

Microstructural Analysis of Cold Spray Aluminum Alloys

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Characterization Outline

Al 6061

- Helium vs. Nitrogen

Al 5083

- Conventional Al 5083
- Clean Al 5083
- Nano-Crystalline Al 5083

Chemistry

Comparative Properties

Microstructure

Composition

Tensile Data

Particle/Grain Size

Oxygen Content

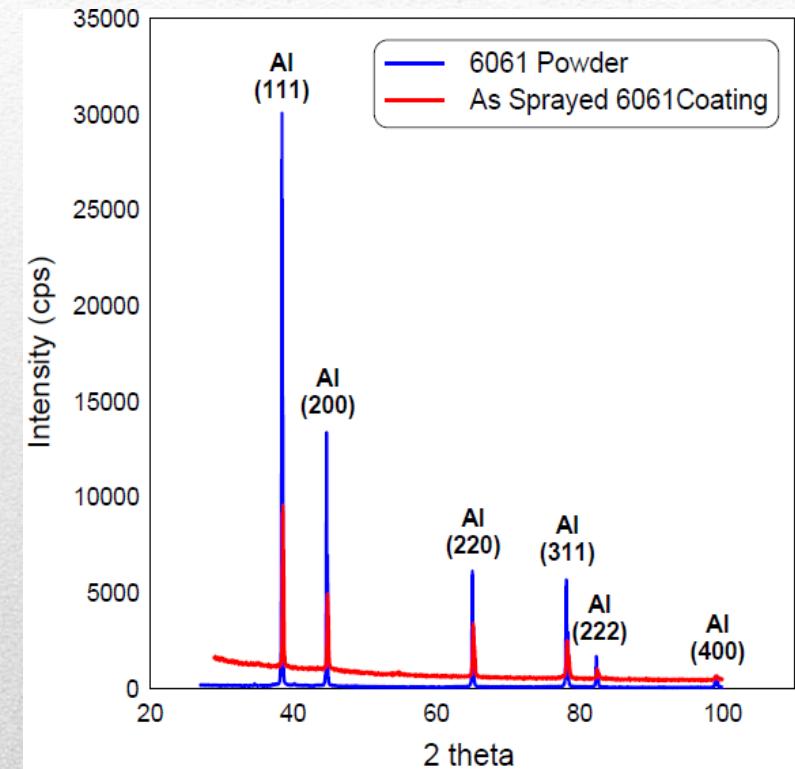
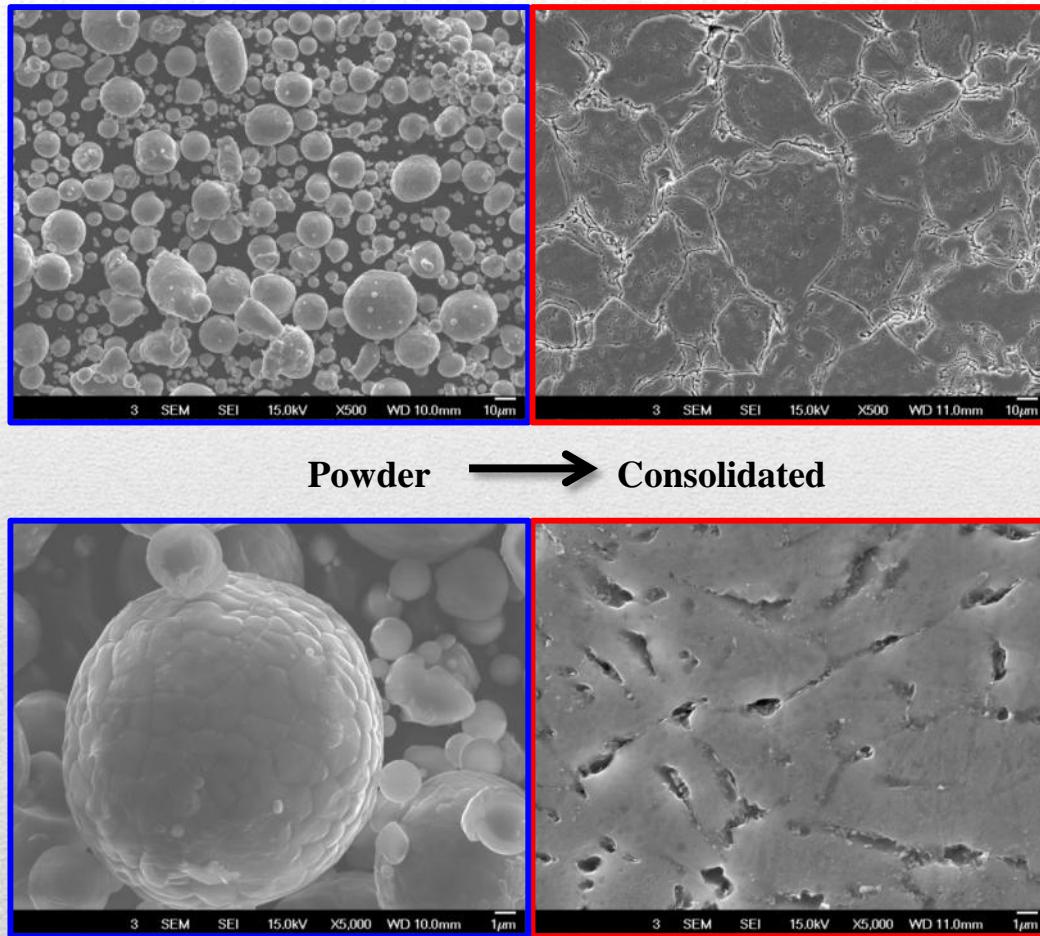
Hardness

Precipitates

Conductivity

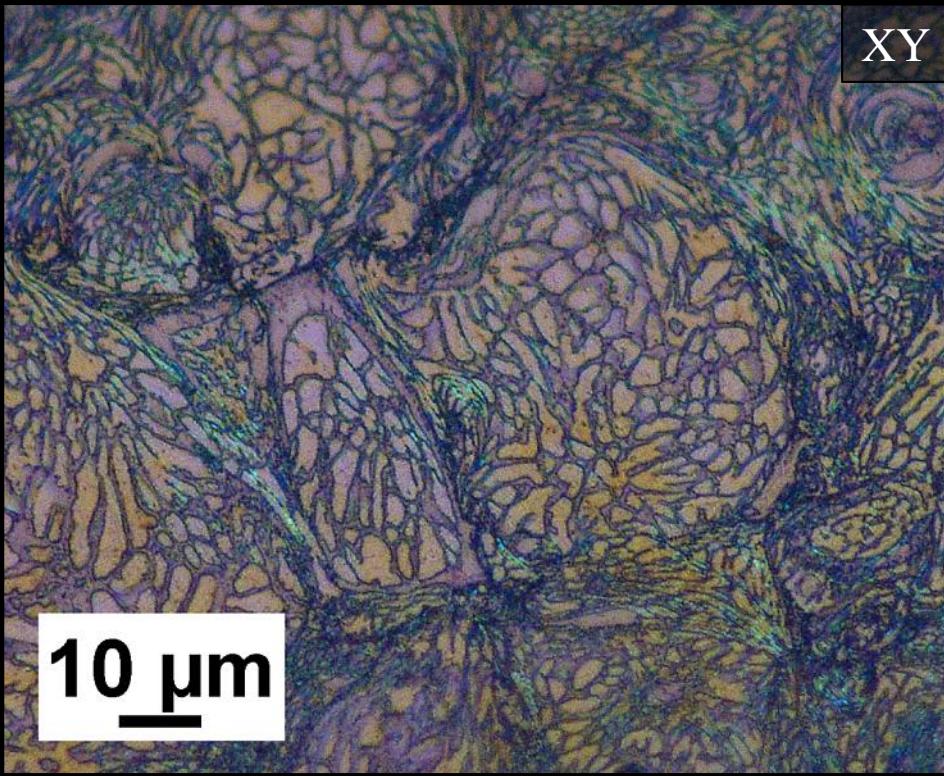


Al 6061 X-RAY Diffraction



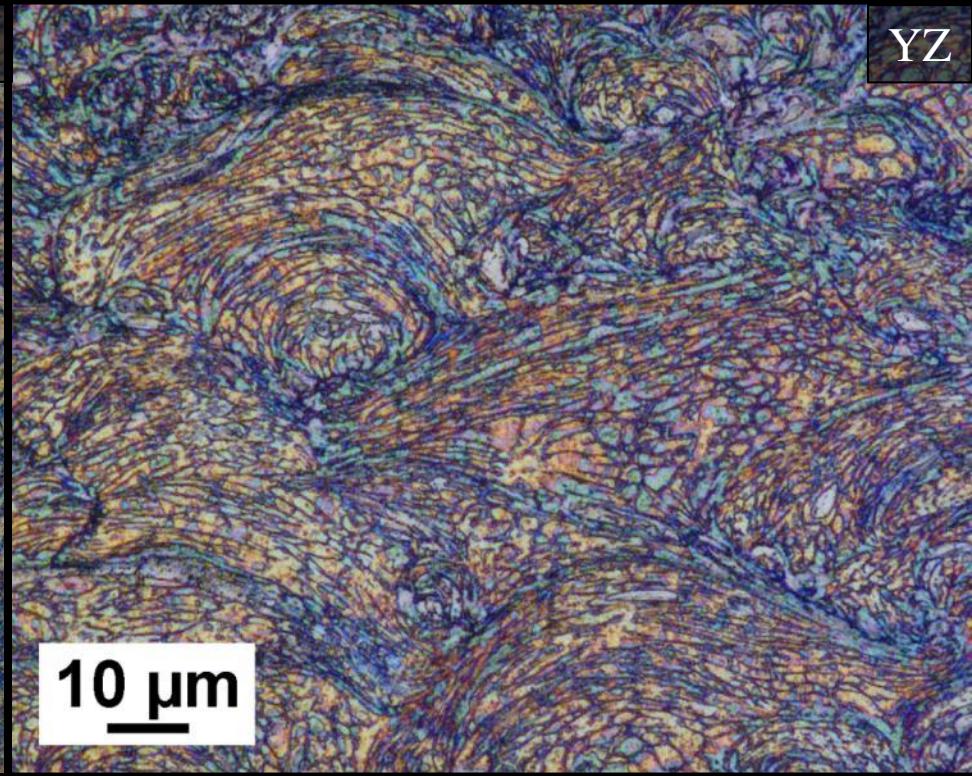
XRD pattern of Al 6061 powder and as-sprayed coating

