Summary of Finite Element Sensitivity Studies Conducted in Support of the NRC/EPRI Welding Residual Stress Program

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U.S. Nuclear Regulatory Commission

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Outline

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- Introduction
- Finite Element Results and Experimental Measurements
- Round Robin Dataset Variability
- Sensitivity Studies
- Summary

WRS Model Validation Program

Joint NRC/EPRI WRS Validation Program

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- Background:
  - Component integrity analyses for PWSCC in DM welds showed that the results were highly dependent upon WRS profiles
  - ACRS letter dated 10/19/07 supported further WRS research
- Purpose:
  - Refine WRS FE model development for 82/182 DM welds through sequential development from Phase 1 to 4
  - Develop reasonable assurance that WRS FE models are defensible through a blind validation using well controlled mockups to various WRS measurement testing techniques
- Expected Outcome:
  - Validation of WRS FE models using well controlled mockups focusing on through-wall axial & hoop stresses
  - Develop uncertainty distributions in WRS modeling

WRS Model Validation Program

Joint NRC/EPRI WRS Validation Program

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- Joint NRC/EPRI WRS Validation Program:
  - Approved MOU Addenda (2009)
  - Phases 1-4 with specific goals and progressively more in-plant representative conditions
  - Validate WRS models to experimental measurements
  - Inform and improve WRS predictions for component integrity calculations
- Joint NRC/EPRI Development of xLPR Code:
  - Evaluate piping integrity with validated WRS profiles
  - Assess variability of WRS (mean, scatter, and distribution)

WRS Validation Program Overview

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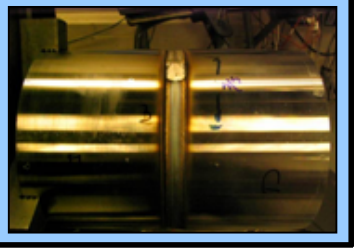
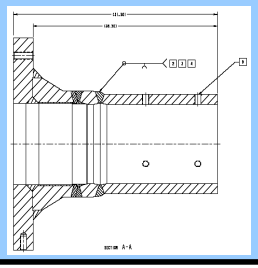
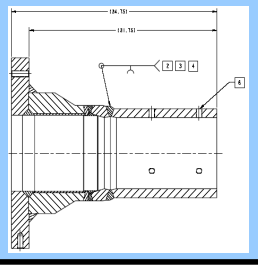
Phase 1 - EPRI

- **Scientific Weld Specimens**
- **Phase 1A:** Restrained Plates (QTY 4)
- **Phase 1B:** Small Cylinders (QTY 4)
- Purpose: Develop FE models.

Phase 2 - NRC

- **Fabricated Prototypic Nozzles**
- Type 8 Surge Nozzles (QTY 2)
- Purpose: Prototypic scale under controlled conditions. Validate FE models.

Phase 3 - EPRI

- **Plant Components**
- WNP-3 S&R PZR Nozzles (QTY 3)
- Purpose: Validate FE models.


Phase 4 - EPRI

- **Plant Components**
- WNP-3 CL Nozzle (QTY 1)
- RS Measurements funded by NRC
- Purpose: Effect of overlay on ID.

WRS Model Validation Program

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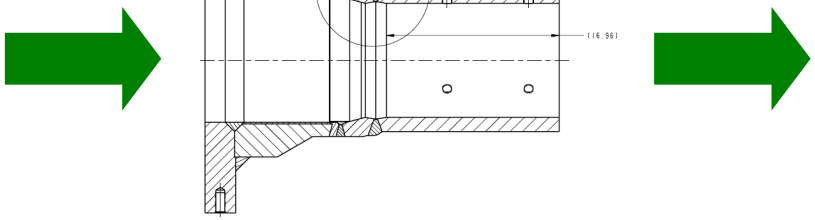
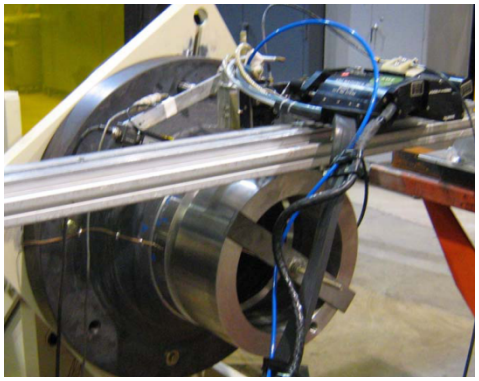
- Phase 2: PZR Surge Mockups (NRC-led, International WRS)





- Validate WRS FE analysis methods with
  - Prototypic components and fabrication history
  - International FE Round Robin
  - Residual stress measurements

Phase 2 Participants

International WRS Round Robin

- ANSTO (Australia)
- AREVA (USA and EU)
- Battelle (USA)
- Dominion Engineering (USA)
- Goldak Technologies (Canada)
- ESI Group (USA)
- EMC² (USA)
- Inspecta Technology (EU)
- Institute of Nuclear Safety System (Japan)
- Osaka University (Japan)
- Rolls Royce (UK)
- Structural Integrity Associates (USA)
- Westinghouse Electric Company (USA)

