Research-to-Power: The sCO_2 Future

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Oak Ridge National Laboratory

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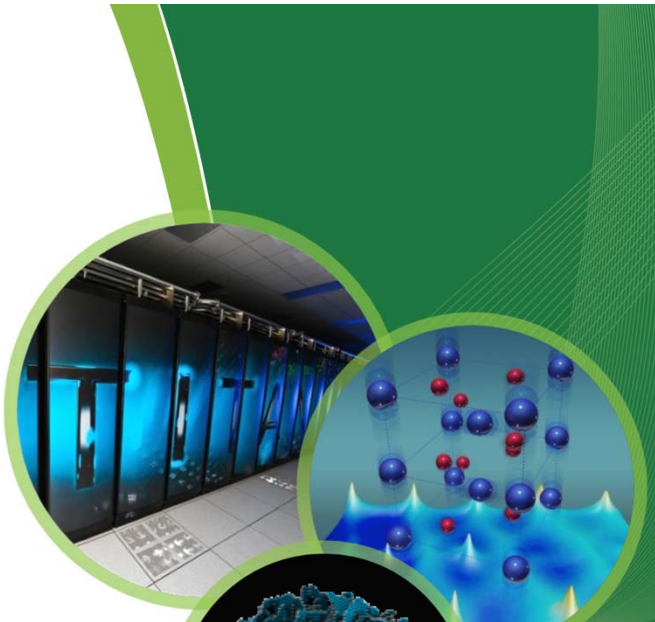

ORNL is managed by UT-Battelle
for the US Department of Energy

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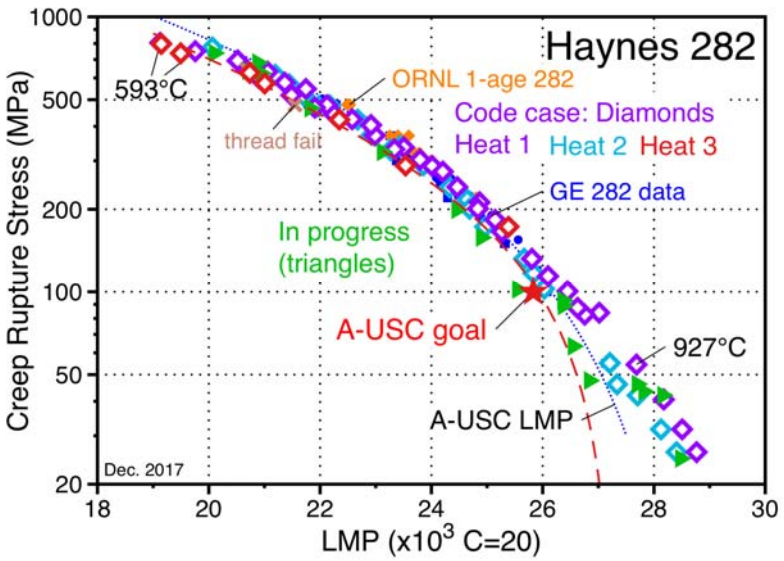
ORNL has supported the development of new energy technologies for 75 years

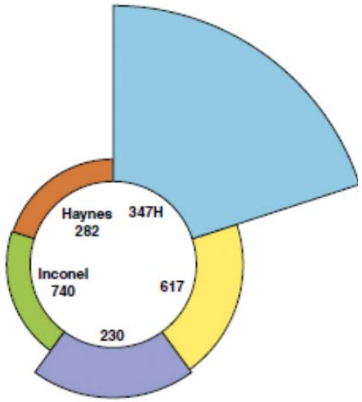
- ORNL has a broad range of expertise
- Engineering divisions for design, development and analysis
- Computation directorate for modeling and simulation
- Materials division can address:
  - Material and coating selection
  - Material and coating performance
  - New material development
    - ~10 R&D 100 awards for alloy development
      - 1982 for Grade 91, first creep-strength enhanced ferritic steel
      - 2017 two awards for two new high strength Al alloys
    - Participating in new DOE Fossil Energy Extreme Materials team

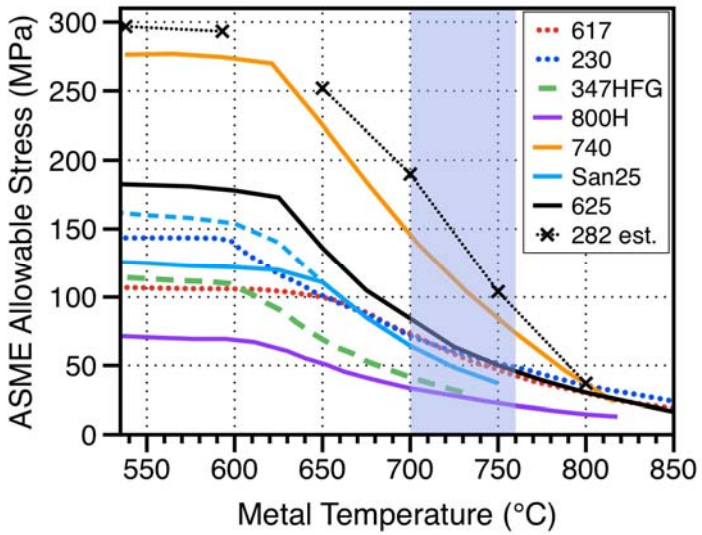
Current sCO_2 relevant projects at ORNL

- ASME Code Case for Haynes 282 (Fossil)
  - Cost-shared by Haynes International
- Lifetime modeling for CSP sCO_2 power block at 700°-800°C (Solar)
  - Completing 3rd and final year of project in 2018
- Corrosion issues in direct-fired sCO_2 cycles (Fossil)
- Design and fabrication of a novel sCO_2 heat exchanger (Fossil)
  - New project using additive manufacturing (AM)

