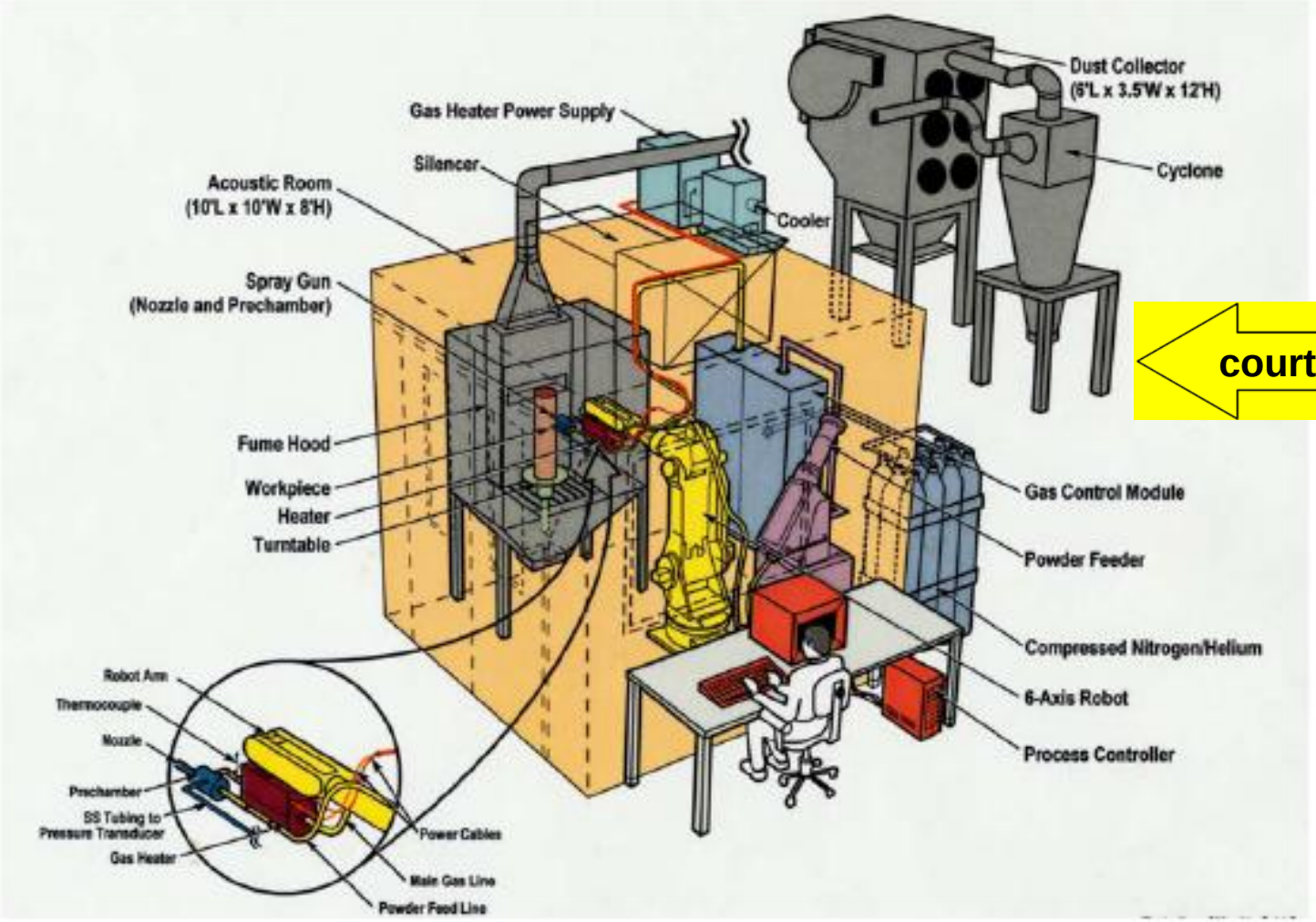
ARL cold spray system



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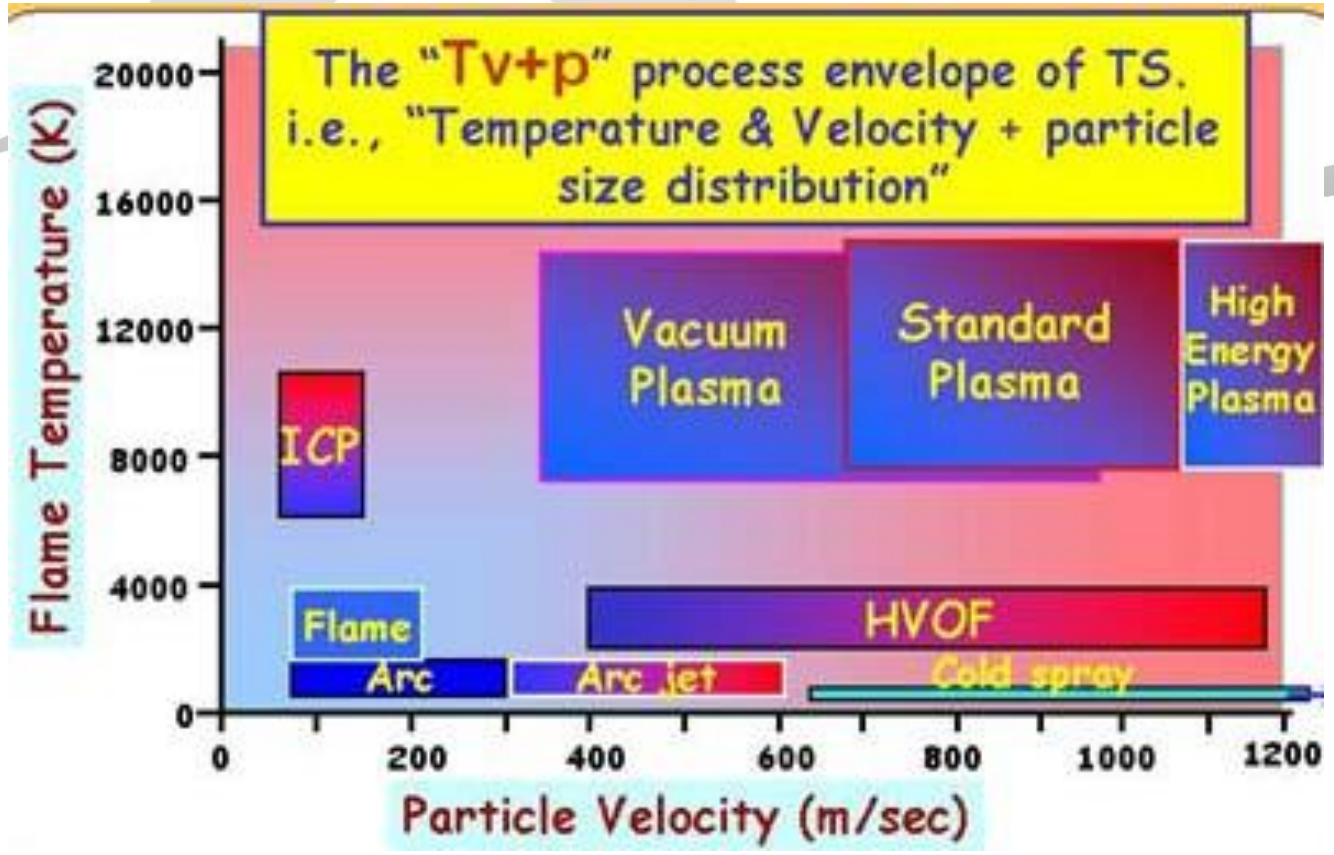

