Modeling Insights in Forming/Rolling Complex Geometries of Highly Loaded Uranium Silicide Dispersion Fuels

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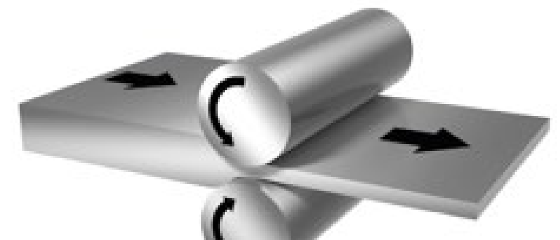
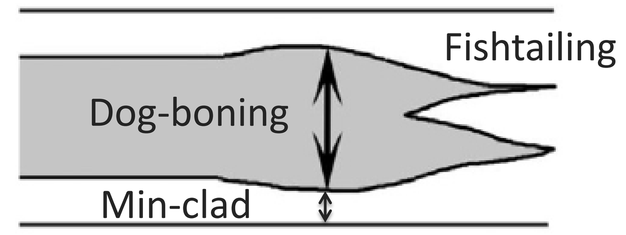
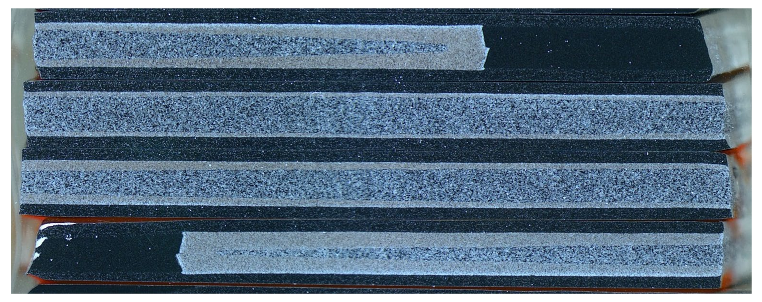
Background and Objective

- U_3Si_2-Al dispersion fuel is proposed for converting the U.S. High Flux Isotope Reactor (HFIR) to a high assay low enriched uranium (HALEU) fuel.
- A rolling process is used to form the fuel pack into the desired fuel geometries
- The objective is to develop/use numerical tools to inform fabrication:
  - Understand the impact of materials properties on the potential defects (dog-boning, min-clad, etc.)
  - Identify an optimal rolling schedule and roll-pack geometry leading to the desired fuel geometry


