The Ohio State University

Nuclear Energy University Programs

Oak Ridge National Laboratory

DOE Advanced Materials Program Review

Novel Dissimilar Joints Between 2.25Cr-1Mo Steel and Alloy 800H

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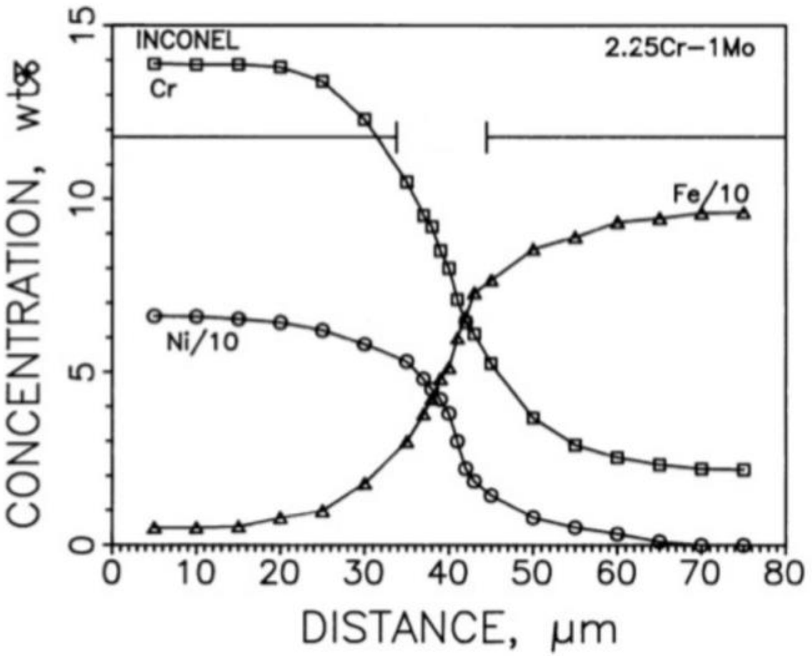
Department of Materials
Science and Engineering

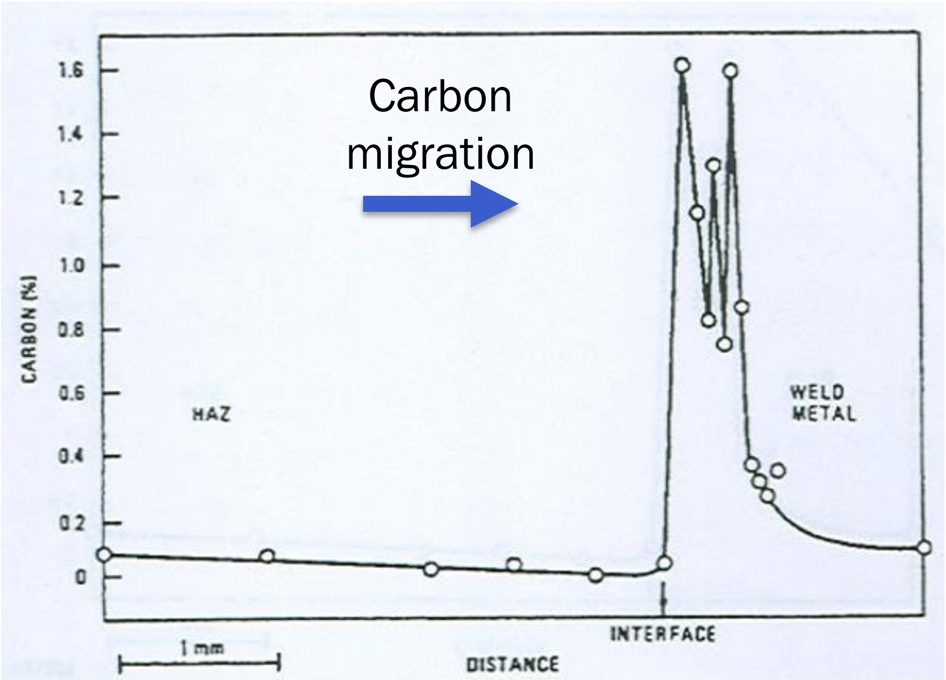
CHANGE THE WORLD

Dissimilar metal welds in power plants
Ferritic (2.25Cr-1Mo Steel) to austenitic (800H) joints

Problem: Carbon diffuses from the ferritic steel towards the austenitic alloy



Laha, *Metall. Mater. Trans A*, 2001



Ryder, *Trends in Electric Utility Research*, 1984

Consequence: Carbon depleted zone in steel → Poor creep performance

Solution: Reduce carbon diffusion to improve creep performance

Approach

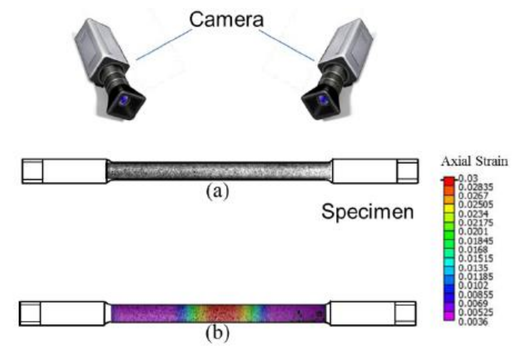
Thermodynamic and kinetic models for composition profiles that minimize carbon diffusion