Berndt & Knight

CHARACTERISTICS:

- no phase or compositional change
- **little or no grain growth**
- **low oxide and porosity levels**
- low residual stress (compressive)
- low surface roughness
- high deposition efficiency
- high deposition rate
- recyclable un-deposited powder
- minimal surface preparation

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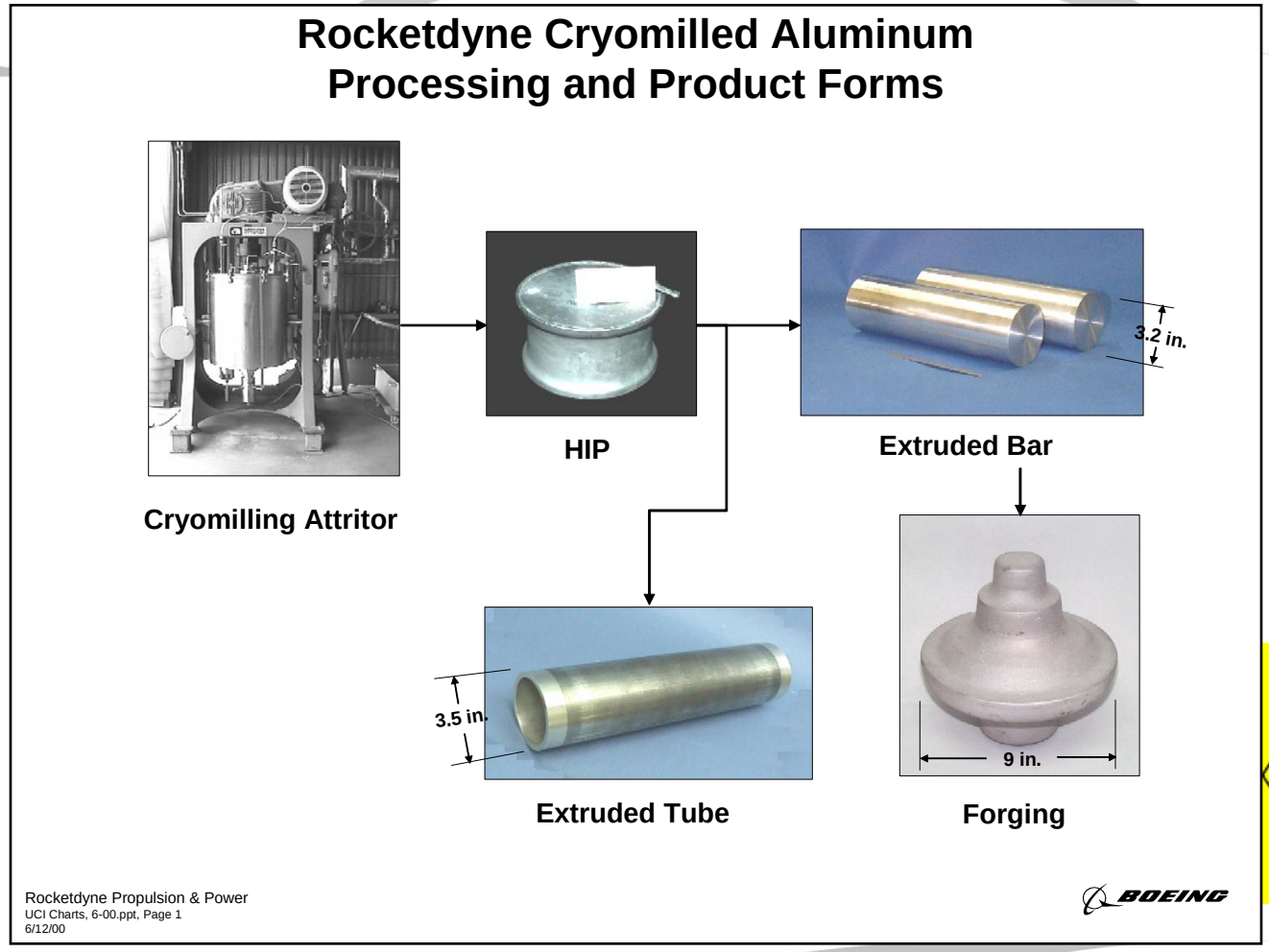
bulk nanostructured aluminum alloy



Lavernia @ UC, Davis

- **double the strength**

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MEFFV Approach to Leap-Ahead Technology

Assault Variant

Reconnaissance Variant

Potential Fire Support Variant

(Post HIMARS/LW155)

Needs

- Reduced Gross Weight Increased Survivability
- Fuel Conservation or Elimination
- Autonomous Defensive Systems
- Regenerative Weapons
- Multi-Spectrum Tactical Awareness

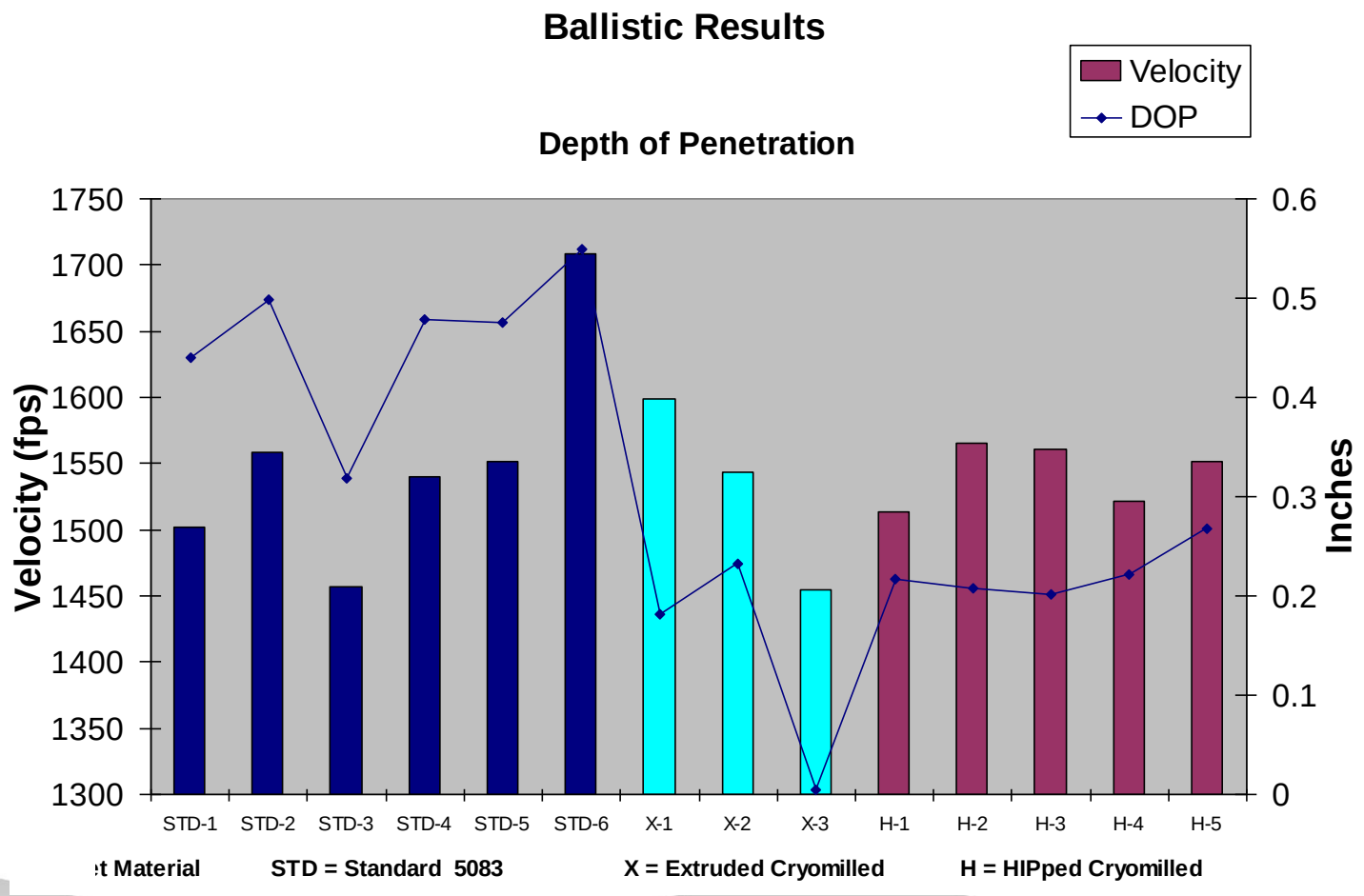
high strength/lightweight & armor protective