WRS Model Validation Program

International WRS Round Robin - Geometry

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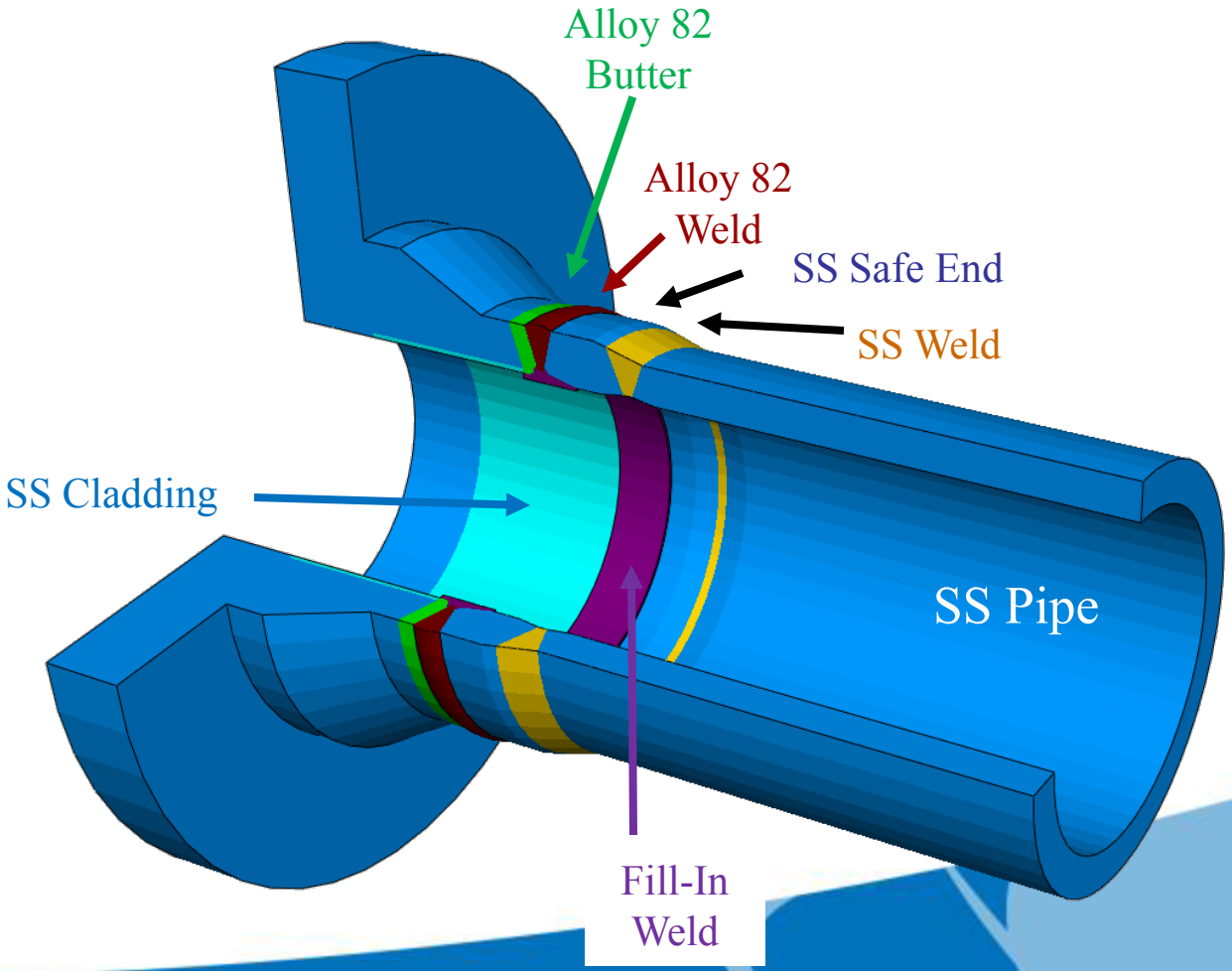
- Pipe and Weld Geometry



FEA Results and Measurements

Axial Stress Results

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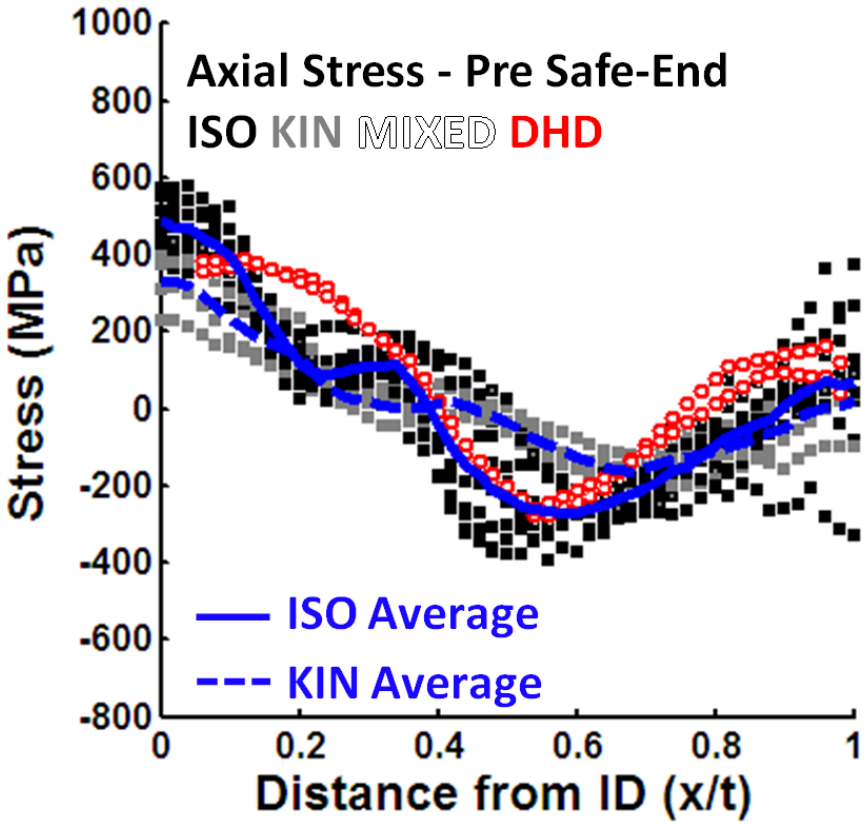

