U.S. DEPARTMENT OF ENERGY
Office of Electricity

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Al/Ca Composite Conductor Characterization

TRAC Program Review

US Department of Energy, Office of Electricity

Presented at Oak Ridge National Laboratory

Oak Ridge, TN

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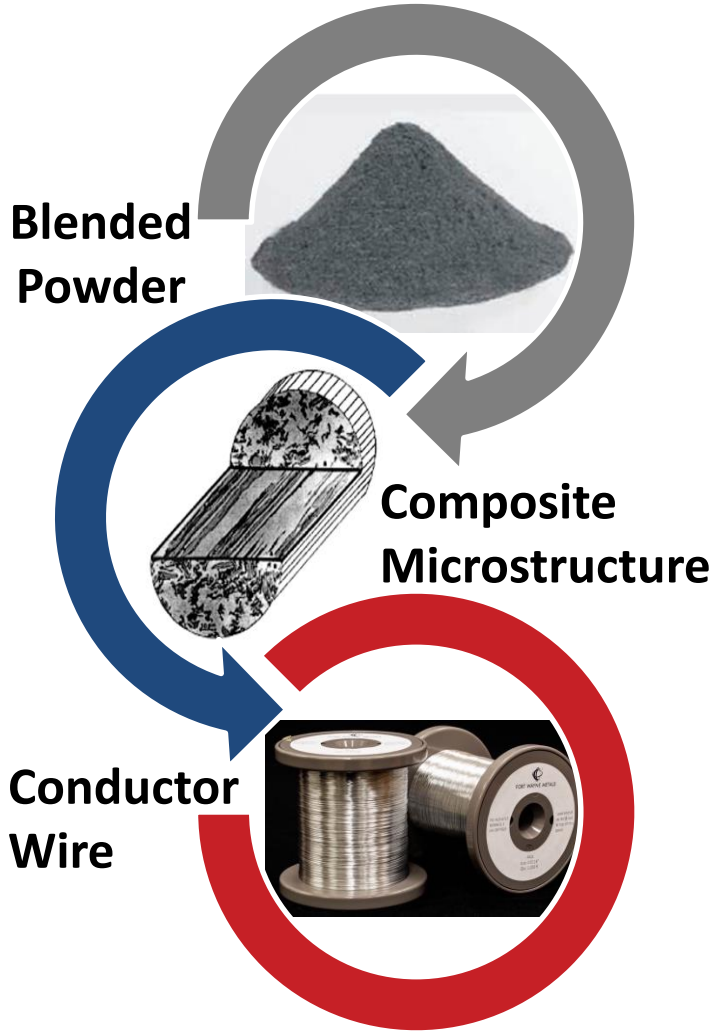
Project Overview

- **Project Summary:**
  - Continued development of core-less cable from Al/Ca composite conductors for overhead transmission lines
    - Greatest advantage for HVDC transmission distances
  - Al/Ca wires have impressive strength and conductivity

- **Technology Needs**
  - Increased upper operating temperature limit by further processing improvements for microstructure stability
  - Refinement of in situ reactive passivation of Ca powder during atomization for rapid technology transition

- **Total value of award: (Federal: $400K)**
- **Period of performance: 10/01/2019 to 09/30/2021**
- **Project lead: Ames Laboratory (USDOE)**

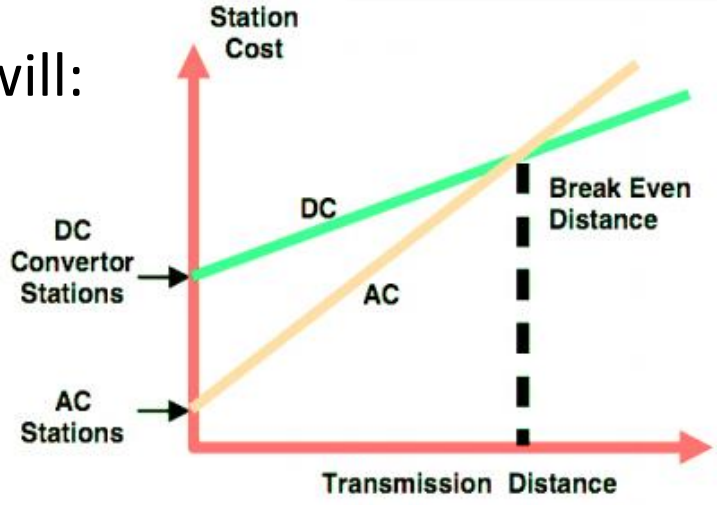


Potential Impact of a New Transmission Cable Material

- Intermittent renewable energy sources (wind & solar) and zero-carbon base load capacity (nuclear fission) need to be connected to population and manufacturing centers by expanded grid.

- High voltage DC (HVDC) transmission lines are the most energy efficient option for long distances (> 100 miles).