ASME code case is ~70% complete (~370,000 h)
Finish in Spring 2019 (began April 2015)







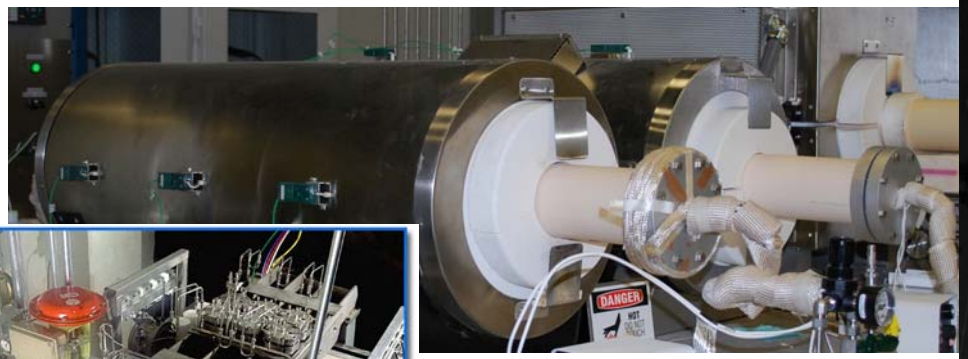
500-10,000 h tests at 593-927°C
- 3 base metal heats
- 2 welds
- Plus all weld metal specimens

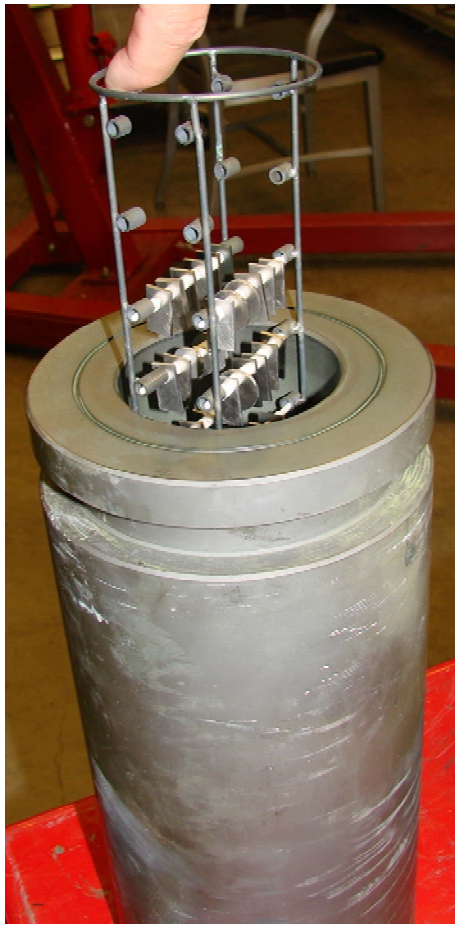
Shingledecker ~2011

Precipitation-strengthened Ni-base alloys 282 and 740H advantageous above 700°C

Several laboratory tests for studying 750°C CO_2 corrosion

1. Automated Cyclic Rigs (1 bar)
   - Relevant to solar duty cycle
2. 3-zone tube furnaces (1 bar)
3. 282 autoclave (300 bar)
4. “Keiser” rig (1-43 bar)





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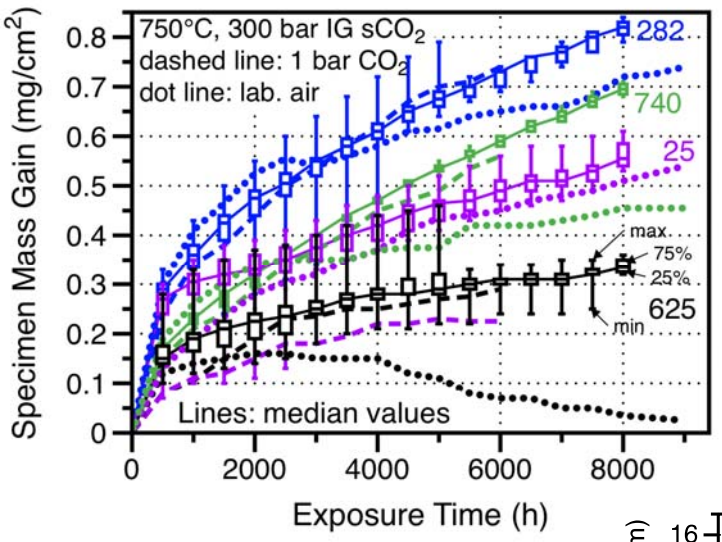
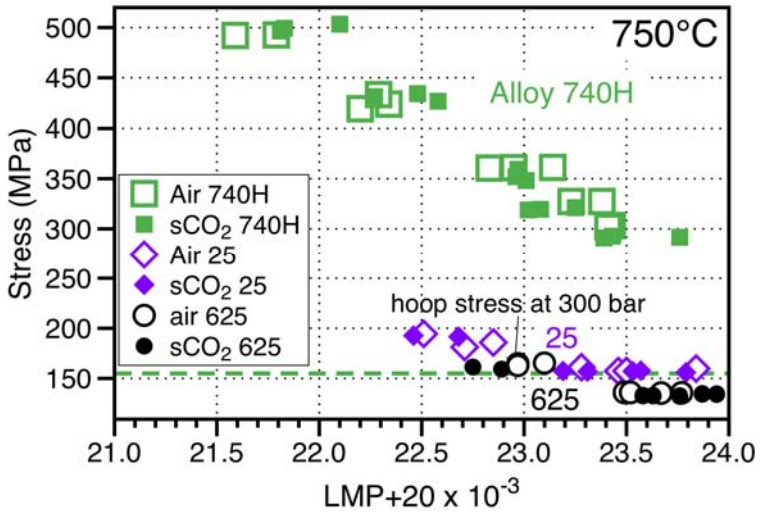
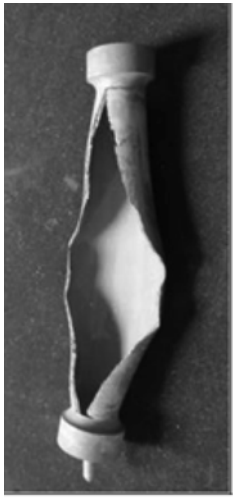
Lifetime modeling for 100,000 h CSP sCO_2 power block