Al 6061 Color Metallography



XY

10 μm



YZ

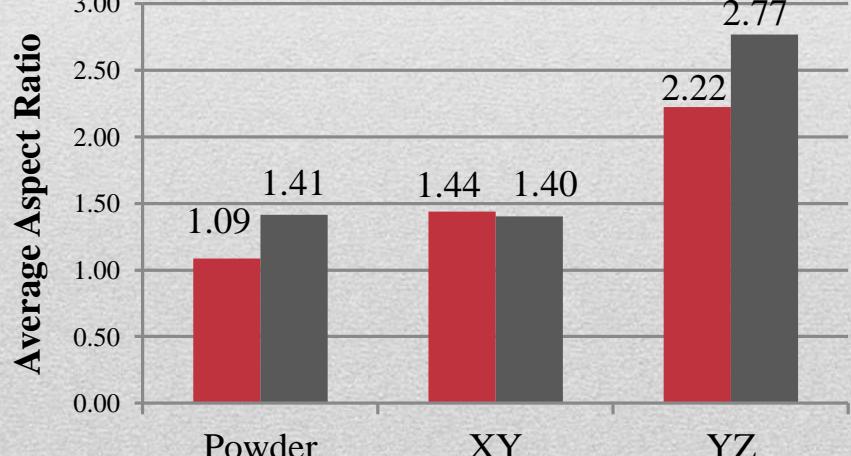
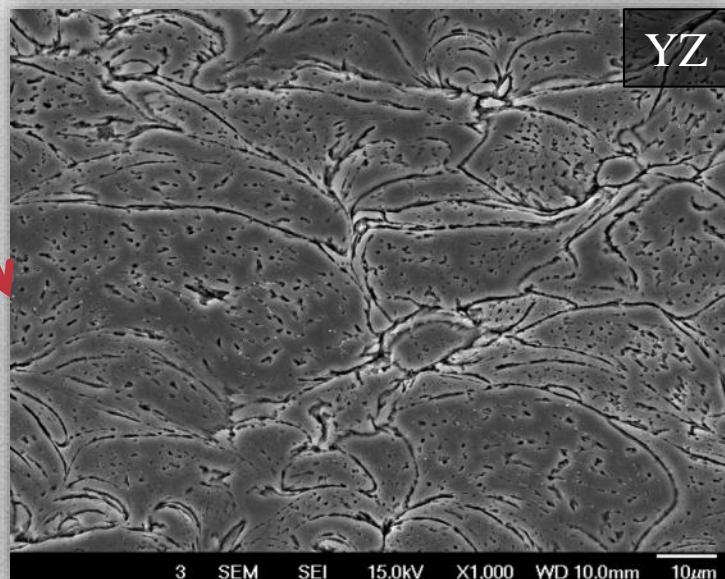
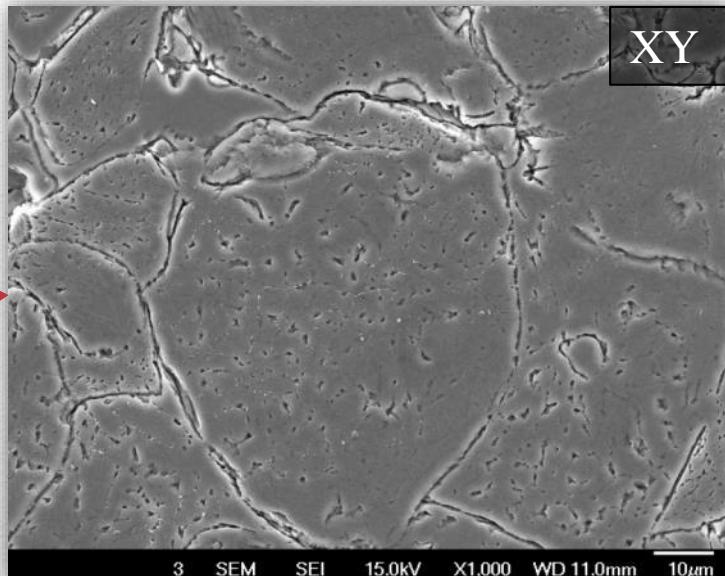
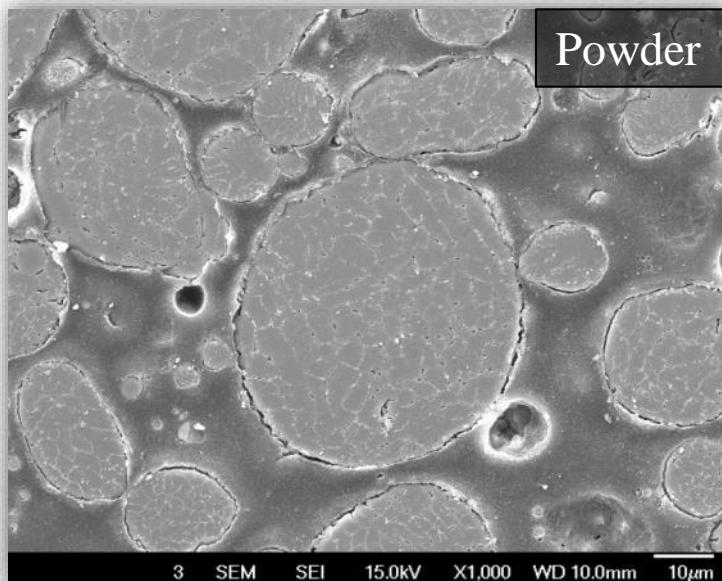
10 μm



WPI

Etched with variation of Weck's reagent and viewed under polarized light

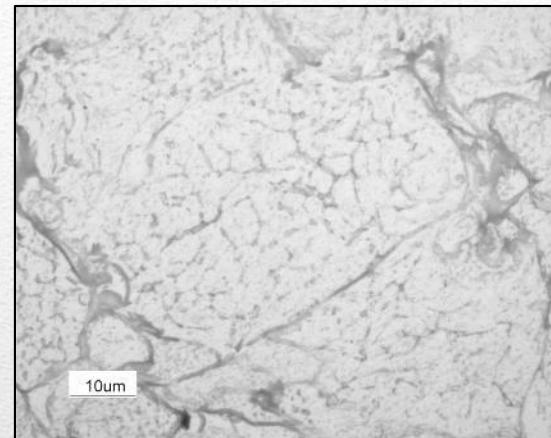
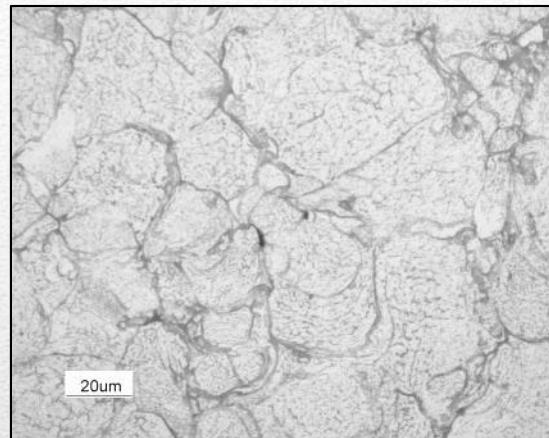
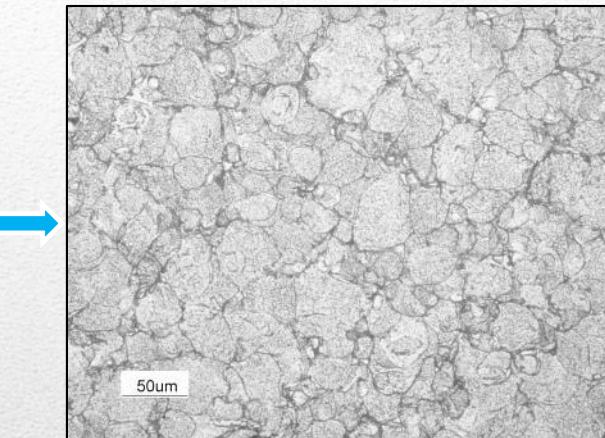
Al 6061 Particle/Grain Size



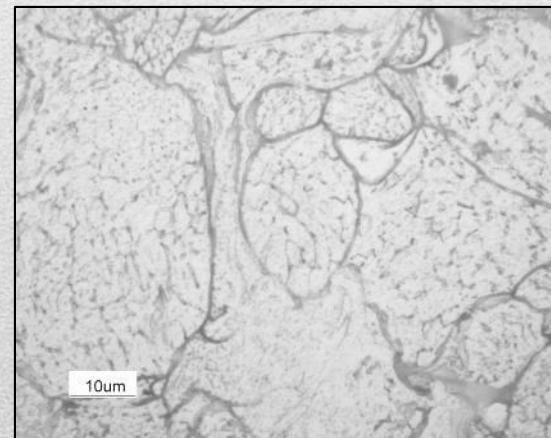
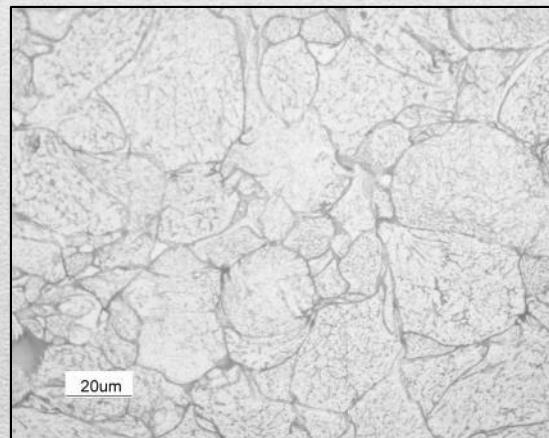
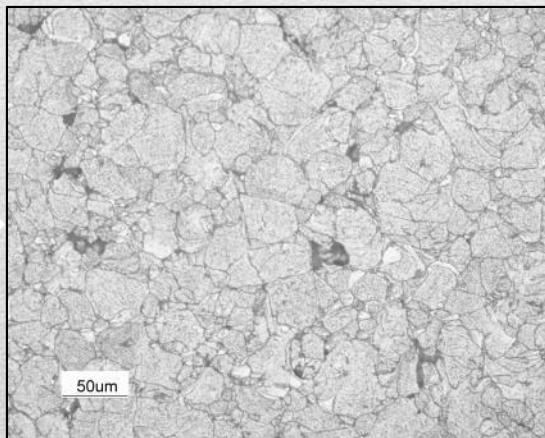
Al 6061 Microstructural Comparison

