FEAA90: Physics-based Creep Simulation of Thick Section Welds in High Temperature and Pressure Applications

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Abstract

Welded microstructures of γ'-strengthened, nickel-based alloy, 740H, contain significant microstructural heterogeneities that can have a strong influence on the dislocation dynamics, resulting in very different creep behavior compared to the base metal. Crystal plasticity-based finite element method (CPFEM) has been widely used to incorporate the effect of microstructural heterogeneities on deformation at the polycrystalline scale and is being utilized in this work to model the creep behavior of 740H GTA welds. Current model development is focused on secondary creep considering dislocation climb, glide, and Orowan looping. A dislocation-density based CPFEM model addressing these mechanisms is currently being implemented in the Multi-Physics Object Oriented Simulation Environment (MOOSE: *mooseframework.org)* software that provides the ability to solve problems involving multiple physics concurrently and implicitly. Short term creep tests at 700-800°C of cross weld and all-weld metal samples from GTA welds in Alloy 740 will be used to determine input parameters for the model. Long term creep tests at 750°C on Alloy 740H GTA welds will be used to validate the results of modeling and simulation. The model will also be applied to welds with microstructures that develop during hybrid laser arc welding (HLAW) of Alloy 740H to evaluate the effect of weld microstructure on of the validity of the model.

Need

Creep of welds are typically the limiting factor in component life. Accurate life predictions are needed for welds under actual service conditions – time-varying temperatures and loads.

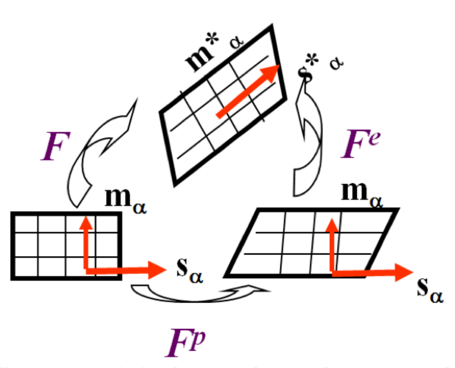
Approach

Crystal-plasticity modeling approach with experimental support for calibration and validation of modeling and simulation.

Modeling & Simulation with Input of Experimental Characteristics and Parameters

Dislocation density-based crystal plasticity model

Dislocation glide and climb:



plastic deformation:

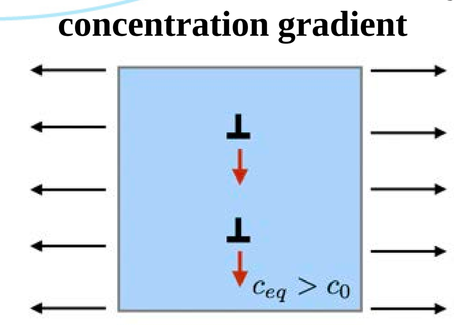
$$F = F^e F^p$$

$$\dot{F}^p F^{p-1} = \sum \dot{\gamma}^\alpha_{glide} m^\alpha_0 \otimes n^\alpha_0 + \sum \dot{\gamma}^\alpha_{climb} m^\alpha_0 \otimes m^\alpha_0$$

slip direction and normal

Slip rate: $\dot{\gamma}^\alpha_{glide} = \rho^\alpha_M b v^\alpha_g$ $\quad \dot{\gamma}^\alpha_{climb} = -\phi_p \rho^\alpha_M b v^\alpha_c$

Dislocation climb in a vacancy concentration gradient



Dislocation/γ' interaction:

Dislocation looping of γ'