PennState

Fabricate transition joints by additive manufacturing

PENNSTATE ARL

Test and characterize fabricated joints



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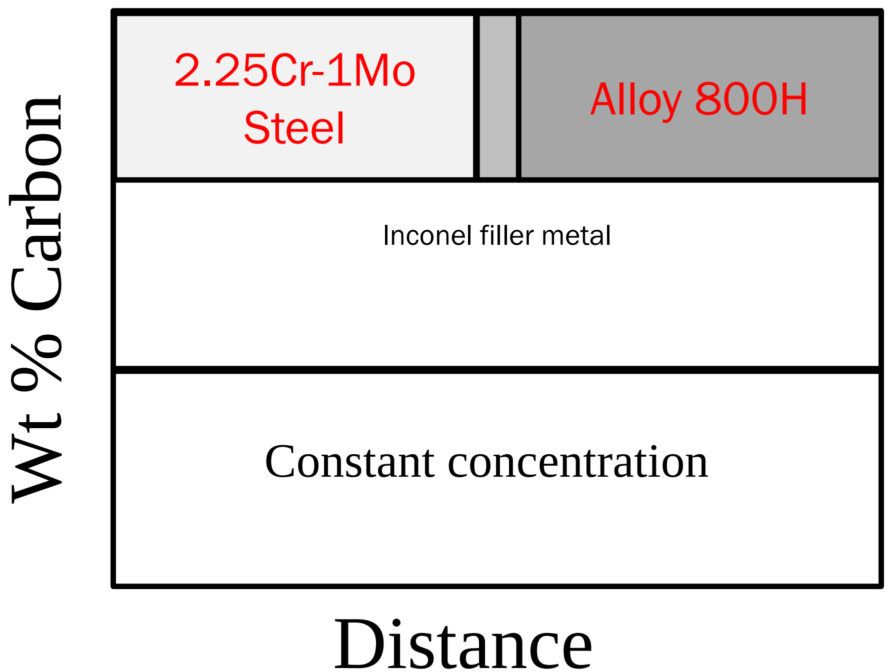
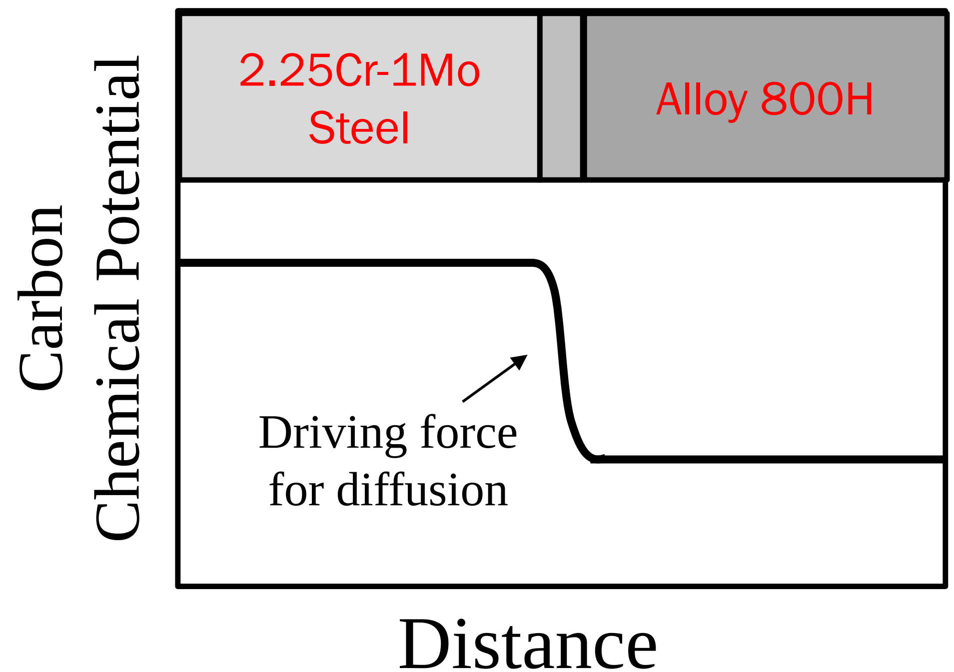
What causes carbon diffusion?