Technology Focus

- Vehicle Integrated Defense and Survivability Suite
- Sensor Data Fusion
- Advanced Weapons
- Advanced Composites Survivable / Lightweight
- Advanced Propulsion

http://www.dtic.mil/ndia/2002combat/gaskill.pdf

preliminary ballistic test



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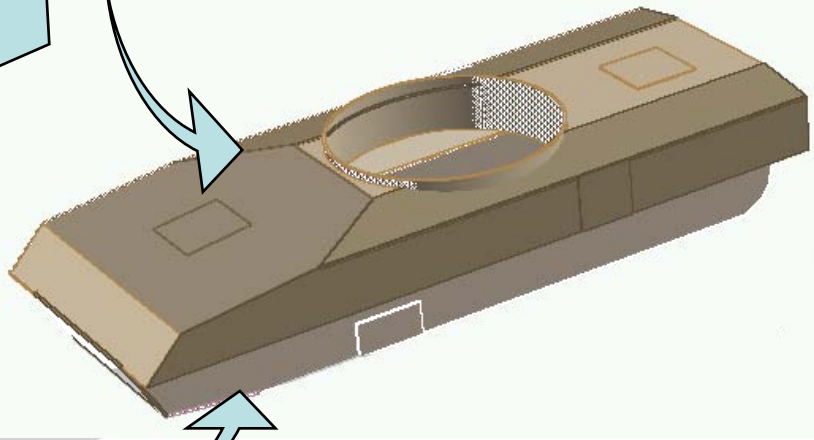
design concepts for cryomilled Al incorporation

Photo from www.pgbradley.com

Lavernia @ UC, Davis

Vehicle Upper Hull
"Superior Ballistics Performance and Minimal Weight"
Cryomilled Al w/ Elongation and Bimodal Al



Vehicle Lower Hull
"Highly Loaded, Reinforcing Stiffeners"
Cryomilled Al and Al-MMC Nanocomposite

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cryomilling processing

Perpetual technologies

Cryomilling → **Degassing** → **Hipping** → **Extrusion**

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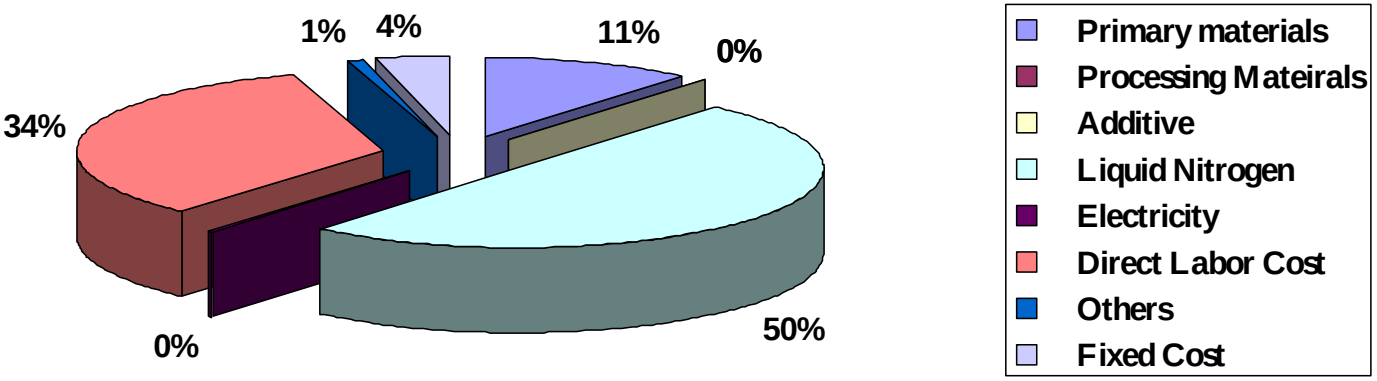

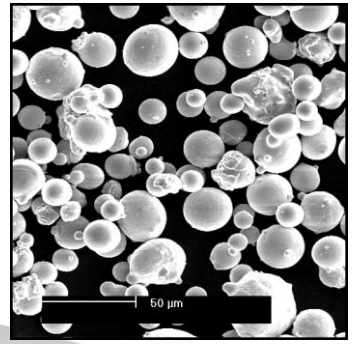

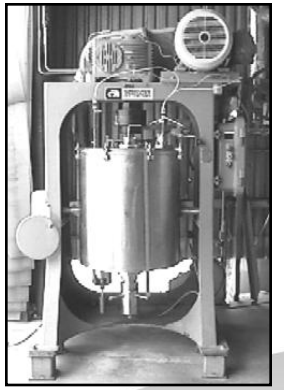

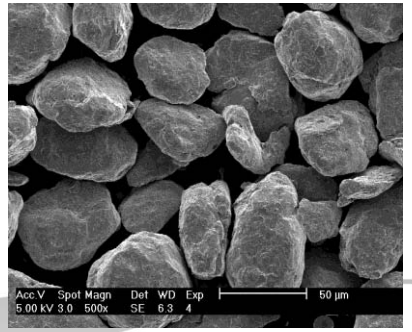

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introduction

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corrosion of nanostructured materials

"The limited work to date on corrosion resistance of nanocrystalline materials indicates that no generalizations can be made."

However …

- **numerous researchers have reported that nanocrystalline materials show a greater resistance to localized corrosion, i.e., pitting [1-7]**

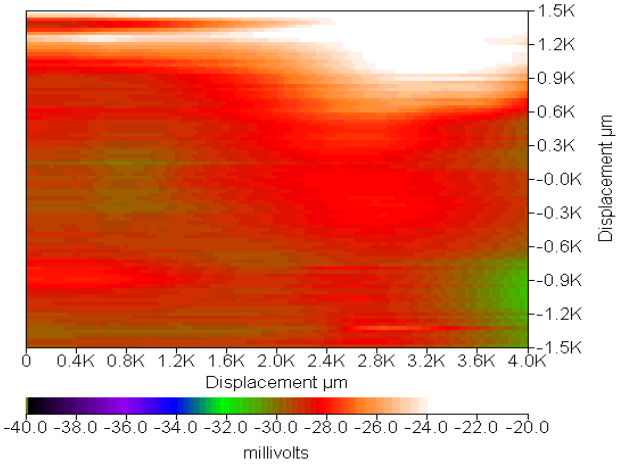
1. Rofagha, R., R. Langer, A.M. El-Sherik, U. Erb, G. Palumbo, and K.T. Aust. 1991. *Scr. Metall. Mater*. 25:2867.
2. Inturi, R.B., and Z. Szklavska-Smialowska. 1992. *Corrosion* 48:398
3. http://www.parteq.queensu.ca/company/nanometa.html
4. E. Sikora, X.J. Wei, and B.A. Shaw, Corrosion, 2004, vol. 60, no4, pp. 387-398
5. Mala M. Sharma and Constance W. Ziemian, JMEPEG (2008) 17:870–878
6. Li Liu, Ying Li, Fuhui Wang, Electrochimica Acta 54 (2008) 768–780
7. Li Liu, Ying Li, Fuhui Wang, Electrochimica Acta 53 (2008) 2453–2462

