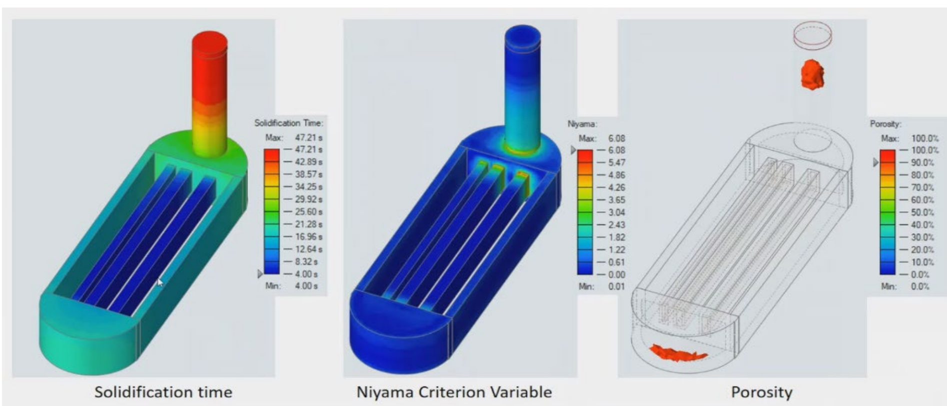
The Novel Cast Aluminum-Cerium Heat Exchanger



Oak Ridge National Laboratory
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Project Summary

Timeline:

Start date: October 2018

Planned end date: September 2021

Key Milestones

1. Fabricate and evaluate first 1 kW cast heat exchanger (HX) (Sept 30, 2020)
2. Complete the evaluation of the thermal performance of the second prototype heat exchanger (June 30, 2021)

Budget:

	DOE funds	Cost share
FY19	445K	50K
FY20	445K	25K
FY21	445K	-

Key Partners:

Oak Ridge National Laboratory; University of Maryland; Eck Industries, Inc. (Specialists in premium aluminum castings); Virginia Tech

This resulted in CRADA partnership

Project Outcome:

- Development of the first HX that is casted in one piece, including the headers, eliminating the need for brazing or welding
- Successfully development of a method of manufacturing low-cost high-pressure microchannel HXs

Leveraging the ORNL invented the Al-Ce alloy under Critical Material Institute to develop next generation HX

Project Team

- **Oak Ridge National Laboratory**
  - Kashif Nawaz (Sr. R&D staff)
  - Ayyoub Momen (Director, Ultra Sonic Tech)
  - Mingkan Zhang (R&D staff)
  - Jamison Brechtl (Post Doc associate)
  - Michael Kessler (R&D staff)
  - Orlando Rios (Associate Professor- add UTK)
  - Jiahao Cheng (R&D staff)
  - Xiaohua R&D staff)
- **Eck Industries Inc.**
  - David Weiss (VP R&D)
- **University of Maryland**
  - Jiazhen Ling (Associate Professor)
  - Vikrant Aute (Associate Professor)
- **Virginia Tech**
  - Reza Mirzaeifar (Associate Professor)
  - Ryan Lane (Graduate Research Assistant)