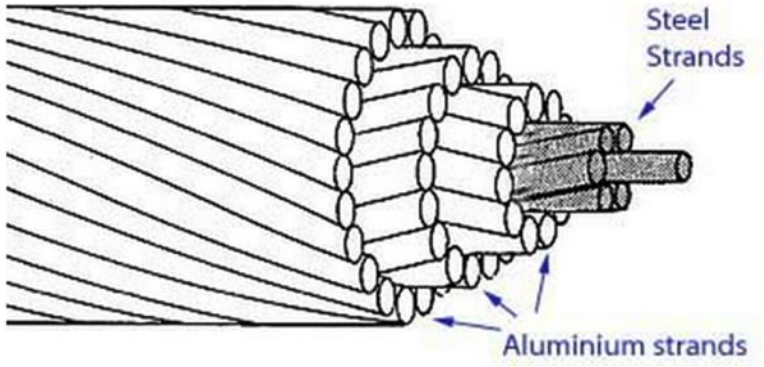
- New type of cable for HVDC power transmission will:
  - Lower transmission losses
  - Use wider-spaced towers
  - Have greater resistance to line sag



State of the art: HVDC & HVAC Transmission Cables

Technology	Abbreviation	Features	Overheating
Aluminum Conductor Steel Reinforced	ACSR	Common, pure Al	Immune (Δ CTE)
All Aluminum Alloy Conductor	AAAC	All Al alloy	Weakens/sags
Aluminum Conductor Aluminum-Alloy Reinforced	ACAR	Al & Al alloy	Weakens/sags
Aluminum Conductor Composite Core	ACCC	HS, pure Al	Core limited
Aluminum Conductor Composite Reinforced	ACCR	HS, pure Al	Immune

ACSR

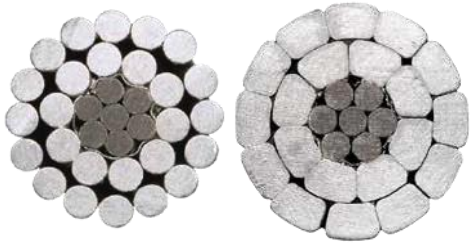


AAAC

ACCC

ACAR

ACCR



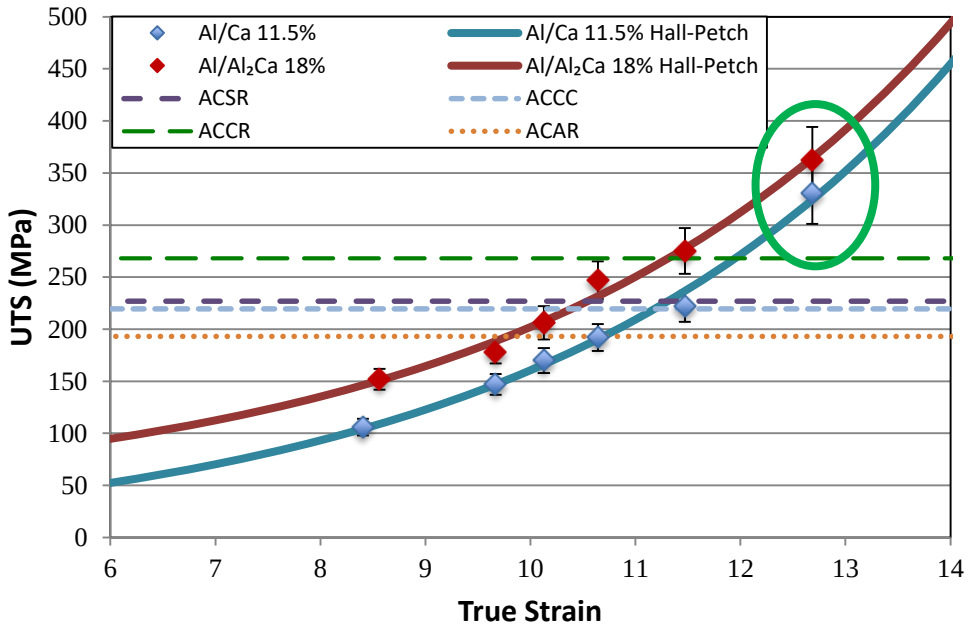
ACSR catalog, 2012, Southwire, Carrollton, GA.

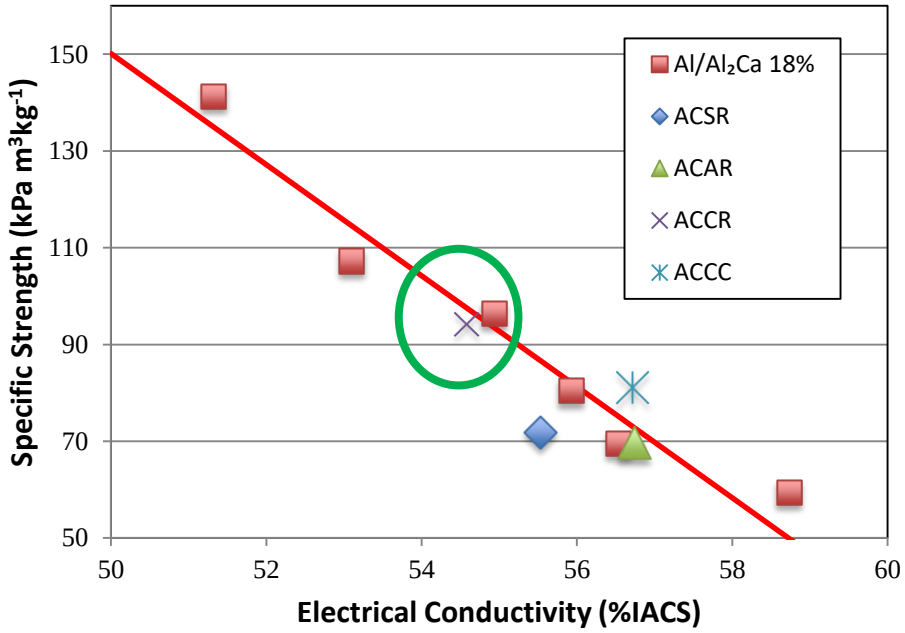
Heavily Deformed Al/Ca Composite Conductors