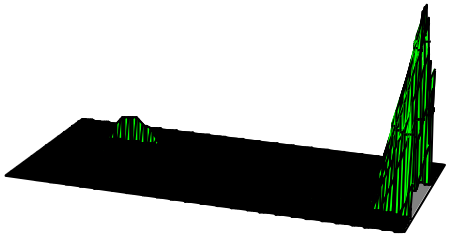
localized corrosion of bulk n-Al alloy

SRET Analysis of Bulk n-Al Alloys from cryomilled powders

Sample 1 –
coarser grains

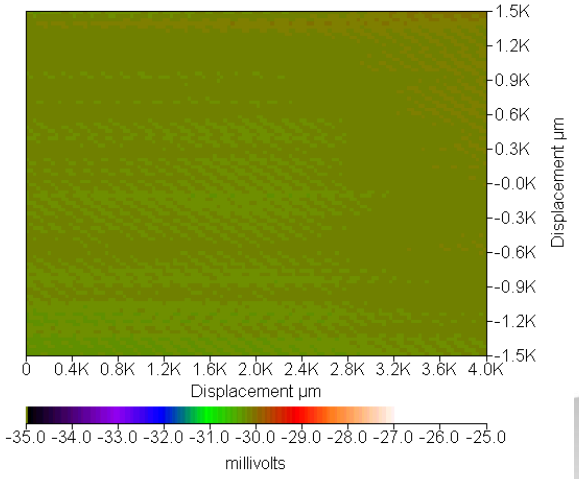
300-500 nm





Sample 2 –
finer grains

~ 100 nm



pitting is generally the cause of failure or of replacement for most military applications; finer grained Al alloy shows reduced propensity for localized corrosion

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objective

"To evaluate the possible use of cold spray processing of nanostructured aluminum alloy for corrosion and wear protection"

- **use n-Al alloy powder designed for P/M in cold spray application**
- **must be cost-effective**

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target applications

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target application - LCACs

LANDING CRAFT AIR CUSHION (LCAC)

- **rebuild localized damage**
- **provide protection**

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target application – aircraft skins

Objective is to develop an alternative to current ALCLAD process for the protection of aircraft skin from corrosion.

- **effective galvanic corrosion protection**
- **no compromise on fatigue resistance**
- **easily depot applied**
- **capable of localized damage repair**
- **compatible with existing aircraft coatings**

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cold spray of Al

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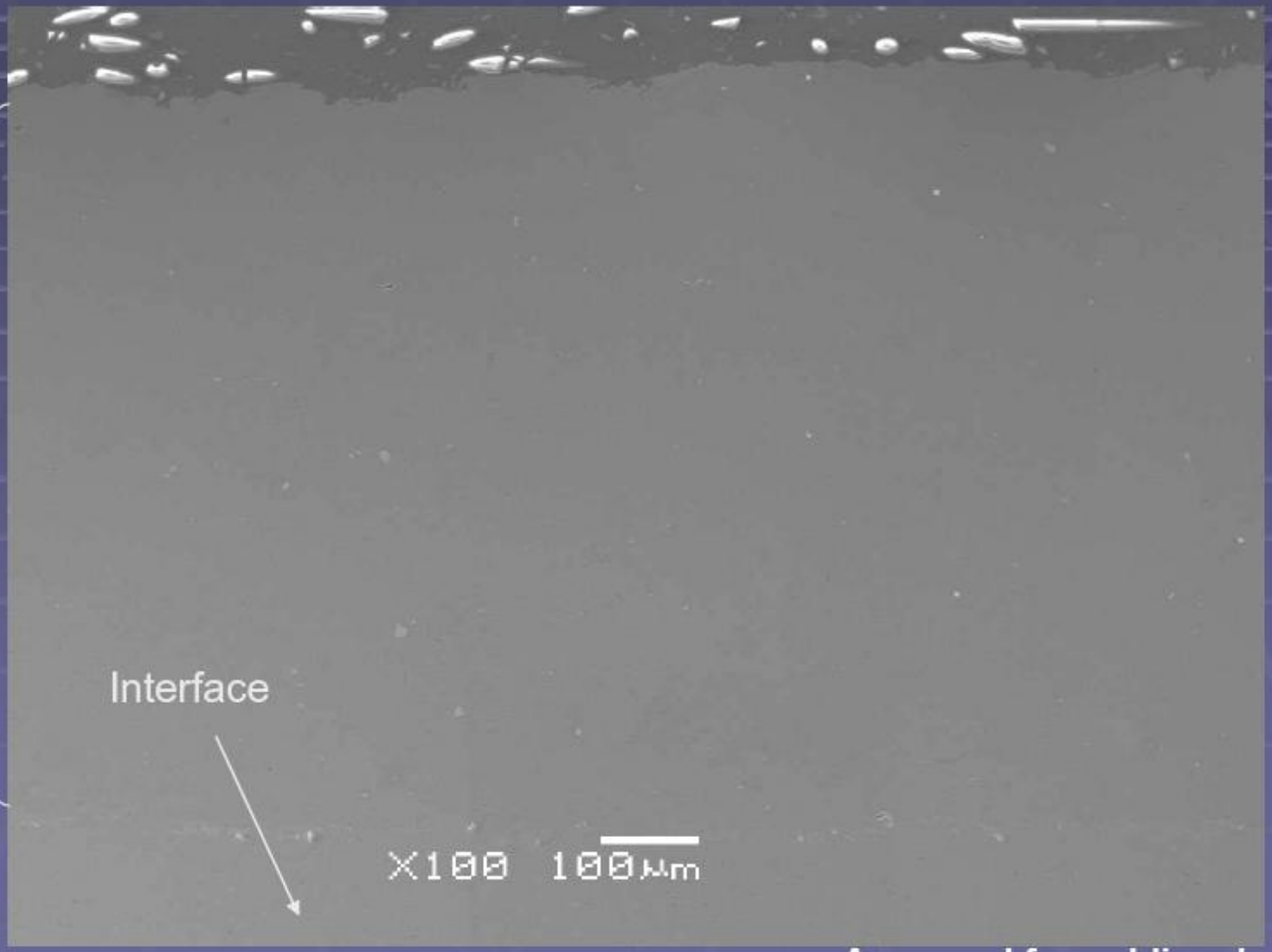
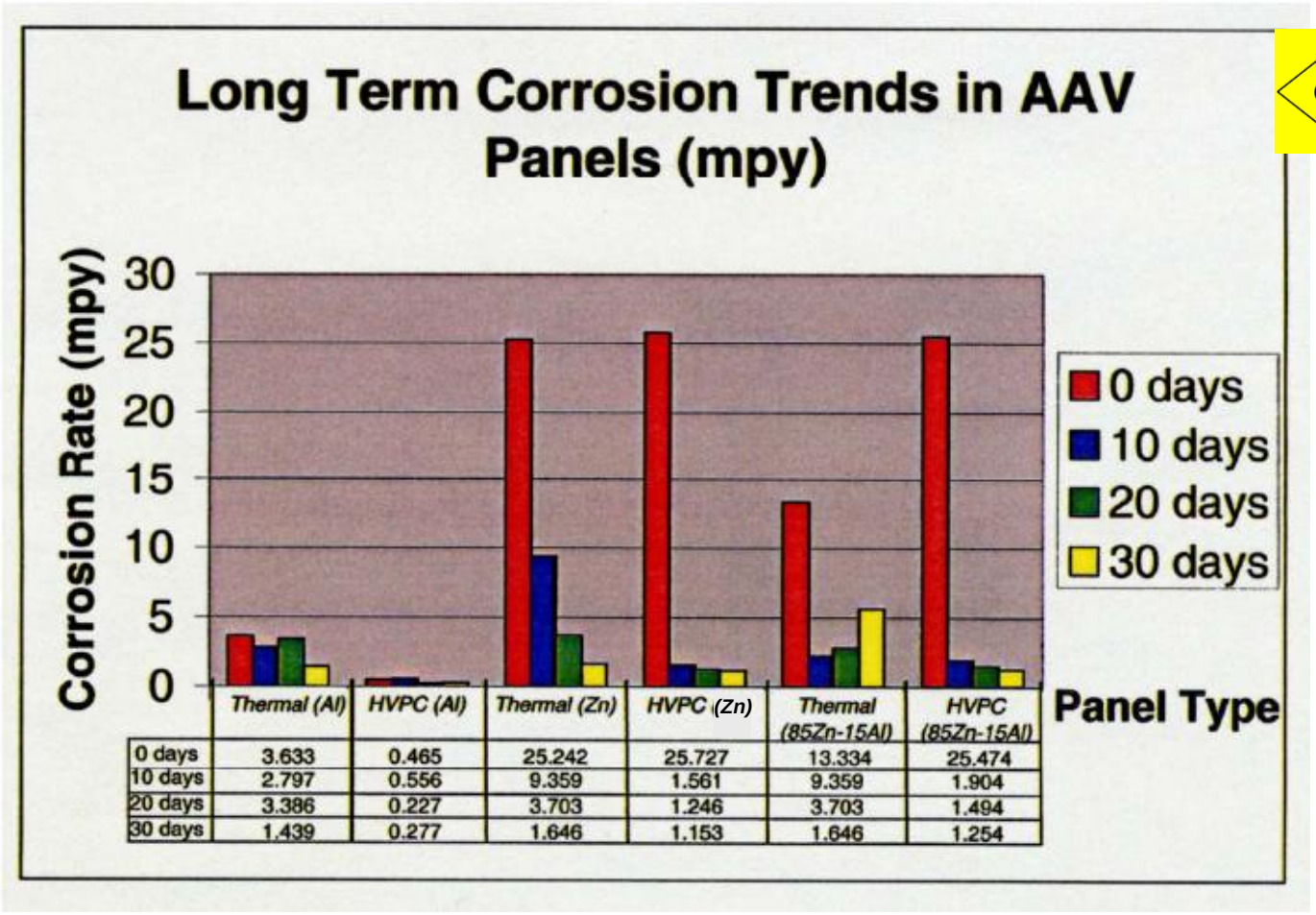
5056 Al Deposit Using Helium as the Carrier Gas