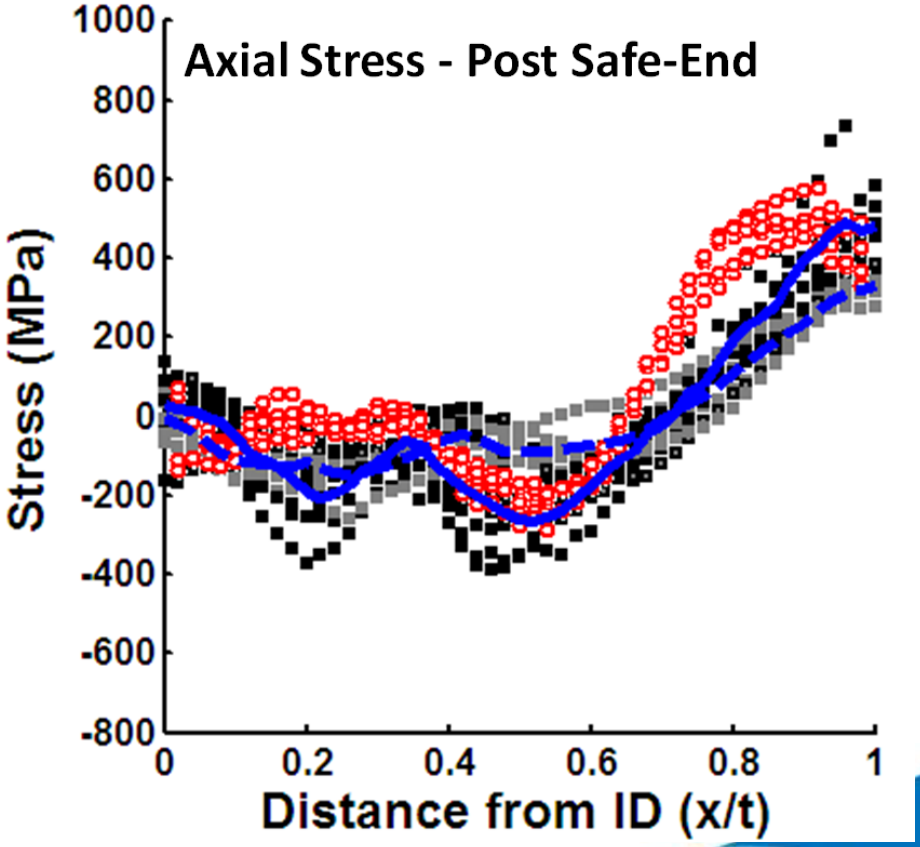

FEA Results and Measurements

Hoop Stress Results

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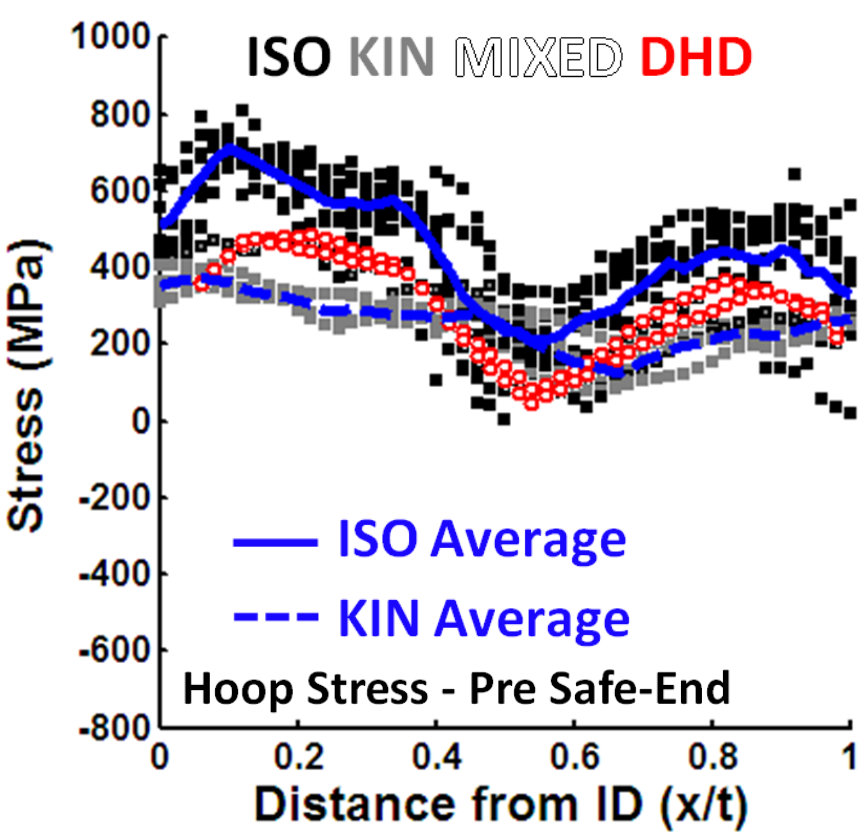