Multiple laboratory environments explored

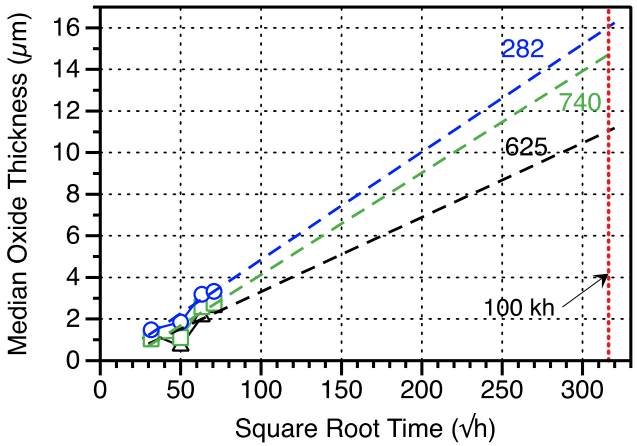


Creep rupture in sCO_2 and air





Extrapolation



Larson Miller Plot
LMP = T(in K) (20 + log(time in h))
Open symbol: pressurized air
Closed symbol: sCO_2

Brayton Energy LLC

SunShot U.S. Department of Energy

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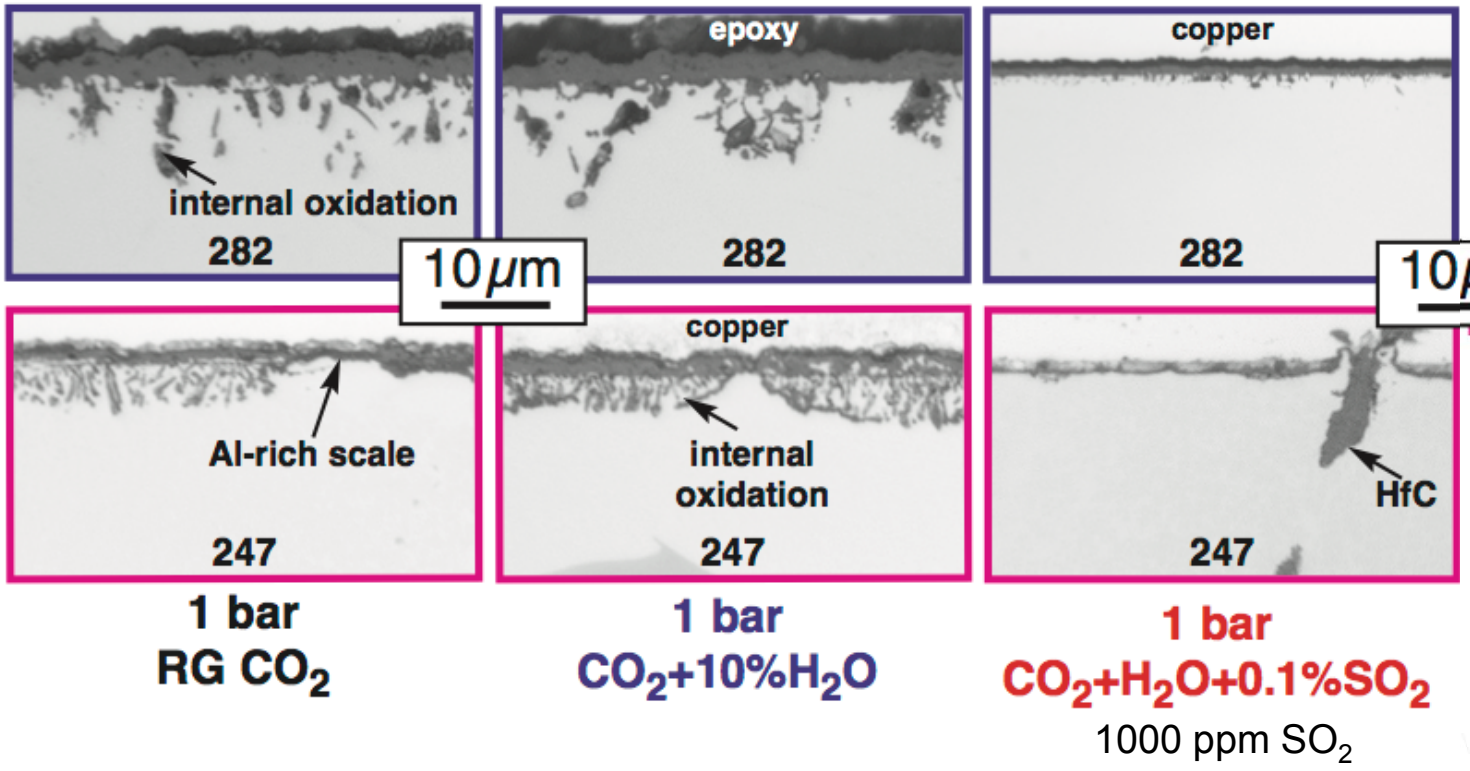
Complexity of direct-fired environment:
sCO_2: dual oxidant environment (O, C)
Direct-firing: possibly 4 oxidants: (O, C, OH, S)