Uniform carbon concentration → Chemical potential gradient





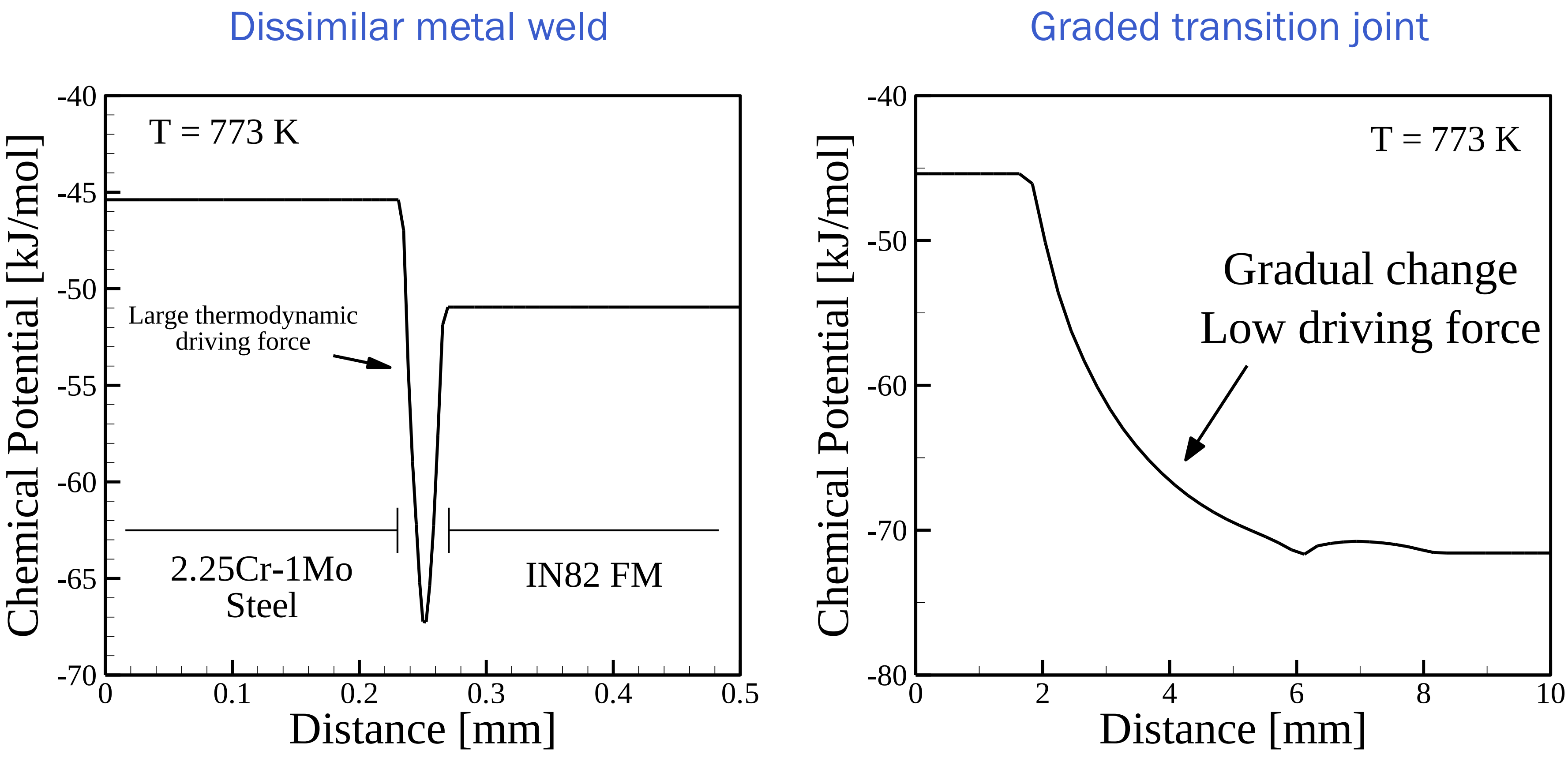
Fick's first law of diffusion

$$J_i = -D_i \frac{dc_i}{dx} \quad \Rightarrow \quad J_i = -\frac{L_i}{T}\frac{d\mu_i}{dx}$$

Depends on alloying elements

Thermodynamic modeling

Goal: Reduce carbon chemical potential gradient

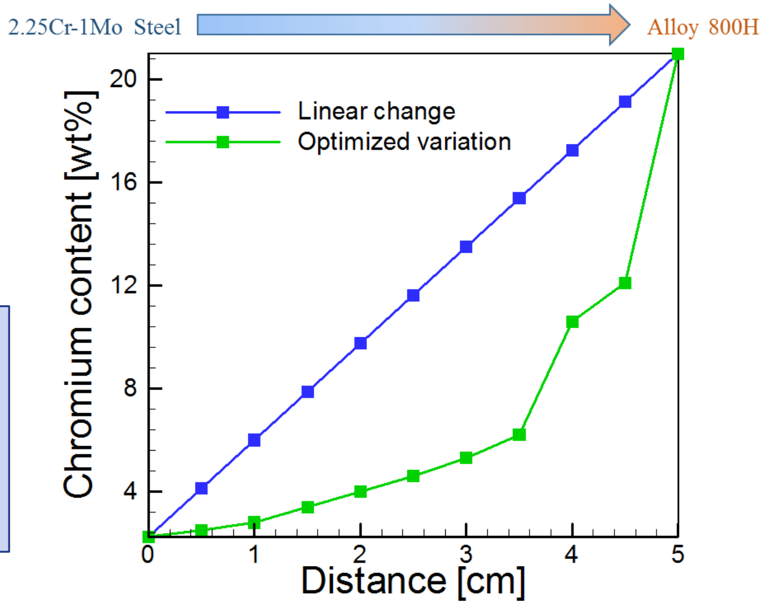


Thermodynamic modeling

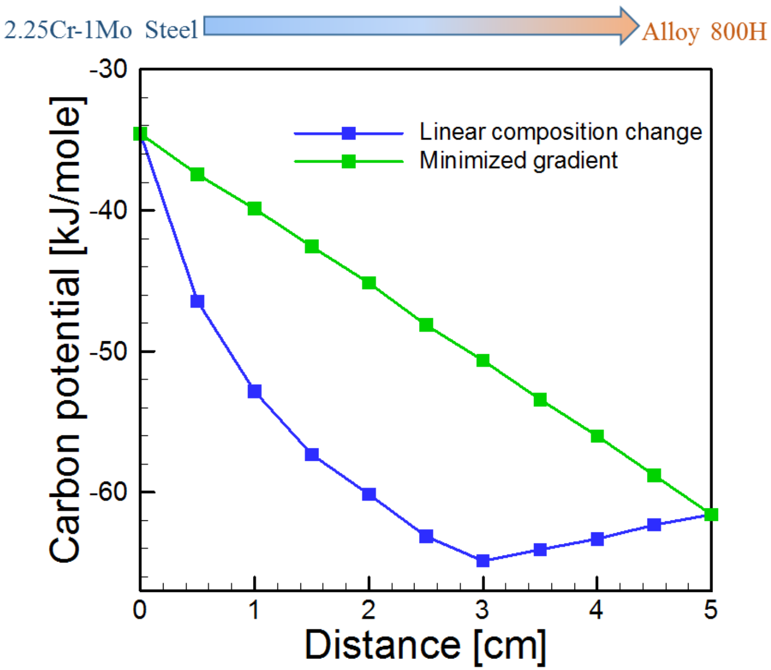
Minimizing the driving force for diffusion