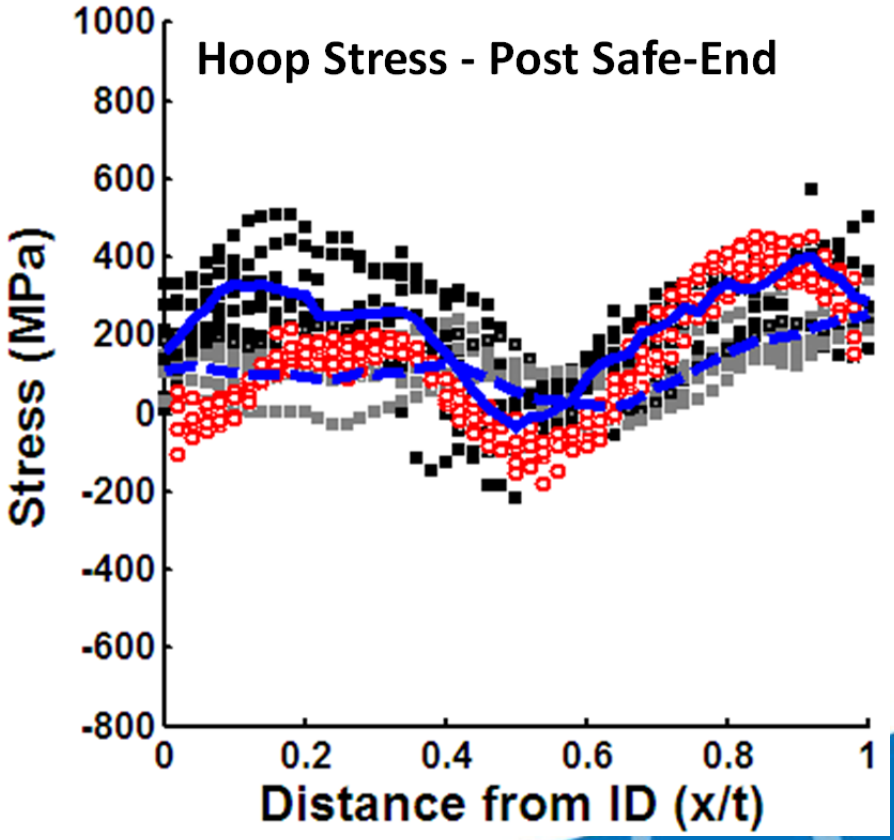

FEA Results

2σ and min/max Pre-Safe End Weld

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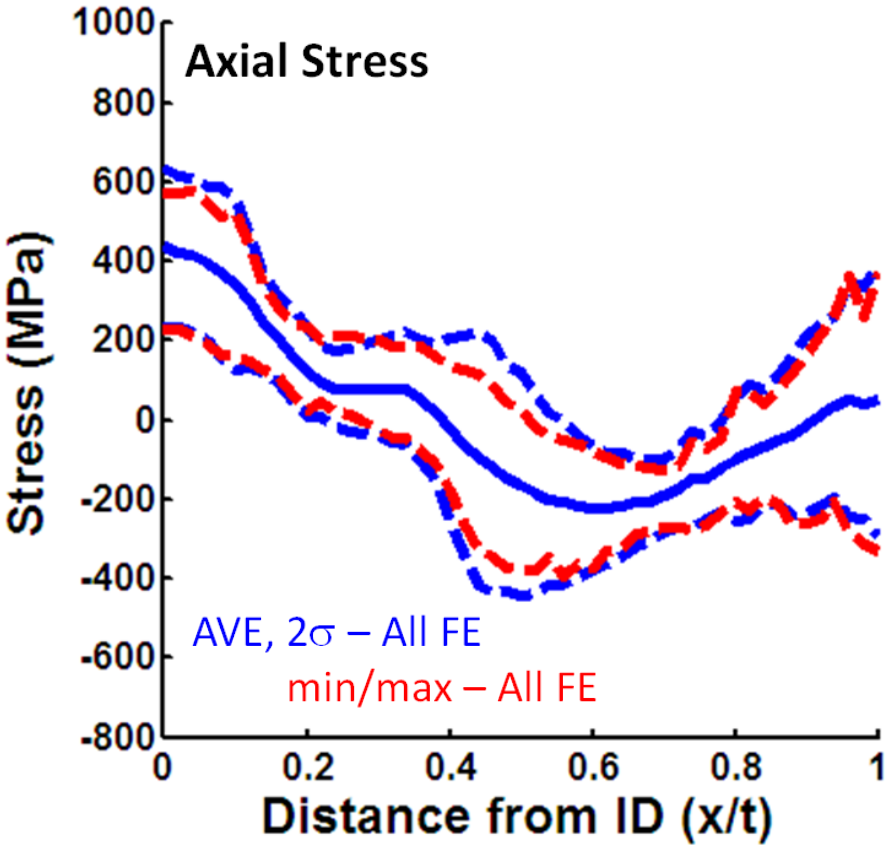

