U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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Washington, D.C.

Manufacturing of Al-Ce/Metal-Matrix Composites (MMC) for Harsh Environments| AMMTO

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2.1.0.410| Oct.1, 2020-Sept. 30,2023

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Project Overview

- **This project supports AMMTO mission to advance energy-related materials and manufacturing technologies to increase domestic competitiveness and build a clean, decarbonized economy by:**
  - *(i) Pushing the performance boundaries for clean energy technologies (e.g., Nuclear)*
  - *(ii) Increasing energy efficiency and life-cycle benefits for large-volume powertrain applications.*
  - *(iii) Increased manufacturing efficiency and decreased embodied energy compared to incumbent materials*
  - *(iv) Addressing critical materials challenges through high-volume and high-value applications of overly-produced Ce*
- **Challenges:**
  - Developing highly-processable materials (e.g., casting, powders, etc.) with increased high temperature strength, while maintaining room temperature ductility and high thermal conductivity.
- **Impact**:
  - New materials will allow for safer storage of hotter spent fuels and increased energy efficiency in heavy duty powertrains, which will decrease emissions and increase durability.
  - Industrial partners in powder synthesis, nuclear storage materials, and power-train component synthesis will enable commercialization

Project Outline

Innovation: Develop New Al-Ce/metal-matrix composites for power train components and spent nuclear fuel storage

(i) Increased strength at elevated temperatures (storage and power train)

(ii) Decreased manufacturing energy (storage and power train)

(iii) Increased energy efficiency during service (power train)

Project Lead: Ryan Ott, Ames National Laboratory

Project Partners: Intelligent Composites, Loukustech, Holtec Government Services, and Eckart

Timeline: October 1, 2020 – September 30, 2023, 90% Complete

Budget:

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$1,622,275	$1,625,855	$413,440	$3,940,000
Project Cost Share	--	$102,700	$3,100	$1,000,000

End Project Goal: *Transition Al-Ce/MMC developed in project into commercial production of cylinder liners are storage casks.*

Background & Strategic Approach

- Clean energy technologies require pushing performance boundaries in multi-modal harsh environments (Elevated temperatures, Corrosion, Radiation, etc.)
- Al alloy metal-matrix-composites (Al/MMC) are exceptional materials for:
  - Low density, high strength
  - Corrosion resistance
  - High thermal conductivity

Power Train Cylinder Liners
- Cast iron
- A356* with SiC coating
- A390*/MMC

**Heat-treated alloys*

Dry Storage Casks Spent Nuclear Fuel
- Al + nano alumina + B_4C
- Extruded powders

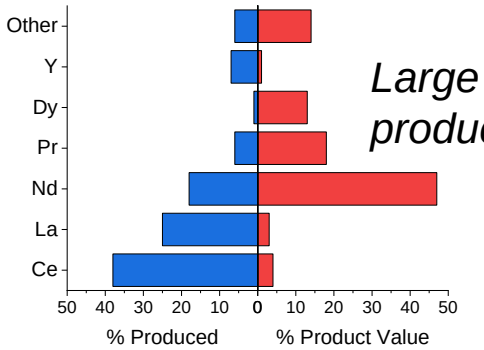
Performance Targets:

- **25% increase in elevated temperature strength for Al/MMC spent fuel dry casks.**
- **15% increase in operating temperature for cylinder liners in combustion engines.**
- **50% decrease in manufacturing energy for synthesis of Al/MMCs**

Background & Strategic Approach

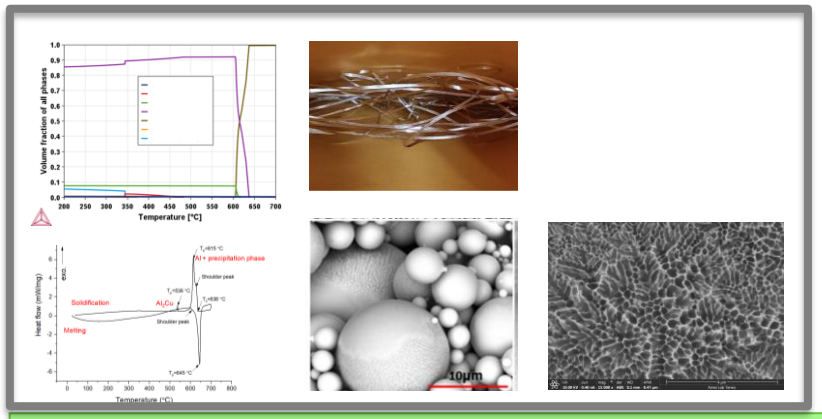
Motivation: **Improved performance of power train components and spent nuclear fuel storage materials through development of Al-Ce/MMC via melt and powder processing**