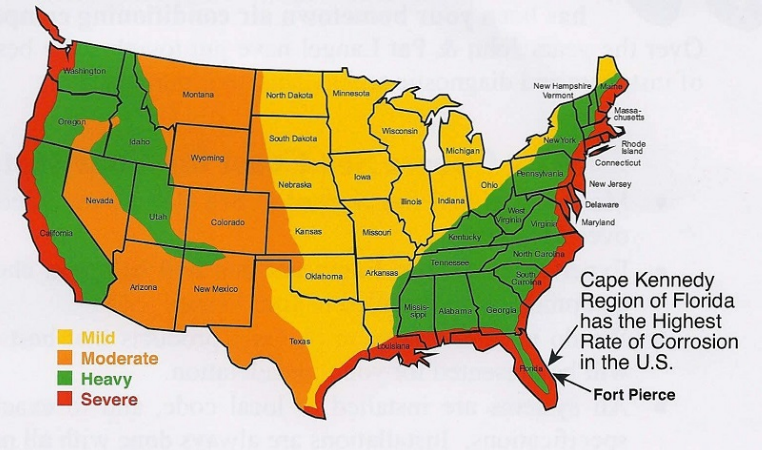




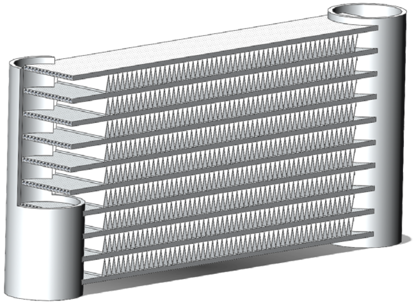


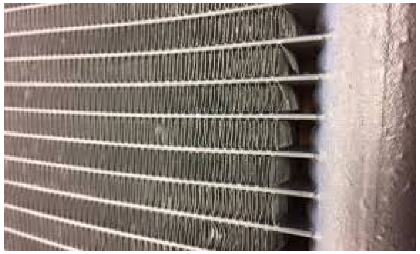
Challenge

- Heat exchanger is an essential component of any energy conversion process.
- Overall, heat exchangers account for more than 50% energy consumption and refrigerant inventory in a heat pump.
- Joints at headers are the weakest points and brazing makes the microchannel expensive
- Header deployment for most of the recent compact heat exchanger to reduce the refrigerant charge is a major technological challenge
- High-pressure HXs are expensive (CO_2 HXs are very expensive)



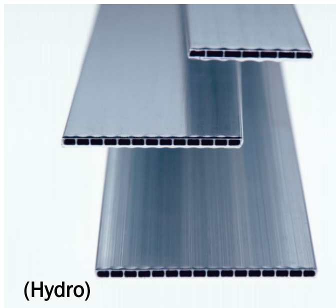
Corrosion map of the U.S.

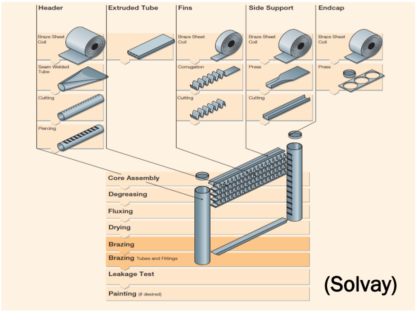




HXs fail in corrosive environments (i.e. in FL coastal regions HVAC condenser aluminum fins corrode within 5 years)

Challenge


(Hydro)

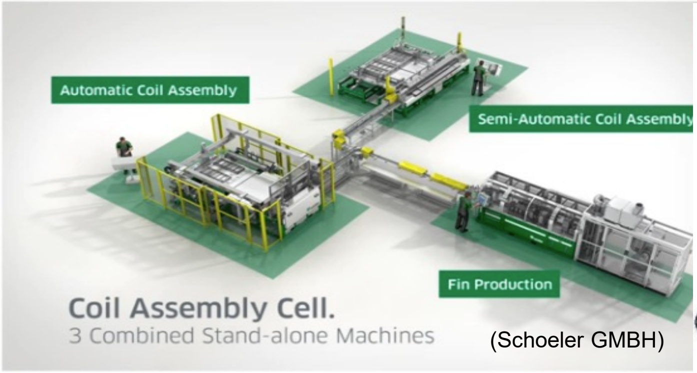


(Solvay)

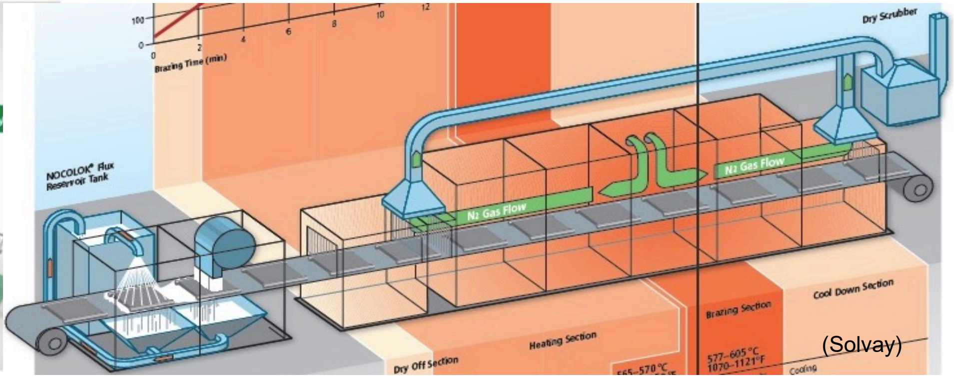

(Sanhua)

Extruded microchannels: Small feature sizes: 0.1 mm fins, <1 mm channels

Fin stamping, assembly, fluxing, drying, brazing in controlled atmosphere brazing (CAB) furnace



