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Changing the World's Energy Future

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Unraveling the Mechanics: Computational Modeling of Residual Stresses in U10Mo Fuel with Aluminum Cladding

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Synopsis: Finite element Modeling of residual stresses in U10Mo fuel post HIP fabrication process

Keywords: Creep, Residual stress, U10Mo Fuel, Cladding

Research Background and Motivation

Introduction to Nuclear Fuel

LEU (Low-enriched uranium) fuel system facilitates to replace and eventually eliminate use of highly enriched uranium with proliferation-resistant, low-enriched uranium (235U < 20%) for civilian applications.

U-10Mo alloy-based monolithic fuels are considered for the conversion of high performance of reactors. These plate-type fuel elements are comprised of a high-density, low-enrichment, U–Mo alloy-based fuel foil, encapsulated in a cladding material made of aluminum. The plates are fabricated by HIP (Hot Isostatic Pressing) technique, as shown schematically below

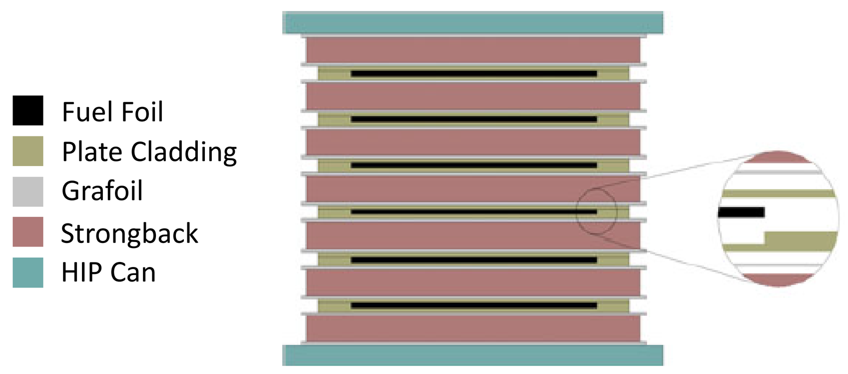


Fig: Schematic of the stack inside a HIP can.

Damage of Nuclear Fuel

Understanding the mechanism of possible failure modes of nuclear fuel is critical to mitigate potential consequences. The stresses are a contributing factor in various failure modes, and greatly affect the **integrity under temperature, pressure and irradiation**. These stresses could originate from various sources, including manufacturing, and operation, and can lead to deformation, cracking, or even complete failure of fuel elements.

Objective

Develop a computational model that **can accurately predict the residual stresses** generated during fabrication.

Challenge?

During the **HIP process, the Aluminum cladding** transitions from (Al 6061-T6 to O temper), making it challenging to fully capture the **change in material properties**.

Methodology

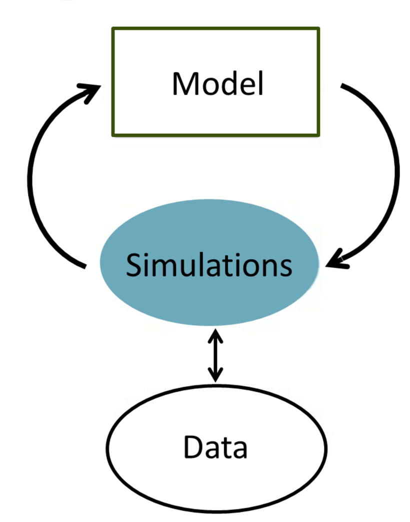
1 Model Foundation

Obtaining Experimental data
Using prior knowledge
Forming the Hypotheses

2 Model Construction Process

2a Developing the model : Creep coefficients for cladding are modified to align with values from experiments.

2b Refining the model



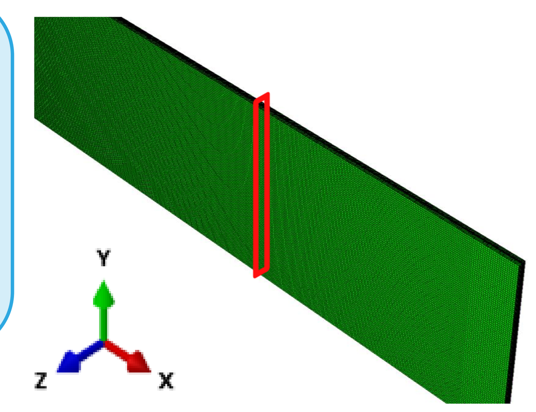
3 Model Validation

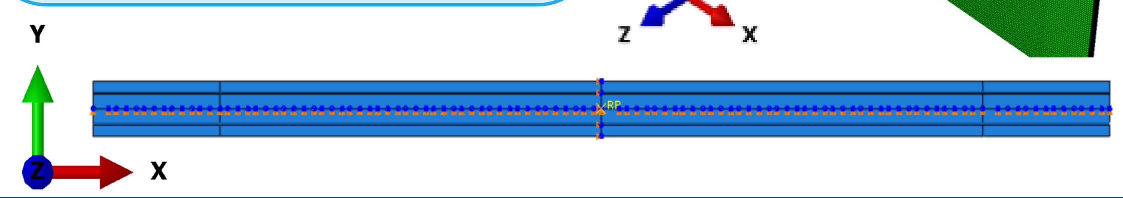
Testing the model on new data

The modeling of the fuel plate involves capturing various multi-physics phenomena, including:

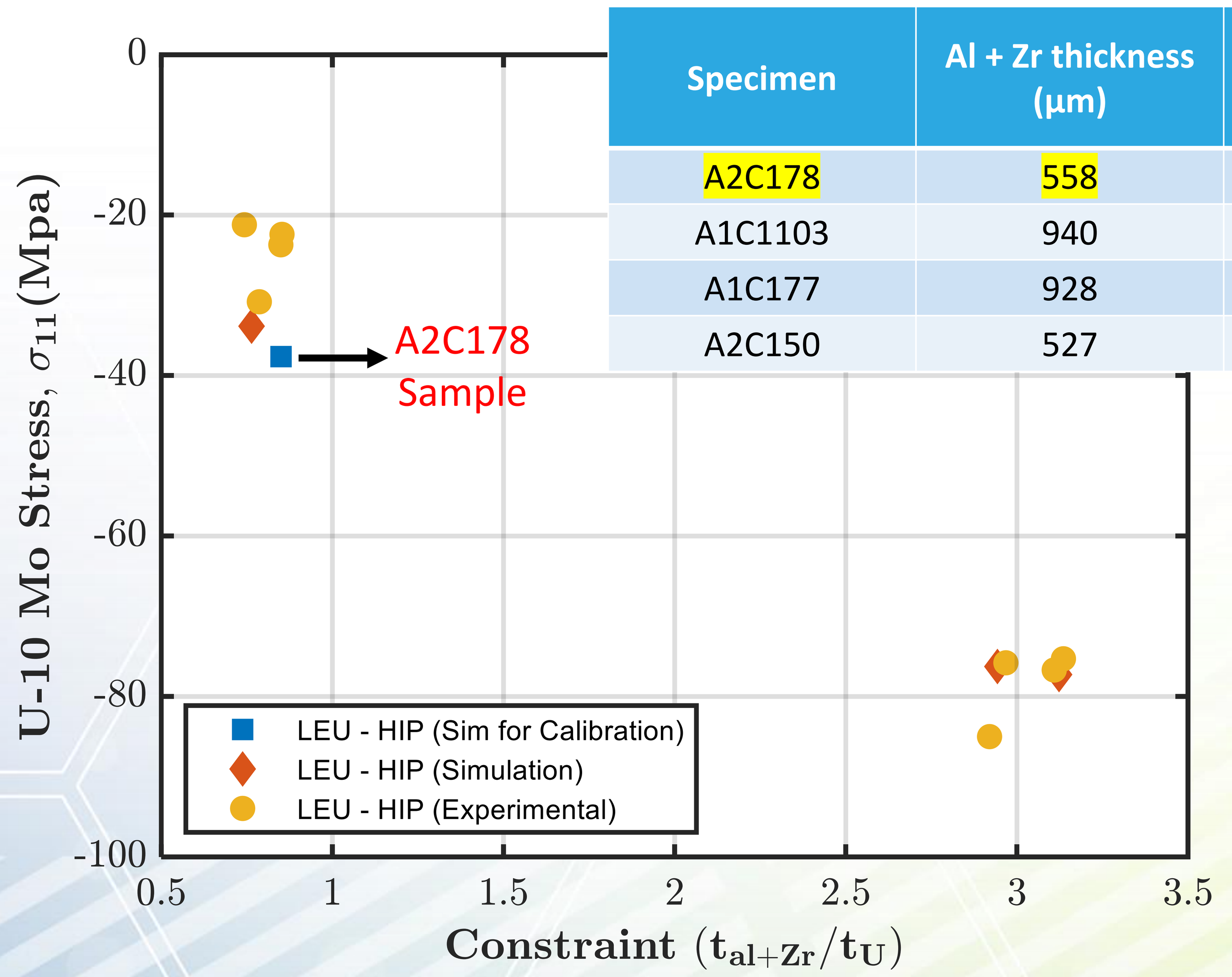
- *Swelling*
- *Thermal expansion*
- *Creep (New Hyperbolic Sine model for Cladding)*
- *Plasticity*
- *Non-linear elasticity*

A novel 2D finite element model of the fuel plate was developed to accelerate the process of material modeling.





Results and Inferences



Specimen	Al + Zr thickness (µm)	U10Mo Foil thickness (µm)
A2C178	558	657 LEU
A1C1103	940	301 LEU
A1C177	928	315 LEU
A2C150	527	690 LEU

Sample used for developing the hyperbolic sine creep model.

Conclusions and Impact

- ✓ **Accuracy and Efficiency:** The proposed creep model effectively captures the material behavior and residual stresses in U10Mo fuel plates following the HIP bonding process. Notably, this model requires **less than 2 minutes** to complete, making it **200 times faster** compared to the full **3D model.**
- ✓ **Versatility:** The proposed method can be applied to any kind of fuel plate. Moreover, the new creep material model could be used to perform irradiation studies in a 3D setting.
- ✓ **Impact:** Modeling residual stresses is vital for accurate predictions of fuel stresses during irradiation and ensure safe operating conditions.

Future Work

Using the proposed hyperbolic sine creep model, a 3D FEA model can be used to accurately predict the stresses in fuel plate post the HIP bonding process. Moreover, the current framework can be extended to model the residual stresses in blister annealed fuel plates.

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