Cr_2O_3-former

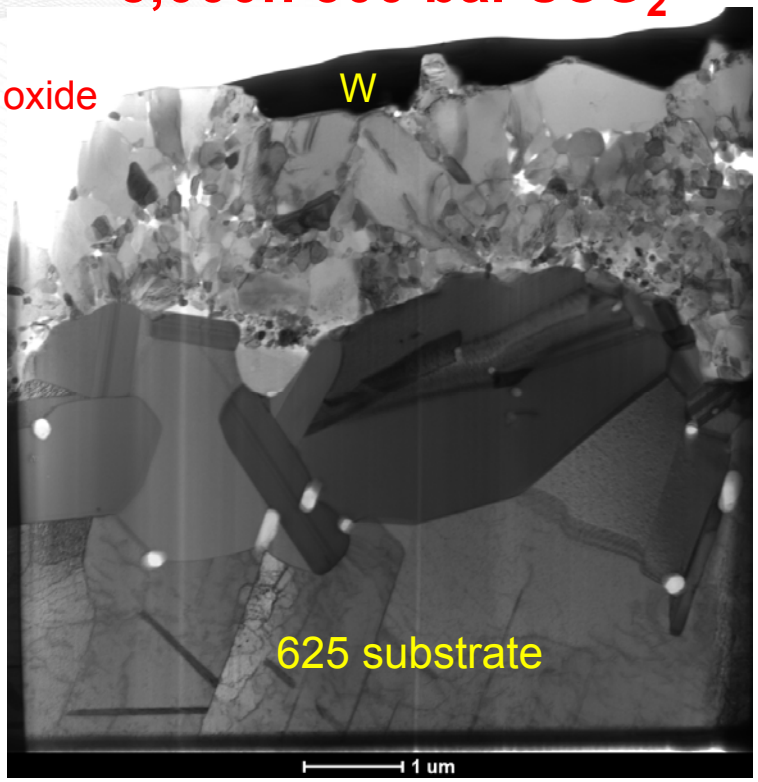
800°C, 500h

Al_2O_3-former

Similar results for SO_2 reported by Young (UNSW) and Quadakkers (Jülich)

