U.S. DEPARTMENT OF ENERGY
Office of Electricity

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Development of Al/Ca Composite Conductor for Mono-Type Transmission Cable

TRAC Program Peer Review Event

US Department of Energy, Office of Electricity

Presented at: ORNL, Hardin Valley Campus

Knoxville, Tennessee

June 28, 2023

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Ames Lab contract DE-AC02-07CH11358

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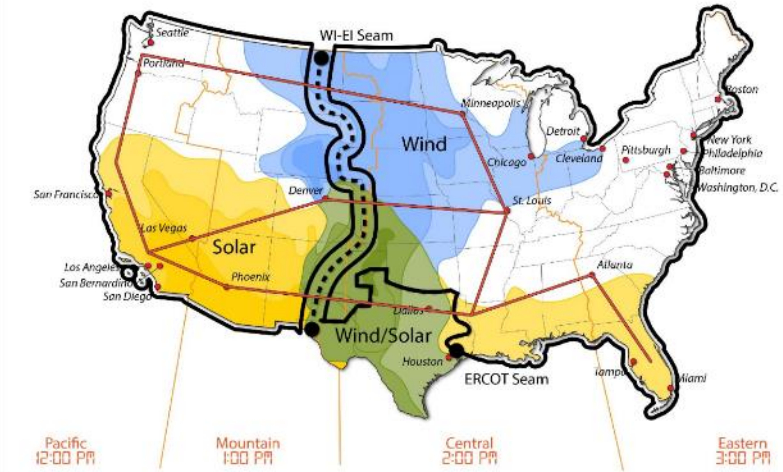
The Numbers

- DOE PROGRAM OFFICE:
  OE – Transformer Resilience and Advanced Components (TRAC)
- FUNDING OPPORTUNITY:
  Agreement # 35317 (1.22.510)
- LOCATION:
  Ames, Iowa
- PROJECT TERM:
  08/01/2022 to 10/31/2024
- PROJECT STATUS:
  Ongoing
- AWARD AMOUNT (DOE CONTRIBUTION):
  $550,000
- AWARDEE CONTRIBUTION (COST SHARE):
  $0
- PARTNERS:
  Ervin Industries, Tecumseh, MI (CRADA)

Motivation for Overhead Conductor Technology

- **Increased global demand for new conductor cable, 16 million miles by 2030**
- **Macrogrid study, cost-effective design utilizing HVDC to connect renewables in the United States**
- **Opportunity: Need for increased ampacity, increased utilization of HVDC for grid stability**
- **Advantages over HVAC**
  - Resistive and corona losses
  - High-temperature stability
  - Reduced foot-print



IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 37, NO. 3, MAY 2022

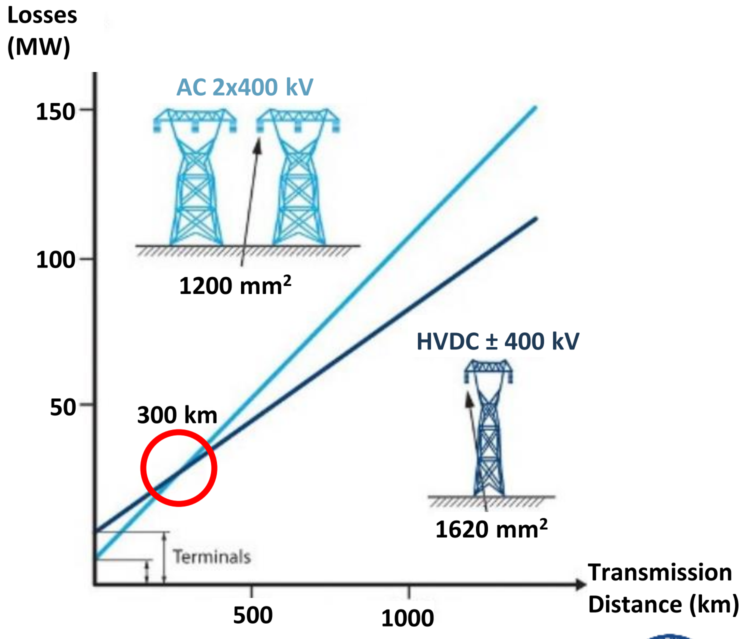
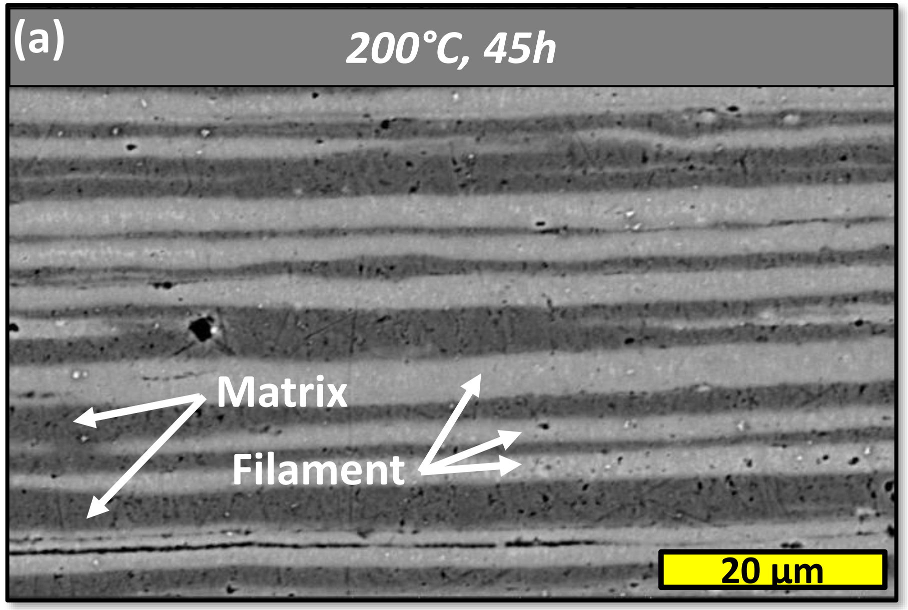