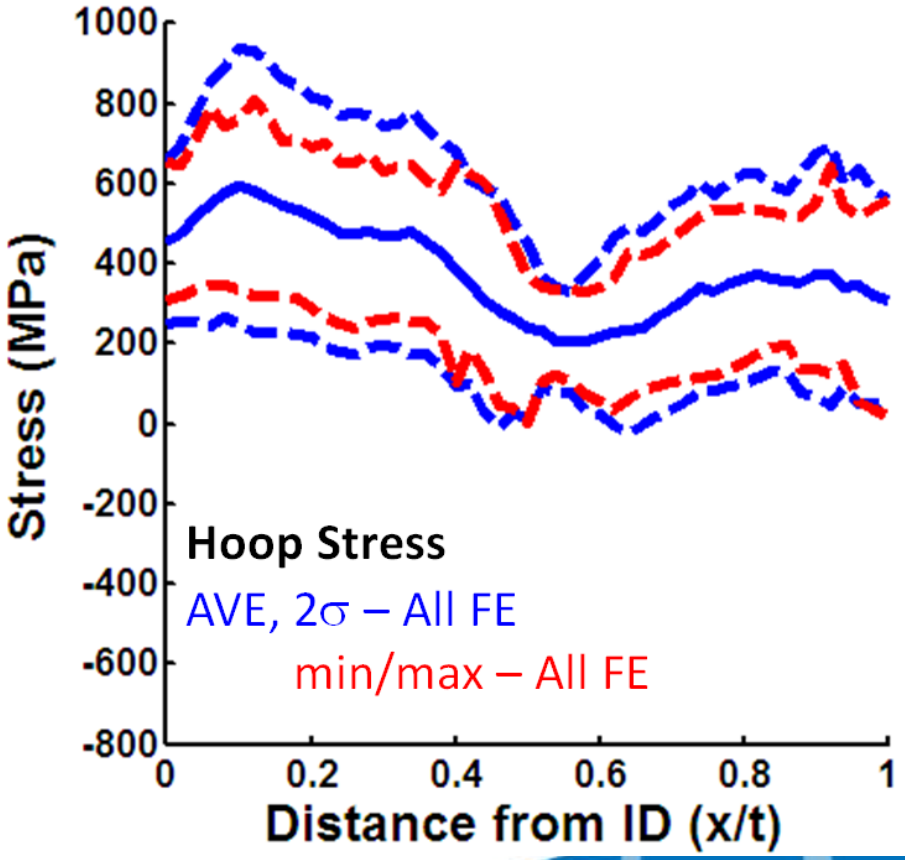

Sensitivity Study

Heat Flux Magnitude

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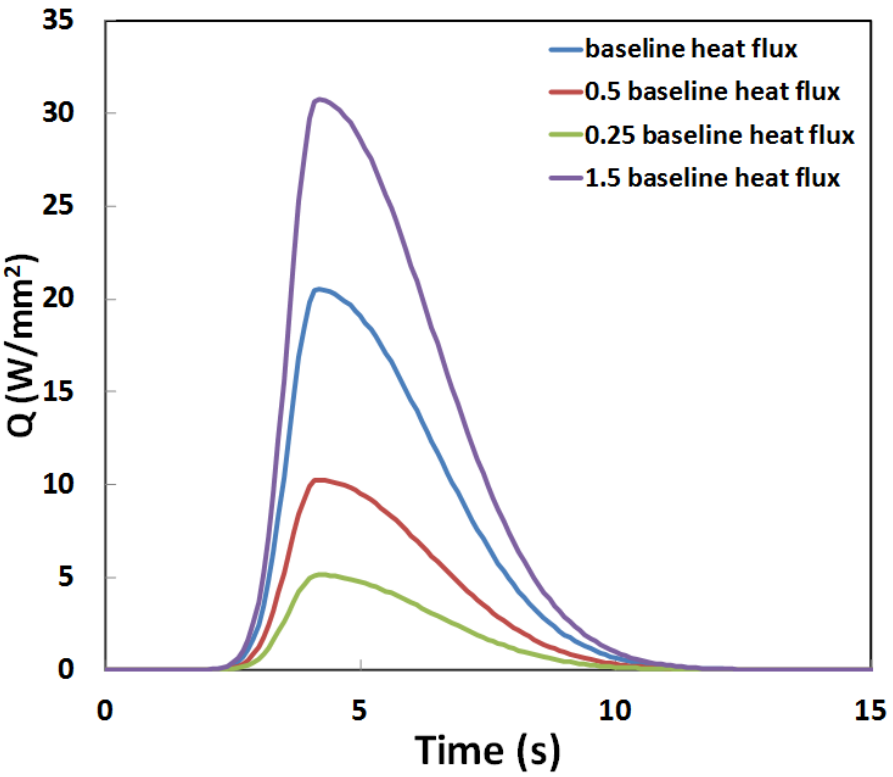