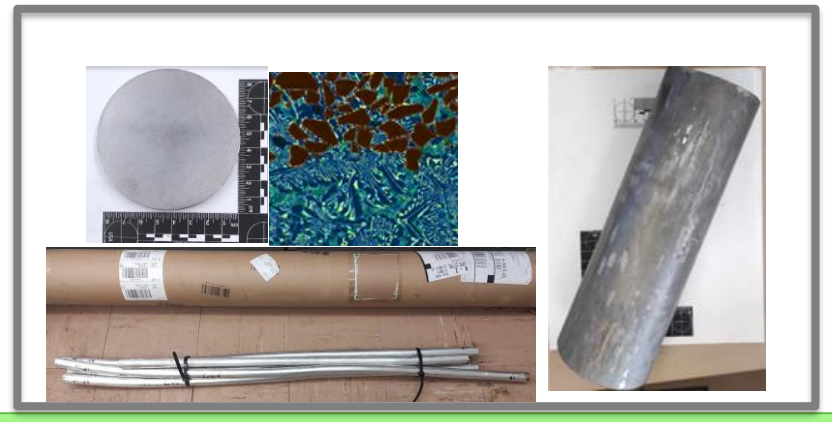
- Al-Ce alloys show good processing flexibility (castings and powder synthesis)
- Very low solubility of Ce in Al and sluggish diffusion (thermal stability)
- Good corrosion resistance
- Minimal heat treatments needed (e.g., stress relief anneal)
- No critical/expensive elements (e.g., Sc, Er)

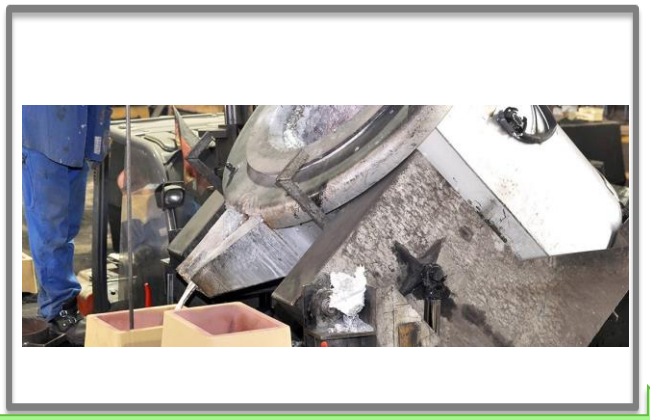


Large amount of Ce produced in US, low value

Team : **Ames National Lab** (alloy development, casting, pilot-scale powder synthesis, extrusion and melt processing), **University of Tennessee** (alloy development and mechanical testing), **Idaho National Lab** (thermo and fluid dynamics modeling), **Oak Ridge National Lab** (corrosion testing), **Intelligent Composites, IC** (cylinder liner synthesis), **Loukustech** (alloy and composite castings), **Holtec Government Services** (storage cask materials and synthesis), **Eckart** (powder synthesis)



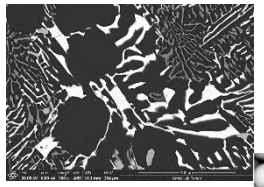


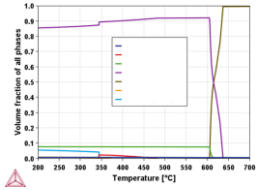


Lab (Ames, INL, ORNL, UTK) Pilot (Ames, Loukustech, Holtec, Eckart) Commercial (IC, Holtec, Eckart)