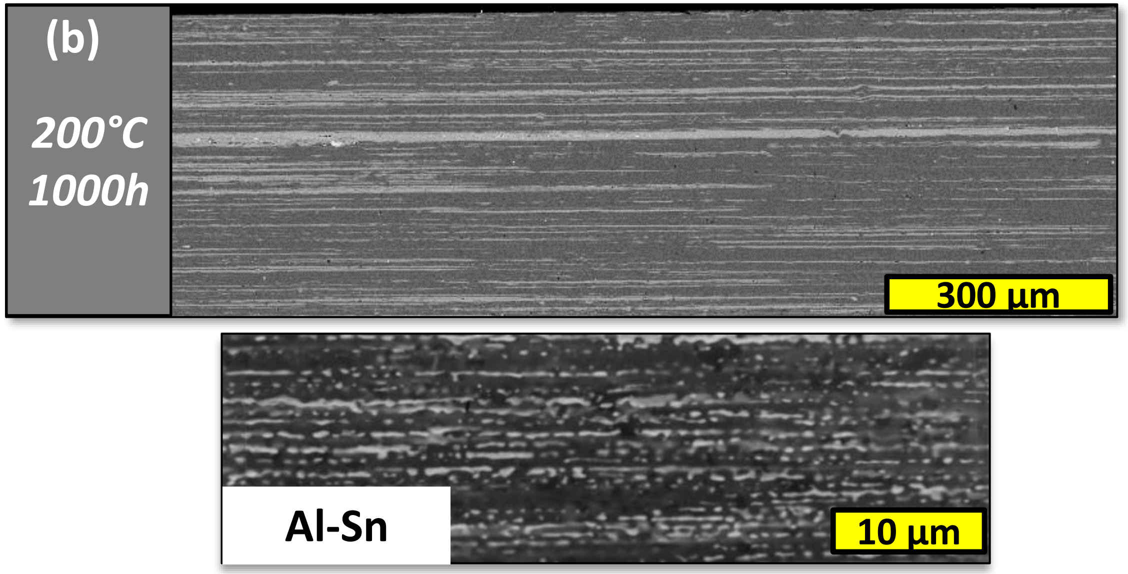
ABB (n.d. b)

<u>Conventional</u>

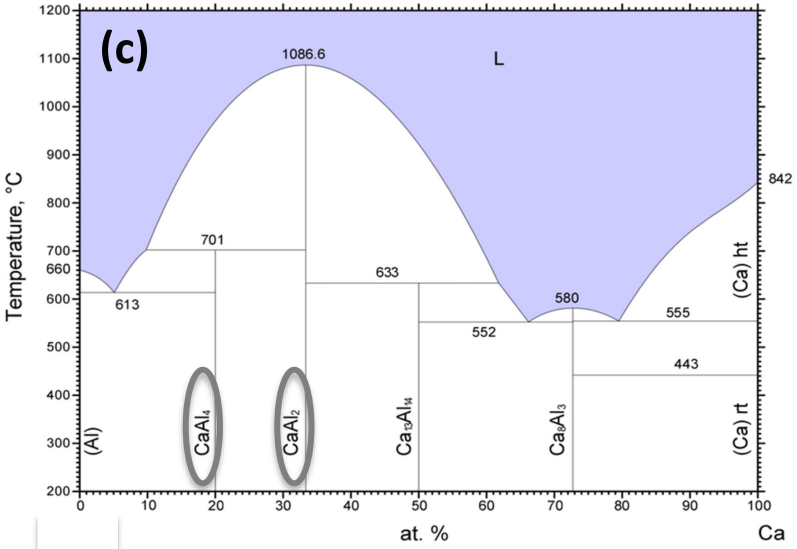
<u>Monotype Composite</u>

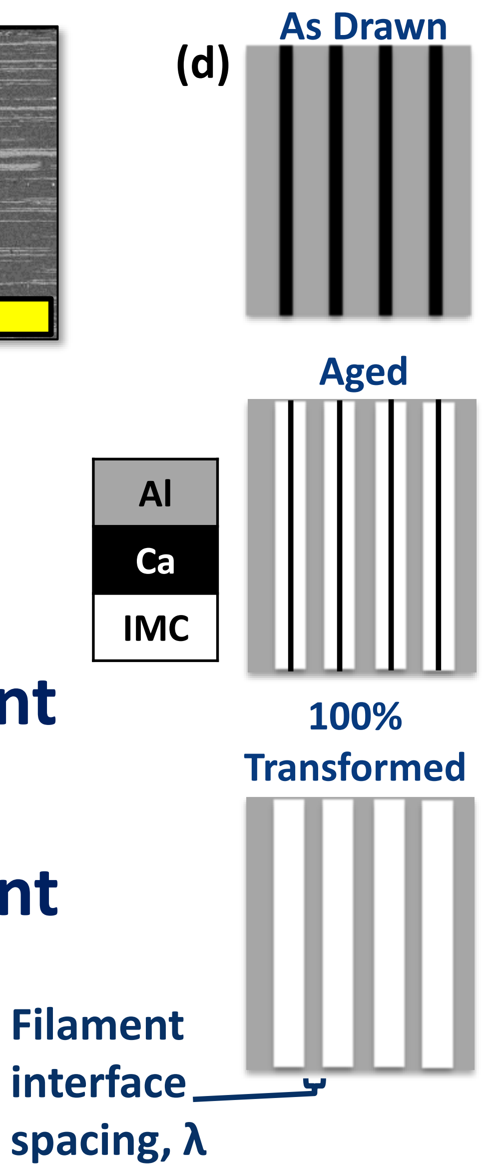
Al/Ca Composite Filamentary Reinforced Strands





Journal of Materials Science **37,** 5209–5214 (2002).