Helium vs. Nitrogen

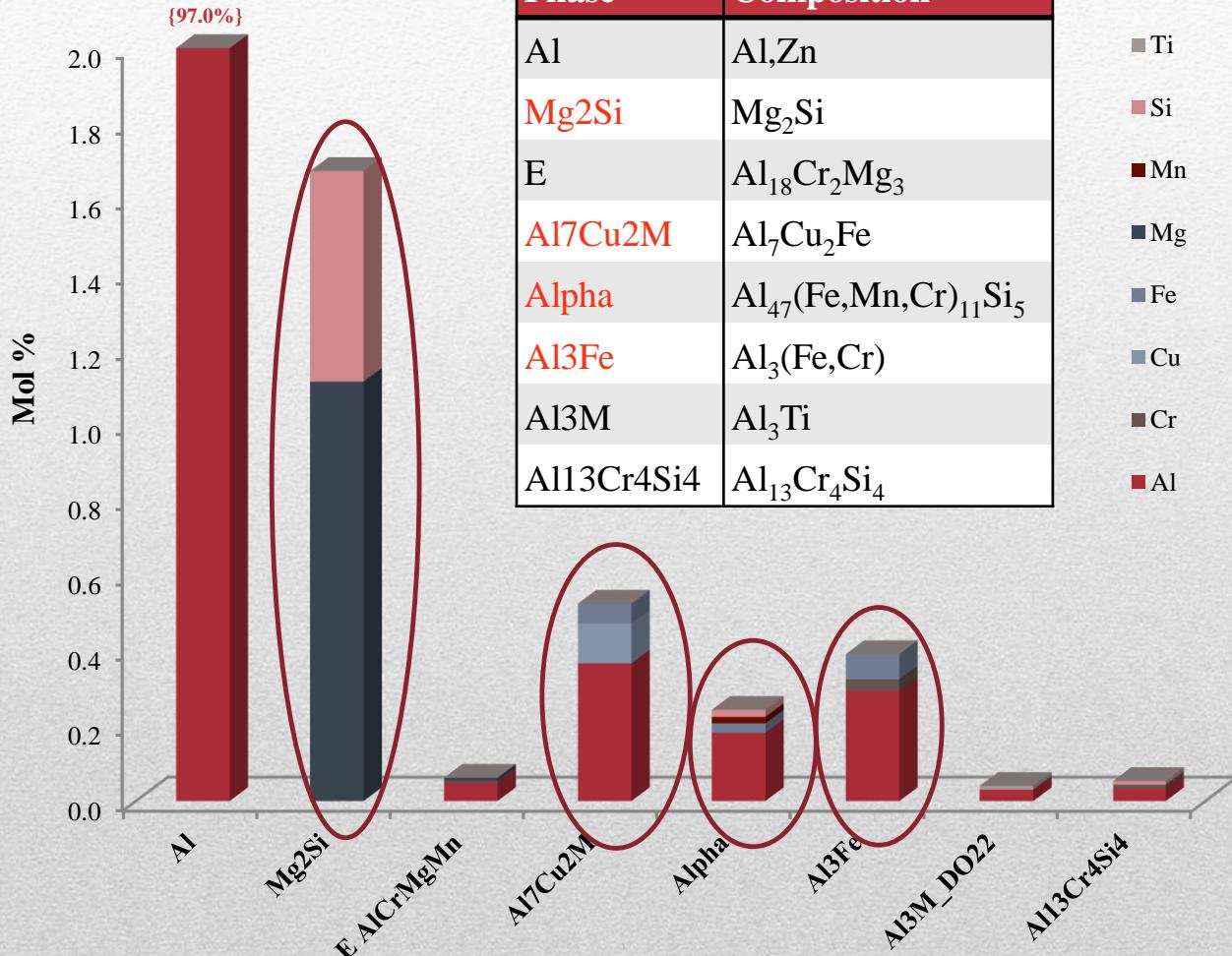
He



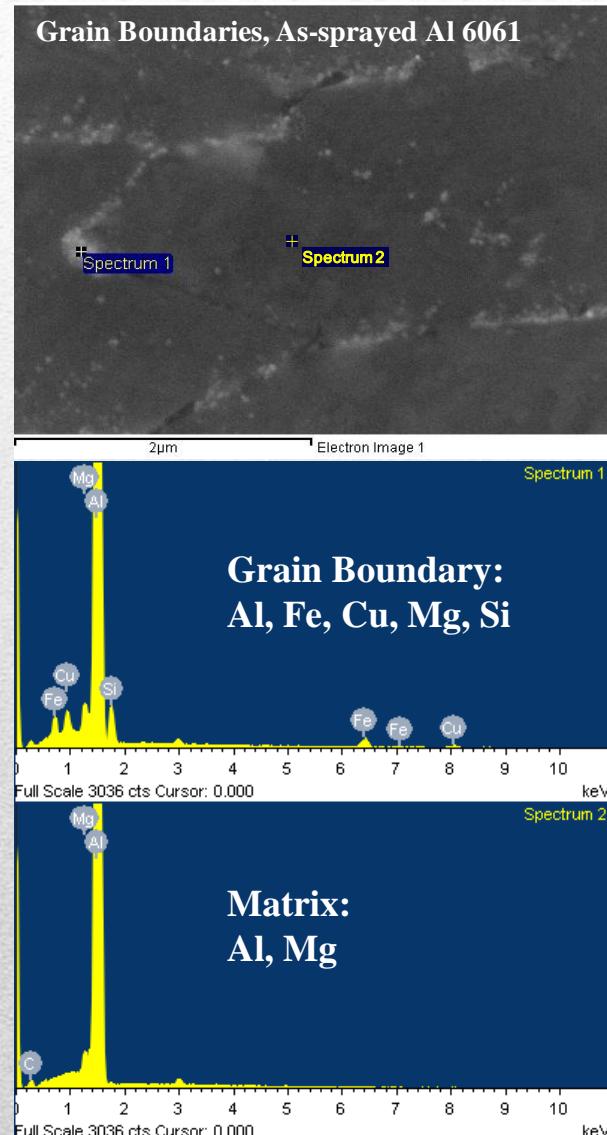
N₂



Al 6061 Precipitates at Grain Boundaries

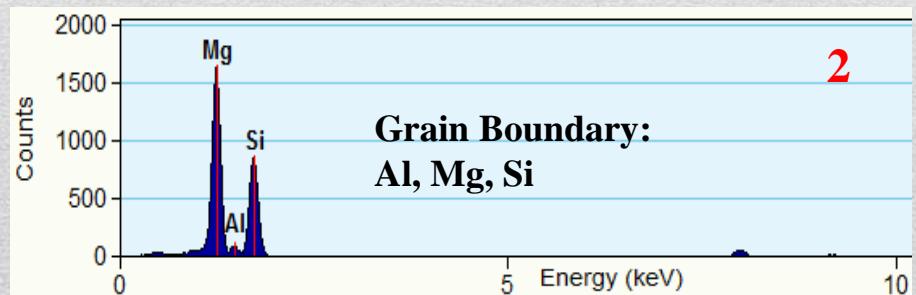
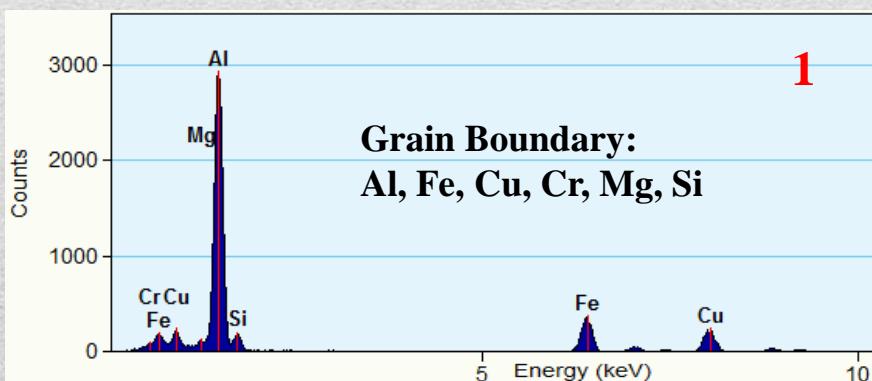
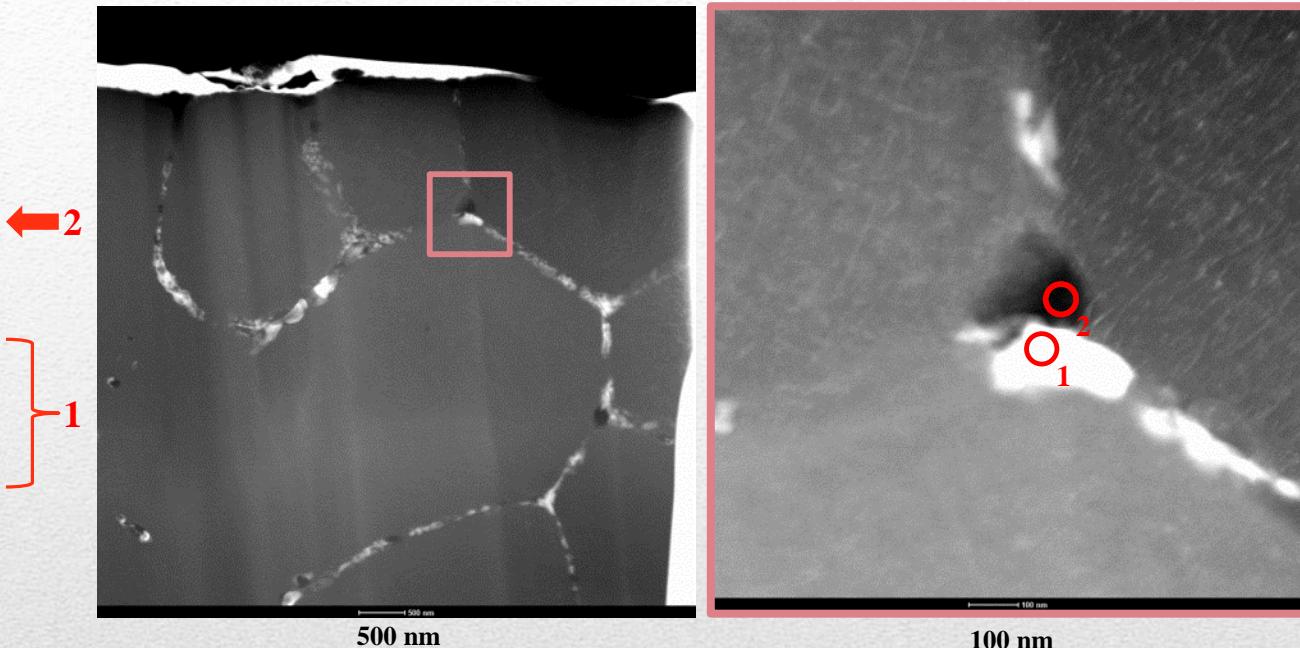