(Schoeler GMBH)



(Solvay)

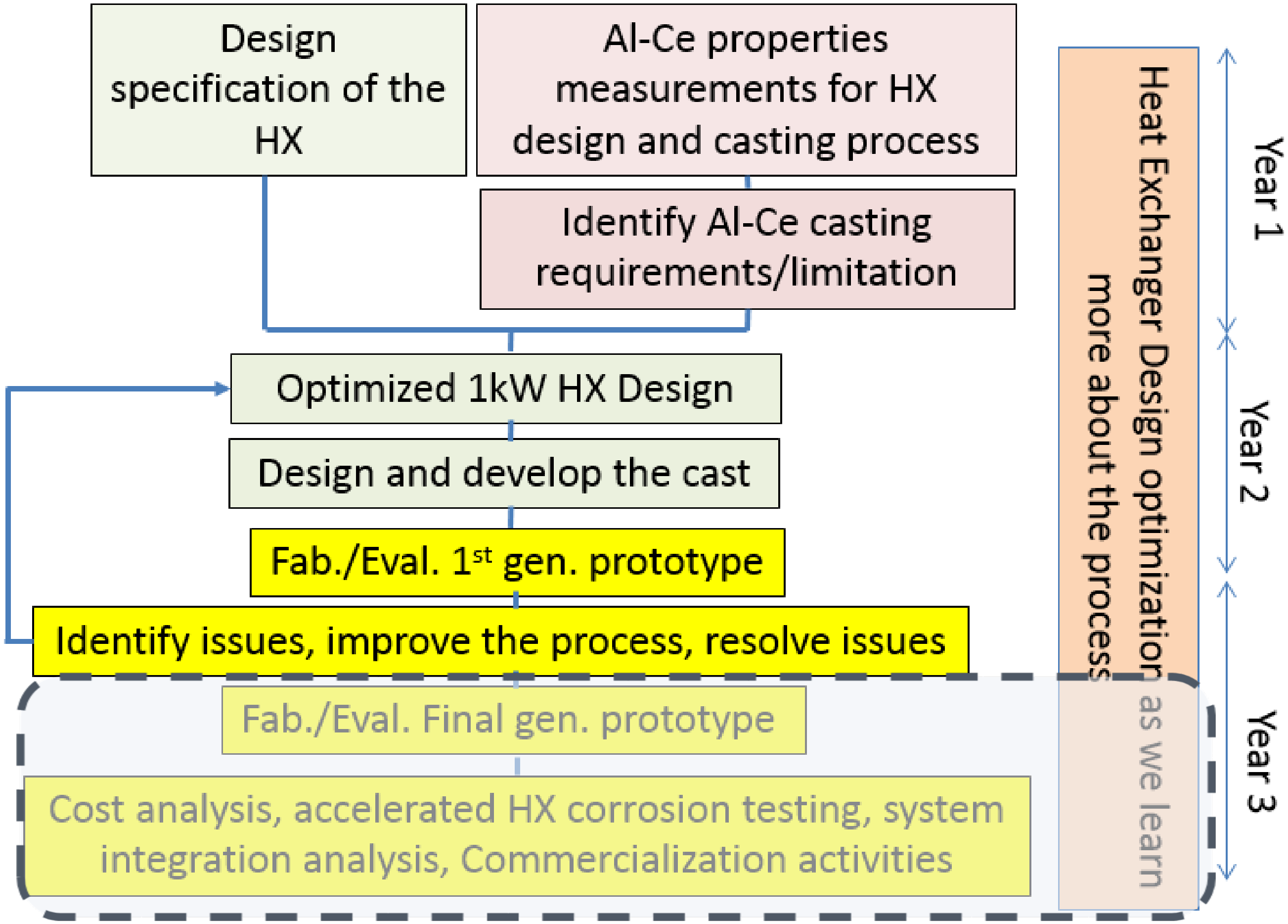
- Throughput: 500,000 units/year
- Manufactured cost: ~$2–$4/lb (excludes the capital cost/markup)

Historical Overview

- Aluminum was more expensive than gold in 19th century.
- In 1850, aluminum was $37,200/kg, but gold was $20,500/kg
- In 1884 when the Washington Monument was finalized, a 2.8 kg aluminum pyramidon was placed at the top
- In 1889, the Bayer, Hall process was developed, which significantly reduced the cost of aluminum extraction
- Today, aluminum is being used in HVAC, automotive, aviation, power generation, and other industries

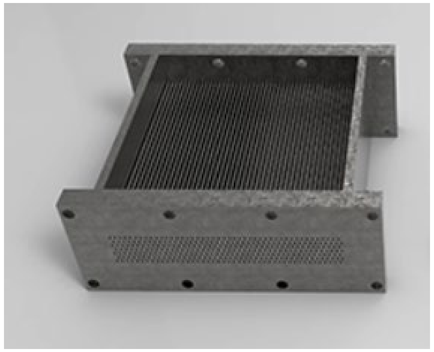
A new material/alloy/manufacturing processes could potentially revolutionize many industries!