courtesy of ARL



long term corrosion study



	Thermal (Al)	HVPC (Al)	Thermal (Zn)	HVPC (Zn)	Thermal (85Zn-15Al)	HVPC (85Zn-15Al)
0 days	3.633	0.465	25.242	25.727	13.334	25.474
10 days	2.797	0.556	9.359	1.561	9.359	1.904
20 days	3.386	0.227	3.703	1.246	3.703	1.494
30 days	1.439	0.277	1.646	1.153	1.646	1.254

courtesy of ARL

Comparison of corrosion rates of Al, Zn, 85Zn-15Al sacrificial coatings sprayed onto steel.

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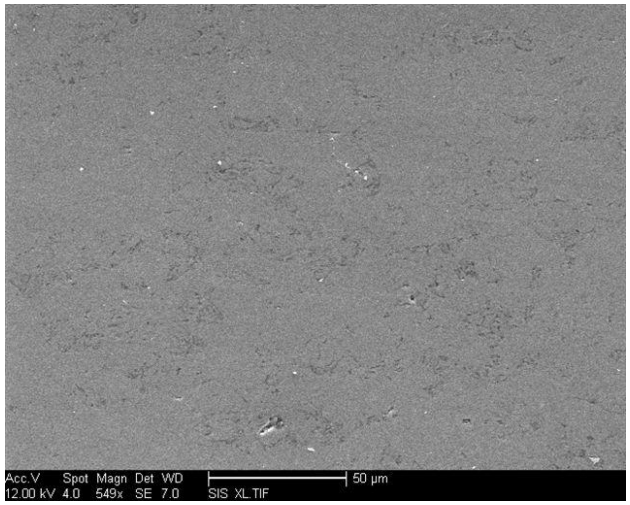
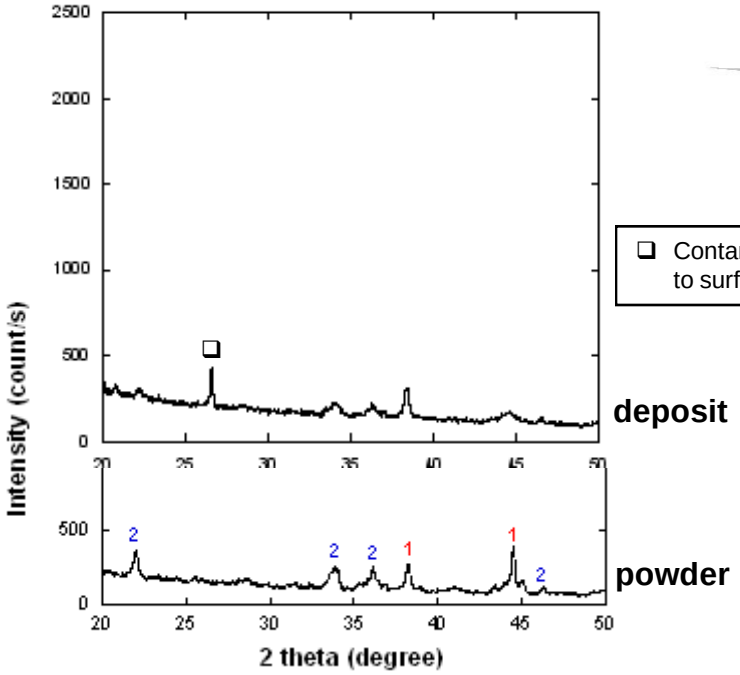
CSP of Al-Co-Ce





CSP deposits:

- very dense coatings with no sign of oxidation
- little change in composition and grain size