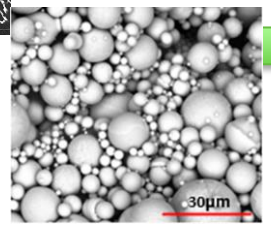
Background & Strategic Approach

Approach:

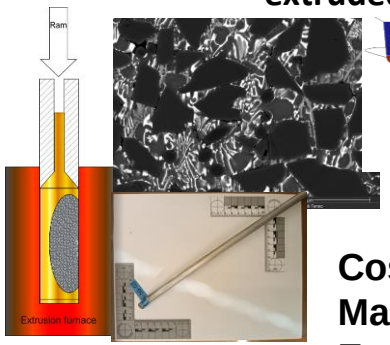


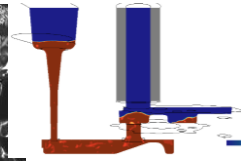


Can matrix alloy be cast and/or atomized into powder?

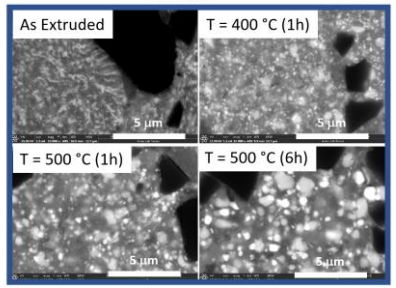


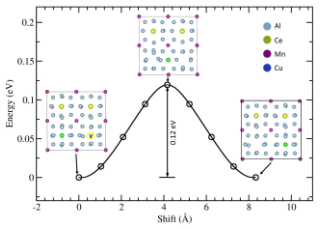
Can composites by extruded or cast?





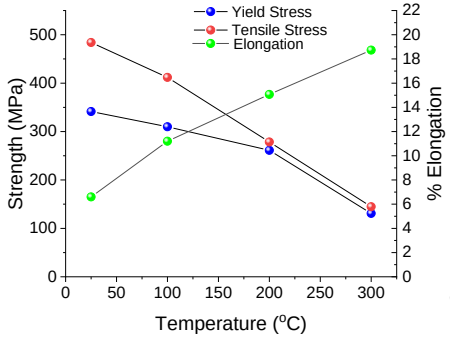
Cost? Manufacturing Energy?

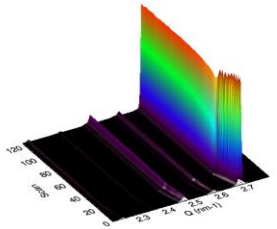




CTE of alloys?
Thermal conductivity?
Long term testing?

Pilot/Commercial Synthesis





Thermal stability?
Elevated temp. strength?

Advanced modeling/theory combined with processing capabilities and characterization at the DOE Labs and industry

Key Challenges:

- Power Train:
  - Casting of composites is difficult – *Powder metallurgy as alternative*
  - Coefficient of thermal expansion (CTE) of Al-Ce alloys is higher than Al-Si casting alloys – *SiC to lower CTE*
- Dry Storage Casks:
  - High strength at elevated temperatures and room temperature ductility – *Tailor fine-scale microstructures*
  - High thermal conductivity required – *Eliminate solid solution strengthening*
  - Cost of Al-Ce alloy powder – *Utilize larger range of powder sizes in composites*

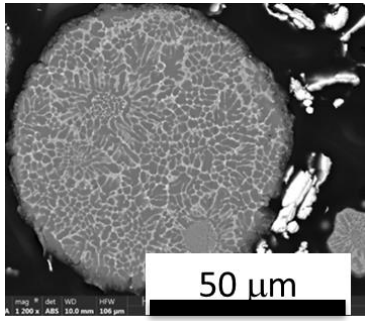
Results and Achievements

New Al-Ce alloy for cast and powder MMCs

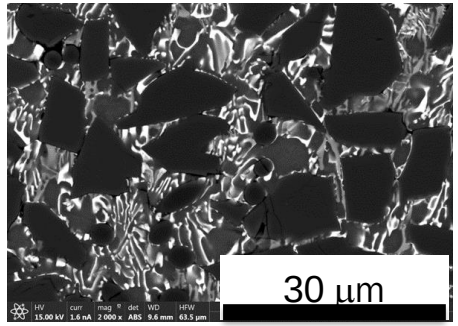
- Al-Cu-Ce-Mn-Zr and Al-Ce-Ni-Zr alloys shows exceptional castability:
- Compatible with gas atomization
- High thermal stability – retains strength at high temperature