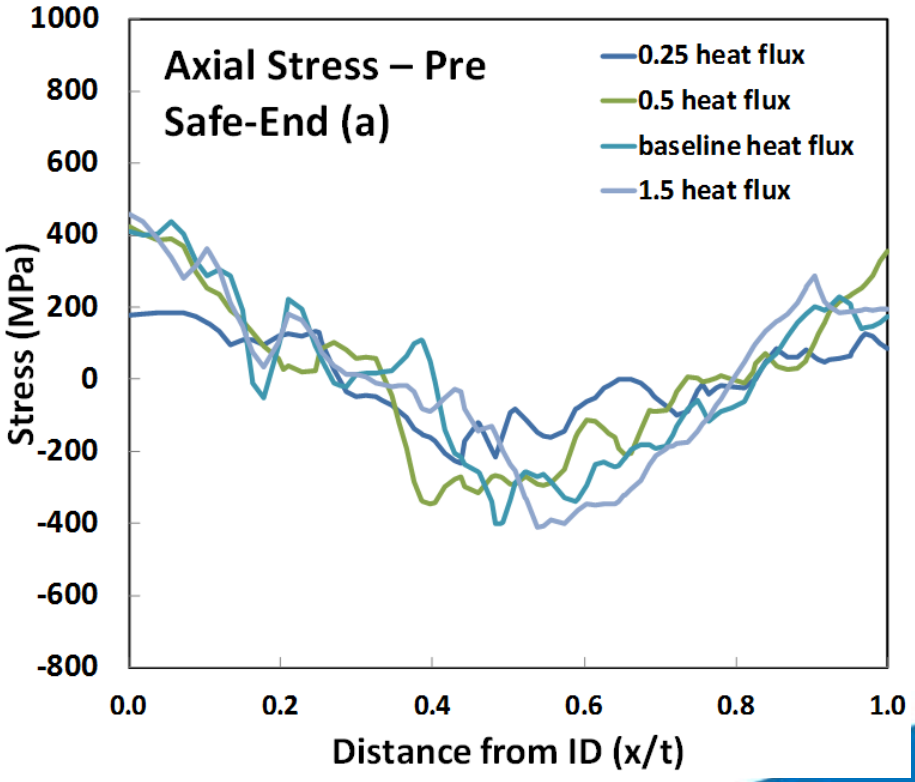

Sensitivity Study

Heat Flux Duration

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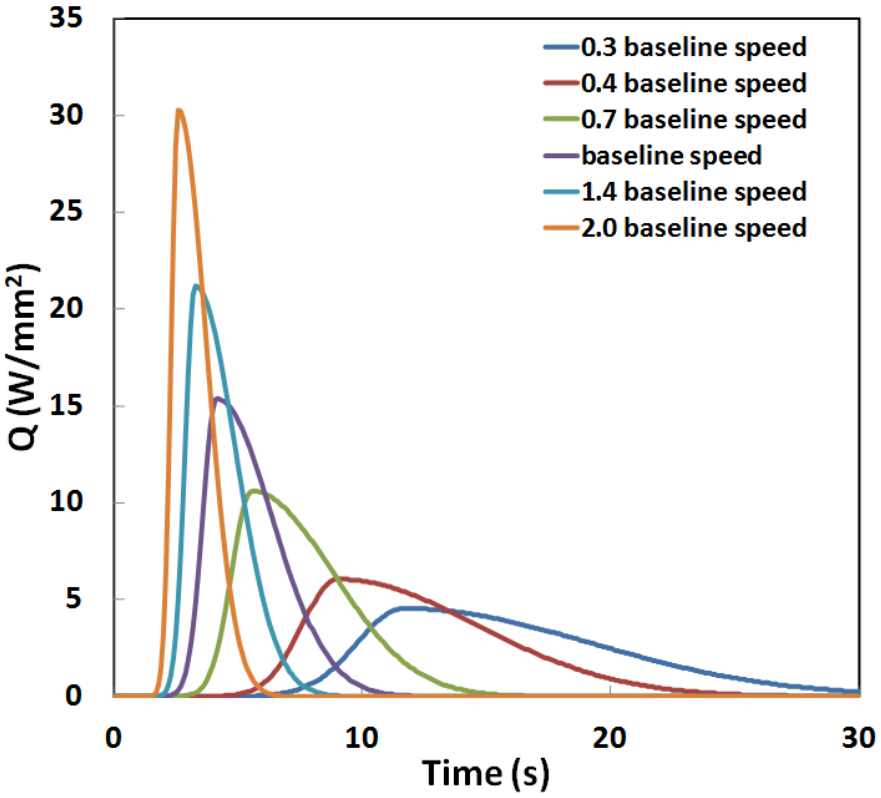