Solution Approach



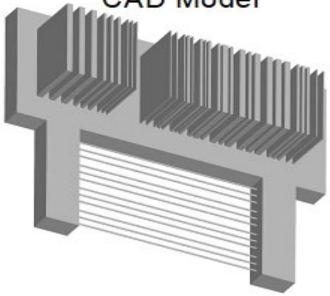
Project Impact

- **Castability leading to reduced manufacturing cost**
  - Unlocks new potential geometries that otherwise cannot be cost effectively manufactured
  - Increase leak resistance
  - Development of customized headers that can minimize refrigerant flow maldistribution
- **Corrosion resistance**
  - Better corrosion resistance than conventional aluminum alloys
  - Reduced degradation of Al fins in **coastal** areas.
  - Indoor coils—avoids formicary corrosion that can cause refrigerant leaks in copper tubes
  - Corrosive exhaust gases
- **Mechanical strength (including at high-temperatures)**
  - High-pressure applications and temperature (~300 C)
- **Lower manufacturing cost**
  - Low-cost casting manufacturing process
  - Eliminates the need for post-heat treatment
- Substantial reduction in refrigerant charge, CO_2 emissions reduction

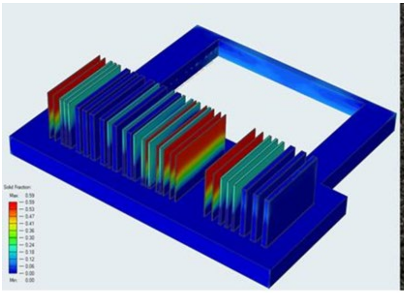


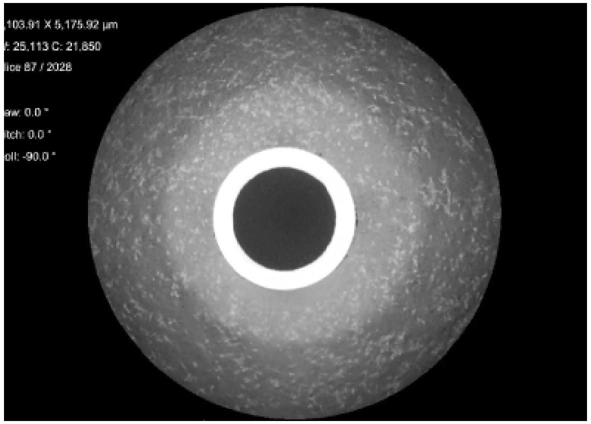
Project Progress

CAD Model



Test Mold





Excellent interfacial contact for the metallurgical bond between the Al-Ce manifold and the SS tube

Project Progress

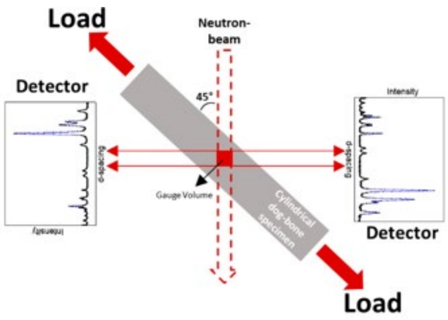
- The alloys studied for this project consist primarily of aluminum, cerium, and magnesium
- Alloy formed by melting pure forms of the various elements in a furnace
- Samples were either as-cast or extruded (ratios up to 52:1)
- Some samples also underwent heat treatment
  - T4: 540 ^{o}C for ten hours and then rapidly quenched in water
  - T6: 540 ^{o}C for ten hours, rapidly quenched in water, and then aged at 150 ^{o}C for 3 hours