<u>Unique</u> Advantages:

- Blended powder method:
  - a) Flexible design
  - b) Low cost potential
  - c) Lower density than Al and all Al-alloys
- No cable core: single wire-type cable
- High strength: 360 MPa UTS (>ACCR @ 270 MPa), after HT
- Good conductivity: 55% IACS (=ACCR @ same specific strength)

Funded by DOE:
Russell, et al, "Aluminum/Alkaline Earth Metal Composites and Method for Producing," U.S. Patent No. 8,647,536 B2, issued February 11, 2014





$\rho_{Al} = 2.7 g/cm^3$

$\rho_{Ca} = 1.55 g/cm^3$

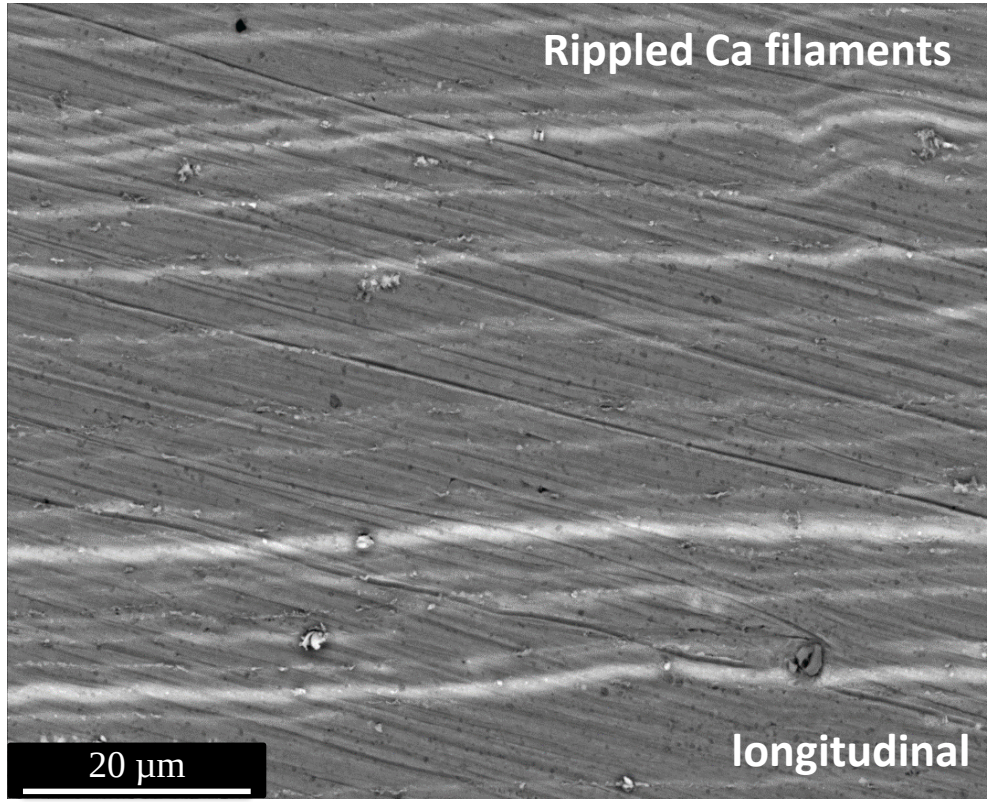
$\rho_{Al/Ca\ 11.5\%} = 2.56 g/cm^3$

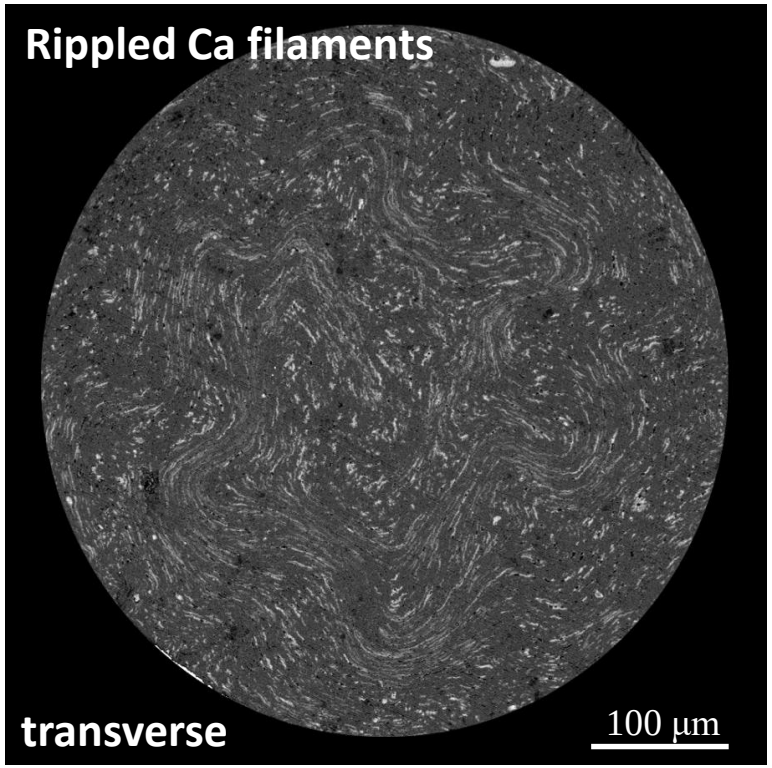
Significance of Results

- New type of cable material for HVDC power transmission
  - Lower transmission losses
  - Greater resistance to line sag