Thin reaction products make characterization a challenge

5,000h 300 bar sCO_2

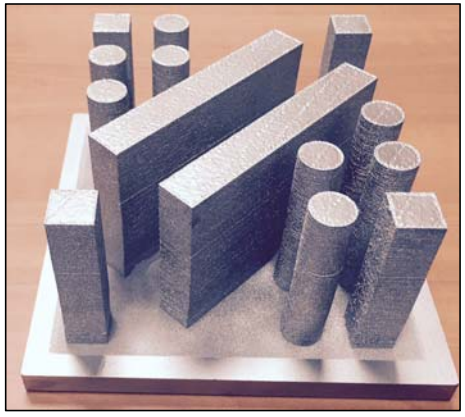


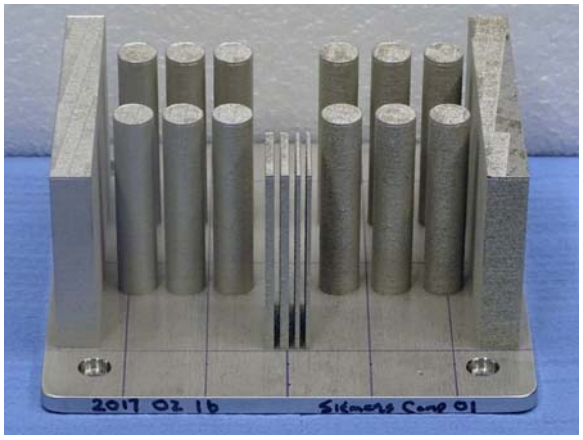
625: Ni-22Cr-9Mo-4Nb-4Fe-0.1Al-0.2Ti

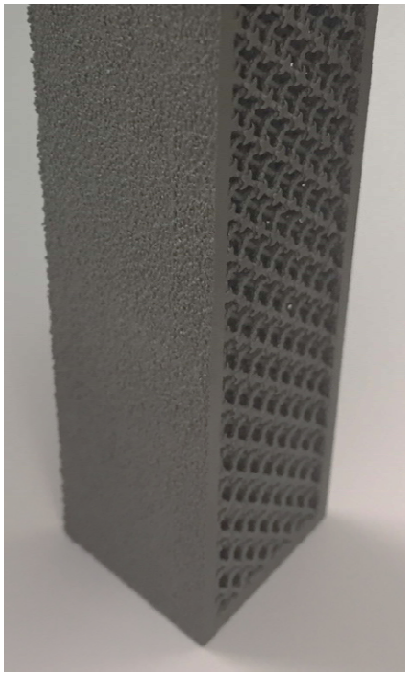
- Multi-oxidant environments
  - Fundamental knowledge
- High pressure
- Thin-reaction products difficult to:
  - Identify phase composition
  - Quantify porosity
  - Detect C and S ingress
- Requires high resolution techniques
  - Limited sampling area

Additive manufacturing is an ORNL focus area

- Current project in conjunction with NETL and Ames Lab.
- Phase 1: designing a novel heat exchanger
- Phase 2: trial builds and evaluations
- PI: Adrian Sabau

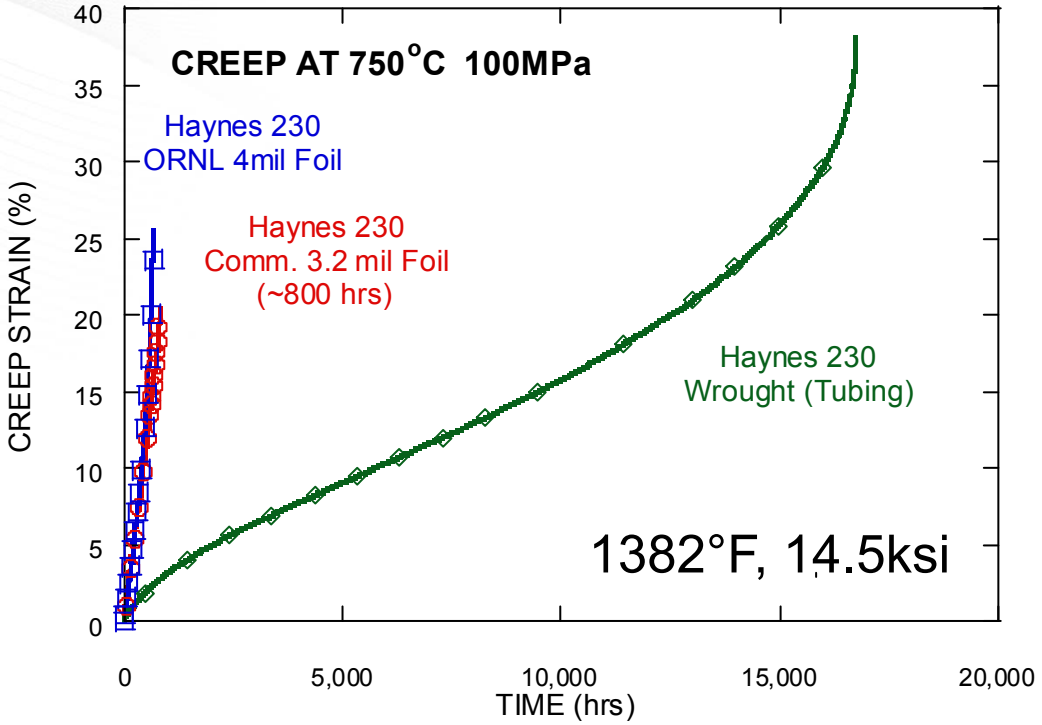


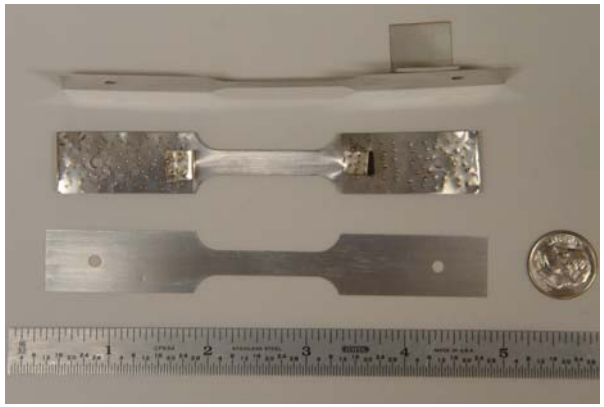




Example of a complex 282 mesh structure fabricated by electron beam melting

What has not been explored is the creep performance of thin-walled components





HR230 (NiCrW) is sensitive to grain size, which makes the creep resistance of foils much less than thicker plate/tube