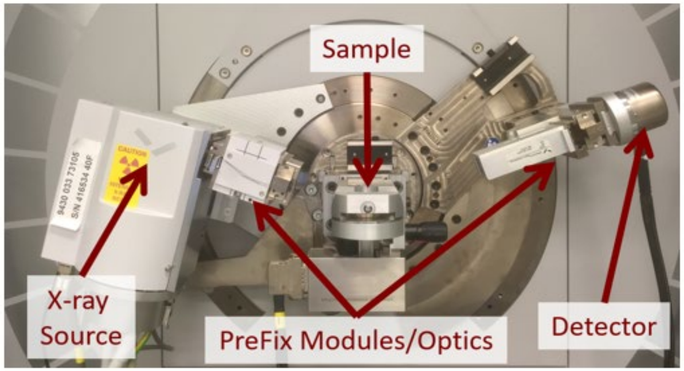
Sample Composition (weight percent) and condition for the experimental work

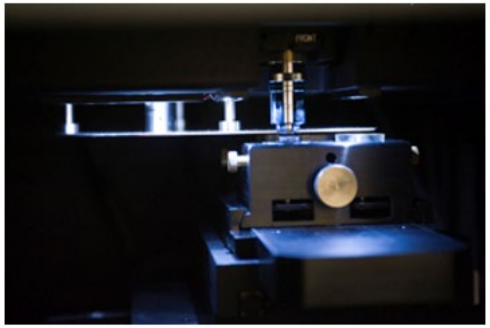
Aluminum	Cerium	Magnesium	Condition
87.6%	12%	0.4%	As-cast
82%	8%	10%	52:1 extruded

Project Progress

- Mechanical testing:
  - In situ compression and tension testin
  - Nanoindentation
- Microstructural characterization Methods materials and component level
  - X-ray diffraction
  - Neutron diffraction
  - Scanning electron microscopy
- Computational approaches
- Finite element analysis