Phase	Composition
Al	Al, Zn
Mg ₂ Si	Mg ₂ Si
E	Al ₁₈ Cr ₂ Mg ₃
Al ₇ Cu ₂ M	Al ₇ Cu ₂ Fe
Alpha	Al ₄₇ (Fe,Mn,Cr) ₁₁ Si ₅
Al ₃ Fe	Al ₃ (Fe,Cr)
Al ₃ M	Al ₃ Ti
Al ₁₃ Cr ₄ Si ₄	Al ₁₃ Cr ₄ Si ₄



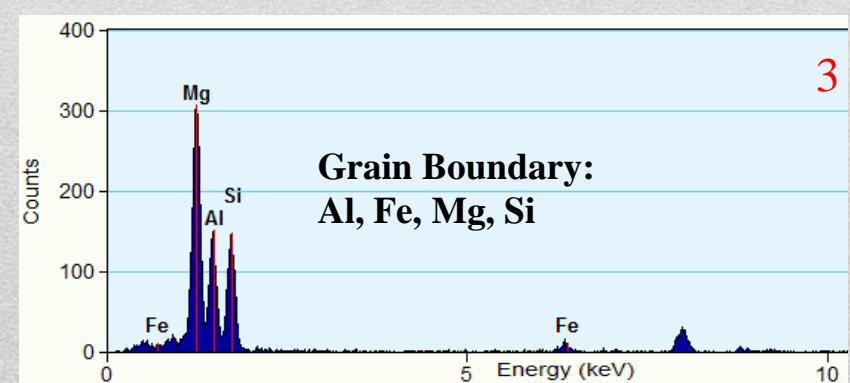
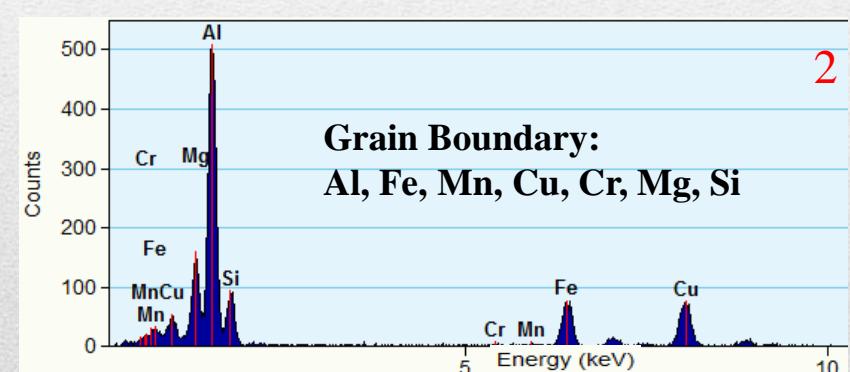
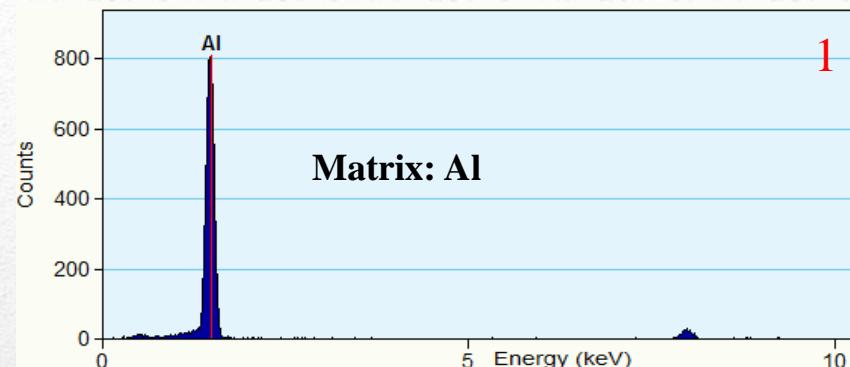
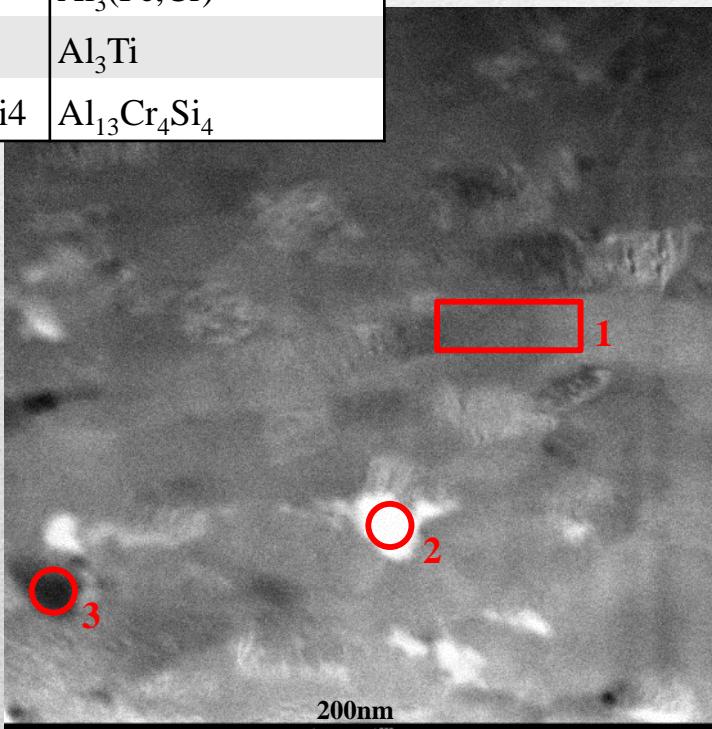
Al 6061 Powder Precipitates

Phase	Composition
Al	Al,Zn
Mg ₂ Si	Mg ₂ Si
E	Al ₁₈ Cr ₂ Mg ₃
Al ₇ Cu ₂ M	Al ₇ Cu ₂ Fe
Alpha	Al ₄₇ (Fe,Mn,Cr) ₁₁ Si ₅
Al ₃ Fe	Al ₃ (Fe,Cr)
Al ₃ M	Al ₃ Ti
Al ₁₃ Cr ₄ Si ₄	Al ₁₃ Cr ₄ Si ₄

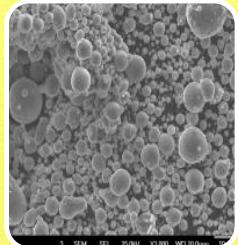


Al 6061 Consolidated Precipitates

Phase	Composition
Al	Al,Zn
Mg ₂ Si	Mg ₂ Si
E	Al ₁₈ Cr ₂ Mg ₃
Al ₇ Cu ₂ M	Al ₇ Cu ₂ Fe
Alpha	Al ₄₇ (Fe,Mn,Cr) ₁₁ Si ₅
Al ₃ Fe	Al ₃ (Fe,Cr)
Al ₃ M	Al ₃ Ti
Al ₁₃ Cr ₄ Si ₄	Al ₁₃ Cr ₄ Si ₄