(a) Al matrix/Ca filament reinforcement

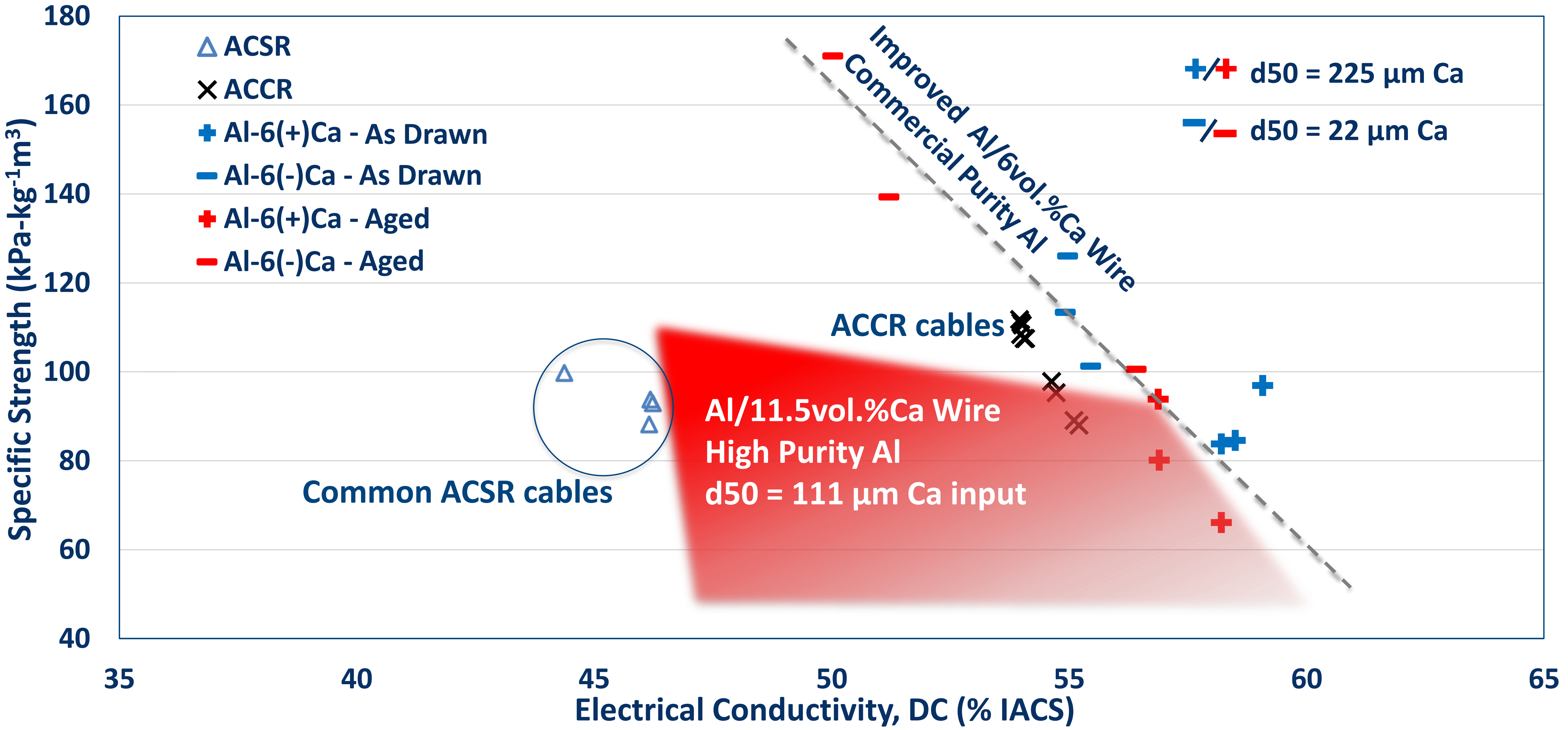
both dutile for extrusion/drawing

(b) HT: strong, thermally stable filament

(c) Ca phase transforms: IMC shell

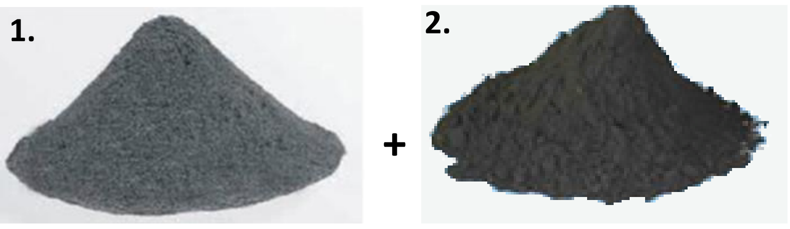
(d) One-way diffusion, Al → Ca

Material Properties: Conventional vs. Monotype

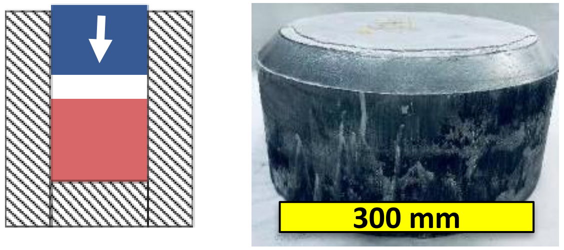


Commercial Purity (CP) Al/6vol.%Ca Wire Synthesis

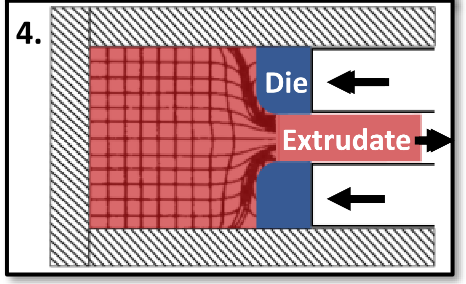
CP Al + CP Ca (6 vol.%) Gas Atomized Powder



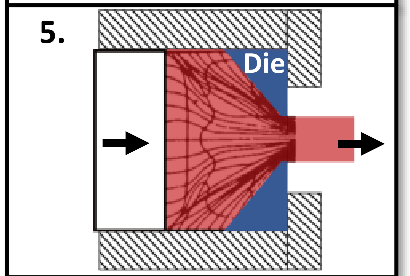
Billet Compaction (180°C)



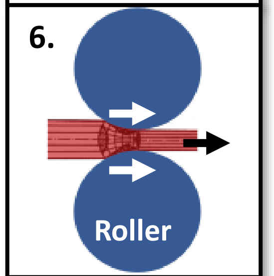
Indirect Extrusion (150°C)



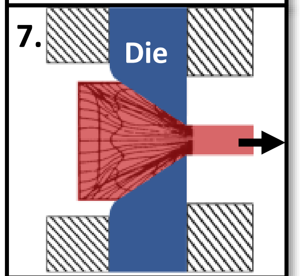
Direct Extrusion (150°C)



Rod Roll (RT)

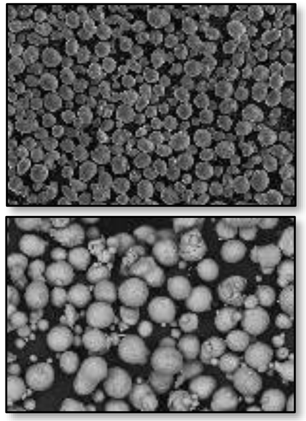


Wire Draw (RT)



Al

Ca



(1) Commercial Purity (CP) Al (99.8 wt.%)

(2) CP Ca (99.5 wt.%)