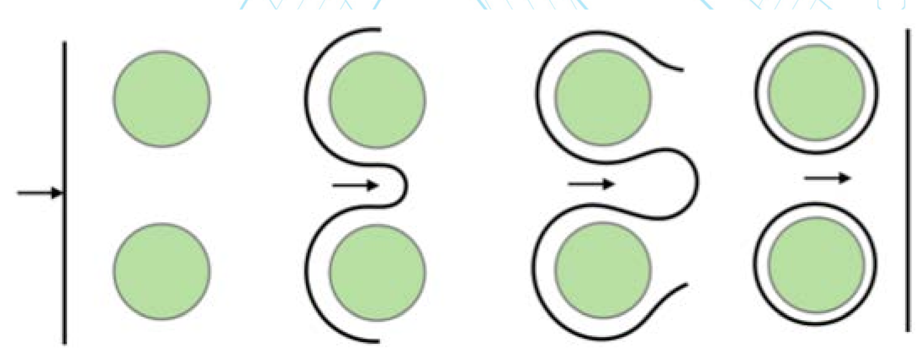


Figure 1. Orowan looping mechanism.

Athermal slip resistance

$$s^\alpha_a = \sqrt{\tau^2_{disloc-disloc} + \tau^2_{looping}}$$

Critical bowing stress

$$\tau_{looping} = \frac{Gb}{L_s}$$

γ' particle spacing

$$L_s = \sqrt{\frac{8}{3\pi f_p}} r_p - r_p$$

L_s = spacing between precipitates
f_p = volume fraction of precipitates
r_p = radius of precipitates

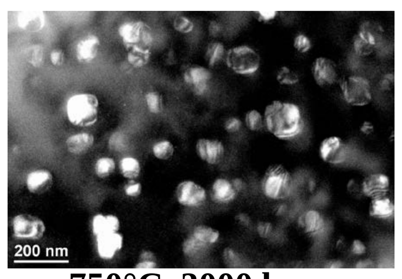
Characteristics of the γ' distribution:

$$\langle r^3 \rangle = kt + \langle r^3_o \rangle$$

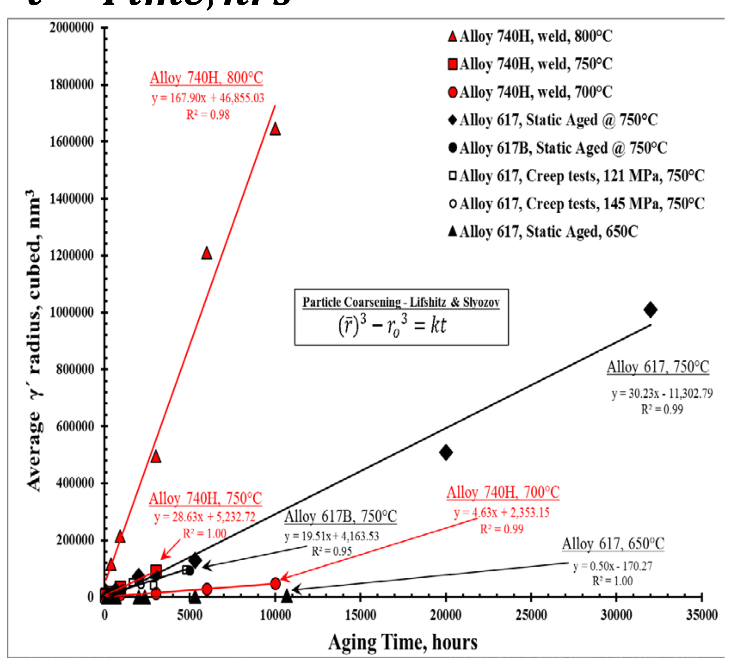
$r = \gamma'$ *radius, nm*
$k =$ *growth rate constant,* $\frac{nm}{hr}$
$t =$ *Time, hrs*