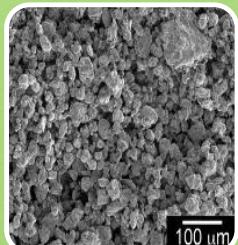


Al 5083 Sample Summary



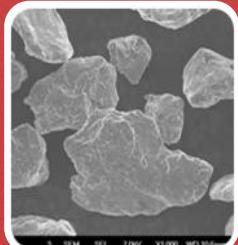
Conventional Al 5083

- No Powder Preparation
- Sprayed with He



“Clean” Al 5083

- Reduced Iron Content
- Cryomilled
- Dynamically Degassed
- Sprayed with He

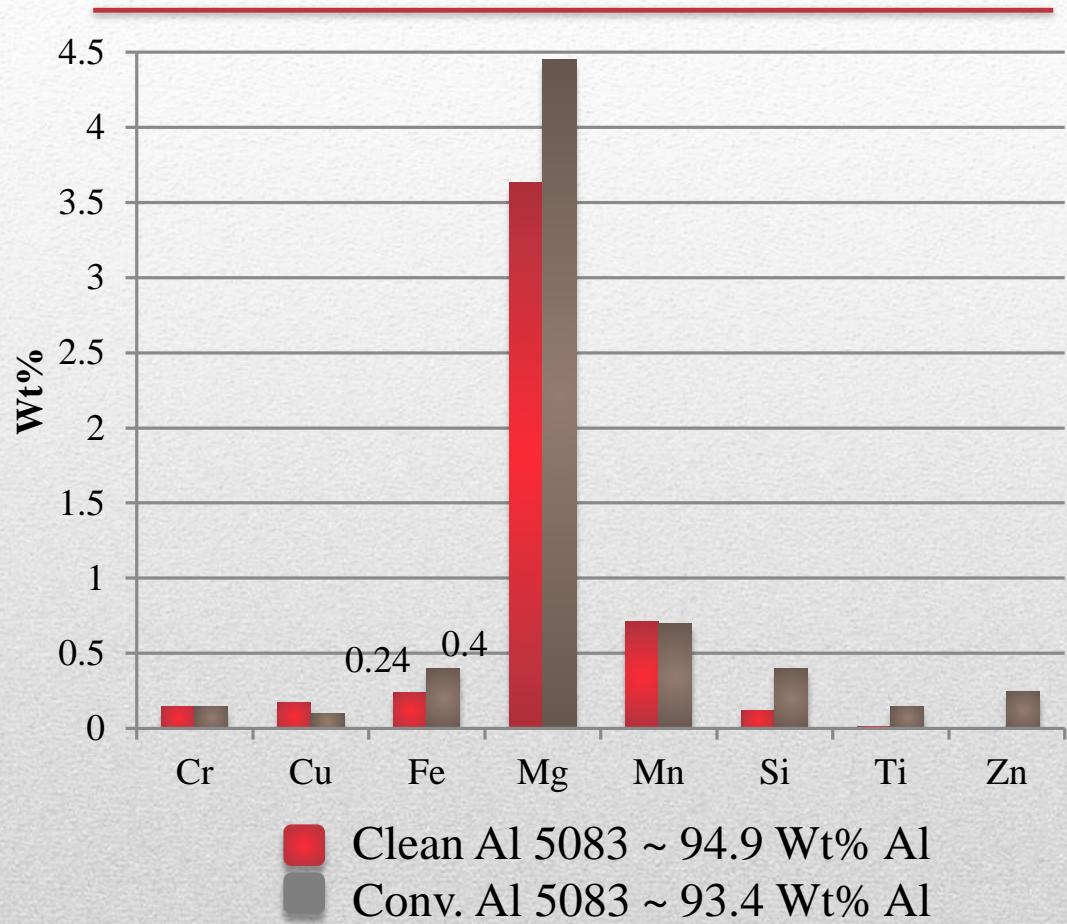


Nano-Crystalline Al 5083

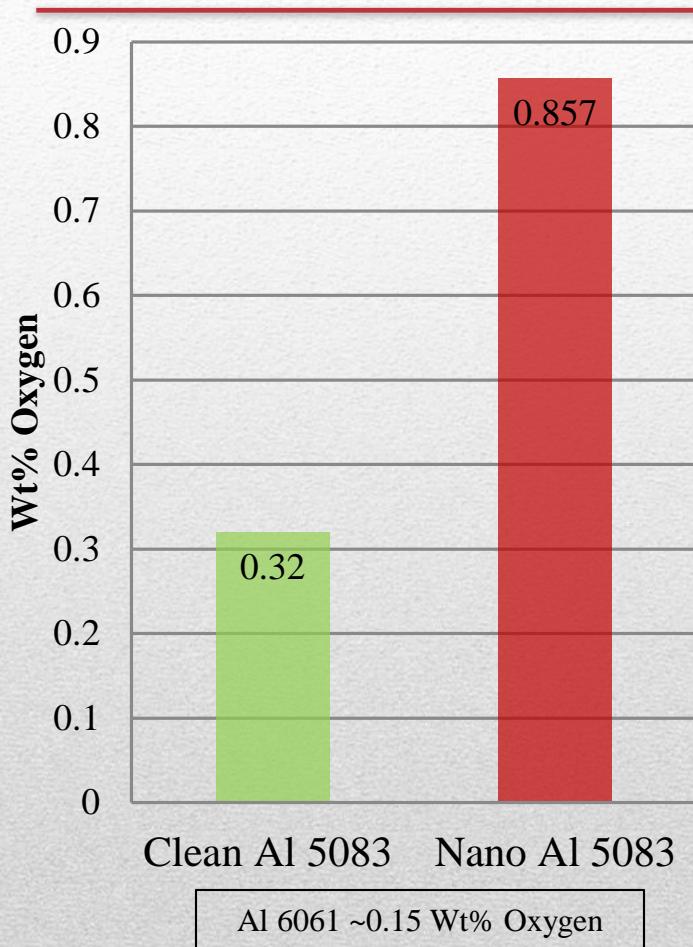
- Milled
- Dynamically Degassed
- Sprayed with He

Al 5083 Chemistry

Chemical Composition

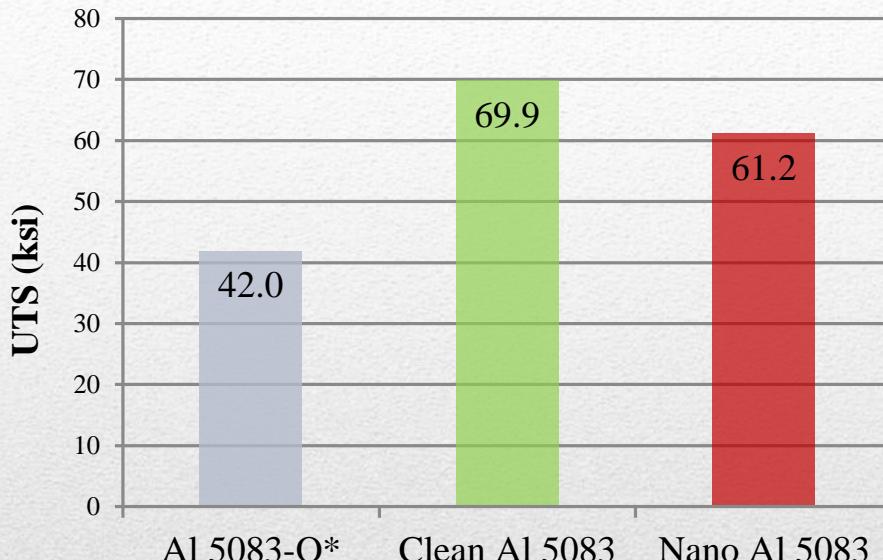


Oxygen Content

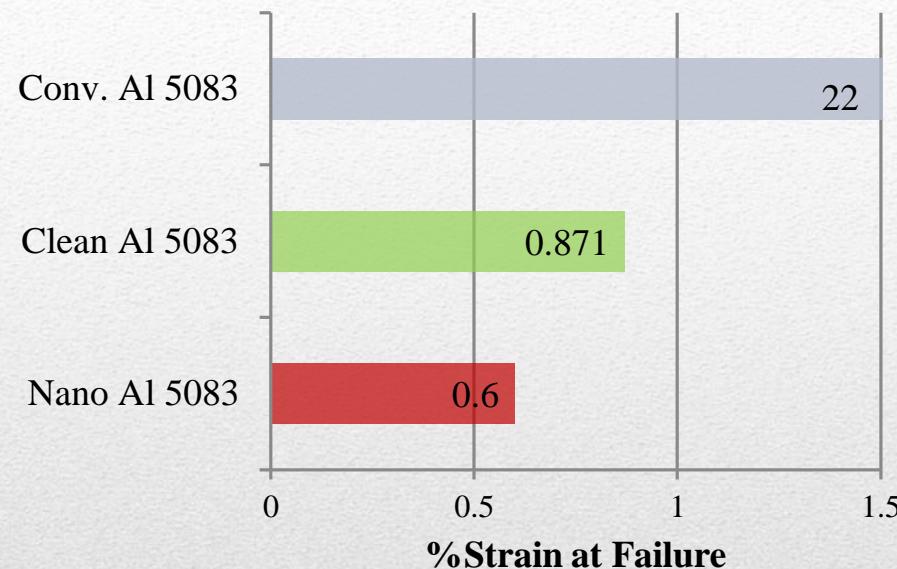


Al 5083 Properties

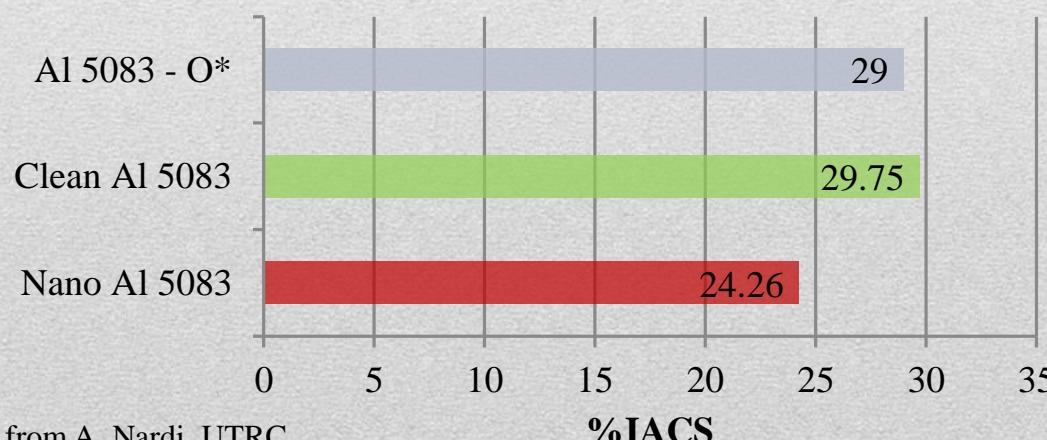
Ultimate Tensile Strength of Al 5083



%Strain @ Failure for Al 5083



Electrical Conductivity

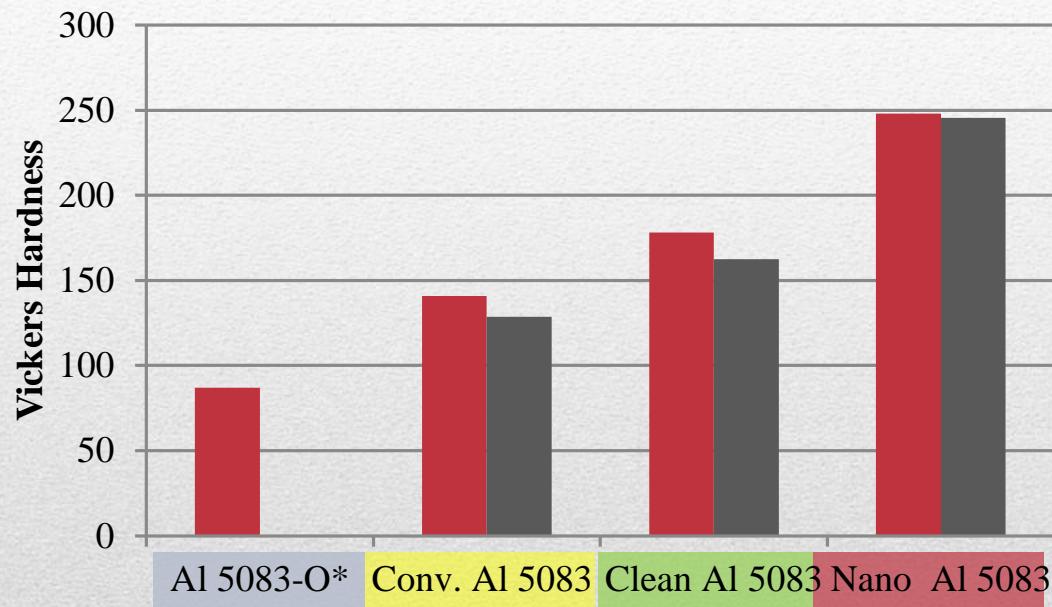


Data from A. Nardi, UTRC

*Properties of Wrought Aluminum and Aluminum Alloys, *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Vol 2, ASM Handbook, ASM International, 1990, p 62-122