1. Plot C-potential for a linear composition change and compare to minimized C-potential gradient

2. Calculate C-potential as a function of Cr concentration at all locations along transition joint



3. Use Genetic Algorithm to search for Cr concentration that gives target C-potential value



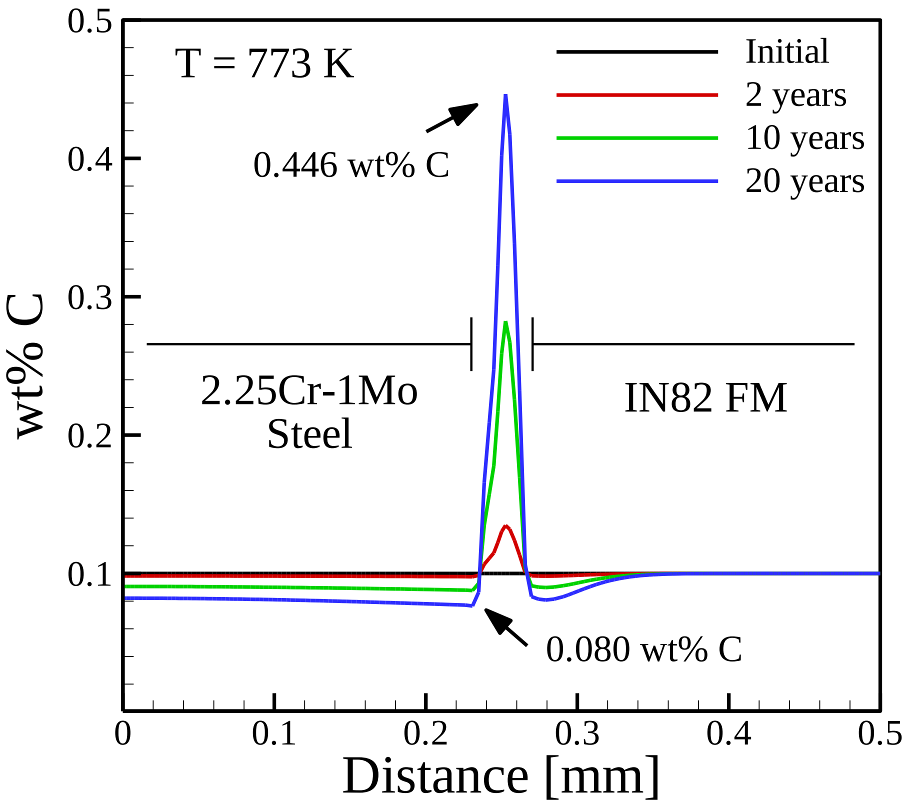
4. Repeat steps 1-3 for all locations. Output Cr concentration profile