- Up-front economic advantage
  - Installation of fewer, wider-spaced towers over longer distances (> 100 miles)
- US grid infrastructure will be greatly improved
  - Significantly reduced capital cost
  - Lower operating cost
- US energy needs powered with more renewables:
  - Reduced GHG concentration to slow climate change
  - Reduced costs for environmental accommodation

Specific Research Questions

Can upper temperature limit be enhanced by smooth deformation processing to maximize microstructure stability?





- Smooth, continuous “drawing” deformation should reduce extruded billet to wire sizes with straight, stable Ca filaments.

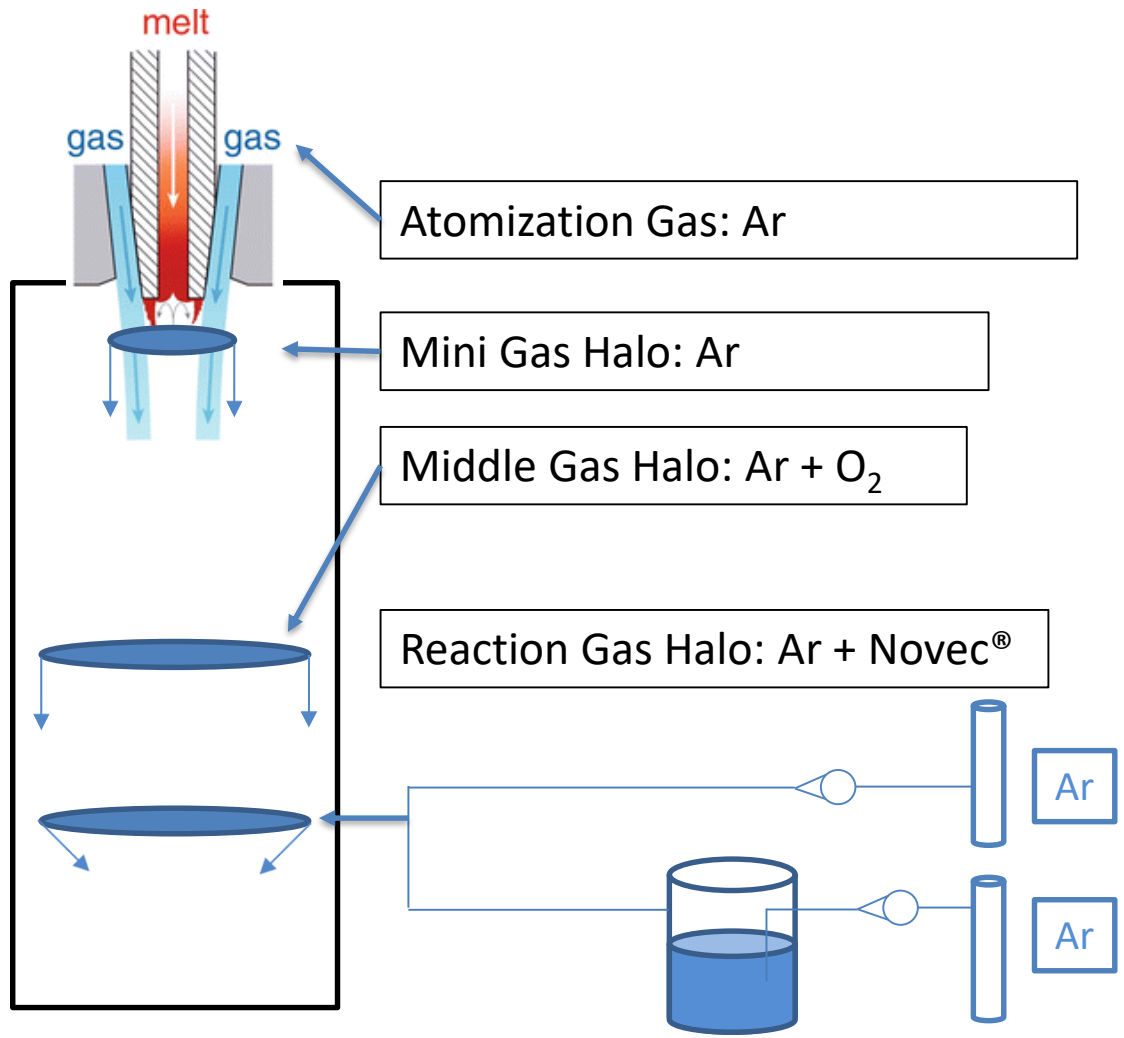
Initial deformation method (swaging) with opposing hammer dies produced rippled Ca reinforcement filaments.