Rolling

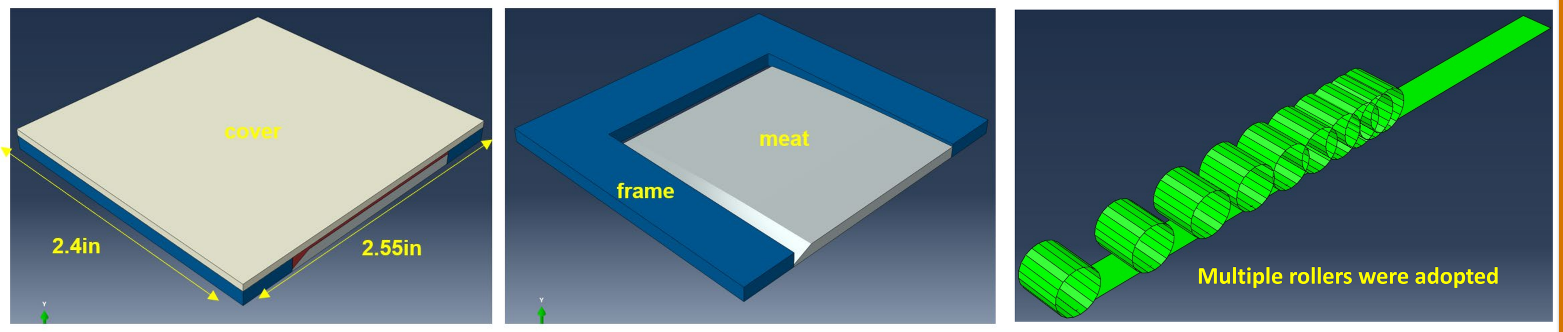

Rolled surrogate plate using geometry from Reference 1



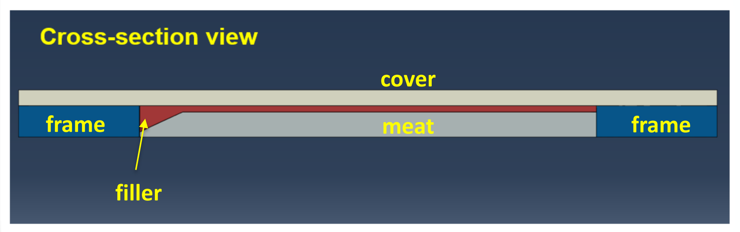


Model development

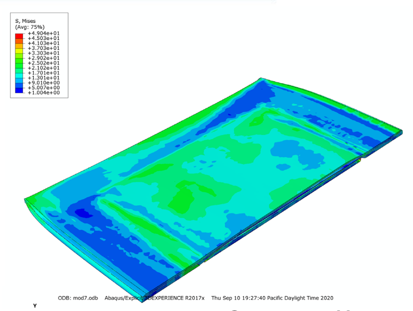
- Quarter (or half)-sized model was used to reduce the computational time while preserving accuracy
- The effects of various material properties and fuel geometries etc. were examined



Iso-view



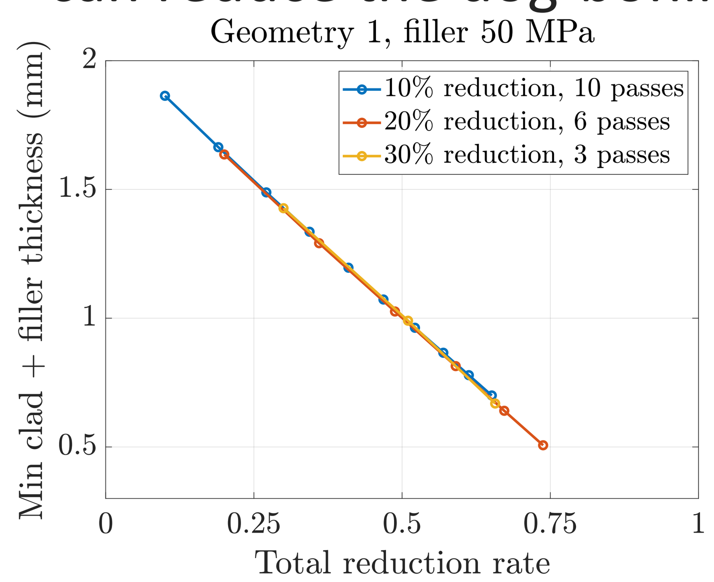
Side-view


Stresses after rolling

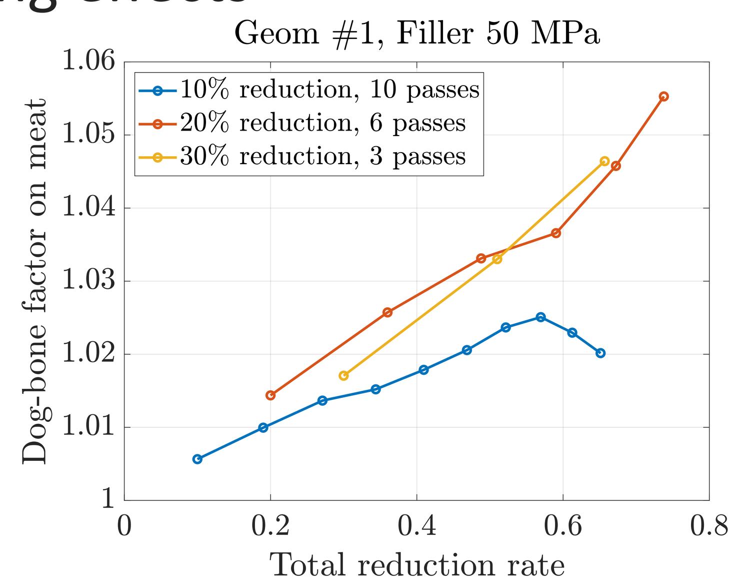
- Element # : 350,000~950,000 for quarter/half models
- Used CPU # : 8
- Simulated ~6 rolling passes
- Remeshing techniques with HPC to be considered for further hot/cold rolling passes

Effects of rolling reduction %

- Min-clad thickness decreases linearly with total reduction, and single pass reduction % and # of passes have negligible effect
- Multiple-passes with lower single pass reduction % can reduce the dog-boning effects



