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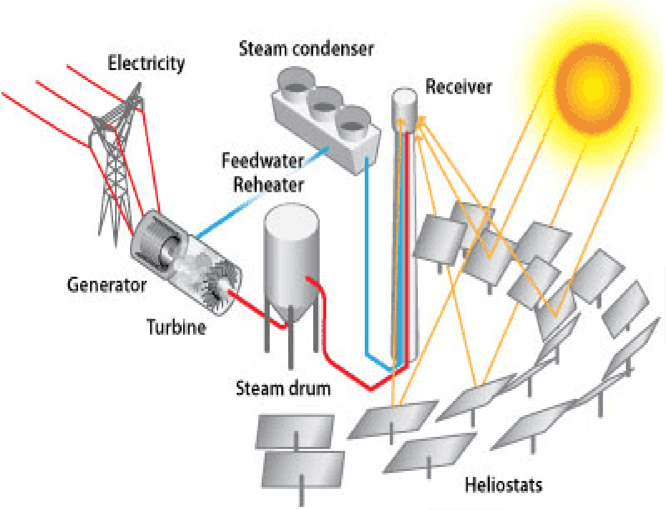

Creep-fatigue Behavior and Damage Accumulation of a Candidate Structural Material for Concentrating Solar Power Solar Thermal Receiver

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DOE Gen 3 CSP Kickoff Meeting

6/25/2018

Orlando, FL

Idaho National Laboratory

Award # DE-EE00033872

Project Objectives

- Overall project goals
  - Provide an accurate description of the creep-fatigue behavior of a CSP thermal receiver candidate alloy
  - Develop a design method for solar receiver components to guard against high temperature creep-fatigue and ratcheting failure modes
    - Design procedure and D-diagram for an advanced nickel alloy for solar thermal receivers
    - Executable design procedure that produces designs that consistently exceed design life

Project Tasks

- Task 1: Creep-Fatigue Testing and Metallographic Analysis
  - Alloy selection
  - Fatigue and creep-fatigue testing
  - Creep testing as necessary
- Task 2: Analysis of Design Methodology
  - Creep-fatigue interaction diagram (D-diagram)
  - Ratcheting design provisions
- Task 3: Assessment of Environmental Interaction
  - Preliminary assessment of additional factors that influence design life

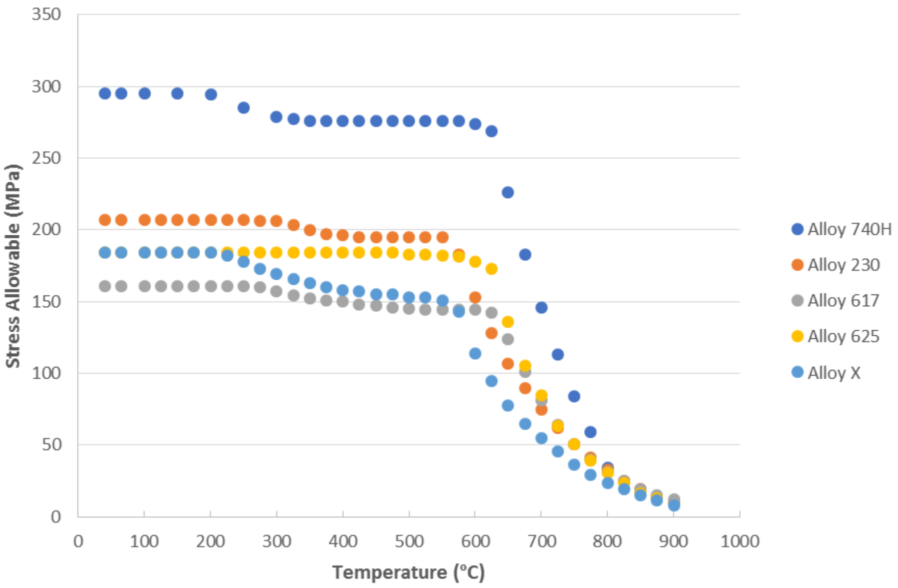
Task 1: Alloy Selection

- Alloy selected for creep-fatigue testing and for design model
  - Candidate alloys: Alloys X, 625, 617, 230, 740H, and 282
  - Alloys evaluated based on available data and high temperature strength

Alloy	Creep	Creep-Fatigue 700 to 800 °C	Creep-Fatigue to 800 to 1000 °C
Alloy 617	Green	Yellow	Green
Alloy 230	Green	Red	Yellow
Alloy 282	Yellow	Red	Red
Alloy 740H	Green	Red	Red
Alloy X	Green	Red	Yellow

Red = limited or none
Yellow = some
Green = considerable

ASME Code Section I Stress allowables



ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, 2017

Task 1: Fatigue and Creep-fatigue Testing

- Preliminary tensile v. compressive dwell sensitivity for a nickel alloy
- Proposed fatigue and creep-fatigue test matrix
- Creep testing as necessary