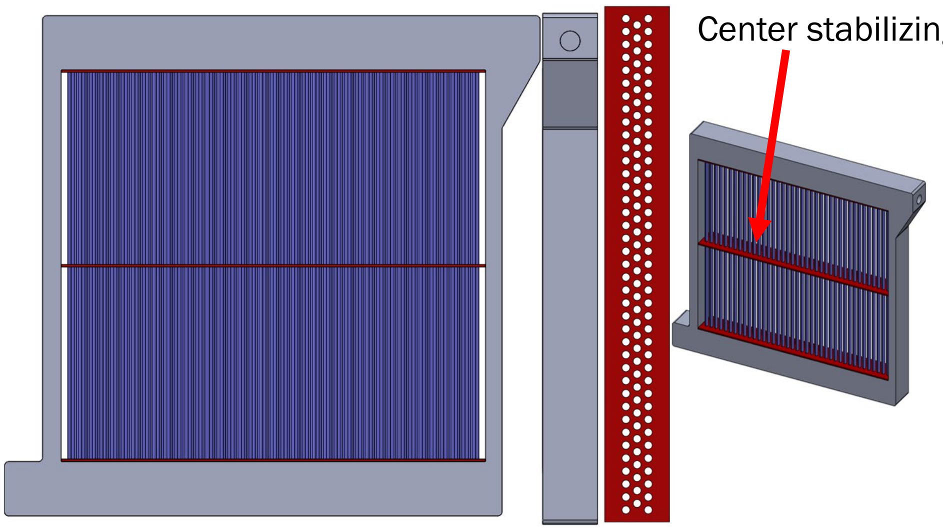


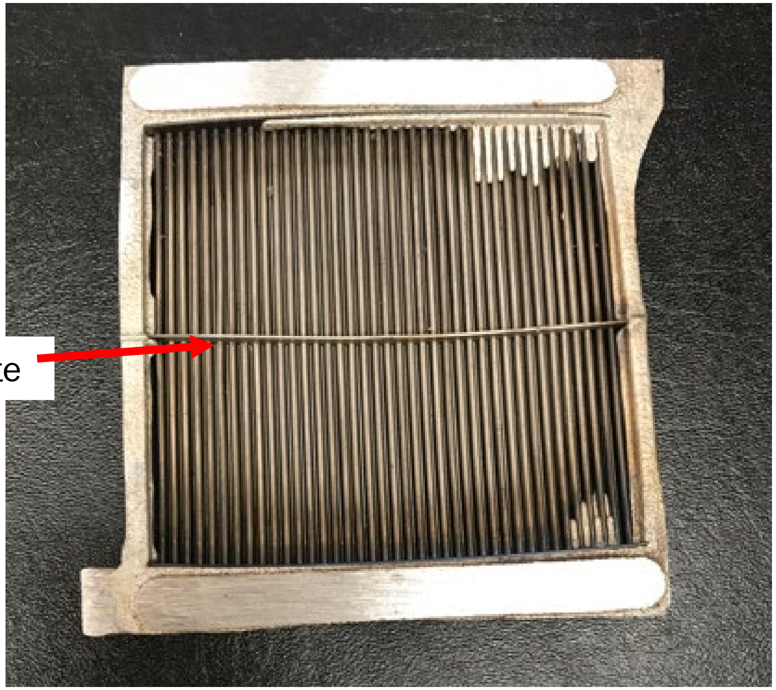


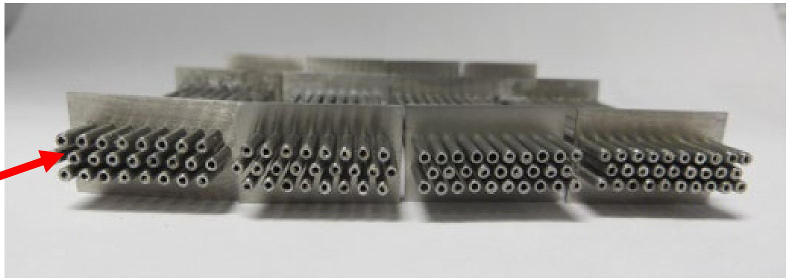


Project Progress

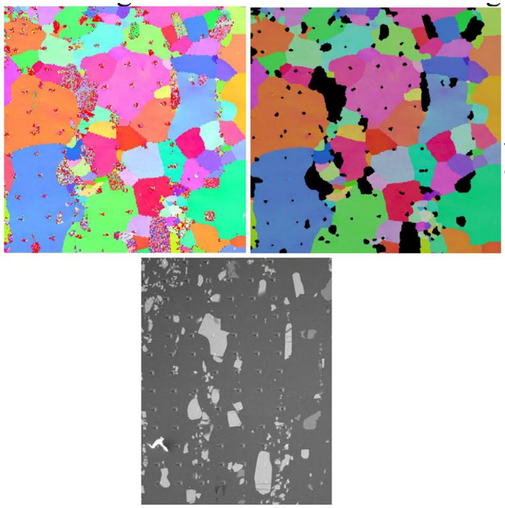
Team demonstrated the ability to cast a full-scale heat exchanger with consistently spaced microchannels by the addition of a center stabilizing plate