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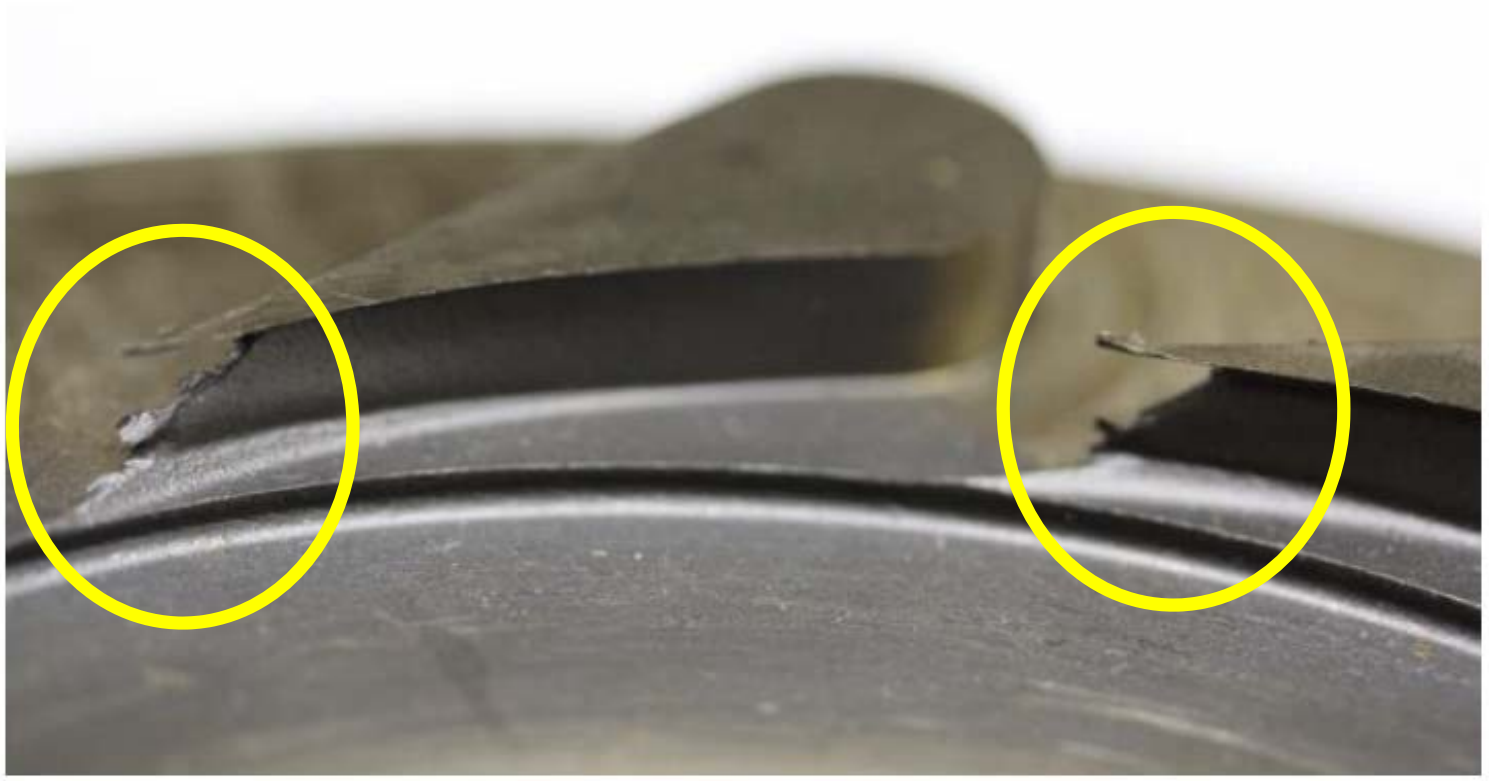
Erosion (by fluid or particles?) not going to be investigated in autoclaves



From Fleming et al. Sandia National Laboratory report, 2014

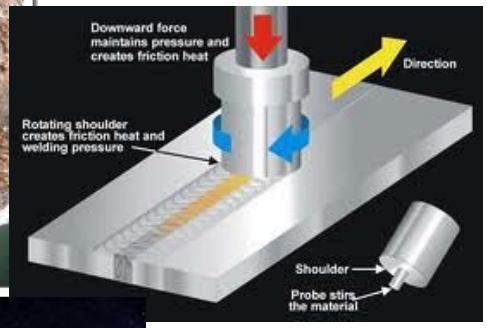
ORNL will support the development of sCO_2 technology

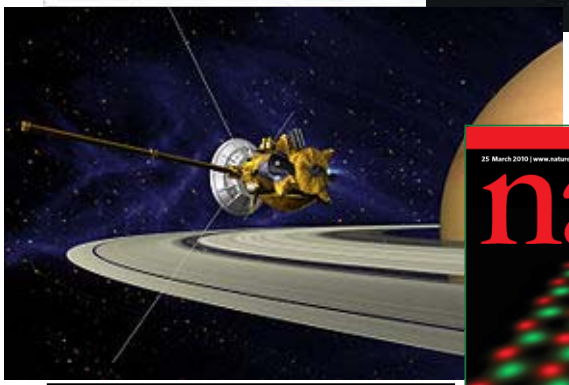
- Engineering: design, analysis and development
- Computation: modeling and simulation
- Materials: selection, performance, new alloy development
  - Corrosion: nothing exciting is good news

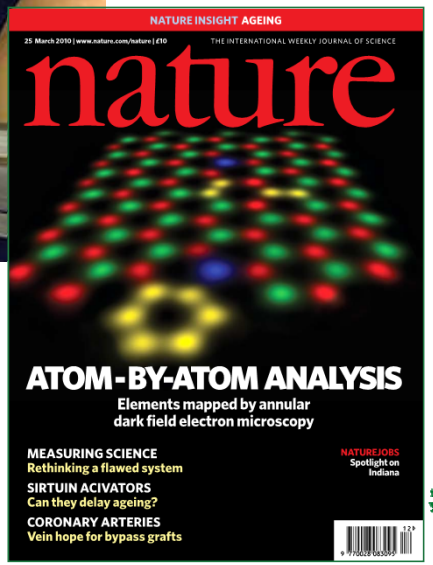
Fantastic new failure mechanisms can derail new technologies