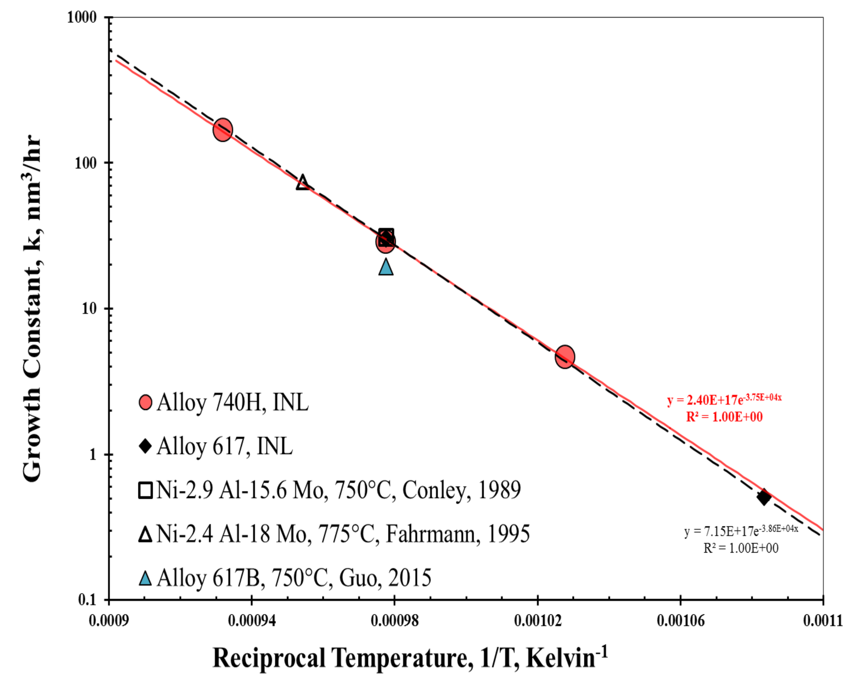
Experimental γ' Growth Parameters

T, C	Rate Constant, k, nm³/hr	r₀, nm
700	4.6	13.3
750	28.6	17.4
800	167.9	36.1



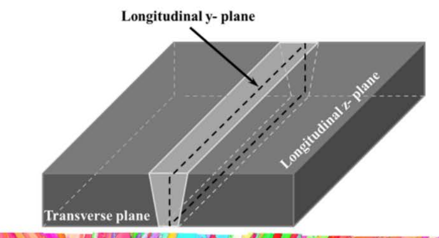
750°C, 3000 hrs



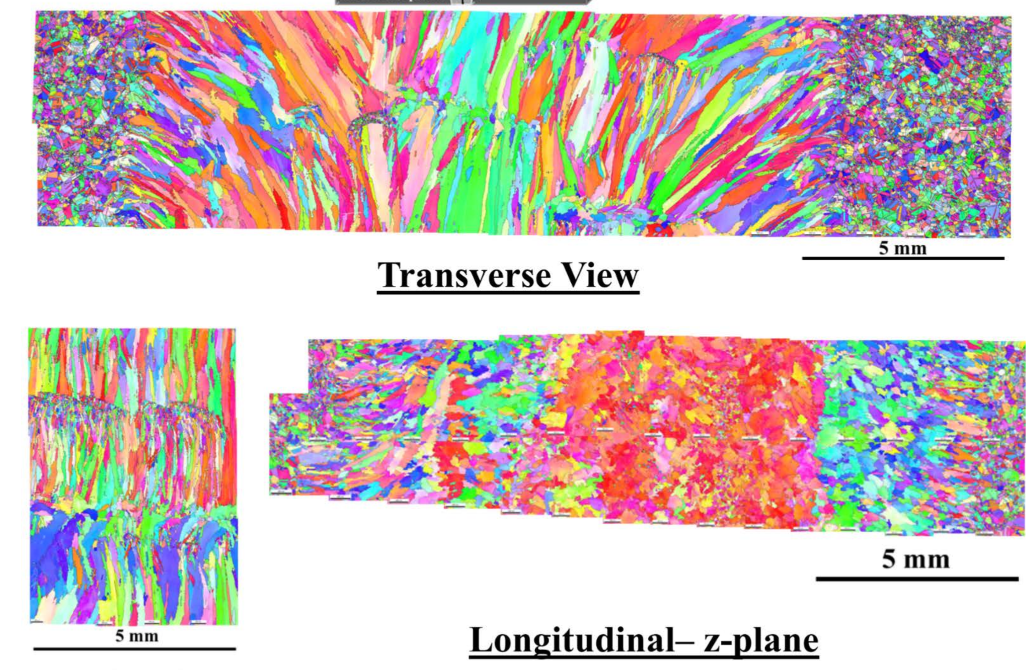


Incorporation of experimental weld microstructure:

Experimental EBSD Weld/Base Metal Microstructures



Transverse View



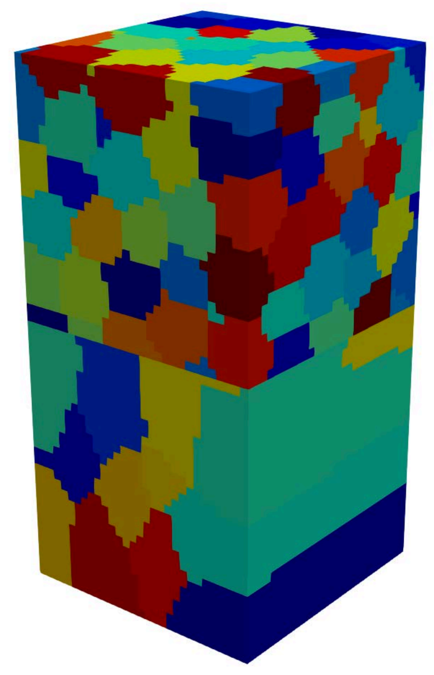
Longitudinal y-plane

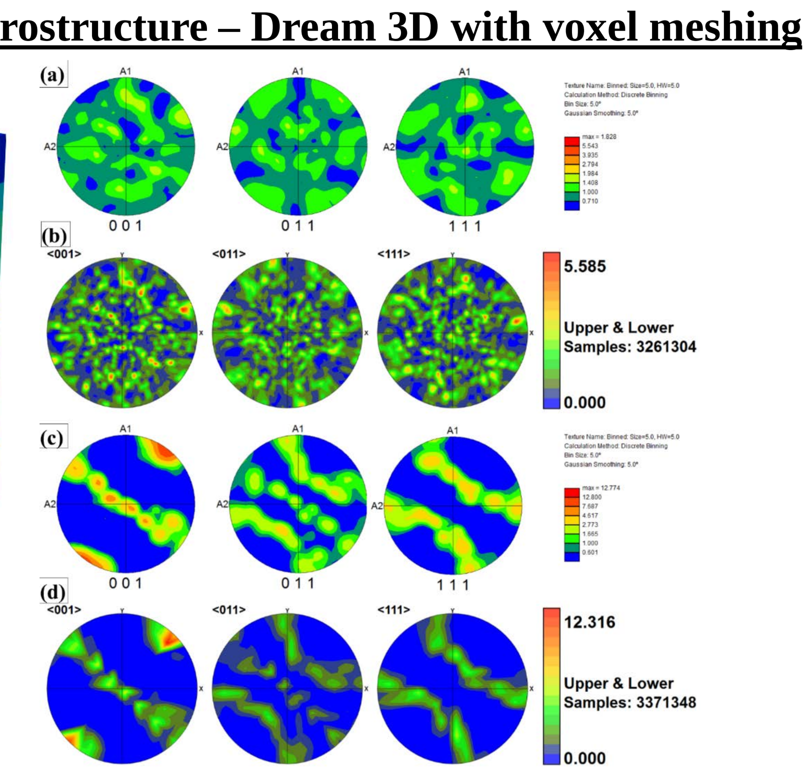
Longitudinal– z-plane

Simulated Weld/Base Metal Microstructure – Dream 3D with voxel meshing

Base Metal

Weld Metal

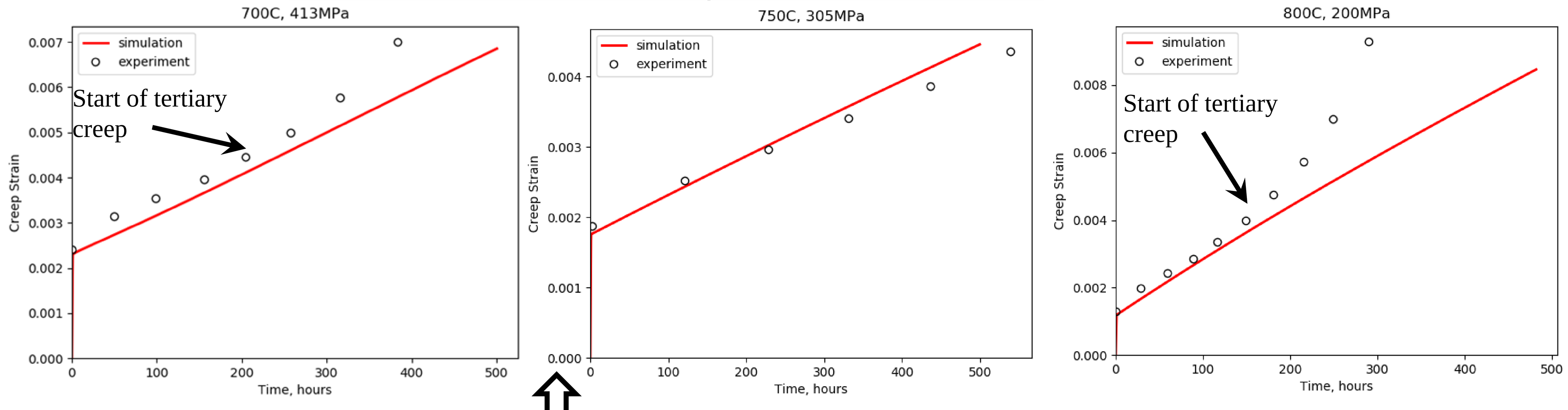