(3) Uniaxial vacuum warm press

(4) Indirect extrusion

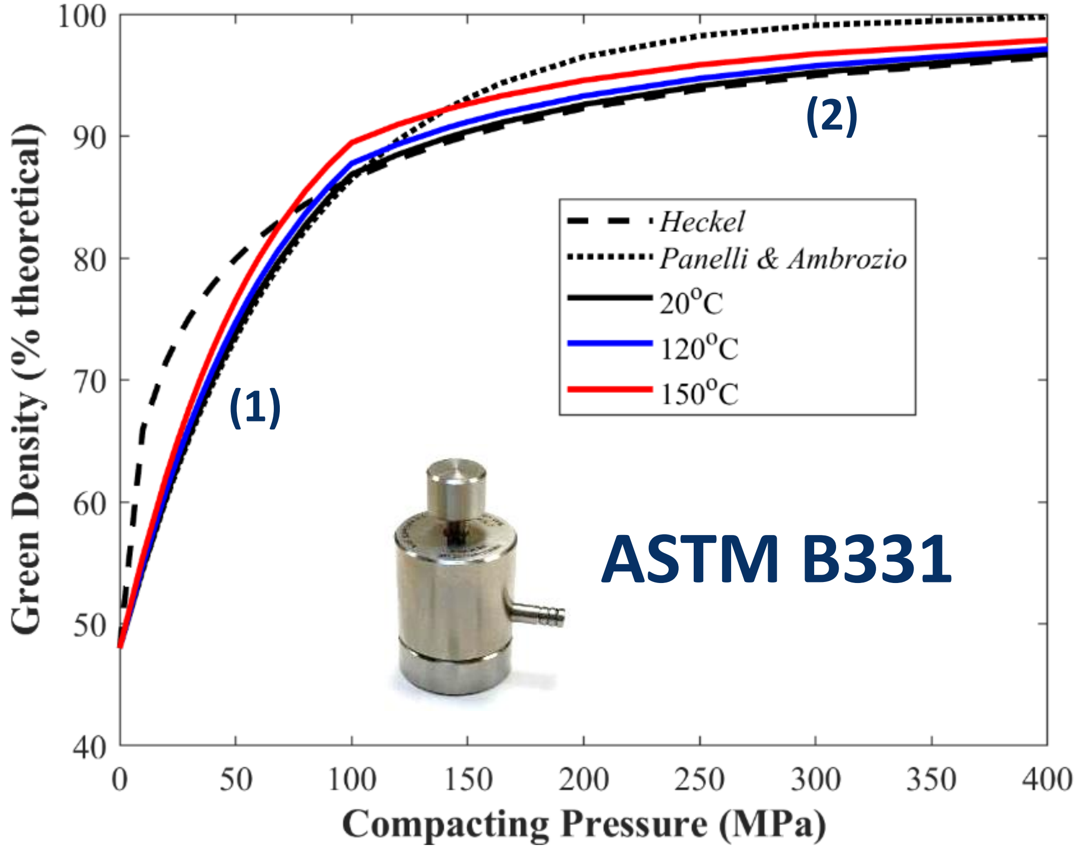
(5) Direct extrusion

(6) Round rod-roll

(7) Wire draw to final diameter

Powder to Wire

Compressibility Modeling for Compaction Parameters



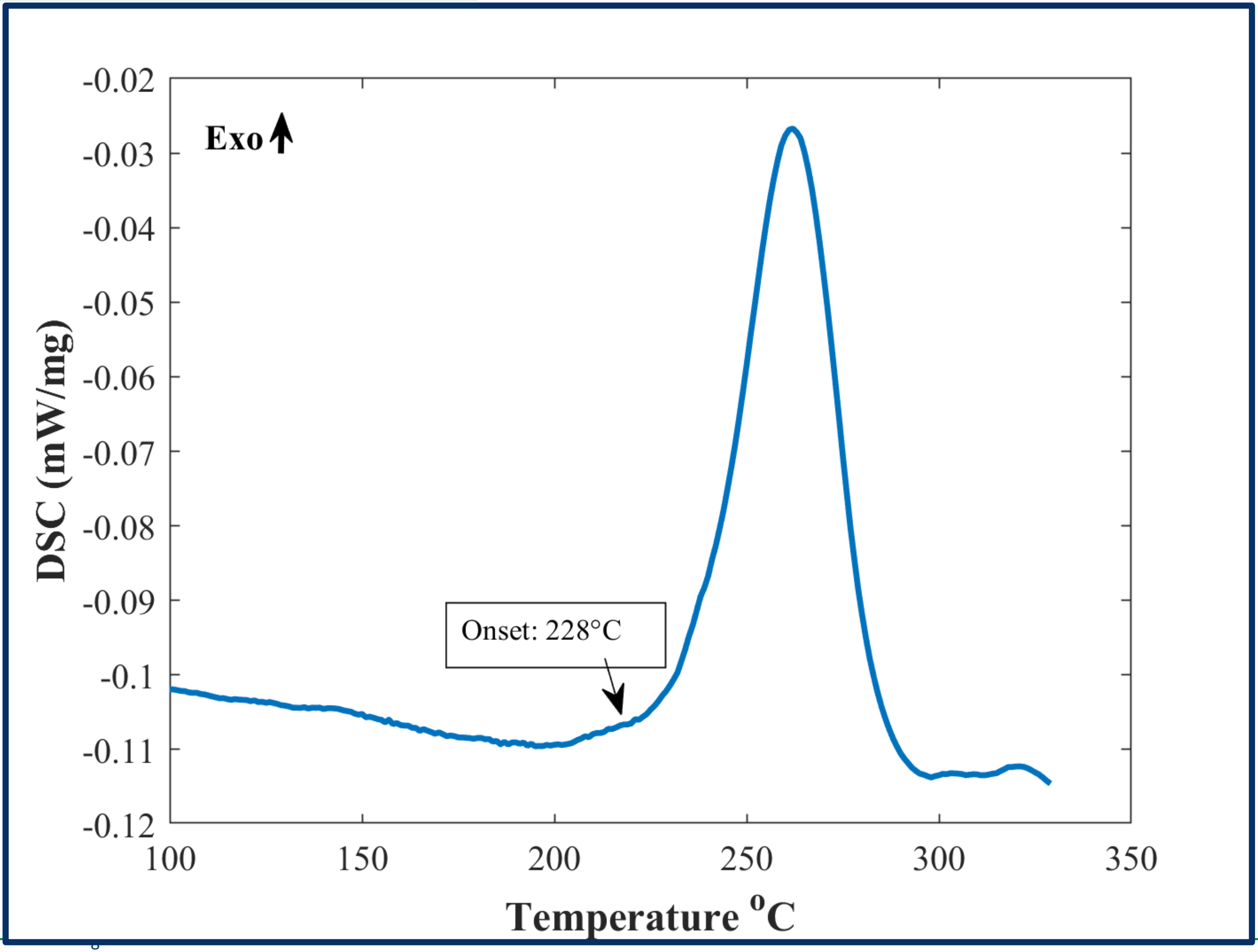
(1) Panelli & Ambrozio compressibility model, low pressure