- Likely to develop instabilities and coarsen
- Cause strength and conductivity decrease

Specific Research Questions

Can kg quantities of fine Ca powder (dia. < 100µm) be produced with robust surface passivation from gas phase reaction?

Gas atomization with in situ gas-based surface reaction*



*US Patent No. 9,650,309 B2, issued May 16, 2017

Specific Research Questions

Is commercial Al powder of required surface quality & size available?

- For blending with Ames Ca powder for extrusion and wire drawing

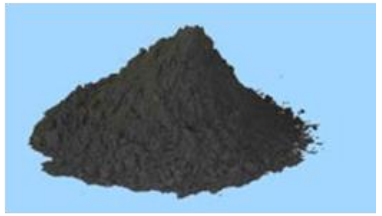
Is resulting conductor wire of sufficient length, strength, and conductivity for short length cable production and testing?

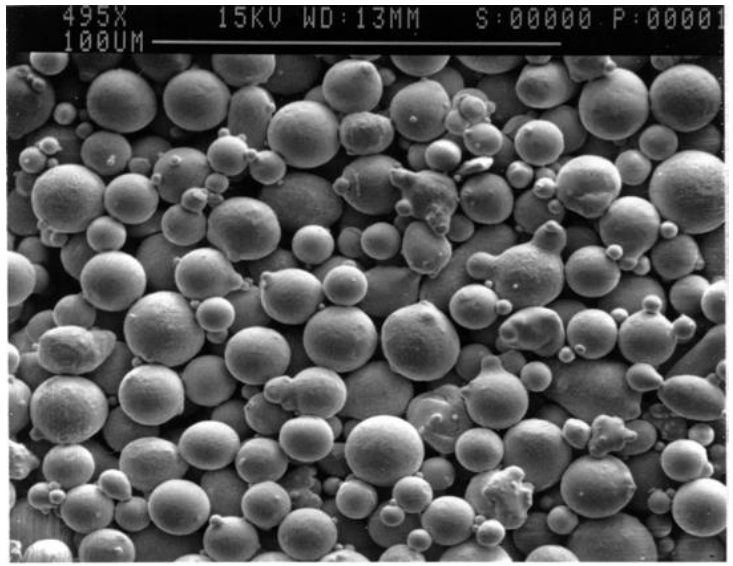
- Generate results from cable for promoting industrial interest

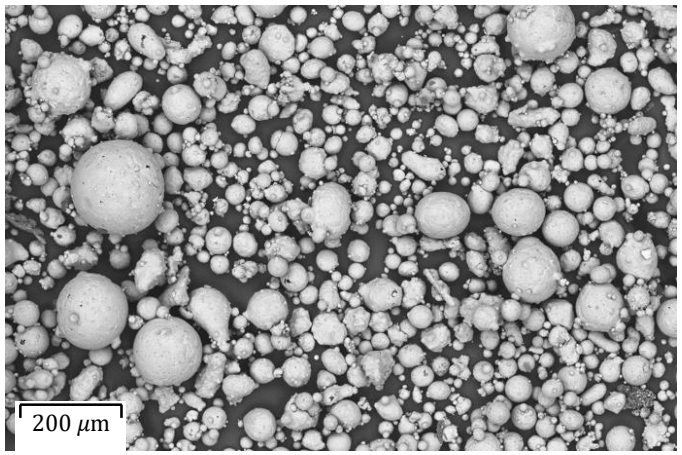
High purity atomized Al

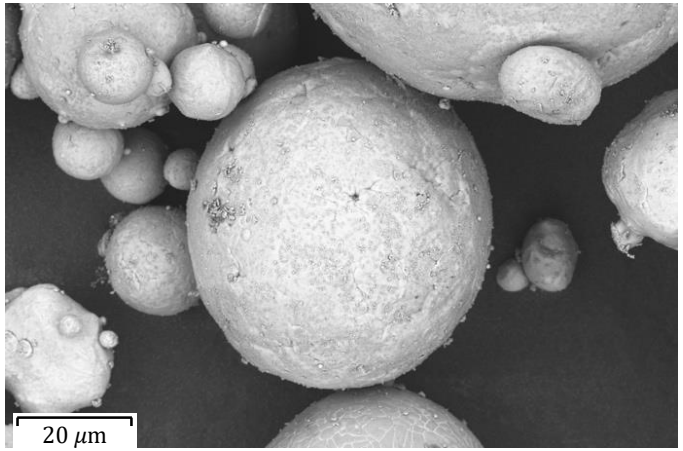
+

High purity fine atomized Ca









Proposed Technical Approach

High purity atomized Al (88.5 vol. %)