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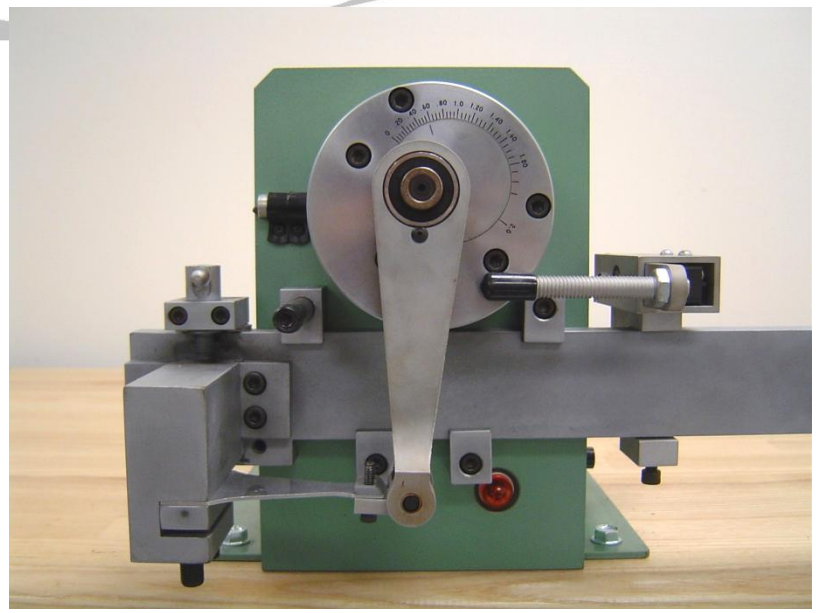
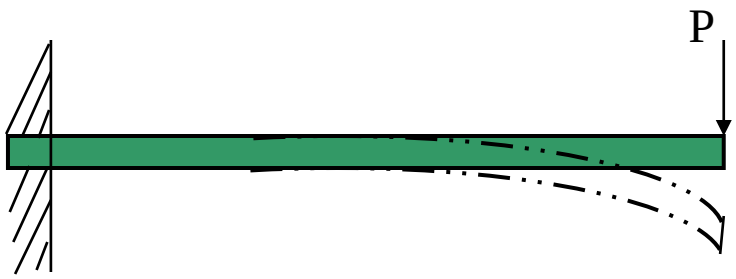
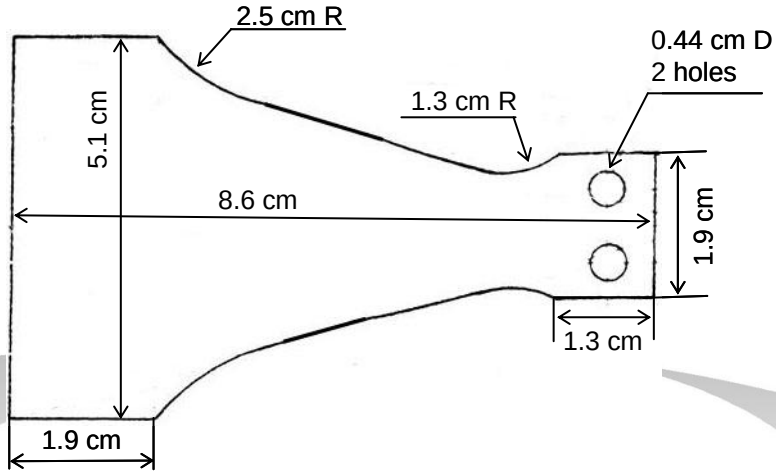
bending fatigue test



- R = 0
- f = 30 Hz
- applied max stress: 30, 40, 50 ksi
- cycles to failure were automatically recorded





Courtesy of Angela Moran @ USNA

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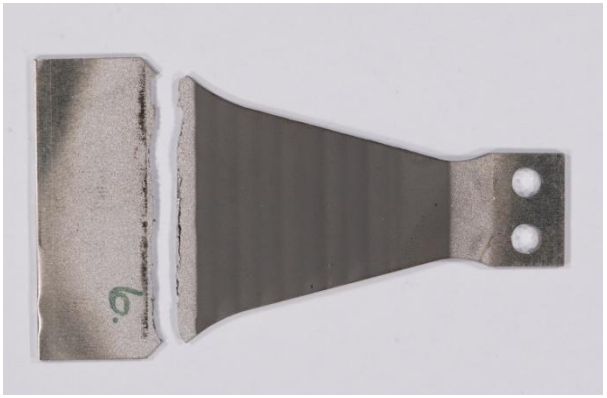
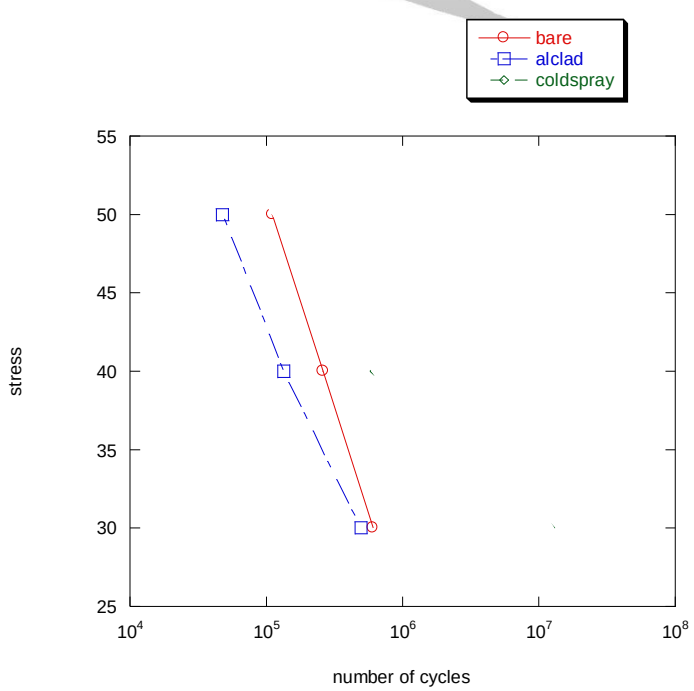
fatigue test result





Fatigue test result:

- **all CSP samples failed outside the coated region**
- **CSP applied Al-Co-Ce samples shows excellent resistance to fatigue, even superior to bare metal**

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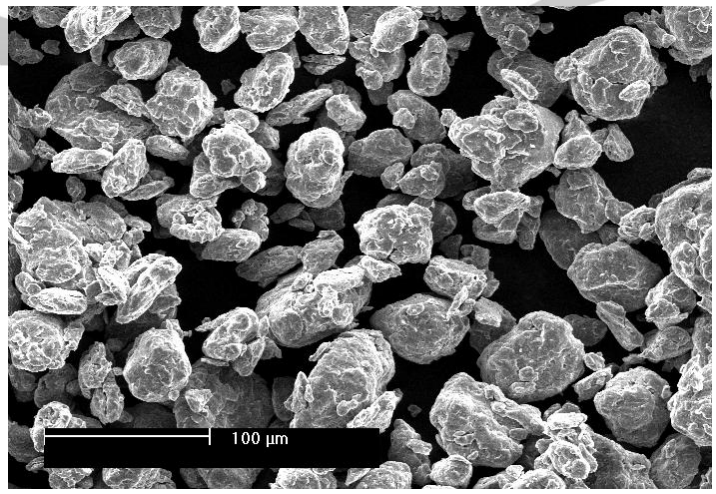
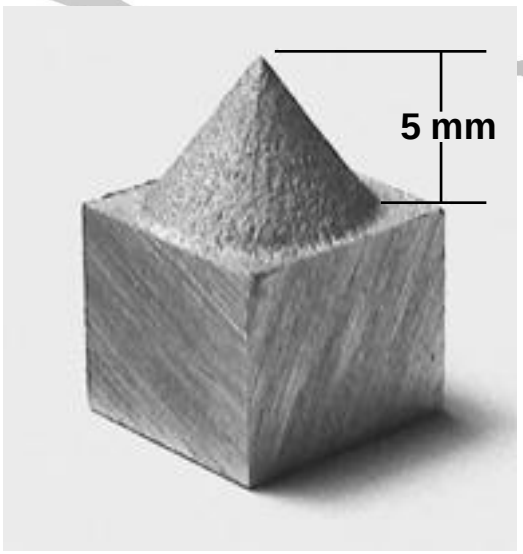
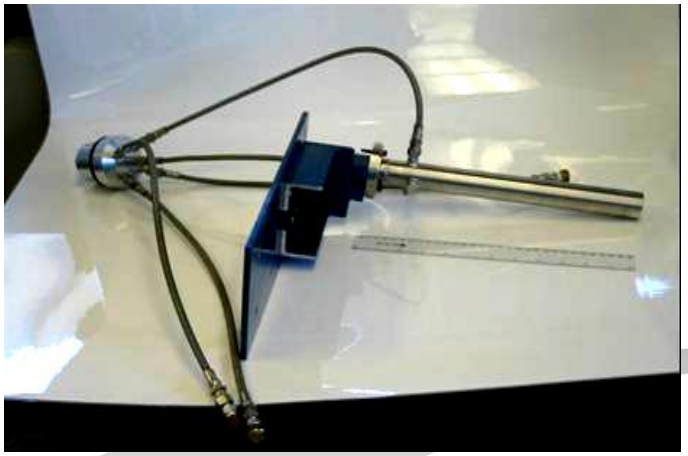
CSP of 5083 Al alloy