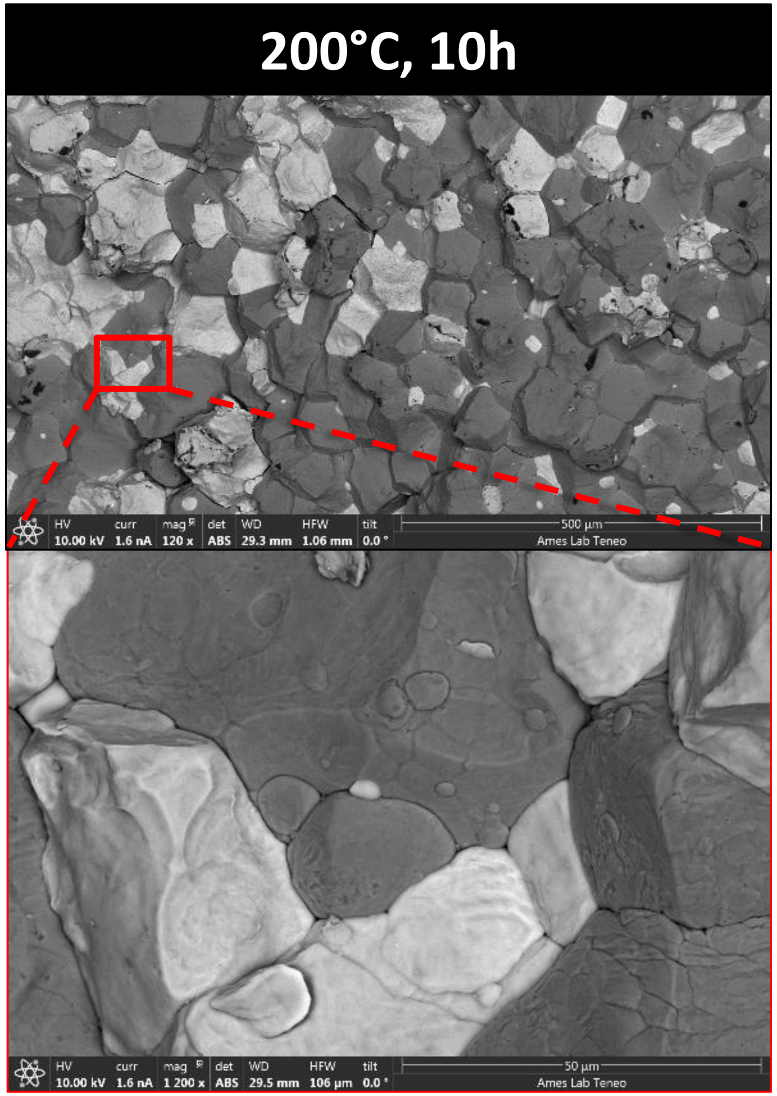
(2) Heckel compressibility model, high pressure >100MPa

Al/6vol.%Ca Green Billets

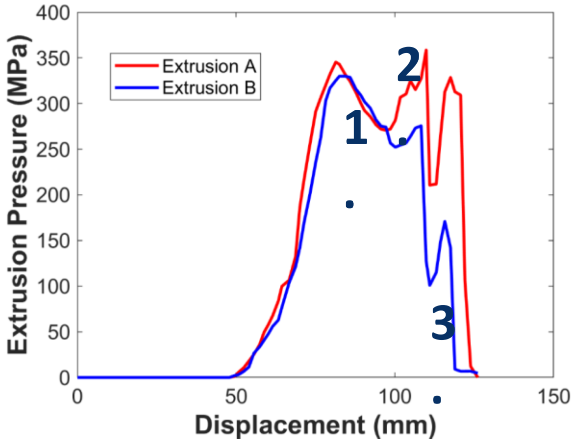
	1”	3”	12”
Pressure (MPa)	600	150	165
Temperature (°C)	120	140	170
Green Density (%)	97.5	93 - 94	96.2

Raise Temperature to Increase Compressibility/Density





Results: 3" Billet Al/Ca(6 vol.%) Direct Extrusion @ 150C



1. Break away pressure
2. Possible "speed cracking"
3. Passage of "follow block"

Current work on 12" billet in-progress at HC Starck.

H.C.Starck
High Performance Metal Solutions

SUPERCON INC

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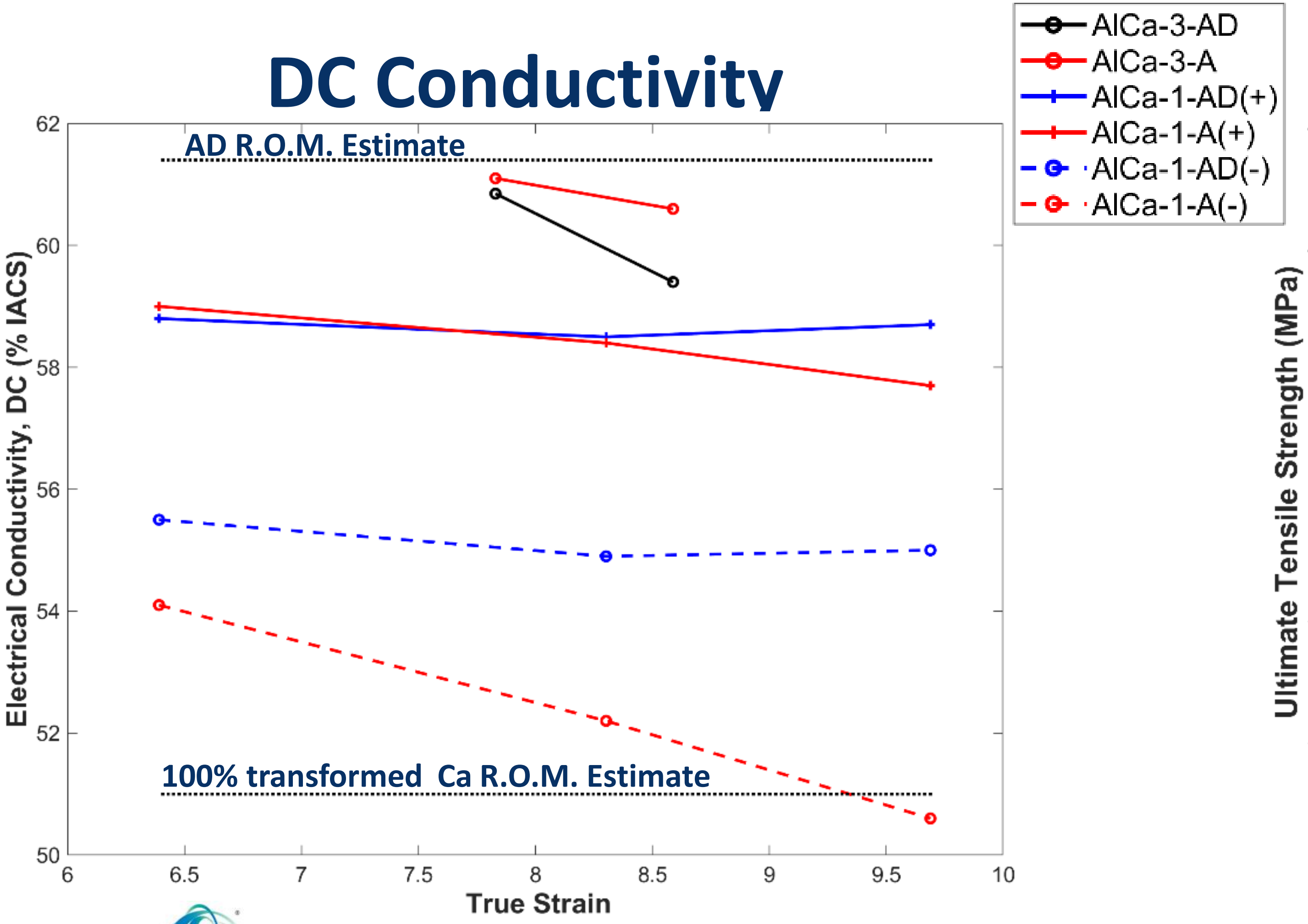
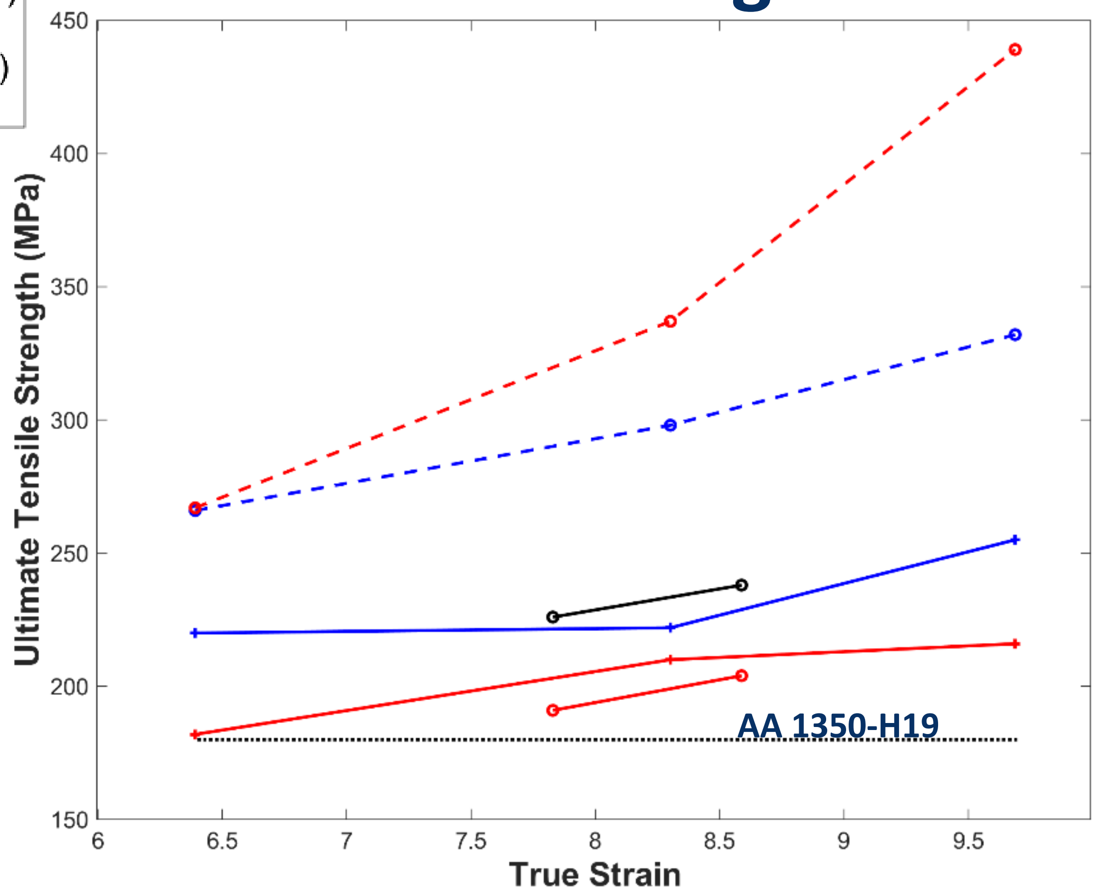
Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY

Consistent Al/Ca (6 vol.%) Wire Physical Properties

DC Conductivity



Tensile Strength



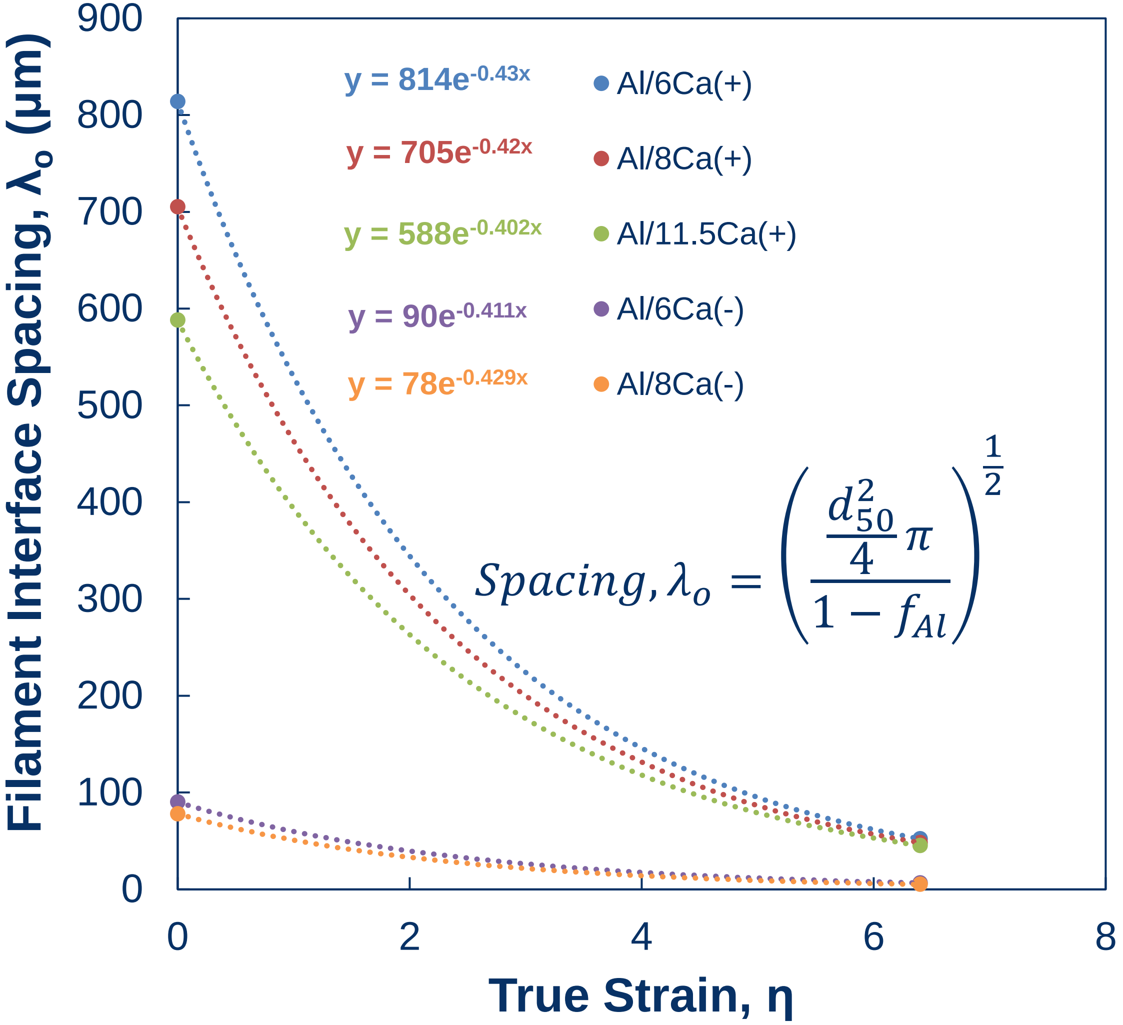
AD: As Drawn

A: Aged (230°C, 2h)

FORT WAYNE METALS
Turning knowledge into solutions.