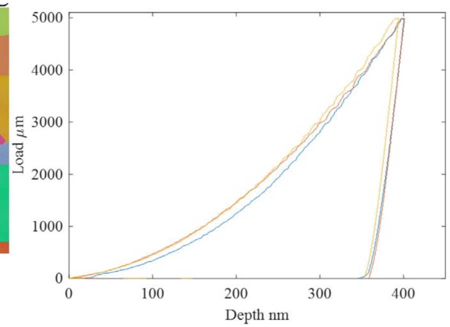




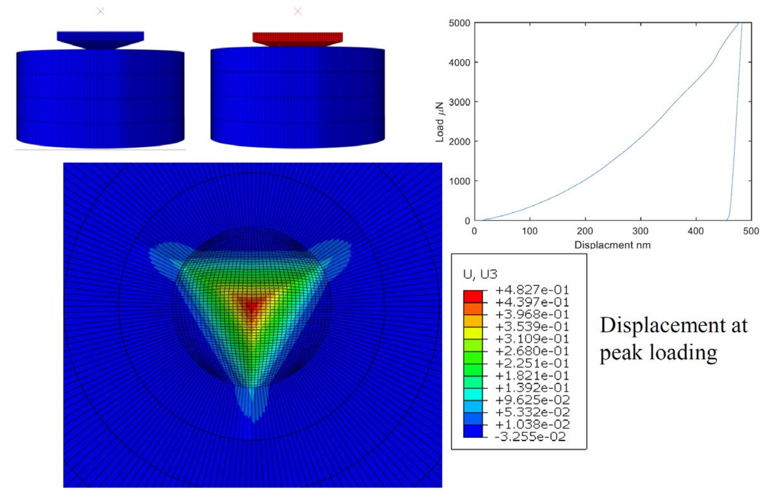


Project Progress



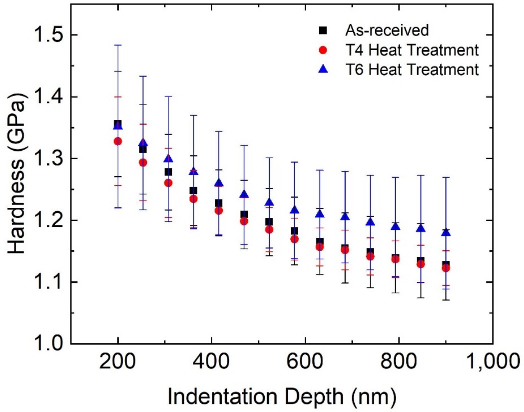


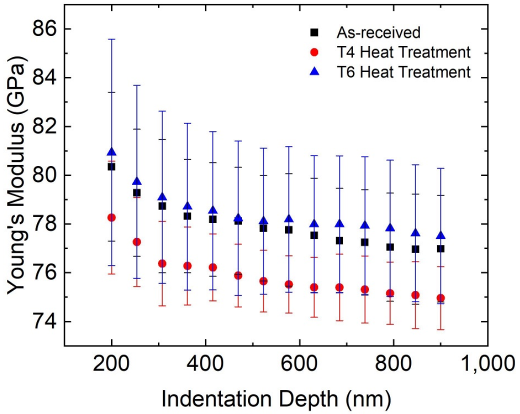
Experimental nanoindentation results for 3 different grain orientation.



Displacement at peak loading

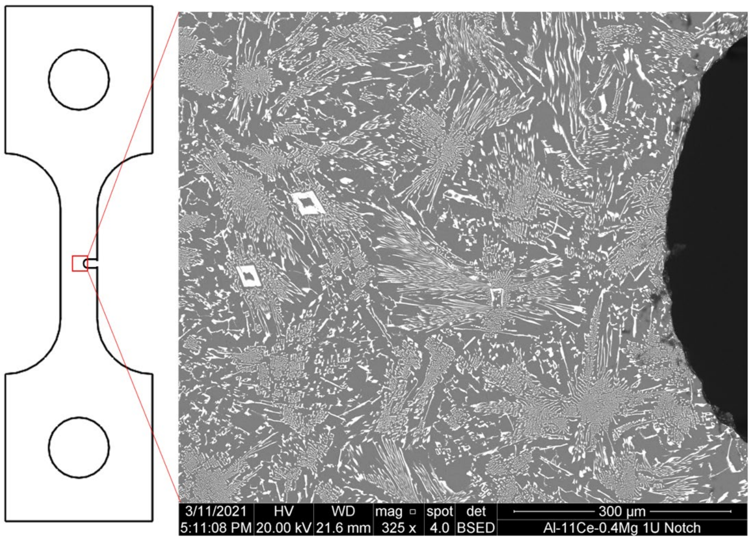
Successful EBSD Mapping and Simulation Work of Nanoindentations on an Al-8Ce-10Mg extruded sample

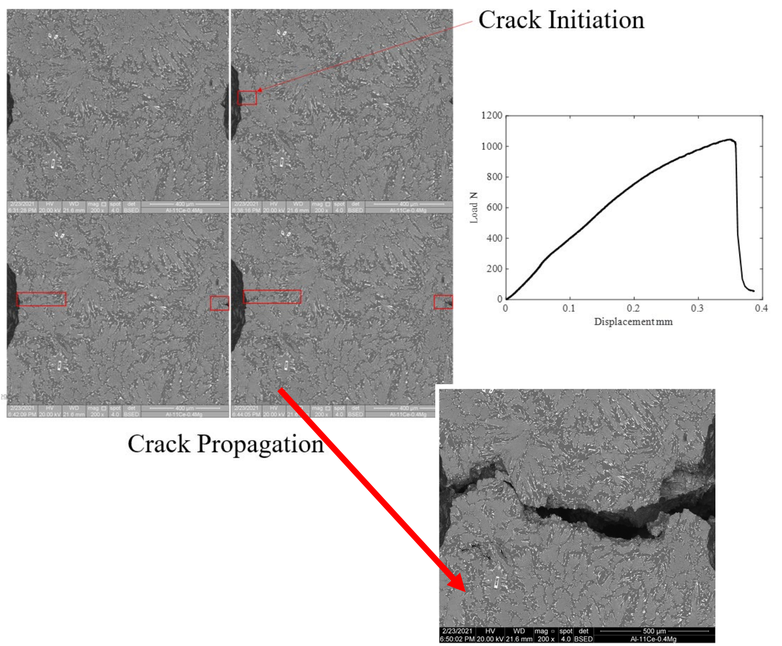




Nanoindentation hardness (left) and Young's modulus (right) data for the as-received, T4 heat treatment, and T6 heat treatment samples.

