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

M. McMurtrey, L. Carroll, M. Messner

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

<table>
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<tr>
<th>Alloy</th>
<th>Creep</th>
<th>Creep-Fatigue 700 to 800 °C</th>
<th>Creep-Fatigue to 800 to 1000 °C</th>
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<tbody>
<tr>
<td>Alloy 617</td>
<td>Green</td>
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<tr>
<td>Alloy 230</td>
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<td>Alloy X</td>
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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

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<th>Strain Range</th>
<th>Estimated Nf</th>
<th>Hold Time</th>
<th>Repeats</th>
<th>Estimated Test Time</th>
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750°C

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850°C
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

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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