Al 5083 Vickers Hardness

Hardness of Al 5083



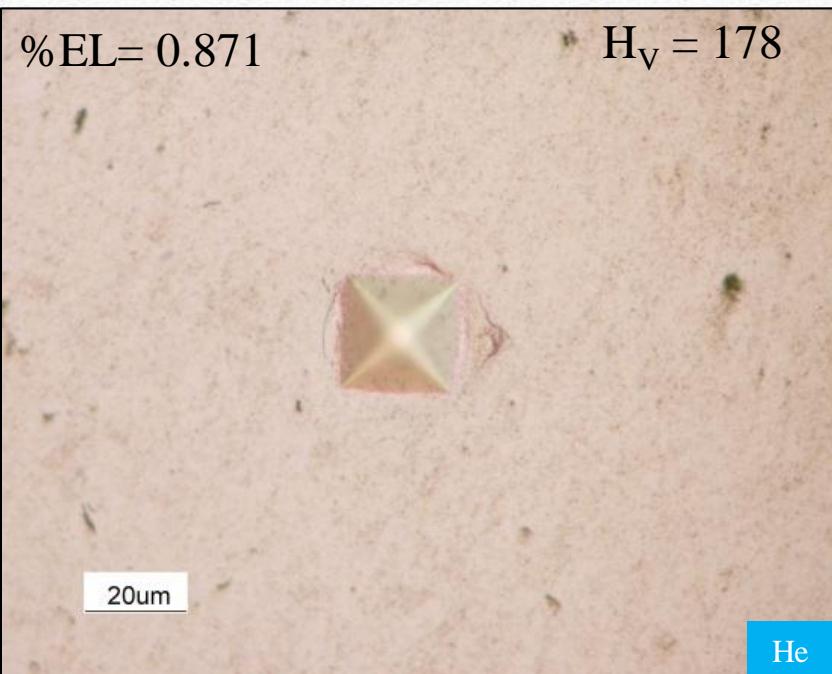
Vickers Hardness		
	XY	YZ
Al 5083-O	87	N/A
Conv Al 5083	141.0	128.8
Clean Al 5083	178.2	162.5
Nano Al 5083	248.2	245.7



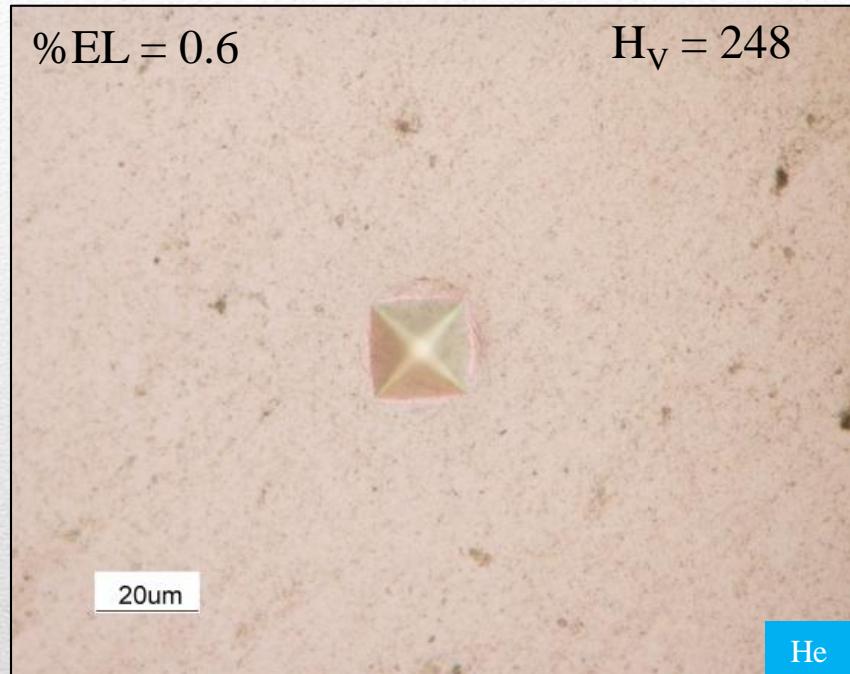
WPI

*Properties of Wrought Aluminum and Aluminum Alloys, *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Vol 2, ASM Handbook, ASM International, 1990, p 62–122

Al 5083 Vickers Indents

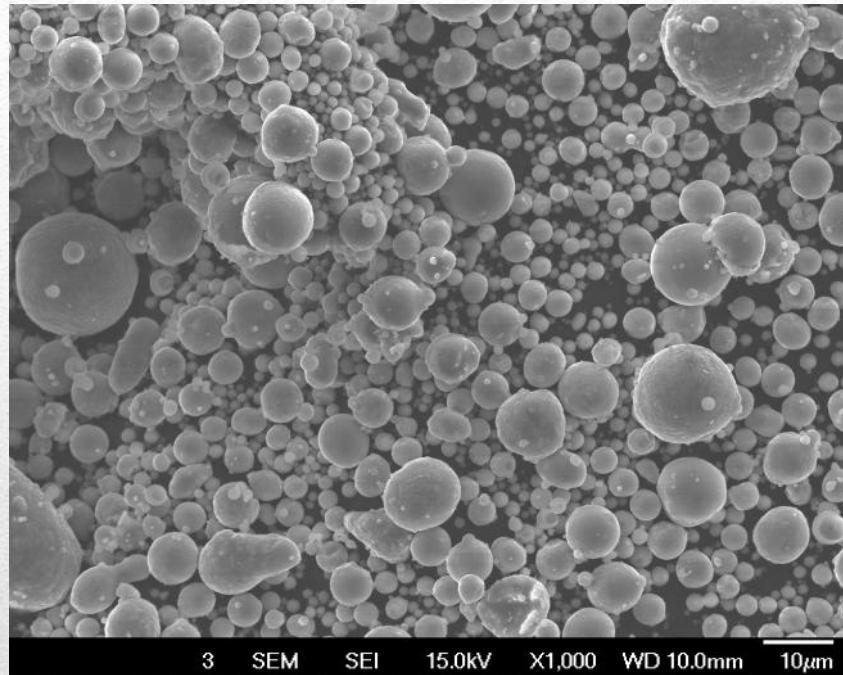


Clean Al 5083



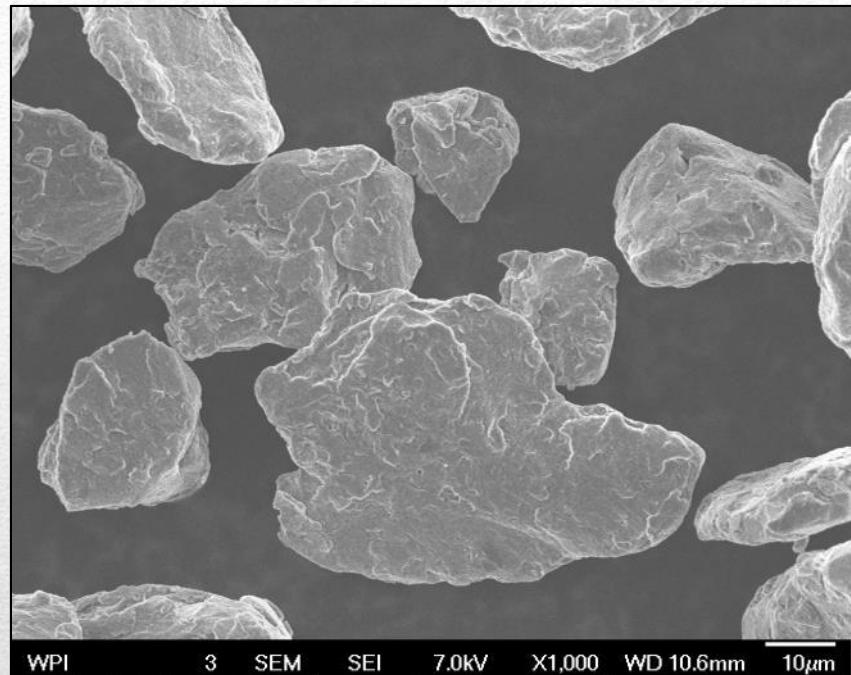
Nano Al 5083

Al 5083 Powder Particle Size



3 SEM SEI 15.0kV X1,000 WD 10.0mm 10µm

Conv. Al 5083



WPI 3 SEM SEI 7.0kV X1,000 WD 10.6mm 10µm

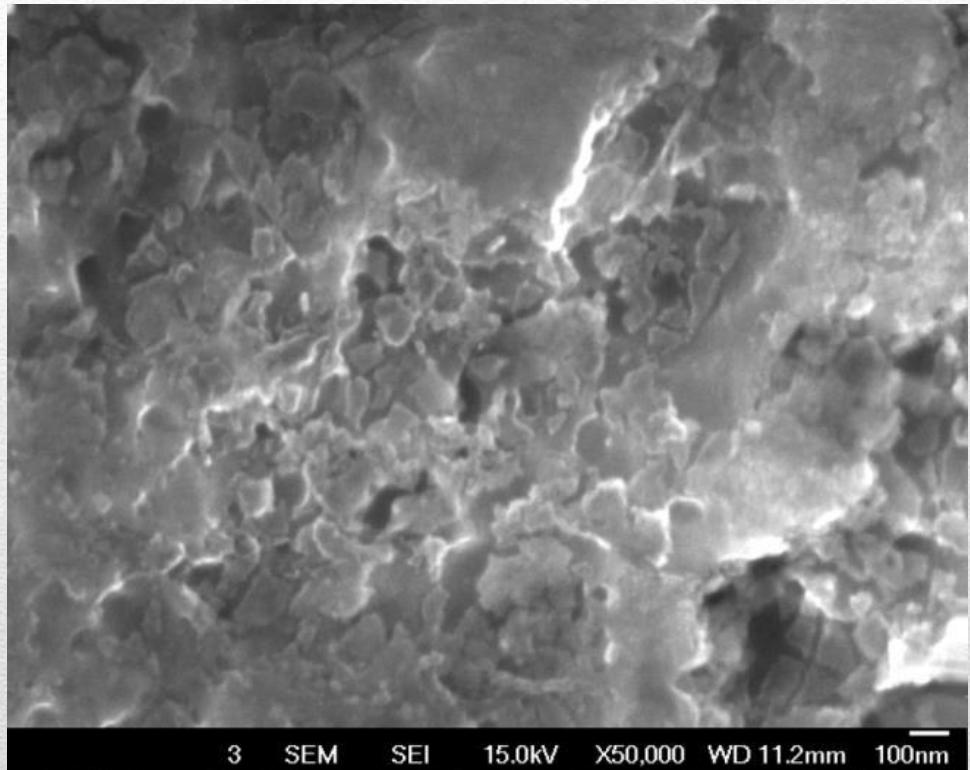
Nano Al 5083

	Major Axis (μm)	Minor Axis (μm)	Average Aspect Ratio
Conv. Al 5083	2.32	2.18	1.04
Nano Al 5083	48.1	33.2	1.45