Unique Expertise for Challenging Materials

- Carbon Fiber and Composites
- Light Weight Metals
- High Temp and Refractory Metals
- Single Crystal, Functional Materials
- Ceramics
- Corrosion / Oxidation
- Joining
- Advanced Processing
- Energy Storage
- Mechanics
- Alloy design
- Characterization & Evaluation
- Theory & Computation







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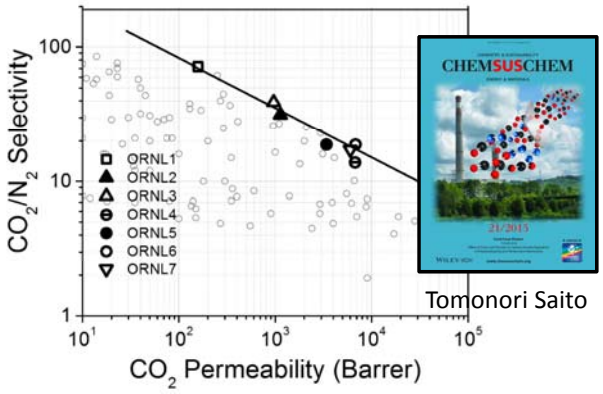
ORNL Legacy of Alloy Development - Alloy & Processing R&D 100 Awards

- 1982 R&D 100 Award "Super 9Cr-1Mo Steel Alloys"
- 1990 R&D 100 Award "ORNL HT-UPS 'Lean' Austenitic Stainless Steels"
- 2003 R&D 100 Award "CF8C-Plus - New Cast Stainless Steel for High-Temperature Performance"
- 2006 R&D 100 Award "TMA 6301 and TMA 4701: Heat-Resistant Alloys" (Muralidharan ORNL lead)
- 2009 R&D 100 Award "AFA: Alumina-Forming Austenitic Stainless Steels" (Pint team member)
- 2011 R & D 100 Award "New Stainless Steel Alloy Tooling For High Temperature Presses that Form Aircraft Components"
- 2012 R & D 100 Award "Asymmetric Rolling Mill: A Novel Route for Processing Sheet and Plate"
- 2012 R & D Award "LRF-501 Low-Cost Plasma Processing System for Research and Pilot Production"

Opportunity: use ORNL computational methodology to develop new alloys to enable higher performance CSP systems

ORNL is Developing Novel Technologies for CO_2 Separation, Capture and Utilization

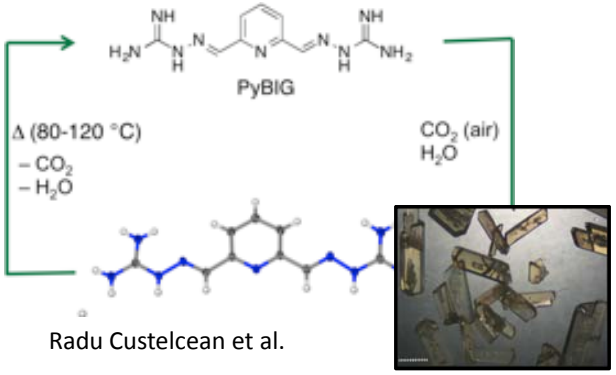
Organic membranes with unprecedented high CO_2 permeability



Tomonori Saito

- Initial funding by **LDRD** program. Current funding by DOE's **Technology Commercialization Fund**.
- Partnership with MTR Inc. for pilot-scale tests. Potential to achieve \$20/ton of CO_2

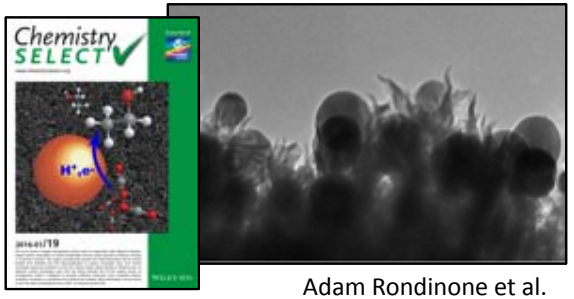
Aqueous guanidine sorbent scrubs CO_2 from air



Radu Custelcean et al.

- Aqueous guanidine sorbent binds CO_2 as insoluble crystalline carbonate salt
- CO_2 can be released at 80-120°C to regenerate guanidine ligand.
- Currently funded by DOE's **Technology Commercialization Fund**.

Carbon Nanospikes for Conversion of CO_2 to Ethanol via Electrocatalysis



Adam Rondinone et al.

- Laboratory Scale Demonstration
- 63% Faradaic efficiency
- 84% Selectivity for CO_2
- 22% Energy Efficiency
- Initial work funded by DOE's OS. Current funding by DOE-FE- CO_2 Utilization Program.