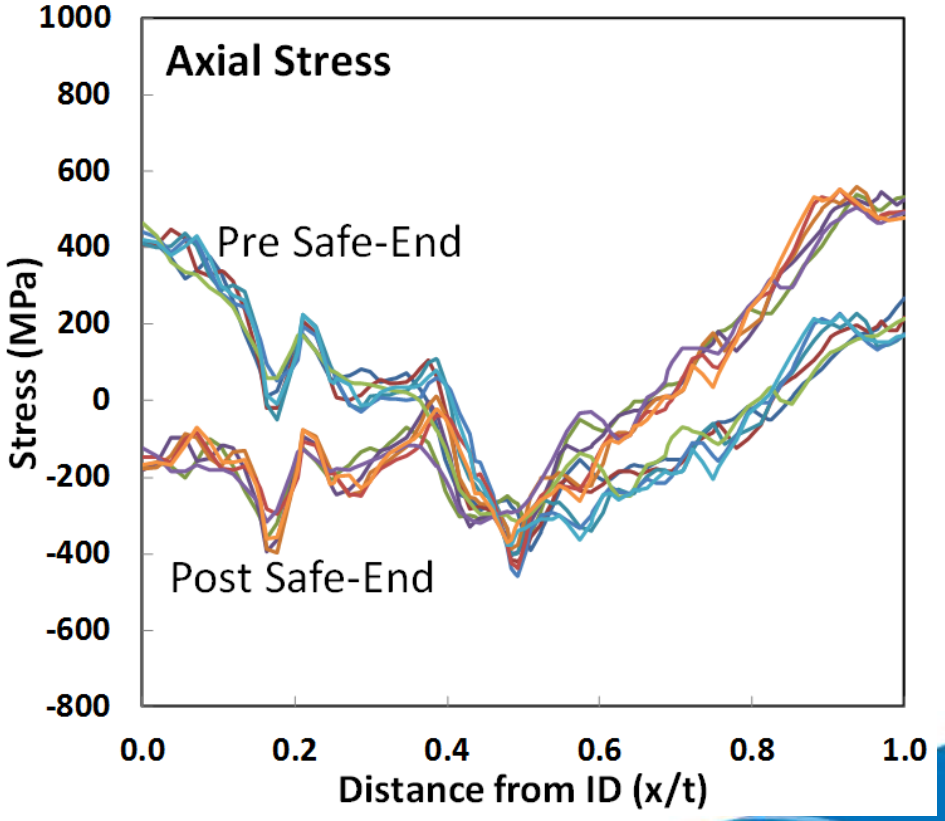

Sensitivity Study

Constitutive Properties

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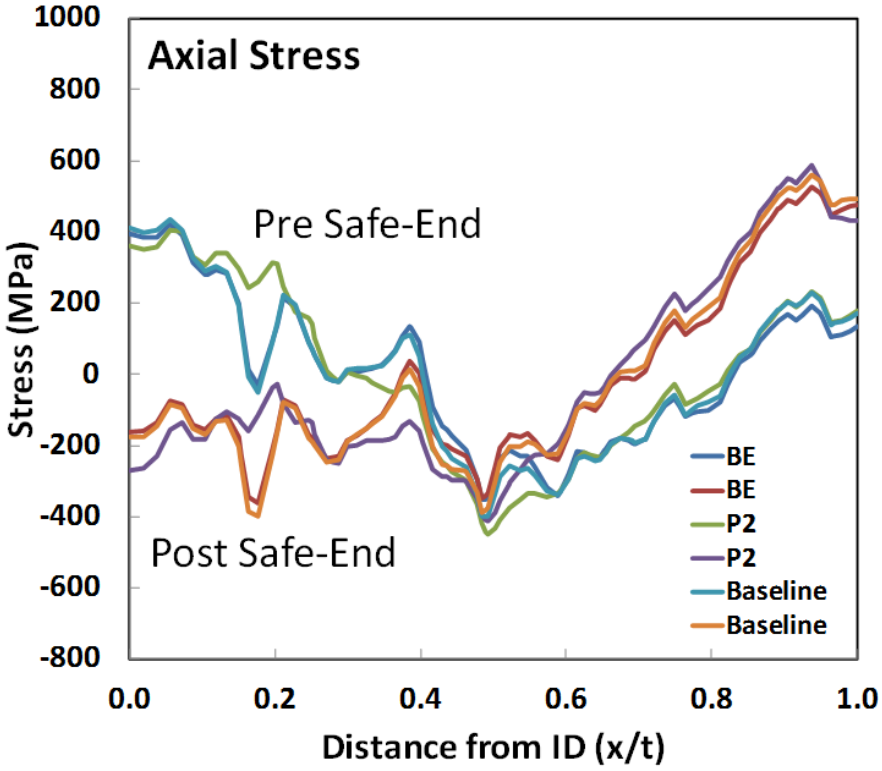