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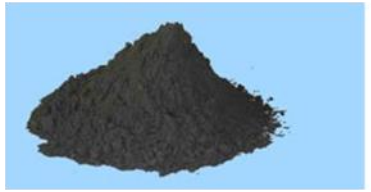
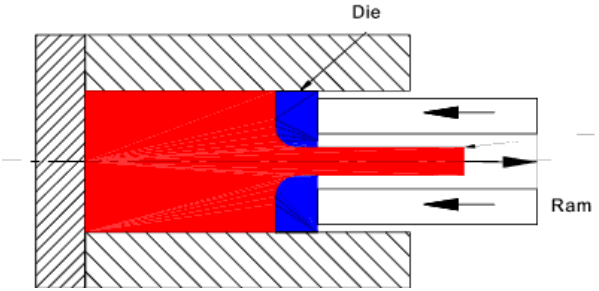


High purity fine atomized Ca (11.5 vol. %)

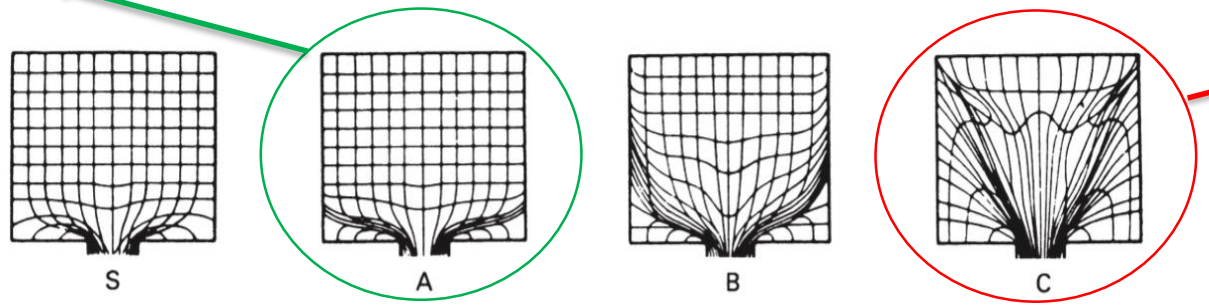
Blended powder compact

Extrusion can loaded with compacts

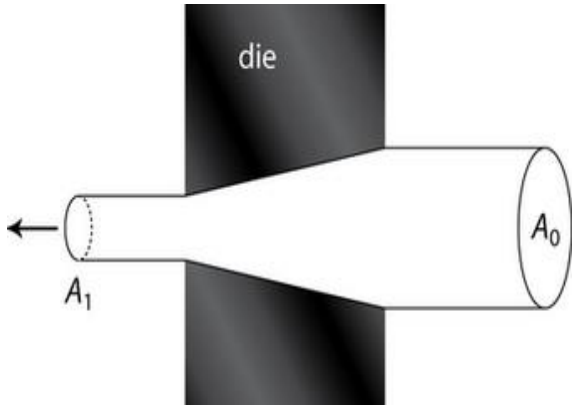
Indirect Extrusion



Deformation Flow Profiles



RT Wire Drawing



Project Task Overview

Task 1. **Materials Processing and Characterization of Conductors:**

a) Characterization of existing wires before and after thermal aging (up to 1000h)

b) Encapsulated compacts warm extruded and fully drawn for stranded conductor cable fabrication

Task 2. **Powder Materials Synthesis:**

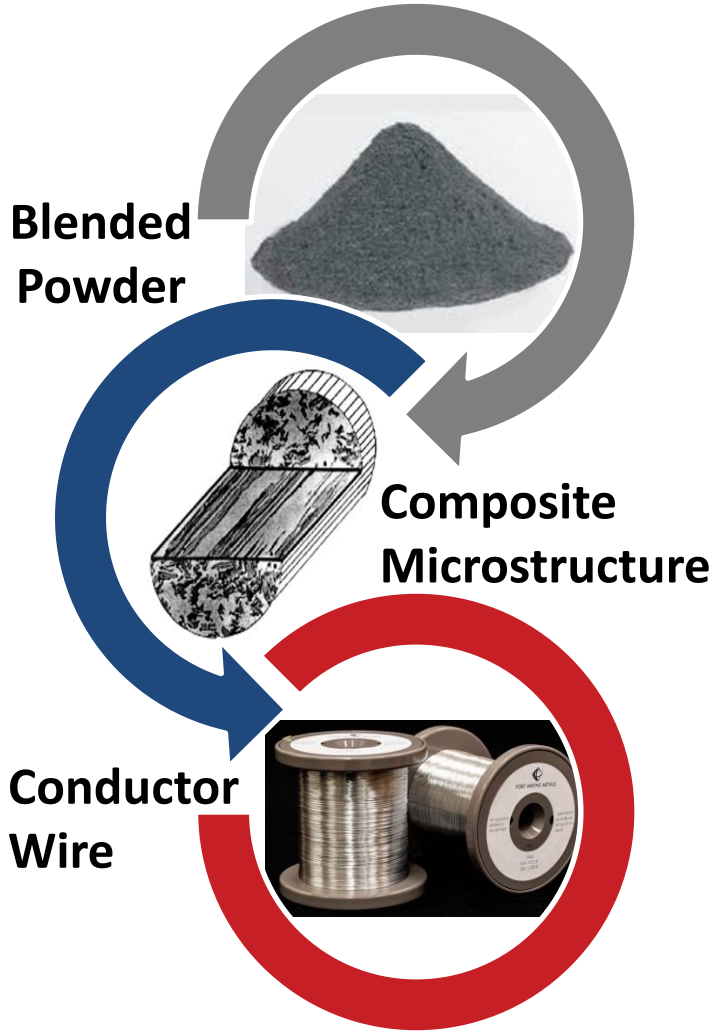
a) Lab-scale gas atomization trials of increased quantity of Ca powder and optimization of passivation treatment