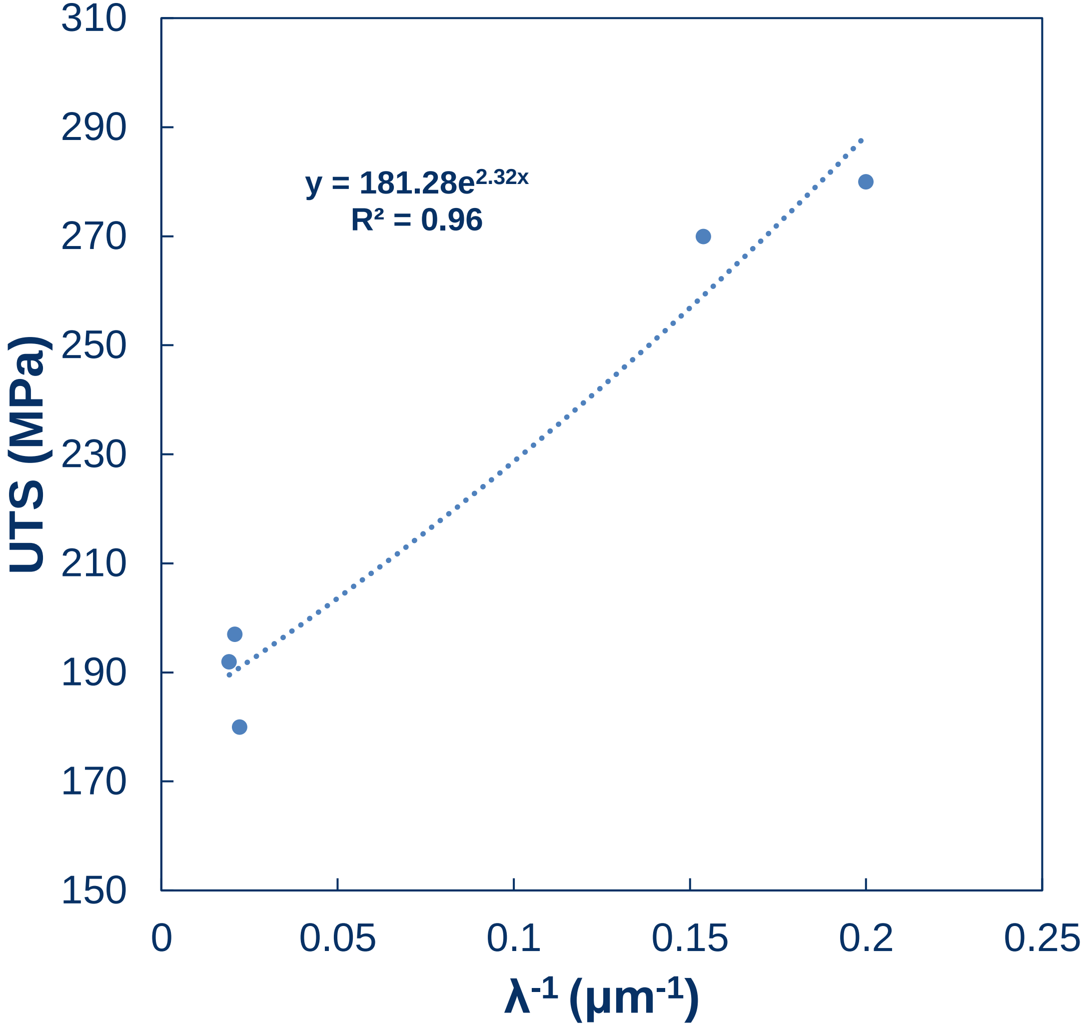
Predicting Strength of Al/6vol.%Ca Wire: Design Issues

Estimating Filament Interface Spacing



$$Spacing, \lambda_o = \left(\frac{\frac{d_{50}^2}{4}\pi}{1 - f_{Al}}\right)^{\frac{1}{2}}$$

Estimating Strength



Predicting Strength of Al/6vol.%Ca Wire: Design Issues

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Strength est. for 12" Al/6vol.%Ca billet, Ca powder d50 = 68 µm

- Final wire diameter: 3.0 mm
- Estimated filament interface spacing: 3.67 µm
- **Strength: 285 MPa**

Strength est. for 17" Al/6vol.%Ca billet, Ca powder d50 = 45 µm

- Final wire diameter: 3.0 mm
- Estimated filament interface spacing: 2.55 µm
- **Strength: 451 MPa**

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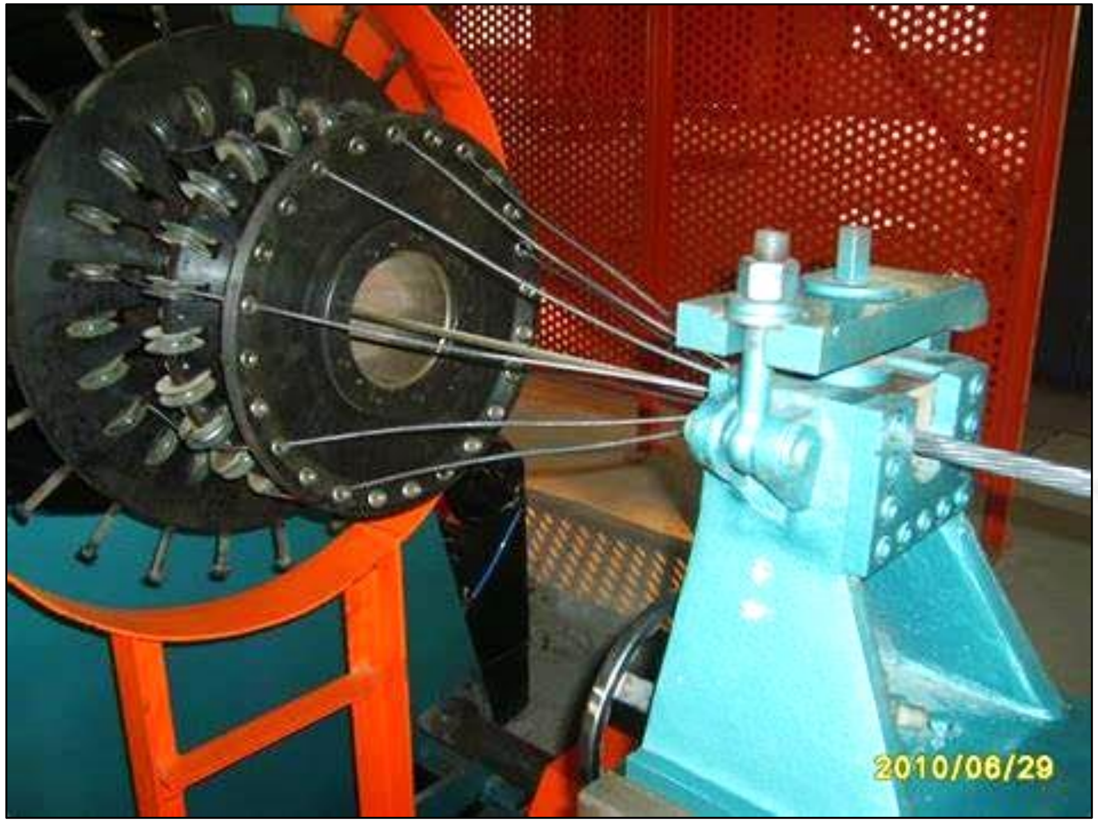
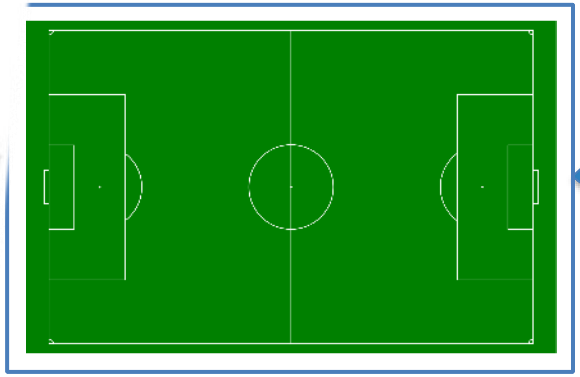
Cable Wire Stranding



