Advanced Alloy Development Field Work Proposal

Research Team
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Program Focus*

- Robust domestic supply chain
- Prediction & Repair to manage flexible fleet of generators that enable high penetration of renewables into the grid
- Low-cost, high performance alloy development to enable the next generation Natural Gas Combined Cycle plants and the Hydrogen economy

*https://netl.doe.gov/coal/high-performance-materials

Advanced Alloy Development FWP
Affordable, Durable High-Performance Alloys.

- Techno-Economic & Market Assessments
- Alloy Development & Manufacturing
  - Simulate and Manufacture of Large-Scale Ingots
  - Cast Versions of Wrought Superalloys
  - Large Area Additive Manufacturing
  - Manufacturing of Compact Heat-Exchangers
  - Ni-, Fe- Alloy Development
- Materials Performance in Harsh Environments
  - Creep & Creep-Fatigue (LCF) modeling
  - Materials Performance in sCO$_2$ cycles
Tuesday, June 15, 2021

- **1:20 PM**: Materials Performance in sCO$_2$ Environments, Omer Dogan
- **2:20 PM**: Design Tool for Creep-Resistant Materials and Low Cycle Fatigue Modeling, Youhai Wen
- **2:40 PM**: Simulate and Manufacture of Large-Scale Ingots & Summary of Past Ni-Alloy Development Work, Paul Jablonski

Eastern Daylight Time
Techno-Economic & Market Assessments

Research Guidance and Direction

Strategic Systems & Analysis Engineering

Previous Accomplishments

• High Performance Alloy Applications In Adjacent Markets
• Understanding the Supply Chain of Advanced Alloys
• Benefits of Advanced Materials for Boiler Tubes
• Export Potential for High-Performance Materials
• GADS Failures subsets analysis for boiler tubes, turbine, and balance of plant.

System Studies & Benefit Analyses
Reports on NETL’s web site
https://netl.doe.gov/crosscutting/publications
Current Effort

Assessment of Advanced Alloy Opportunities for Natural Gas Combined Cycle (NGCC) Plants and \( H_2 \) Production

Identify how can advanced materials contribute to improved performance and reduced cost in NGCCs

- With and without CCS
- Interest in not only efficiency, but cyclability, reliability, service life, etc.
- Identify parameters of interest.
- Establish SOA design features, materials, and performance.
- Identify materials-driven opportunities for improvement - informed by literature and consultants.

Contact: Travis Shultz (travis.shultz@netl.doe.gov)
Assess the economic benefit of novel manufacturing approaches in production of key, cost-driving components of the advanced power system and identify R&D challenges to realizing these benefits.

- Explore the most rapid path to market being used in current AUSC designs
- Investigate near-net-shape manufacturing techniques to reduce post-processing of large cast parts
- Study manufacturing one-off parts, reducing inventory, reducing wait times, and modification of larger parts in power plants

Contact: Erik Shuster (erik.shuster@netl.doe.gov)
Improve Electro-slag-remelting (ESR) ingot quality & melt efficiency.

- Optimize melt parameters (and alloy/slag compositions) to maximize ingot quality.
- **ESR used for mission critical applications**

- Combine CFD (MeltFlow) & CALPHAD (JMatPro, Thermo-Calc) methods with experiments.
- Methodology to predict segregation during ESR melting as a function of process parameter (such as slag temperature, melt rate, fill factor). Important for alloy element retention and control of tramp elements.

By applying models:
- Improved yield during ESR melting of NETL Fe-9Cr alloys (CPJ7, JMP) XMAT alloys (347).
- Achieved 41% reduction in power required to melt at constant melt rate for master alloy production.
- Reduced tramp element concentrations in ESR ingots.
- Controlled chemistry for elements in tight concentration ranges.

Contacts: Paul Jablonski (paul.jablonks@netl.doe.gov) Martin Detrois (martin.detrois@netl.doe.gov)
Current Effort

Apply models to Ni-superalloy melting & upscaling

- Emphasis on NETL developed Ni-superalloys – large range of chemistries & microstructures.
- Provides insights on processability of superalloys (pre-competitive).
- Increase the likelihood of transfer to U.S. industry

Contacts: Paul Jablonski (paul.jablonski@netl.doe.gov)  Martin Detrois (martin.detrois@netl.doe.gov)
Current Effort
Gap Analysis for Feedstocks for LA-WAAM

• Establish an industrial technical committee that actively contributes feedback to gap analysis
• Develop research road map

Contact: Chantal Sudbrack (chantal.sudbrack@netl.doe.gov)
Manufacturing Compact Heat Exchangers

• sCO₂ power cycles – highly recuperated cycle
• sCO₂ power cycle conditions necessitate the use of higher temperature materials
• Demonstrate a diffusion bonding process in accordance with Appendix 42, ASME Section VIII,DIV 1 for Alloy 740H

Prior research on Alloy 230

Transient-liquid-phase (TLP) bonding using Ni-P interlayers developed for Alloy 230.