b) As-atomized Ca powder blended with high purity commercial Al powder for compaction and canning

Task 3. **Cable Preparation and Testing:**

a) Conductor wire with desired strength, conductivity and diameter wound to cable and tested both as-wound and after heat treatment to determine effects of phase transformation on cable strength and conductivity

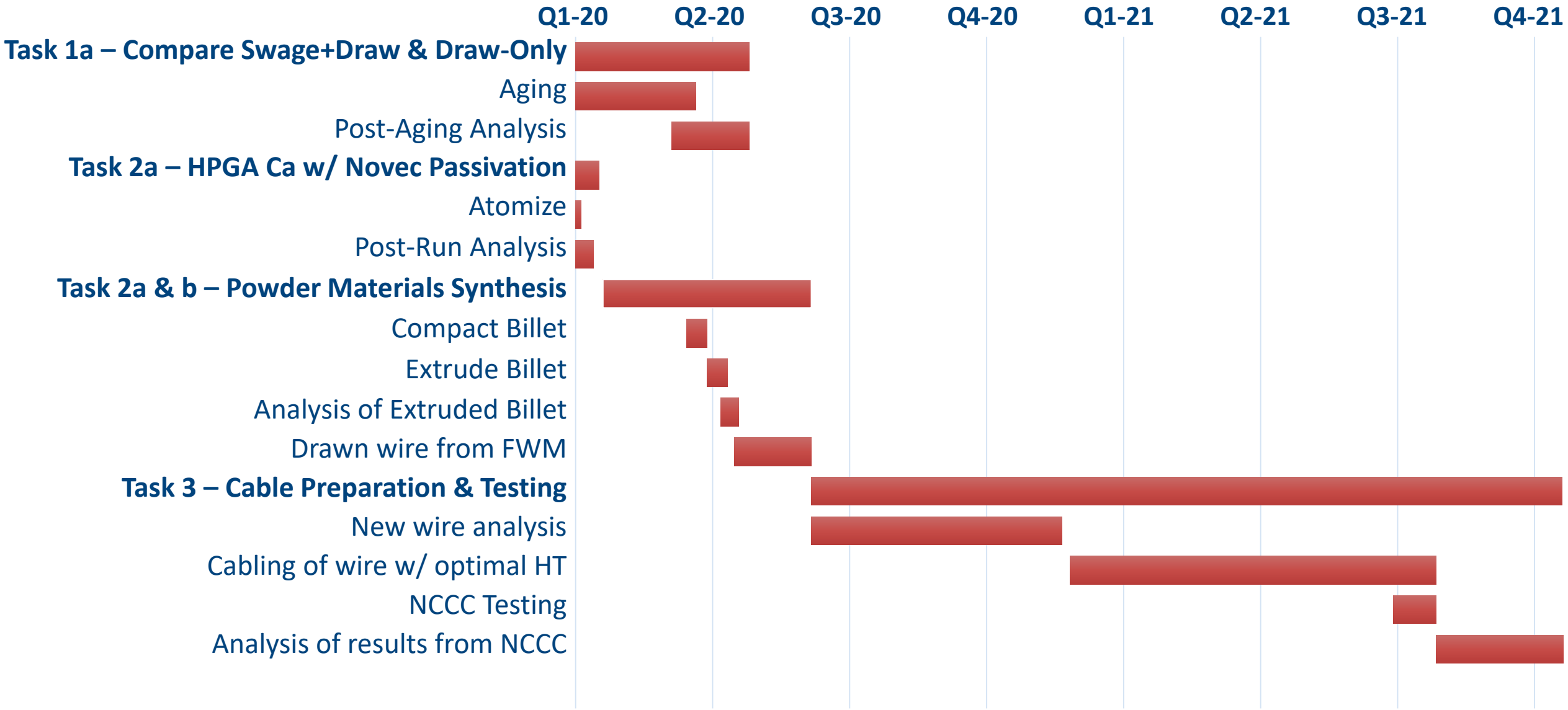
b) Short cable samples tested to provide realistic performance data, within existing industry standards and results reported