750°C

Strain Range	Estimated Nf	Hold Time	Repeats	Estimated Test Time
%	cycles	minutes		days
0.6	60,000	0	3	8
0.6	12,500	10	2	89
0.6	6,000	60	2	251
0.6	3,000	120	1	250
1.0	2,000	0	3	1
1.0	700	10	2	5
1.0	200	60	2	8
1.0	70	240	2	12
1.0	35	240	2	6
1.0	35	600	2	15

850°C

Strain Range	Estimated Nf	Hold Time	Repeats	Estimated Test Time
%	cycles	minutes		days
0.4	10,000	0	3	1
0.4	3,000	10	2	21
0.4	2,000	60	2	84
0.4	1,000	240	2	167
1.0	2,000	0	3	0
1.0	1,000	10	2	7
1.0	500	60	2	21
1.0	200	240	2	33
1.0	200	600	2	83

Task 2: Receiver Design Rules

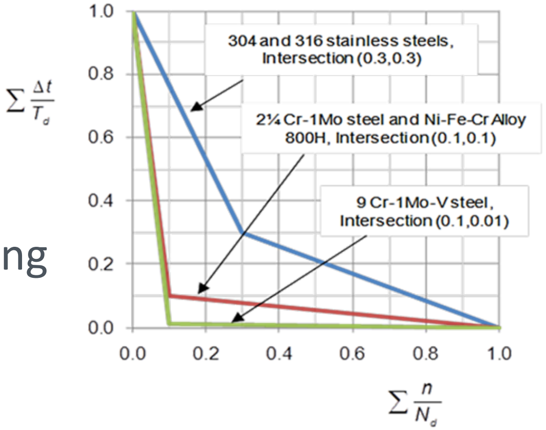
- Previous design studies reference a Sandia National Laboratory report[1] establishing draft design guidelines
  - Amalgamation of provisions from several divisions of the ASME Boiler and Pressure Vessel Code[2]
    - Section III, Division 5
    - Section VIII, Division 1
    - Section VIII, Division 2
  - Most high temperature design provisions guard against failure through the following mechanisms (all relevant for CSP thermal receivers)
    - Time-independent plastic instability
    - Time-dependent creep rupture
    - Creep-fatigue damage
    - Time-dependent, cyclic excessive deformation (ratcheting)
    - Time-independent buckling
    - Time-dependent buckling
- Since the Section VIII rules are widely applied and understood, they will be adopted for this project

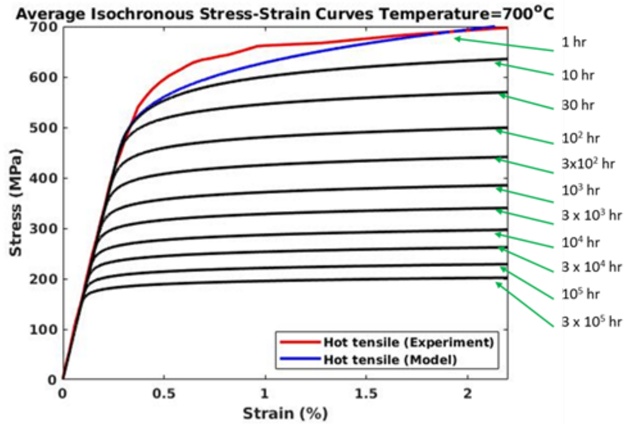
1. I. Berman et al., Sandia National Laboratories, 1979.
2. ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, 2017.

Task 2: Receiver Design Rules

- Focus will be on ASME linear damage summation
  - Creep-rupture correlation (ASME BPVC Code Case 2702)
  - Fatigue curves and D-diagram
- Design rules will guard against
  - Excessive ratcheting
    - Starting point will be Code Case N-47 providing ratcheting strain accumulation rules using a simplified elastic perfectly-plastic analysis
      - Requires a set of isochronous stress-strain curves
  - Creep-fatigue failure
    - Consider Section III rules and previous CSP methods

Creep-fatigue interaction diagram reproduced from ASME Section III, Division 5, Subsection HB, Subpart B





Task 3: Assessment of Environment

- Original proposal called for an assessment of environmental influence at 750°C
- Q1 suggested shifts in focus
  - Potential creep-fatigue testing of weldments
  - Testing of tube/sheet material forms
    - Final design rules should encompass all potential receiver types
    - Current test plan includes only plate material

Summary

- Three tasks
  - Task 1: Creep-Fatigue Testing and Metallographic Analysis
    - Alloy selection
    - Experimental testing and analysis
  - Task 2: Analysis of Design Methodology
    - D-Diagrams, isochronous curves, ratcheting design provisions
  - Task 3: Assessment of Environmental Interaction
    - Preliminary assessment of additional factors that influence design life, proposed focus was gas environment
    - Suggested shift in focus to weldment or tubular/sheet form testing