Strength of the bonded stacks was greater than 85% of base alloy 230 yield stress. Bonded stacks possessed acceptable low-cycle fatigue and creep properties. However, plastic strain localization in the bond region caused low tensile and creep elongation.

Contact: Omer Dogan (omer.dogan@netl.doe.gov)
Manufacturing Compact Heat Exchangers

Demonstrated diffusion bonding of 740H

Contact: Omer Dogan (omer.dogan@netl.doe.gov)
Manufacturing Compact Heat Exchangers

Current Effort
Demonstrate a diffusion bonding process for IN740H in accordance with Appendix 42, ASME Section VIII, DIV 1.

- Produce diffusion bonded stacks of 50 sheets
- Tensile yield stress and elongation > 75% of the bulk material.

Contact: Omer Dogan (omer.dogan@netl.doe.gov)

Acknowledge the collaboration of:

[Images and logos]
650°C Martensitic-Ferritic Steel Development

Improve the temperature capability and performance life of the relatively low-cost Fe-9–12% Cr ferritic-martensitic steel.

NETL-CPJ7 and NETL JMP Steels

★ Cast and wrought forms
★ 70kg (150 lb) ingots produced and reduced to plate (VIM, ESR)
  ▪ Formulated ESR slag chemistry
★ Welding trials/studies
  ▪ Conventional NETL
  ▪ Friction Stir Welding PNNL
★ Material available for evaluation

Contact: Jeffrey Hawk (jeffrey.hawk@netl.doe.gov)

Current Effort

✓ Low cycle fatigue (LCF), Hold-time fatigue, and Project
Materials Performance in Supercritical CO₂ Power Cycles

**HIGH-TEMPERATURE OXIDATION OF STEELS AND SUPERALLOYS**
Effects of impurities and pressure

- No SO₂
- 0.1% SO₂

**Cr-oxide**
Non-protective oxides and sulfates

**LOW-TEMPERATURE CORROSION**
Identifying low-cost steels resistant to acidic condensates

- H₂CO₃
- H₂CO₃ + H₂SO₄

**LINKING OXIDATION BEHAVIOR AND MECHANICAL DEGRADATION**

- Extensive carbide formation during CO₂ exposure

**JOINING**
Dissimilar metal welds investigated
- P22-P91
- P91-347H
- P22-Alloy 263
- Alloy 625-Alloy 263
- 347H-Alloy 263

**Current Effort**
Impact of CO₂ on:
- Creep
- Creep-fatigue

Contacts: Omer Dogan (omer.dogan@netl.doe.gov), Richard Oleksak (richard.oleksak@netl.doe.gov)

Presentation on June 15, 2021, at 1:20 PM (EDT)
Creep & Creep-Fatigue (LCF) modeling

Develop a **microstructure-based life prediction tool** that couples creep, fatigue, and environmental effects.

- Developed a crystal plasticity phase-field model that includes both shear deformation in each slip system of polycrystals and grain boundary sliding (GBS).
- Developed a phase-field model of precipitation process with continuous coherency loss.
- Developed a microstructural based oxide-scale spallation model.

Spallation due to:
- Temperature (Different thermal expansion)
- Oxide growth strain with geometric constraint
- Different creep rate between oxide and metal

Current Effort: LCF modeling

Phase field model to predict the LCF

Contact: Youhai Wen (youhai.wen@netl.doe.gov)

Presentation on June 15, 2021 at 1:40 PM (EDT)
• Tuesday, June 8, 2021, 11:10 AM (EDT): eXtremeMAT Computational Simulations Laurent Capolungo (LANL)
• Tuesday, June 15, 2021, 1:20 PM (EDT): eXtemeMAT Guidelines for Alloy Development Edgar Lara-Curzio (ORNL) & Jeffrey Hawk (NETL)

website: https://edx.netl.doe.gov/extrememat/