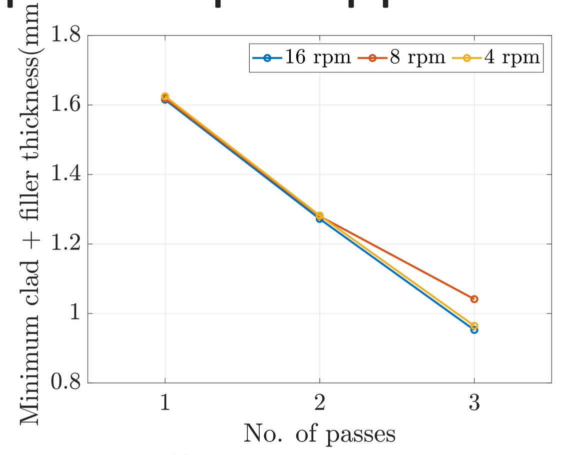
Effects on min-clad



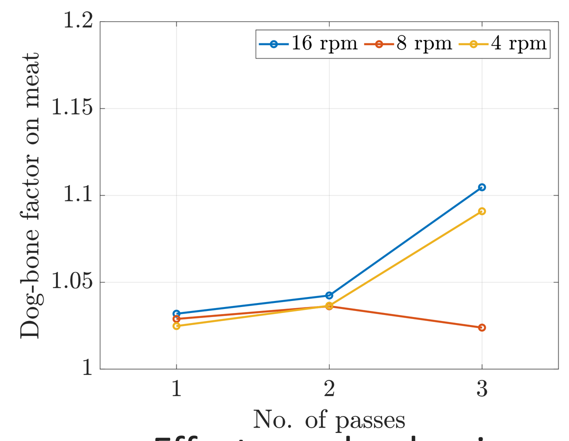
Effects on dog-boning

Effects of rolling speed (rpm)

- Slower rpm tends to increase min-clad thickness and to decrease dog-boning
- Optimal rpm appears to exist



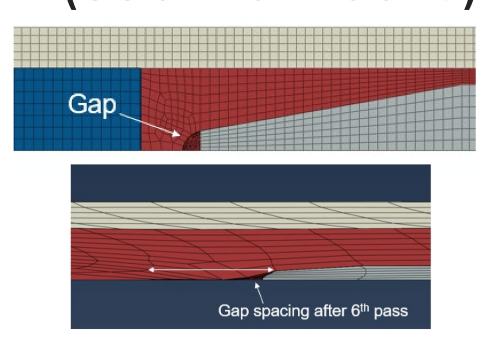
Effects on min-clad



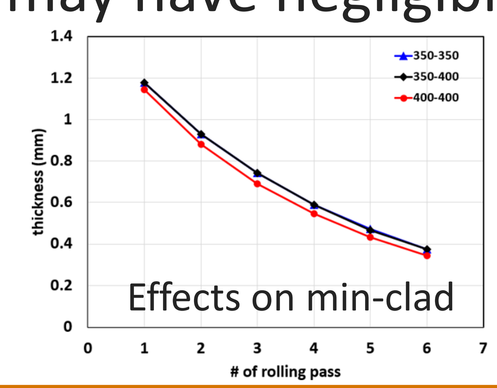
Effects on dog-boning

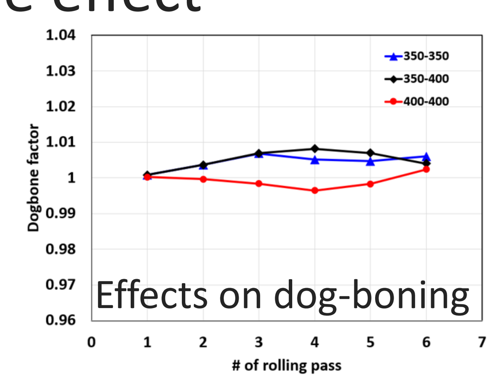
Effects of edge gap/bonding/temperature

- Possible edge gap may disappear after multiple rolling
- Change of bonding conditions or rolling temperatures (350° vs. 400°C) may have negligible effect



Disappearing gap

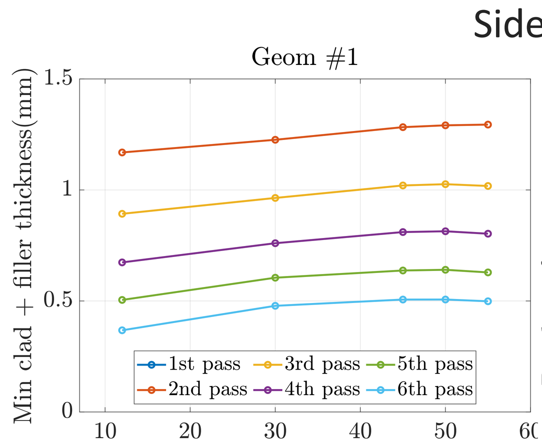

Effects on min-clad


Effects on dog-boning

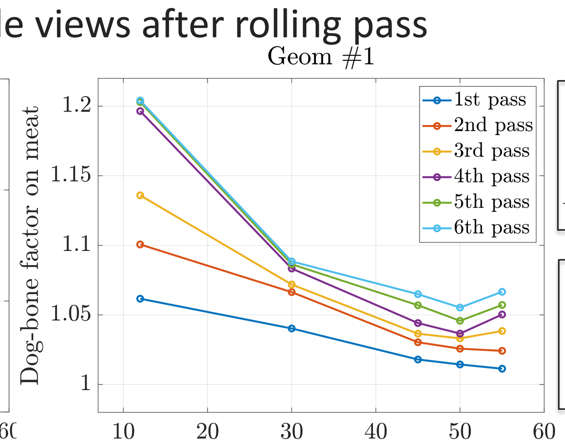
Effects of material properties

- Stronger filler strength can lead to larger min-clad thickness and effectively reduce the dog-boning effects after rolling