Al 5083 Powder Grain Size

Nano Al 5083

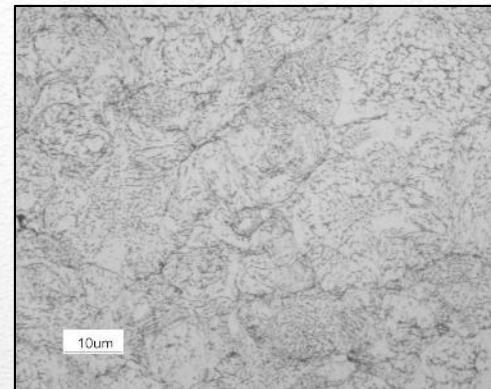
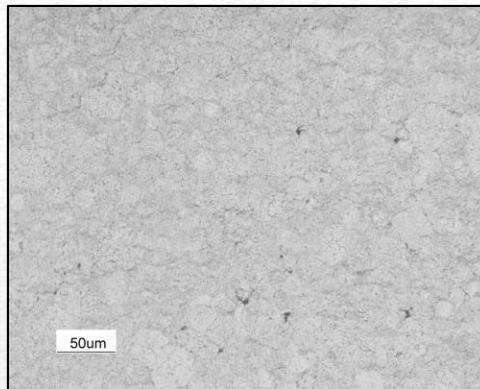
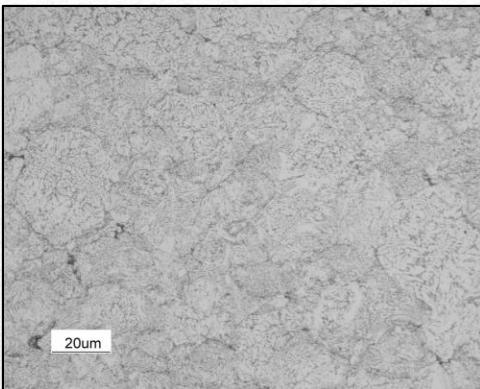
Major Axis	124 nm
Minor Axis	87 nm
Aspect Ratio	1.43



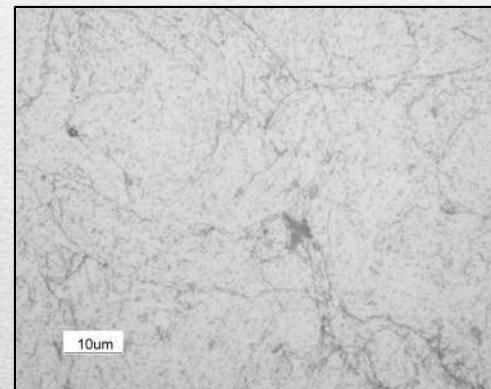
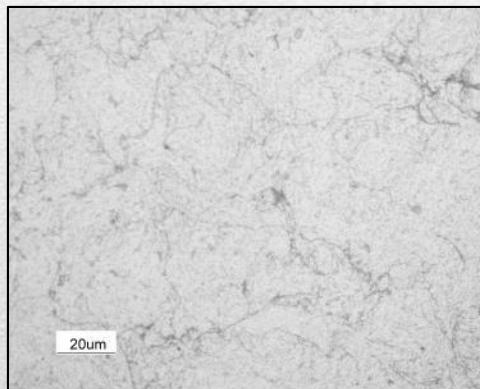
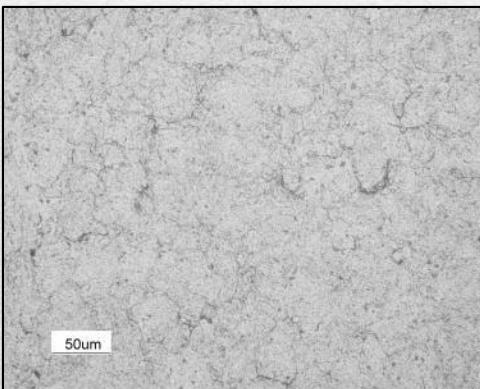
Nano Al 5083

Al 5083 Microstructural Comparison - XY

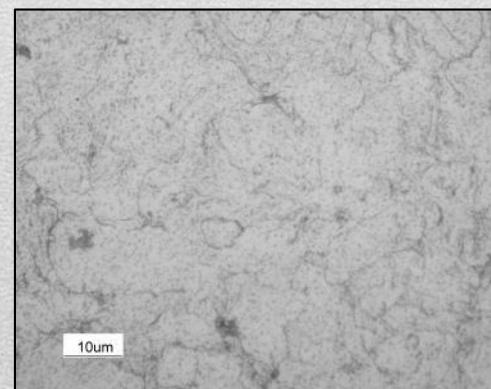
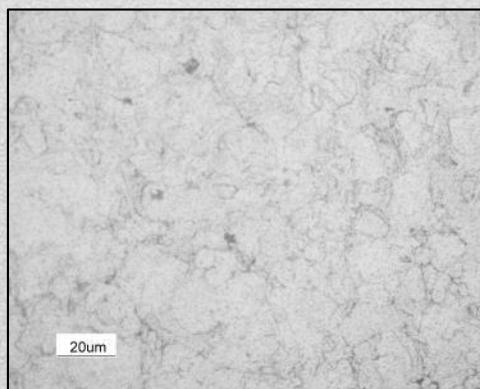
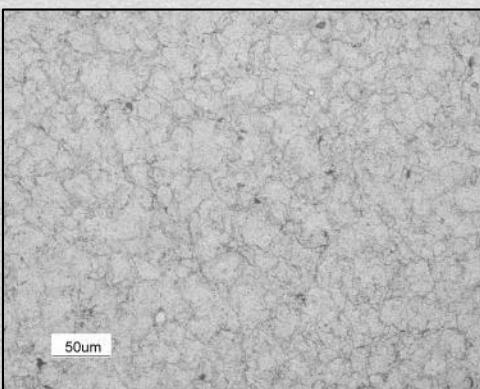
Conv. Al 5083



Clean Al 5083

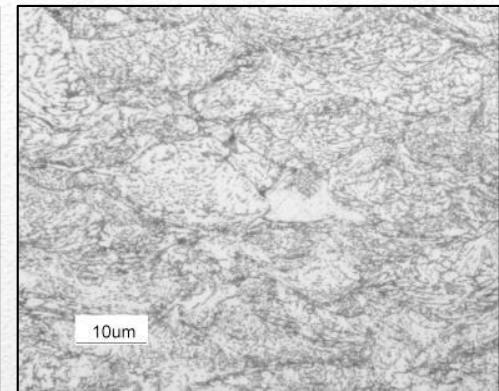
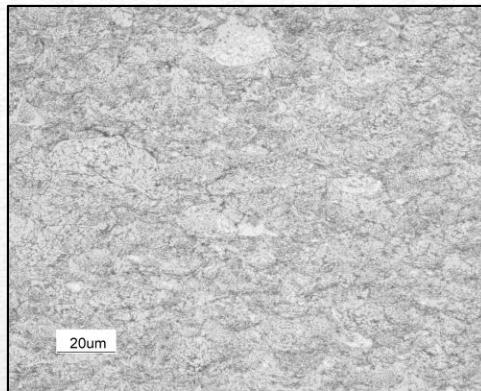
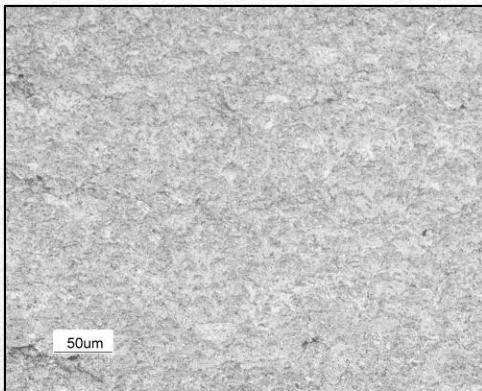


Nano Al 5083

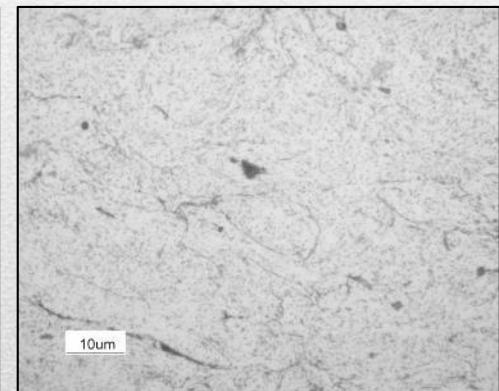
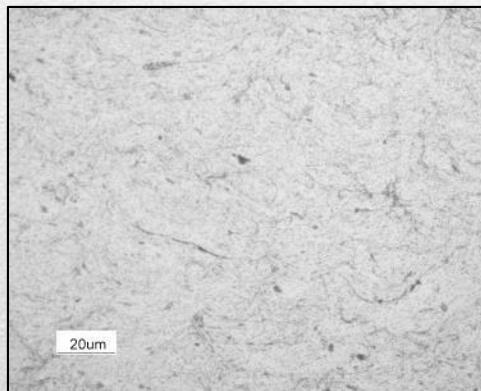
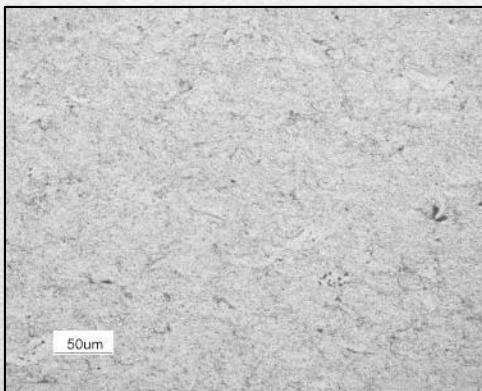


Al 5083 Microstructural Comparison - YZ

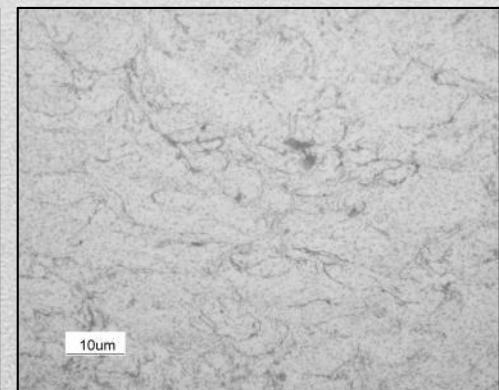
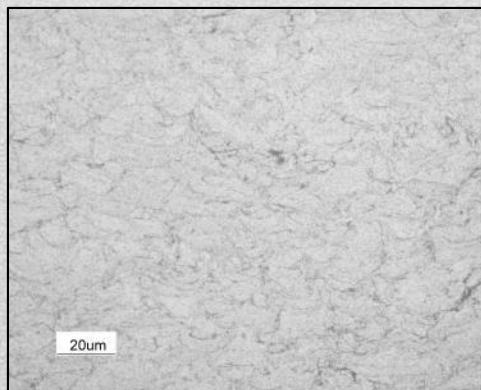
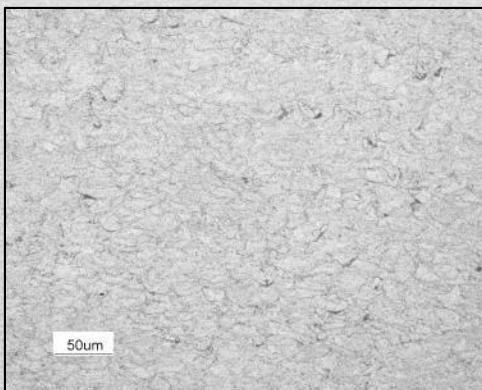
Conv. Al 5083