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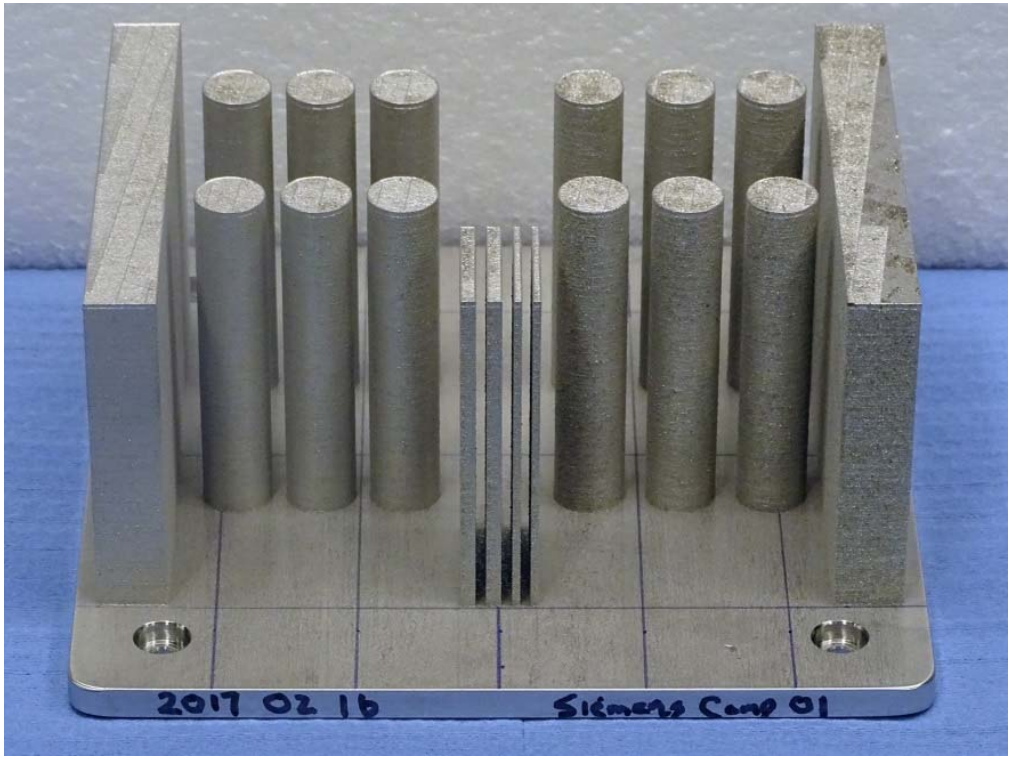
New SLM (SLM-Opt) Build For Extensive HX Characterization

- 35h, ~2000 layers
- 65mm tall
- Rectangular blocks to study properties anisotropy
- Thin wall effect
- Machine available for 2 weeks for process optimization



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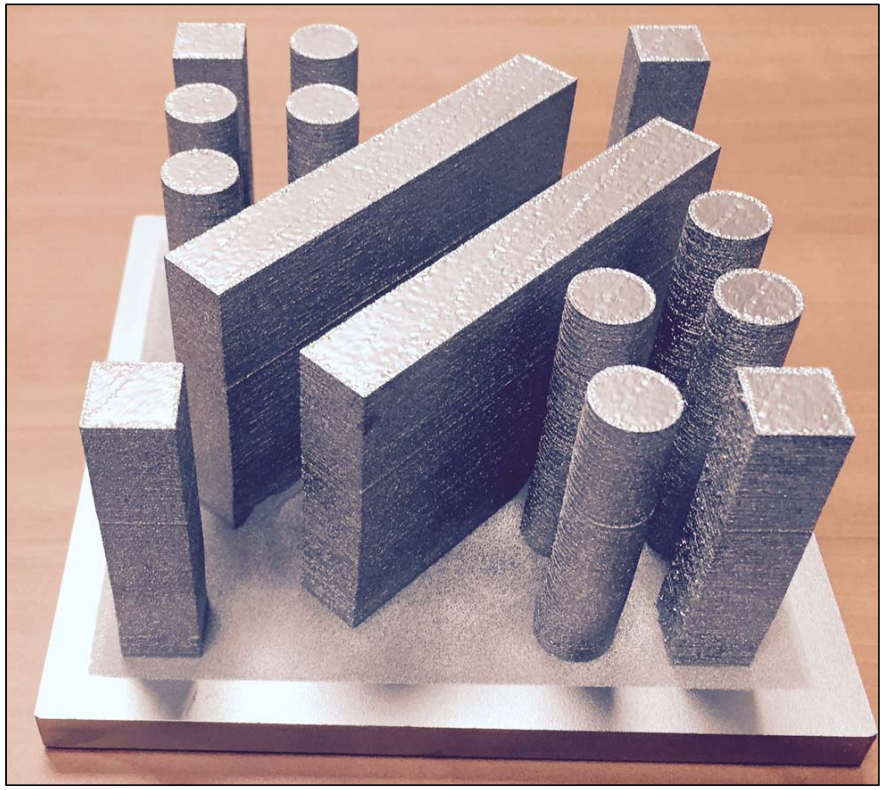
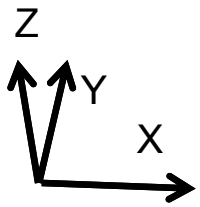
Fabrication of 20-30 EBM HX Specimens For Tensile, Creep and Fatigue Testing

- 27h, 1240 layers, ~65mm
- Small builds first to optimize parameters based on 718 & HX previous work
- Similar build parameters + pre-heat temperature
- Study the effect of post annealing and Hip'ing





5mm