Side views after rolling pass



Effects on min-clad



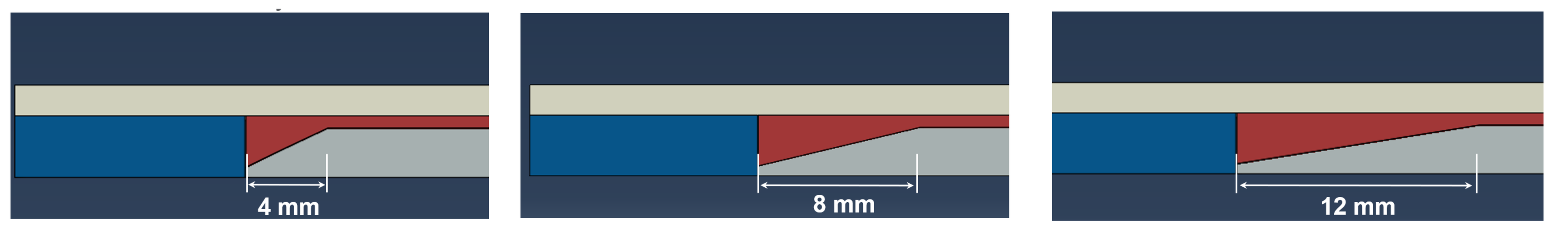
Effects on dog-boning

Min-clad : Minimum cladding thickness

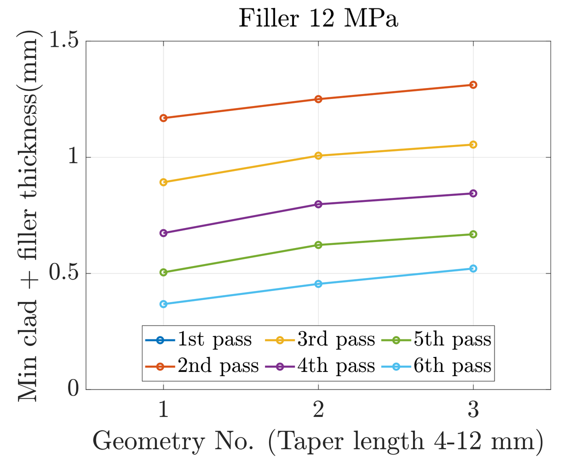
Dog-bone factor $= \frac{\text{Dog-bone thickness}}{\text{meat thickness in the mid area}}$

Effects of fuel end geometry

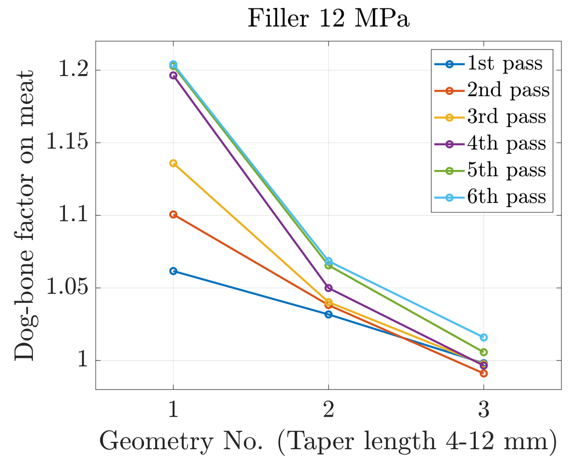
- Longer tapered fuel ends can lead to larger min-clad thickness and less dog-boning defects after rolling



Geometry #1 Geometry #2 Geometry #3



Effects on min-clad



Effects on dog-boning

Conclusions

- Modeling was validated with experimental observations
- Tapered fuel ends, fuel/filler flow stress ratio, rolling reduction %, rolling speed can be adjusted to minimize the rolling defects
- Modeling results provided the surrogate compact geometry needed to form desired fuel shape after rolling

U.S. DEPARTMENT OF ENERGY

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References: [1]Betzler et al., 2021. *High Flux Isotope Reactor Low Enriched Uranium Low Density Silicide Fuel Design Parameters.* United States. https://doi.org/10.2172/1773657