Cryomilled 5083 Al powder





Bertrand Jodoin @
U of Ottawa

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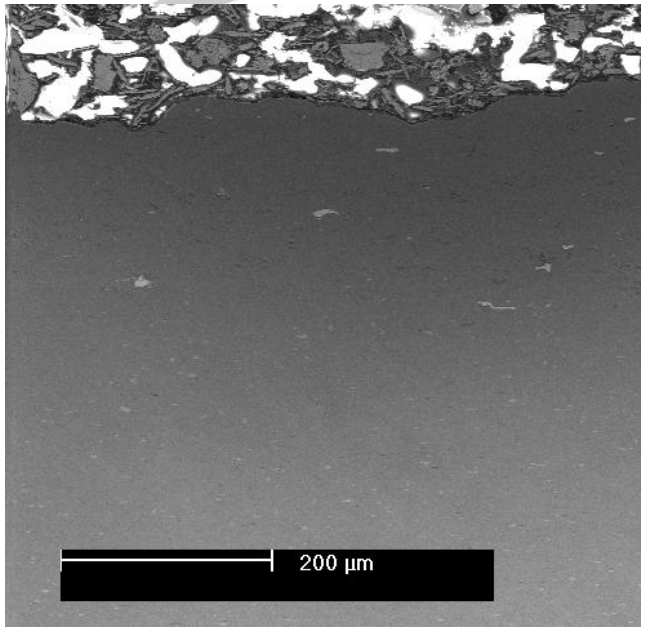
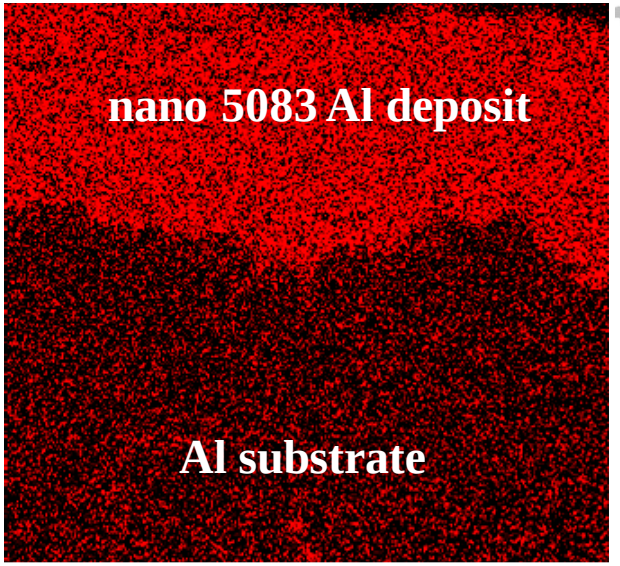
microstructure and hardness

nano 5083 Al



Leo Ajdelsztajn @ UC, Davis

Mg elemental mapping



Sample	Microhardness ($HV_{0.3}$)
cast 5083 Al	87 - 104
CSP 5083 Al	127
CSP n-5083 Al	261

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non-cryogenic processing of nanostructured metal powder

- **need to reduce cost of powder to pursue military applications**

n-metal powder processing

"Objective is to develop an economical means of producing equi-axed nanostructured metal powder using a NON-CRYOGENIC technology"

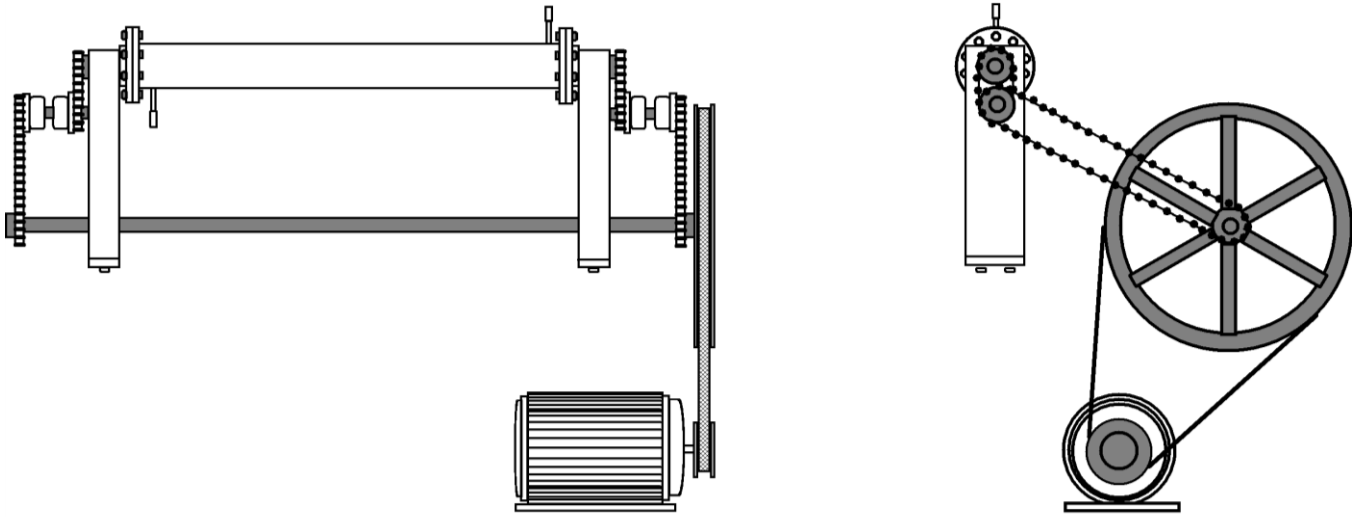
Immediate Target Materials:

- **AA5083**
- **NiCrAlY**

Partially Supported by United States Office of Naval Research

Dr. Lawrence T. Kabacoff – Program Officer

planetary grinding mill

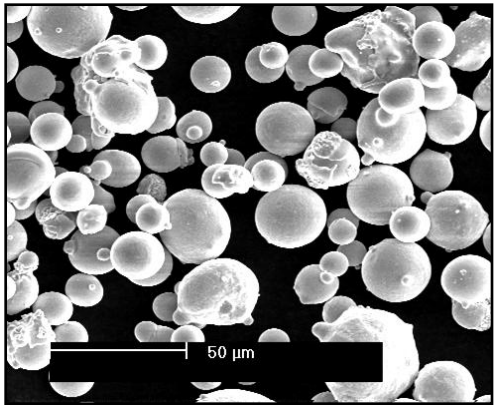


Characteristics:

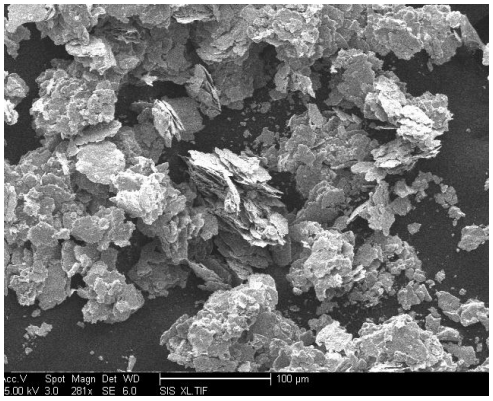
- **continuous feed capability**
- **high energy**
- **low wall contamination due to little movement of media w.r.t. chamber wall**
- **very rapid size reduction and dispersion**
- **good efficiency**
- **grinds metals, ceramics, intermetallics, and polymers to submicron or nano particle size range.**

non-cryogenic milling: lower cost processing of n-metallic powder

as-received



3.5 years

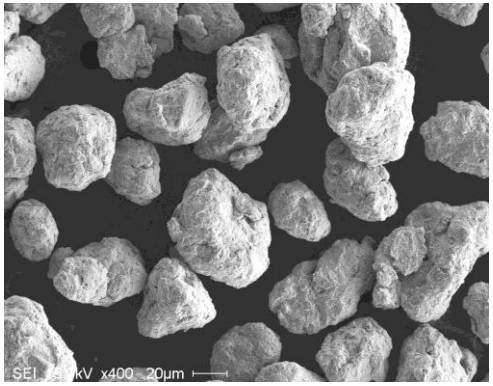


flake particles

"milling metal powders without LN2 is difficult!"

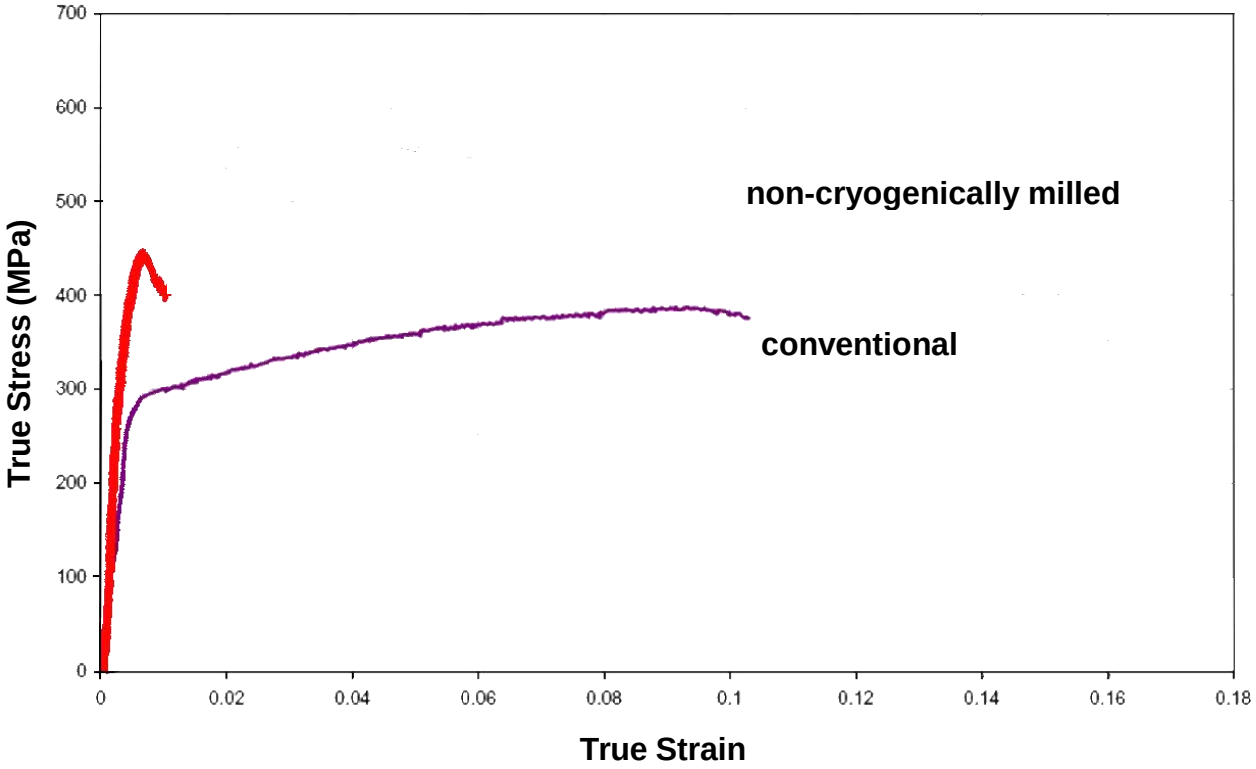
LN2 mitigates:
- **excessive welding of particles**
- **formation of flat particles**
- **oxidation of particles**

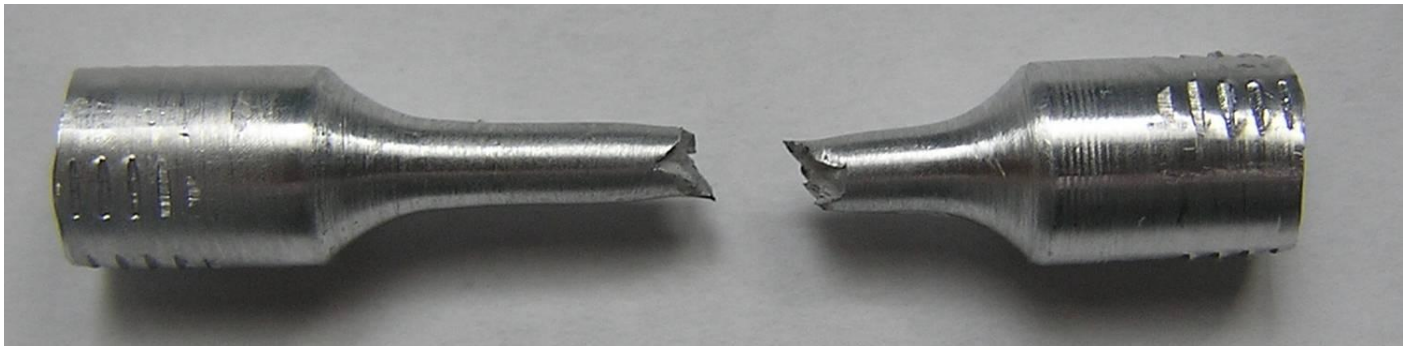
2007



equi-axed powder

non-cryogenic milling: AA5083 bulk sample tensile test results





non-cryogenic milling: AA5083 bulk sample tensile test results

Advantages:

- **no liquid nitrogen involved in process**
- **shorter processing duration**
- **enhanced strength with high ductility in P/M bulk samples; funded by ONR to optimize milling process and to identify mechanism for high ductility**

future work

- **ARL will develop cold spray parameters for the non-cryogenically milled AA5083 powder**
- **evaluation of the deposits will be carried out, i.e., metallography, XRD, microhardness**
- **US Naval Academy will evaluate cold sprayed nanostructured deposits for corrosion resistance and fatigue performance**
- **wear testing will also be carried out**

summary

- **bulk nanostructured Al alloys show a higher resistance to localized corrosion**
- **cold spray process was successfully used to deposit quality nanostructured Al alloy coatings**
- **cold sprayed Al-Co-Ce onto Al alloy samples showed superior fatigue resistance over ALCLADed and substrate-only samples**
- **cold sprayed n-Al alloys have potential for the repair of localized damage of aluminum structures and/or for the protection of metal surfaces against corrosion and wear**

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- **Mathieu Brochu (McGill U.)**
- **Bertrand Jodoin (UOttawa)**

Thank You!

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