Project Progress





In situ (SEM) Tension Tests Help Examine Stress-induced Crack Propagation in As-received Al-11Ce-0.4Mg Alloy

Progress: Stakeholder Engagement

Engagement:

Weekly meetings: ORNL-VT

Biweekly meetings: ORNL/ECK/UMD/VT/OTS

Publications/Inventions/Reports:

Invention Disclosure 201804134, DOE S-138,801

Multiple milestone reports

Multiple publications (fundamental and applications)

- Ryan J. Lane, Ayyoub M. Momen, Michael S. Kesler, Jamieson Brechtl, Orlando Rios, Kashif Nawaz, and Reza Mirzaeifar, The Development of a Crystal Plasticity Finite Element Model for Al-8Ce-10Mg Alloys, submitted to Journal of Alloys and Compounds
- Jiahao Cheng, Ryan Lane, Michael S. Kesler, Jamieson Brechtl, Xiaohua Hu, Reza Mirzaeifar, Orlando Rios, Ayyoub M. Momen, Kashif Nawaz, Experiment and Non-Local Crystal Plasticity Finite Element Study of Nano-Indentation on Al-8Ce-10Mg Alloy, submitted to International Journal of Solids and Solutions

Industry input:

Optimized Thermal SYSTEMS

Heat Transfer Technologies LLC

Eck Industries, Inc. Specialists in premium aluminum castings

SHILOH®

Thank you

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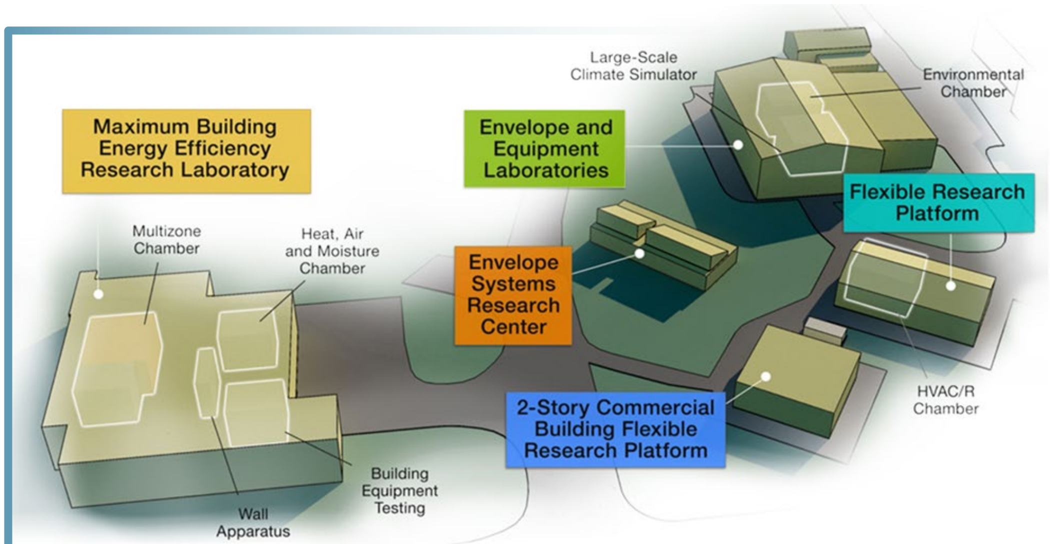

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

Project Budget

Project Budget: $1,335 K (open lab call 2018)
Variances: None
Cost to Date: $890K
Additional Funding: Note

Budget History					
FY2019 – FY 2020 (past)		FY 2021 (current)		FY 2022 –	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$890K	$50K	$445K	$25K		

Project Plan and Schedule

Project Schedule												
Project Start: 10/1/2018		Completed Work										
Projected End: 9/31/2021		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed										
		Milestone/Deliverable (Actual) use when met on time										
	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1: Market assessment												
Q2: Property measurments												
Q3: HX design specifications												
Q4: HX design showing 15% improvement												
Q1: Design the cast												
Q2: Complete CFD simulation												
Q3: Complete cast fabrication												
Q4: Evaluate the cast HX performance												
Q1: Documenting the manufacturing flaws												
Q2: Complete the fabrication of second HX												
Q3: Evaluate the thermal performance												
Q4: Cost analysis, commercialization activities, report												