37 strand x 18 AWG (2 mm) wire concentrically stranded by Southwire

Estimated cable length: 120 m



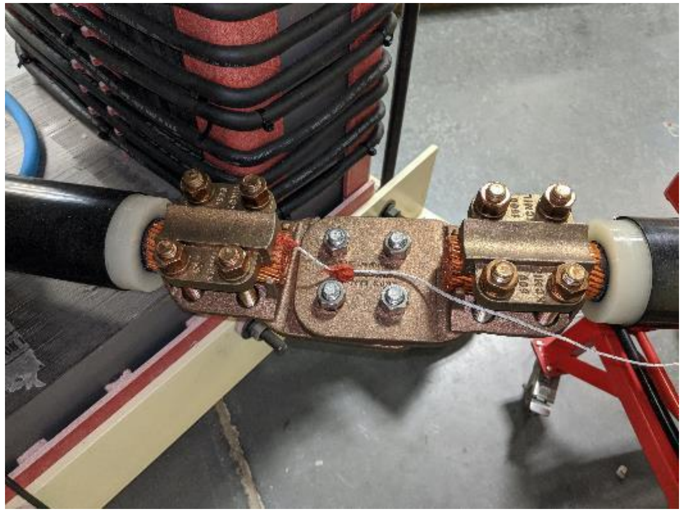
Cable Performance Testing

UNC CHARLOTTE
EPIC

Flexible Energy Laboratories Suite at Energy Production and Infrastructure Center (EPIC) conducts standard compliance and functional performance testing of power and energy systems.

High voltage testing up to 100kV for testing cables, overhead wires, transformers and other high voltage equipment.

Load cycle testbed capable of injecting up to 4000 A using current transformers, to analyze the thermal performance of cable / overhead wire.



Estimated electrical conductivity of a single wire strand:
57% IACS As-Drawn
53% IACS As-Aged

Rotating Disk Atomization of Ca

ERVIN

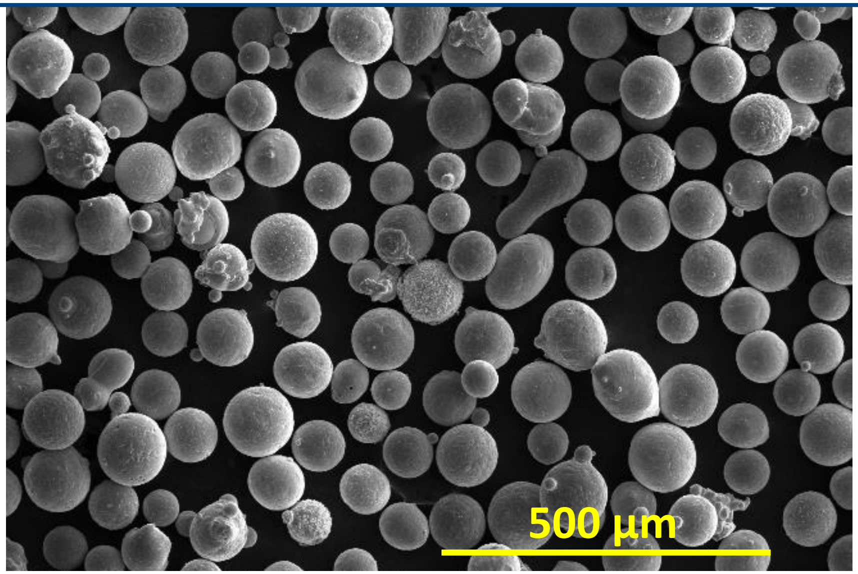
"The World's Standard for Quality"

CRADA Project Progress & Objectives:

Produced native oxide passivated fine (dia. < 125μm) calcium powders with rotating disk atomization.

Transferring (alternative) passivation technology from Ames Lab for safe production and handling of calcium powders.

Will deliver commercial quantity (25-30 kg minimum) of passivated Ca powder for Al/Ca composite wire for cable winding and full-scale performance testing at UNC-C.



Impact/Commercialization

- **If Al/Ca composite conductors are fully developed and their properties are verified in cable form, the benefits of this cable can be exploited to build out the US transmission grid, *"Restringing America"* with thousands of miles of HVDC and HVAC lines. Calculated estimates show that Al/Ca cable (compared to ACSR Bluebird), will have 12% lower losses and need 11% fewer towers to connect isolated renewable or C-free energy sources to cities/factories.**
- **Plan for full processing schedule and testing is set with Ca powder (on-hand) and Al powder (from Valimet) that has been compacted as short cylinders (@Gamma Alloys), but new results show that canning is needed. Warm extrusion to billet @ HC Starck (on-going) and Supercon). Will be rod rolled and drawn to wire (@Fort Wayne Metals), will be wound as cable (@Southwire), and will be tested (@UNCC).**

IP STATUS: **Composite conductor and stranded cable technology granted 2014 US patent and is available for license.**

THANK YOU

This project is supported by the U.S. Department of Energy (DOE) Office of Electricity’s Transformer Resilience and Advanced Components (TRAC) program. It is led by Andre Pereira, TRAC program manager.

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