5. Build transition joint with minimized C-potential gradient

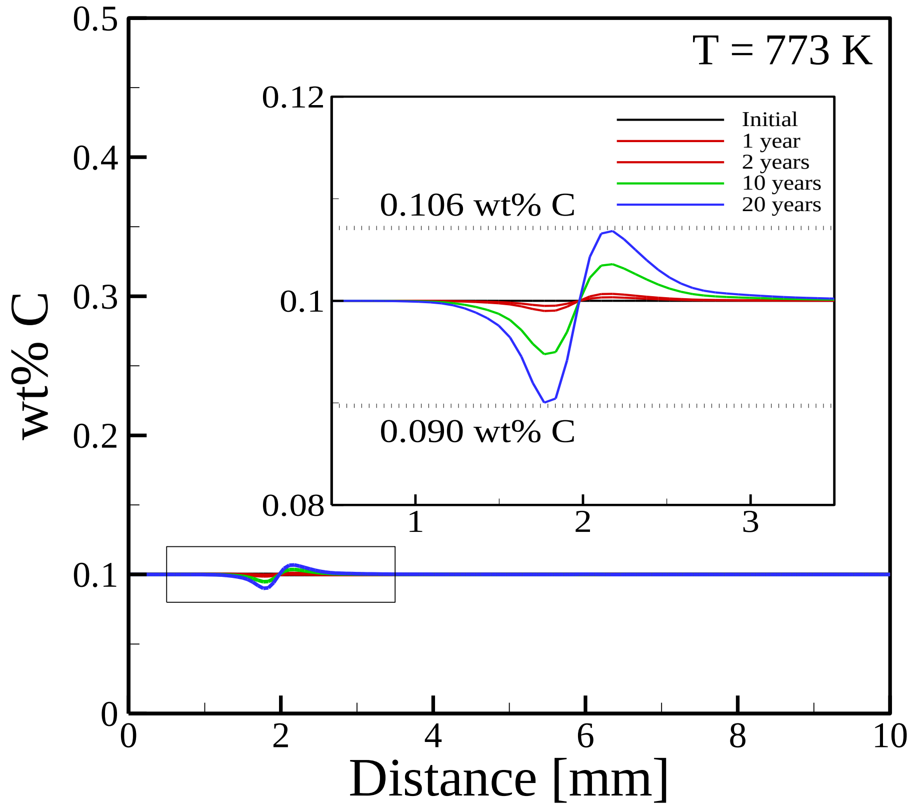
Kinetic modeling

Goal: Predict carbon migration after years of service

Dissimilar metal weld

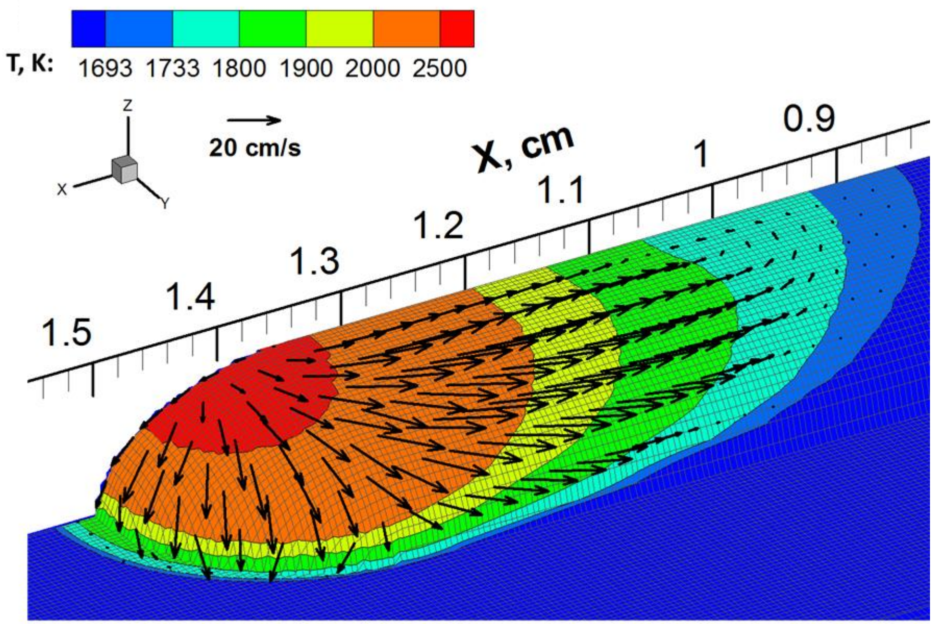


Graded transition joint

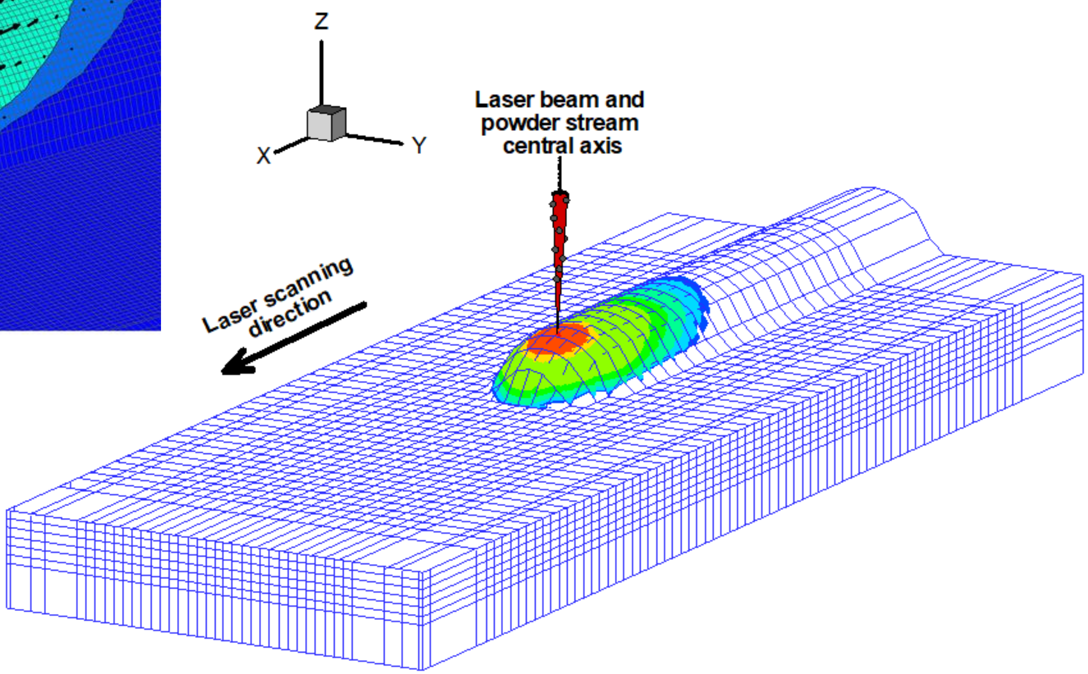


Heat transfer and fluid flow modeling

Newly developed 3D numerical model with curved surface



More accurate calculations of:
- Temperature & velocity fields
- Deposit geometry
- Solidification parameters



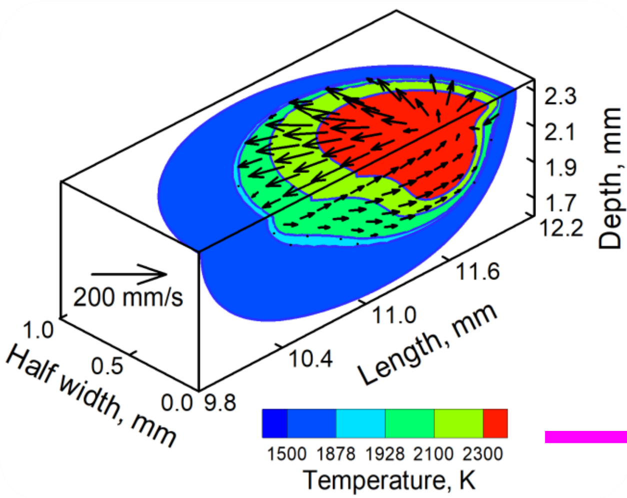
Little additional computational costs

125 billion linear equations solved in approximately 40 minutes

Residual stress & distortion modeling

3D Transient heat transfer and fluid flow model

Temperature and velocity distribution for the domain

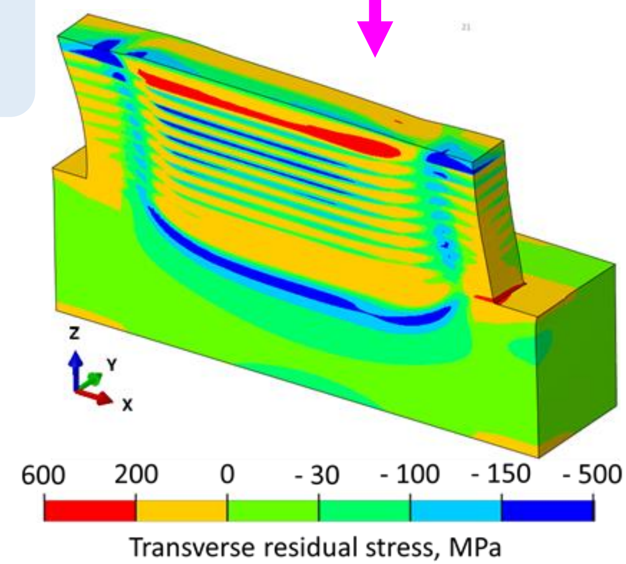


Abaqus output database (.odb) file

Using a Python script

Geometry, mesh and temperature field

Residual stresses, strains, deformation of the domain

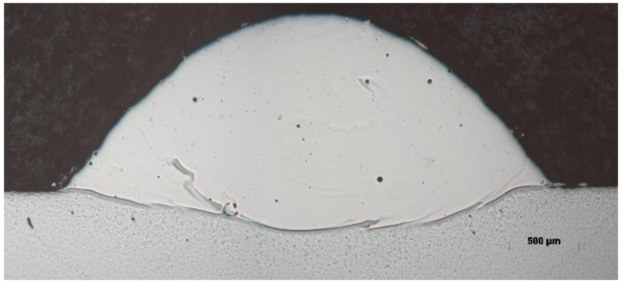


Scales of experiments

Experiments have taken place over many different length scales

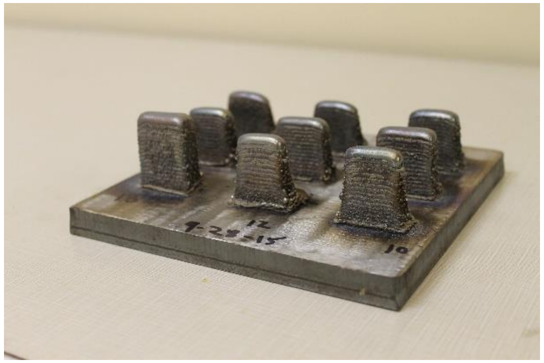
Single layer deposits:

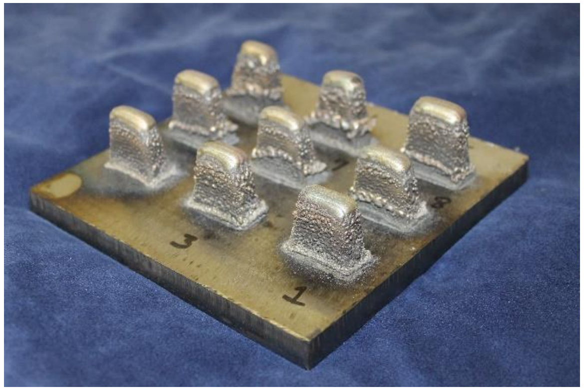
- Process optimization
- Defect formation
- Bead geometry



Sub-size deposits:

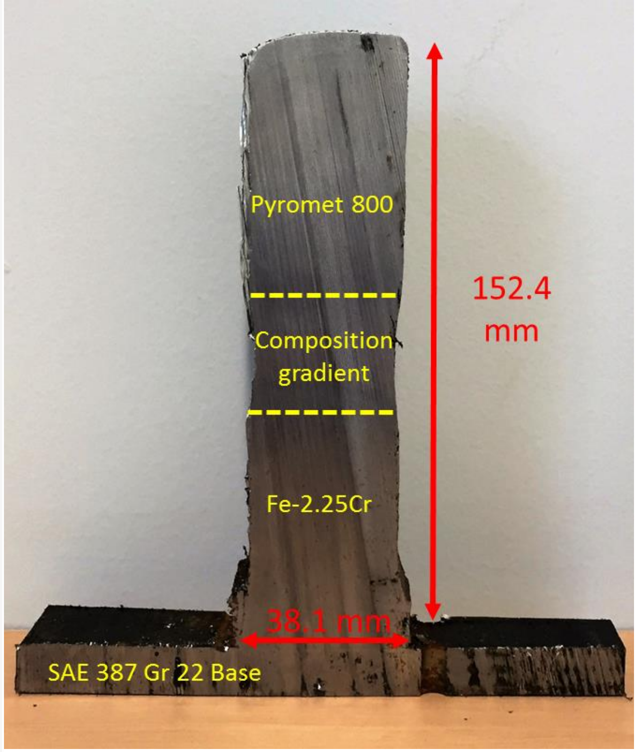
- Characterization
- Diffusion tests





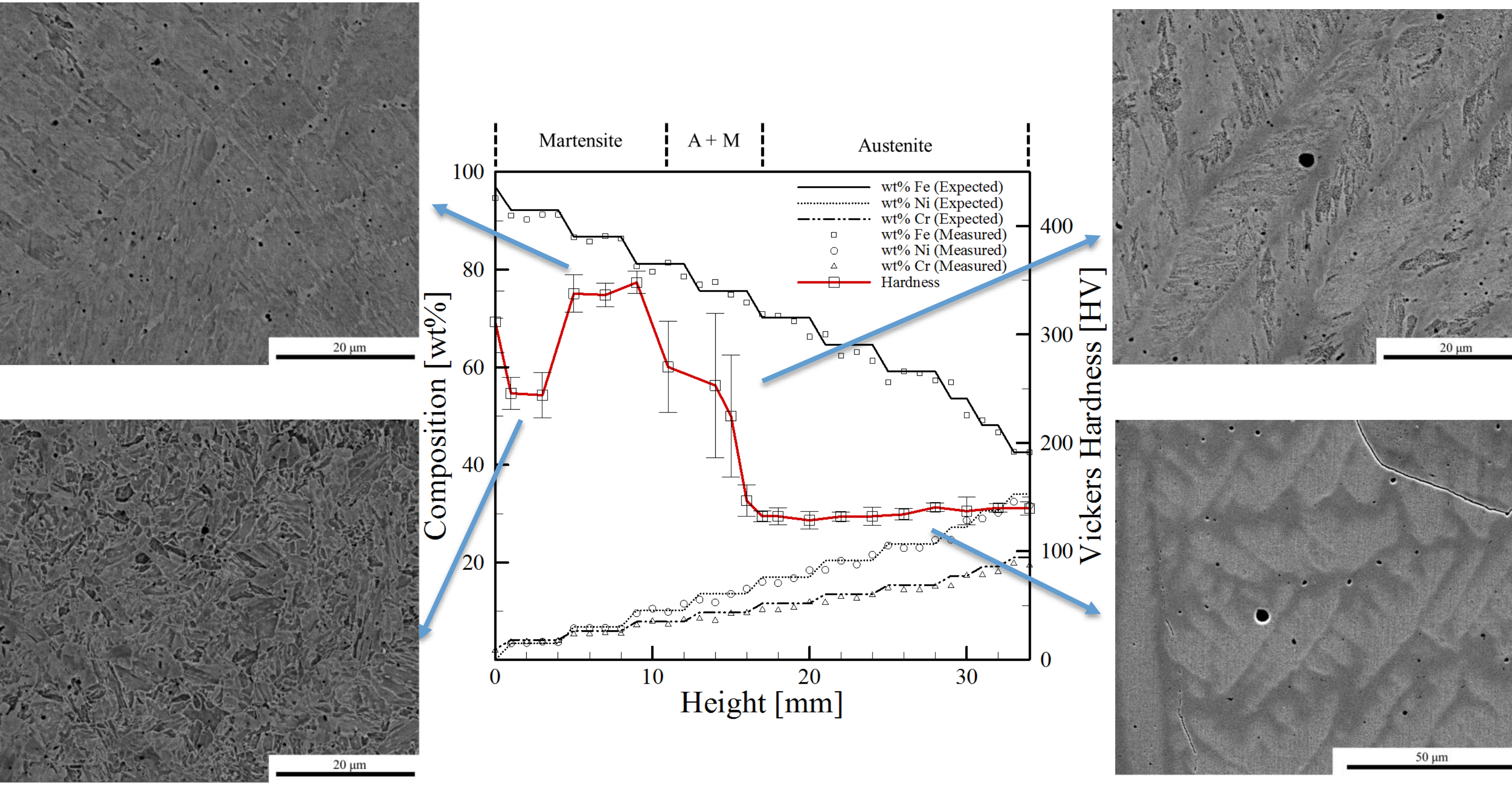
Full-size deposits:

- Characterization
- Creep testing

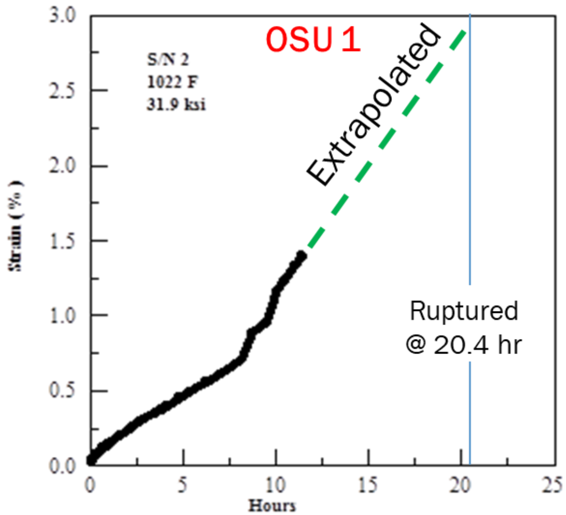


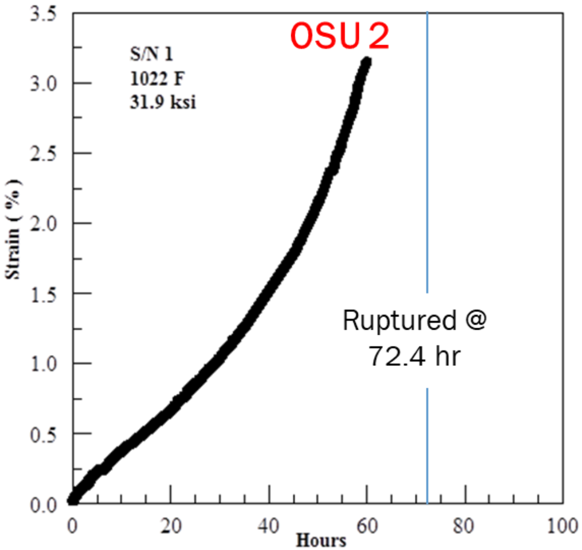
Microstructural characterization

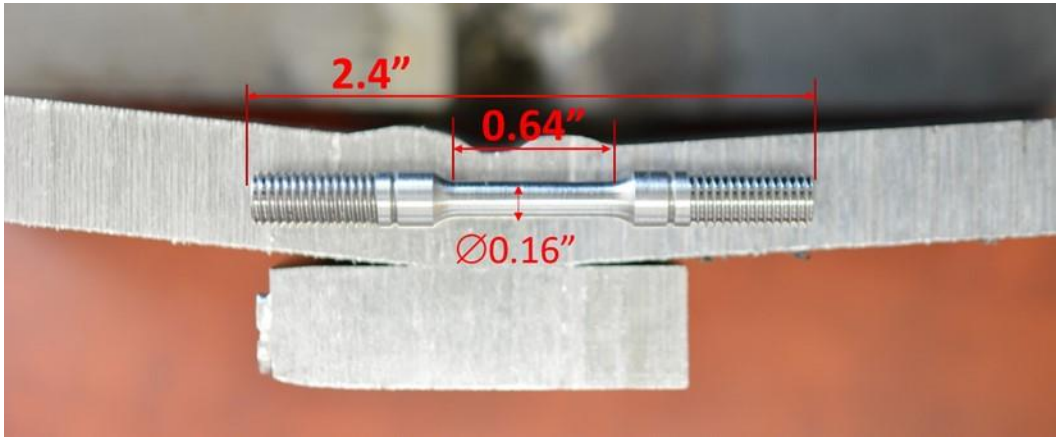
Significant changes in microstructure and hardness are observed