Al-Cu-Ce-Mn-Zr

3” diameter billet

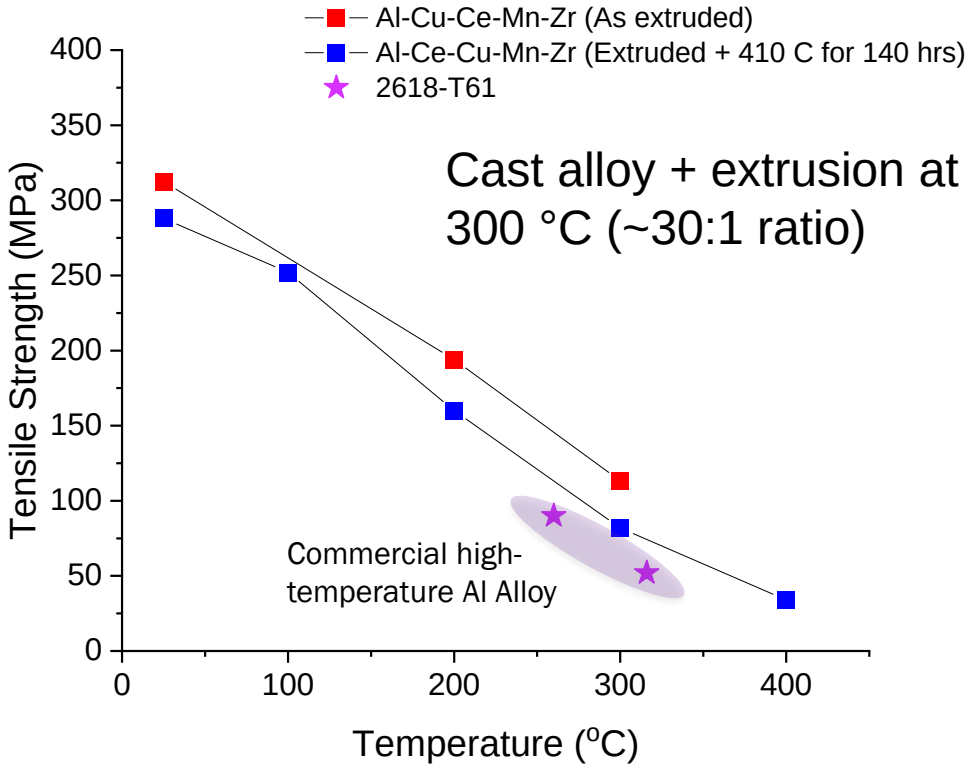


Atomized powder



Al-Ce-Ni-Zr +SiC preform

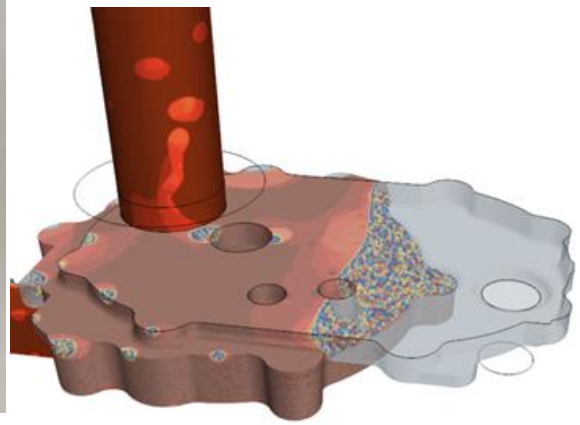
- Alloy show limited loss of strength with high temperature annealing
- Better thermal stability above 250 °C than 2618 Al alloy