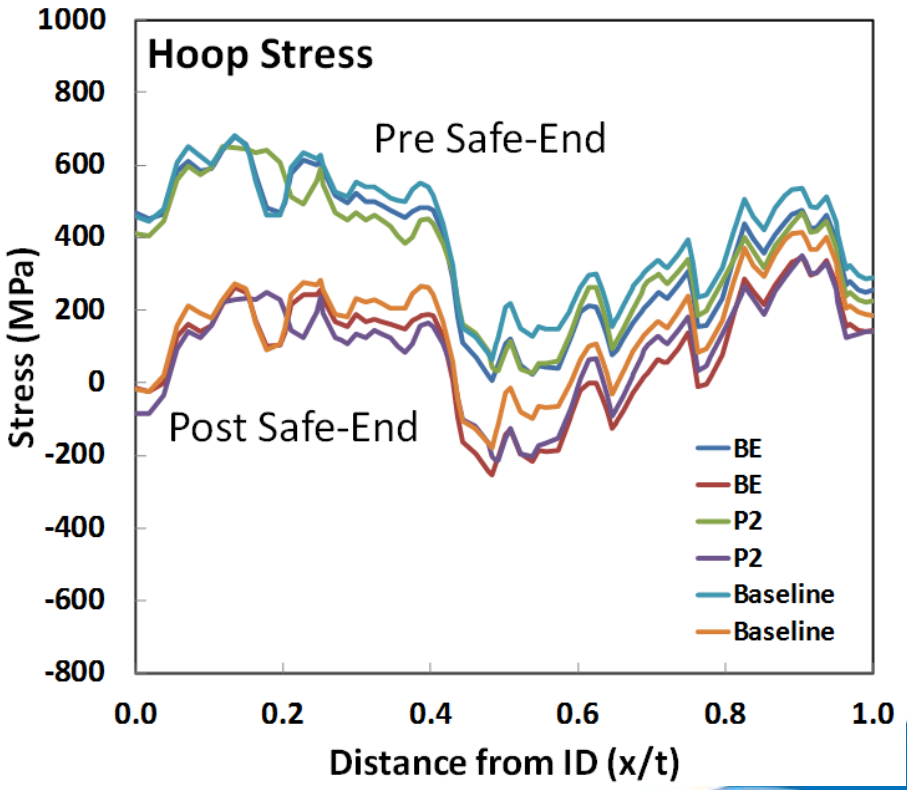

Sensitivity Study

Hardening Law – Isotropic and Kinematic

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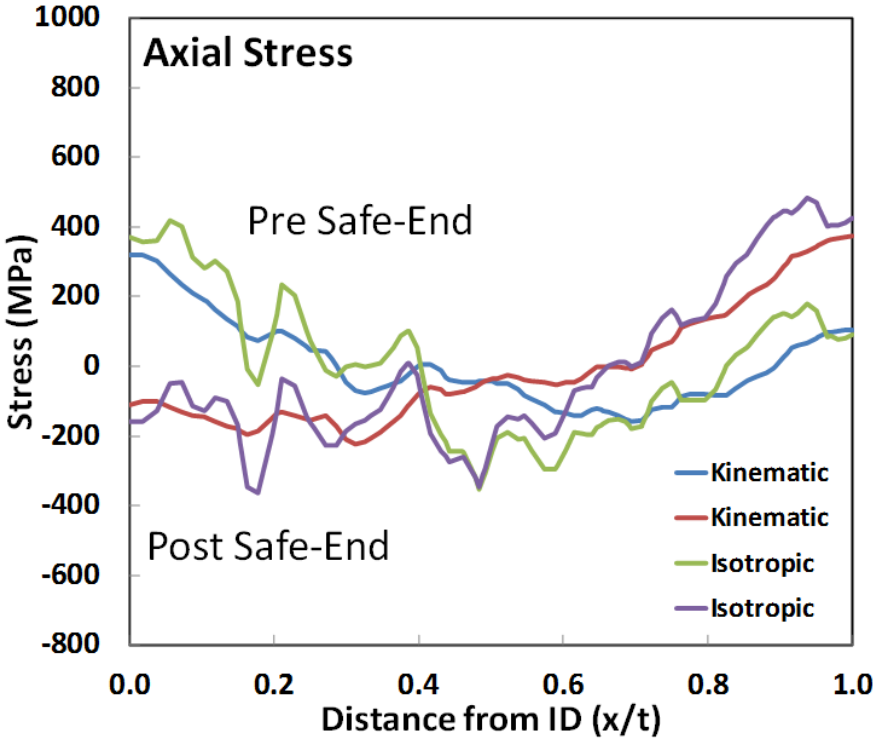

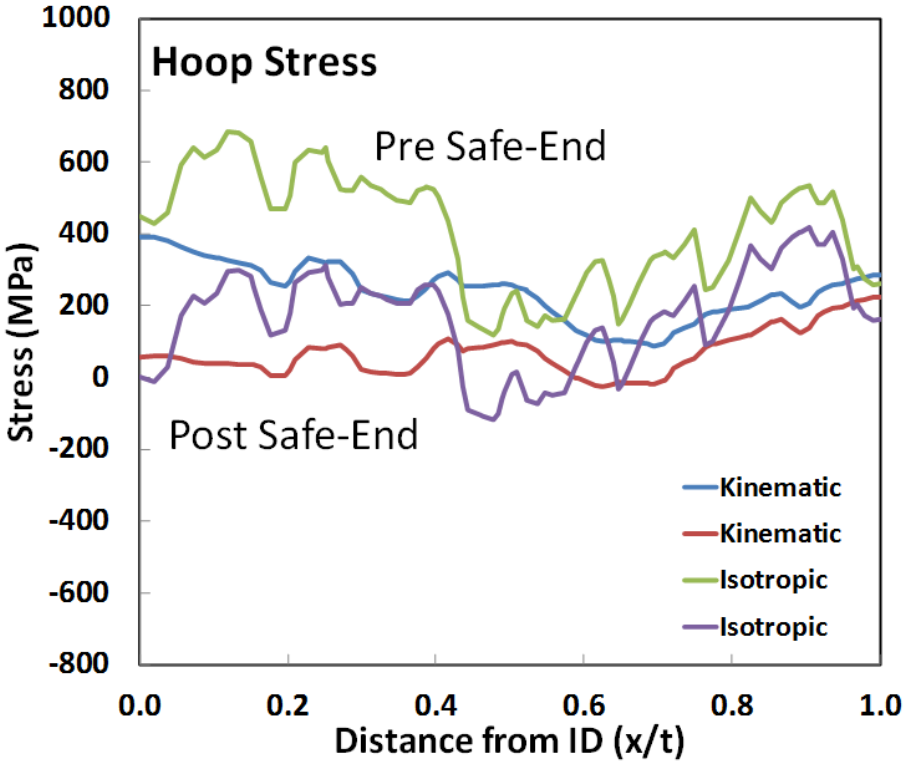

Conclusions

Assessment of Scatter and Sensitivity Studies

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- Average of measured and calculated results have reasonable agreement
- Significant scatter in FEA results
- Sensitivity studies can address scatter

Conclusions (continued)

Assessment of Scatter and Sensitivity Studies

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- Parameters that strongly influence WRS results
  - Hardening law
  - Stress-strain properties
  - Thermal energy input

- Parameters with minimal influence on WRS results
  - Elastic properties
  - Latent heat, conductivity, specific heat
  - Coefficient of thermal expansion