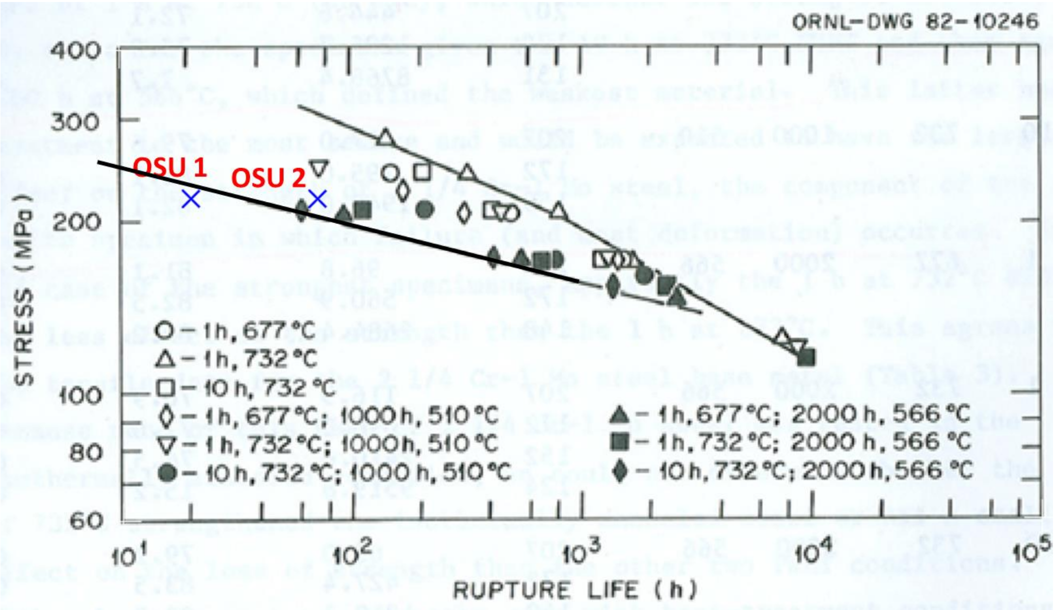


DMW fabrication and creep testing - OSU







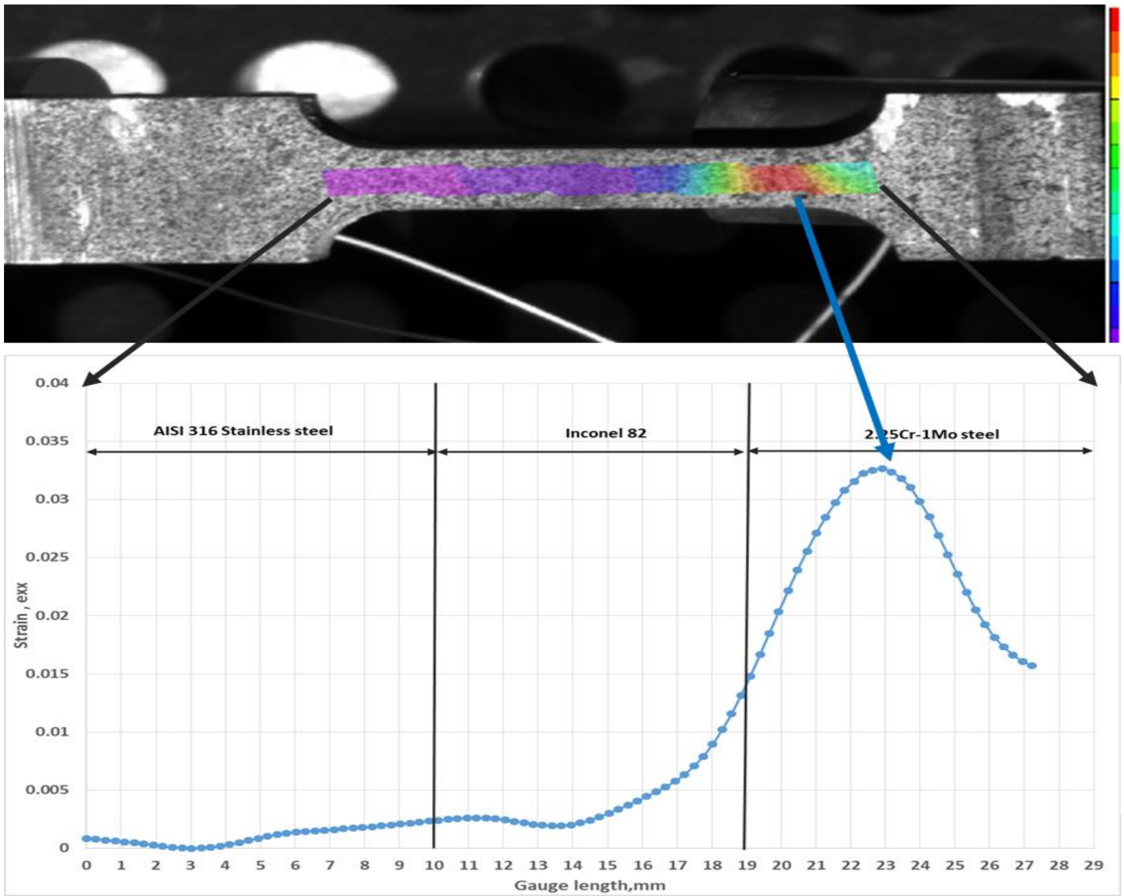


Klueh, K. L. and King, J. F. ORNL, 1982

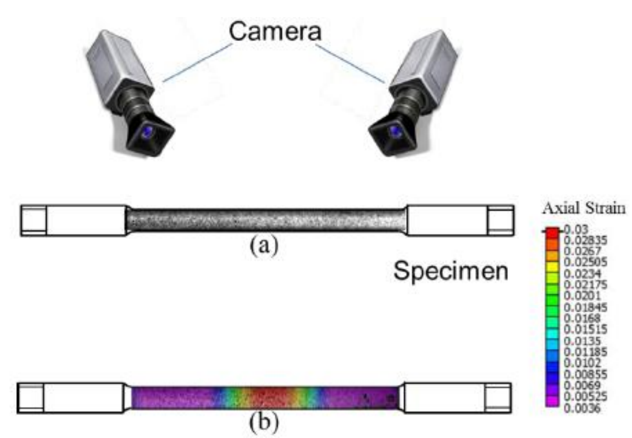
Specialized creep testing – ORNL

Specialized creep testing for inhomogeneous materials

Capable of showing regions of high localized deformation



Digital image correlation is used to measure strain rates at elevated temperatures



Publications

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- T. Mukherjee, J. S. Zuback, A. De and T. DebRoy. Heat and fluid flow modeling to examine 3D printability of alloys. 7th International Symposium on High-Temperature Metallurgical Processing, 2016, pp. 469-478. John Wiley & Sons, Inc.
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Summary and future work

- A collaborative research program has been undertaken by PSU, OSU and ORNL
- Thermodynamic and kinetic modeling shows composition profiles that significantly reduce carbon diffusion
- A new heat transfer and fluid flow model has been developed to predict deposit geometry and important metallurgical variables
- Compositionally graded test specimens have been fabricated by additive manufacturing
- Creep tests are being undertaken to compare the performance of DMW's and graded joints