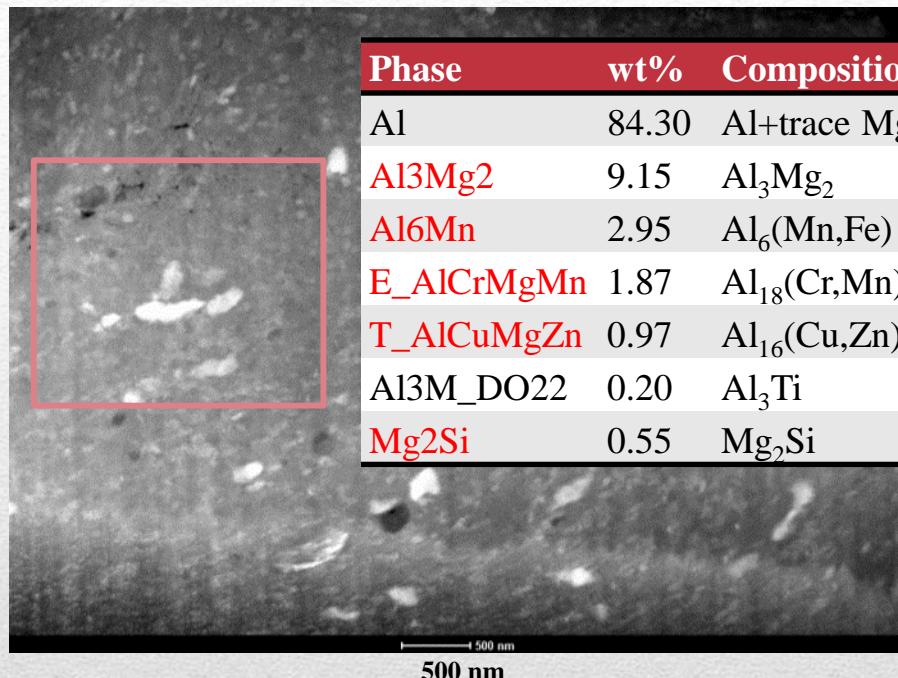
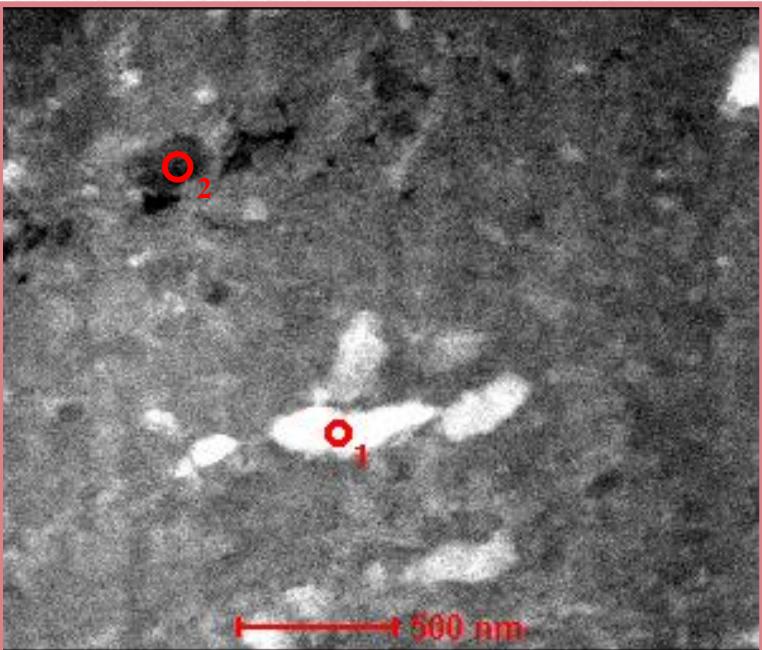
Clean Al 5083



Nano Al 5083

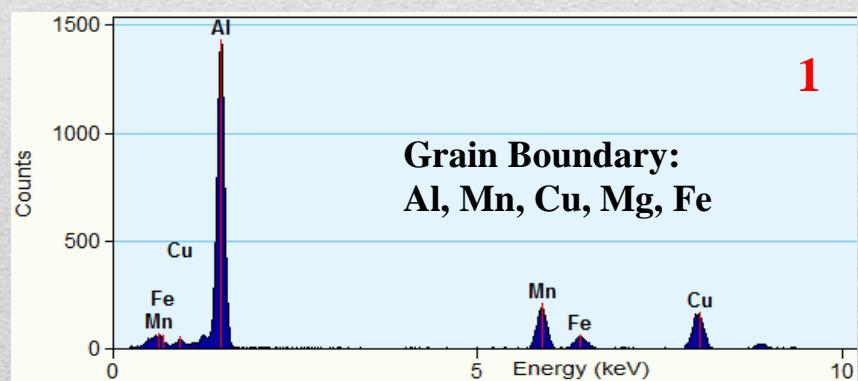


Nano Al 5083 Consolidated Precipitates

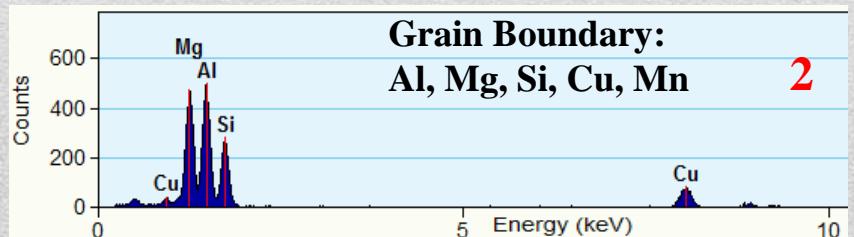


Phase	wt%	Composition
Al	84.30	Al+trace Mg
Al ₃ Mg ₂	9.15	Al ₃ Mg ₂
Al ₆ Mn	2.95	Al ₆ (Mn,Fe)
E_AlCrMgMn	1.87	Al ₁₈ (Cr,Mn) ₂ Mg ₃
T_AlCuMgZn	0.97	Al ₁₆ (Cu,Zn) ₂ Mg ₁₁
Al ₃ M_DO22	0.20	Al ₃ Ti
Mg ₂ Si	0.55	Mg ₂ Si

2
1, 2
2

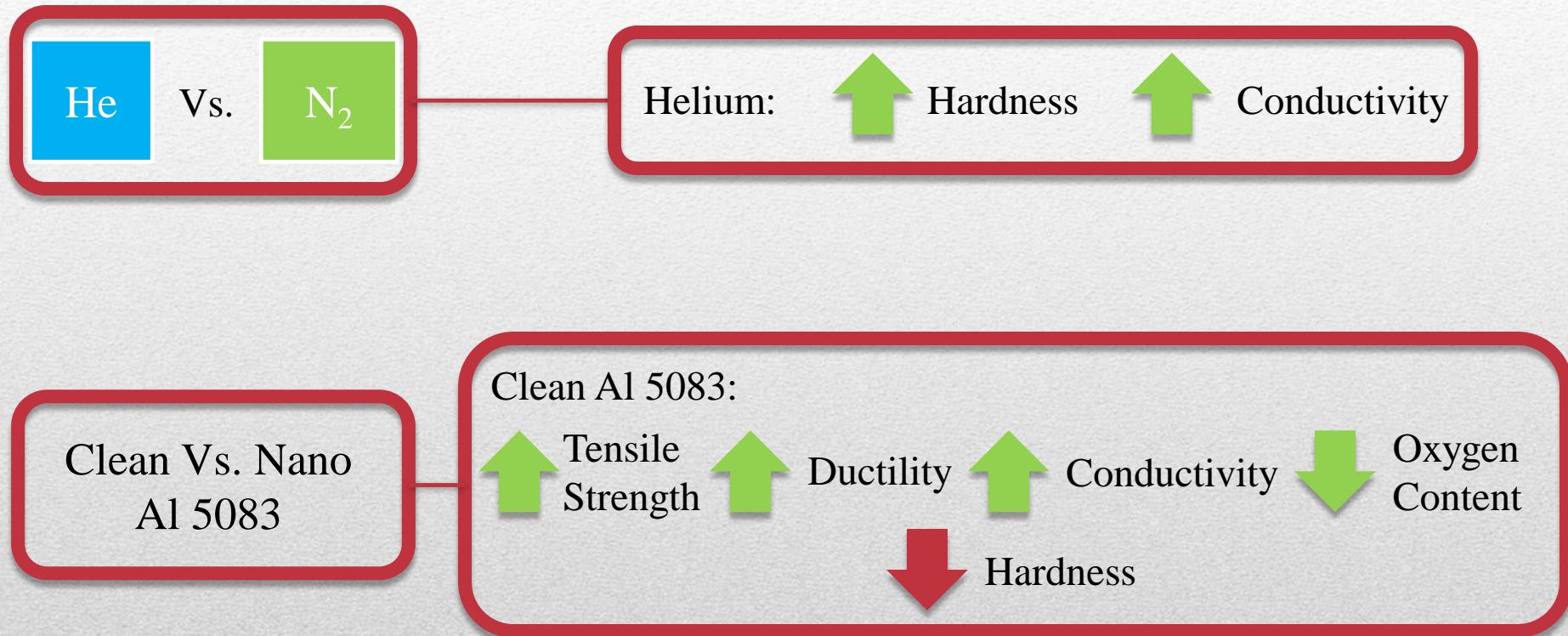


1



2

Summary



Thank You

- Acknowledgements:
 - Vic Champagne, Army Research Lab
 - Contract #W911NF-10-2-0098
 - Aaron Nardi and Matt Mordasky, UTRC
 - Yongho Sohn, University of Central Florida