Project Deliverables & Current Status

#	Task	Deliverable	Milestone
1	2a	Produce atomized fine Ca powder **(in-house)** in a quantity of several hundred grams.	31 December 2019
2	2b	Obtain atomized fine Al powder (***Valimet***) with high purity in kg quantity.	31 March 2020
3	1a	Paper submitted for publication that describes microstructural differences and thermal stability effects of deformation processing on Al/Ca wire.	30 September 2020
4	1b	Sufficient length (about 100m) of conductor for fabrication of short (< 10m) length of multi-strand cable, requiring warm extrusion (***@TU-Berlin or DWA***) and wire drawing **(@*FWM*).**	31 December 2020
5	3a	Fabrication of at least one short (< 10m) length of multi-strand cable and delivery to test facility, requiring cable winding (@***FWM or Southwire***) and cable testing (@***NCCC***).	30 June 2021
6	3b	Report results of testing **(@*UNCC*)** of short transmission cable from Al/Ca composite wire.	30 September 2021

Project schedule:



Anticipated Challenges & Risk Mitigation Strategies

- Thermal stability limit of strength and conductivity may not reach desirable level (150˚C) for broadest market.
  - Draw-only processing enhancing thermal stability must be verified.
  - Industrial processing efficiency favors draw-only.

- Gas-based reactive passivation of molten Ca droplets may not provide sufficient powder handling stability time in ambient air for all processing steps.
  - Several hours (4-5h) of air exposure demonstrated for planar solidified Ca sample; air stability of solidifying Ca droplet likely to be greater.
  - Processing steps can be performed in a glove box and automated, if needed.

Immediate Next Steps

- Longer heat treatments of existing draw-only wire and longitudinal microstructure analysis to verify Ca filament stabilization from smooth deformation
- Confirm tensile strength improvement and conductivity plateau for establishing upper operating temperature limit
- Full lab-scale gas atomization trial(s) for increased yield of fine Ca powder with study of passivation characteristics and sufficient quantity for new large diameter (short height) extrusion billet
- Extensive surface analysis to understand/improve passivation mechanism and reaction with F-containing gases
- Analyze best commercial Al powder for production of large diameter Al/Ca composite extrusion

Broader Impacts

RECENT PUBLICATIONS AND PATENTS:

C. Czahor, T.M. Riedemann, A.R. Russell, I.E. Anderson, "In-Situ Gas-Phase Passivation of Molten Calcium Surfaces to Enable Development of Atomization Method for Generating Calcium Powder," in *Advances in Powder Metallurgy & Particulate Materials—2018*, Compiled by Animesh Bose, FAPMI, and Scott Davis (Metal Powder Industries Federation, 105 College Road East Princeton, NJ) ISBN No. 978-1-943694-18-1, pp. 151-163 (2018).

C. Czahor, T.R. Riedemann, A. Russell, I.E. Anderson, "Deformation Processed Al/Al2Ca Nano-filamentary Composite Conductors," in *Advances in Powder Metallurgy and Particulate Materials-2017*, compiled by Ryuichiro Goto and Joseph T. Strauss, (Metal Powder Industries Federation, Princeton, NJ), ISBN No. 978-1-943694-15-0, pp. 778-790 (2017).

C. Czahor, T.R. Riedemann, A. Russell, and Iver Anderson, "DEFORMATION PROCESSED Al/Al_2Ca NANO-FILAMENTARY COMPOSITE CONDUCTORS," 53, No. 4, Int. J. of Powder Metallurgy (2017) pp. 11-19.

C.F. Czahor, I.E. Anderson, T.M. Riedemann, and A.M. Russell, Deformation processed Al/Ca nano- filamentary composite conductors for HVDC applications. 38th Riso International Symposium on Materials Science (2017) p. 219.

A.M. Russell, I.E. Anderson, H.J. Kim, A.E. Ferichs, "Aluminum/Alkaline Earth Metal Composites and Method for Producing," U.S. Patent No. 8,647,536 B2, issued February 11, 2014.

I.E. Anderson, A.D. Steinmetz, D.J. Byrd, "Stability of Gas Atomized Reactive Powders through Multiple Step In-Situ Passivation, " US Patent No. 9,650,309 B2, issued May 16, 2017.

Broader Impacts

INDUSTRIAL & UNIVERSITY COLLABORATIONS: Supplier Chain Series

Collaborator	Location	Involvement
Ervin Industries	Tecumseh, MI	Ca powder making: interested in trials
Valimet Metal Powders	Stockton, CA	Pure Al powder maker
DWA Composites	Chatsworth, CA	Blend/outgas/compact, experimental extrusion
Alcoa	Layfayette, IN	Large scale extrusion
Technical University-Berlin (TU-Berlin)	Berlin, Germany	Experimental warm extrusion
Fort Wayne Metals (FWM)	Fort Wayne, IN	Al/Ca MMC wire drawing, experimental cable winding
University of North Carolina-Charlotte (UNCC)	Charlotte, NC	Short length transmission cable performance testing
PCAT @ ORNL	Oak Ridge, TN	Long length transmission cable performance testing
Southwire	IL location	Transmission cable maker

Contact Information

- For questions concerning the project:

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