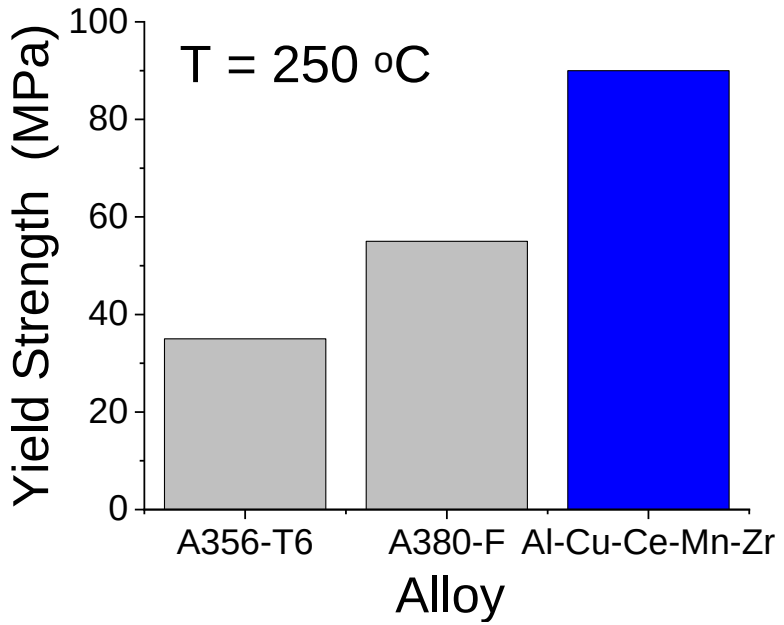


Results and Achievements

Products

- Provisional patent filed July 2022 (*ALUMINUM ALLOYS FOR HIGH TEMPERATURE APPLICATIONS AND RELATED METHODS*) – *Full patent to be submitted*
- Manuscripts submitted:
  - *"Methodology for Thermodynamic Analysis coupled with Computational Fluid Dynamics Modeling for Casting a Novel Aluminum-Cerium Alloy"*
  - *"First-principles study of interfaces in Al/SiC metal-matrix composite system"*
  - 4 manuscripts in preparation
- Validated high temperature performance of cast Al-Cu-Ce-Mn-Zr alloy in commercial component
  - *More than 2x stronger than A356-T6 at 250 °C*
- Al-Ce/MMC prototype cylinder liners using alloys developed in project– *to be completed in May 2023 at Intelligent Composites and Loukustech*





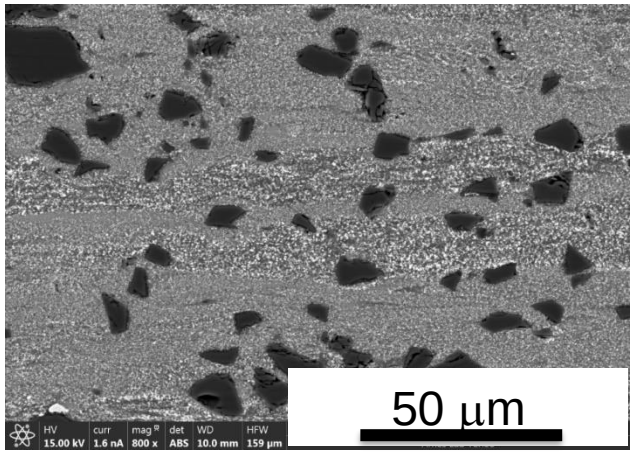
Results and Achievements

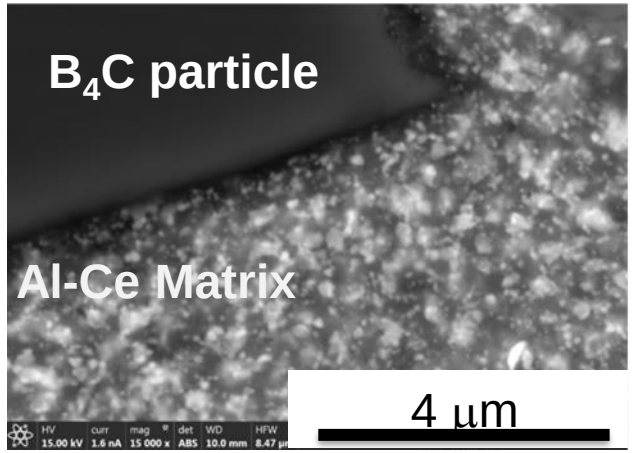
Pilot Scale Synthesis of Al-Ce/MMC

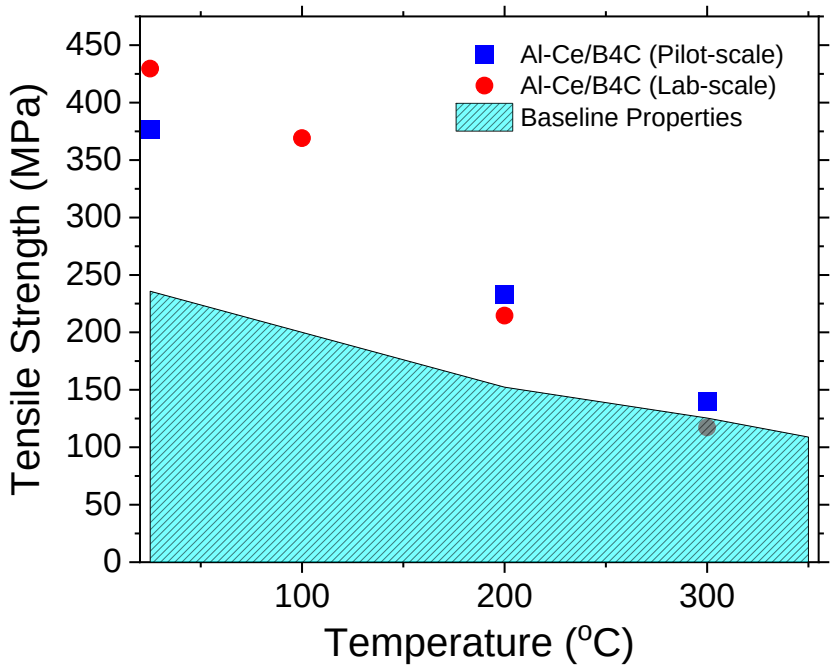
- Atomized four different Al-Ce alloys
  - 3 pilot-scale
  - 1 commercial-scale
- Extrusion consolidation of Al-Ce/X (X = SiC, Al_2O_3, B_4C)
  - Tensile properties measured from 25 - 400 °C
  - Corrosion testing in NaCl and Boric Acid
  - High strength up to 300 °C – thermal conductivity remains challenge
  - Excellent properties for power train applications – manufacturing cost extrusion vs casting?

Products

- 150+ lbs of Al-Cu-Ce-Mn-Zr powder atomized by industrial partner
- Demonstrated synthesis of extruded composites on pilot scale – 3” starting diameter
- Microstructure and thermal stability of extruded Al-Ce alloys informed 2 new AM alloy compositions







Future Work, Technology Transfer, & Impact

Future Work:

- Pilot-scale extrusion of Al-Ce/B4C composites with increase thermal conductivity (> 180 W/m K)
- Cylinder liner casting of Al-Ce/MMC for testing by Tier 1 supplier

Technology Transfer:

- Intelligent Composites and Loukustech are casting Al-Ce/MMC cylinder liners for customer to perform component level testing – *Using alloy developed in this project*
- Collaboration with CMI on developing Al-Ce alloys for Additive Manufacturing (AM) – Two alloys from this project are being tested for AM applications
- Collaborated with AMMTO funded "Fatigue and Fracture Resistance of Al-Ce Alloys for Aerospace Applications" on alloys developed in this project

Impact:

- New Al-Ce alloys and composites with improved performance in harsh service conditions have been developed
- Decreased manufacturing energy through eliminating need for heat treatments
  - Compared to A356 and A390 alloys that require T6 heat treatment (0.06 kWh/kg for solutionizing and 0.02 kWh/kg annealing)
- Increased energy efficiency of powertrain components during service through replacement of incumbent cast iron alloy (density ~ 7.2 g/cc) with lightweight Al-Ce/MMC (density < 3 g/cc)

Questions?

Manufacturing of Al-Ce/Metal-Matrix Composites (MMC) for Harsh Environments | AMMTO

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