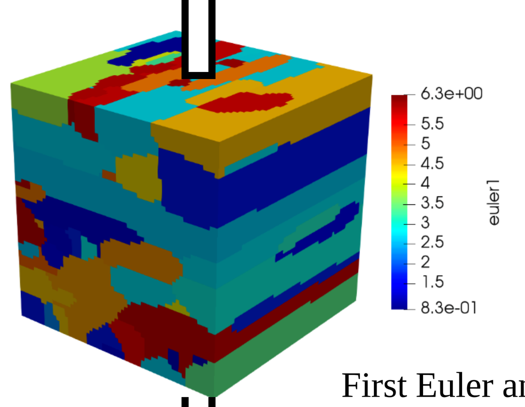


Orientation distributions: (a) base metal, experimental, (b) base metal, Dream 3D , (c) weld metal, experimental and (d) weld metal, Dream 3D.

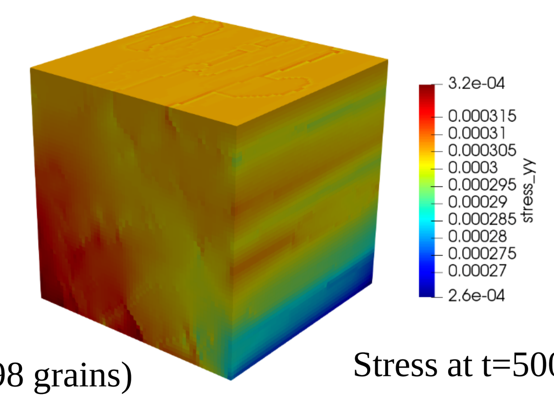
Results and Future Work

Model Calibration Using All-weld Metal Creep Specimens





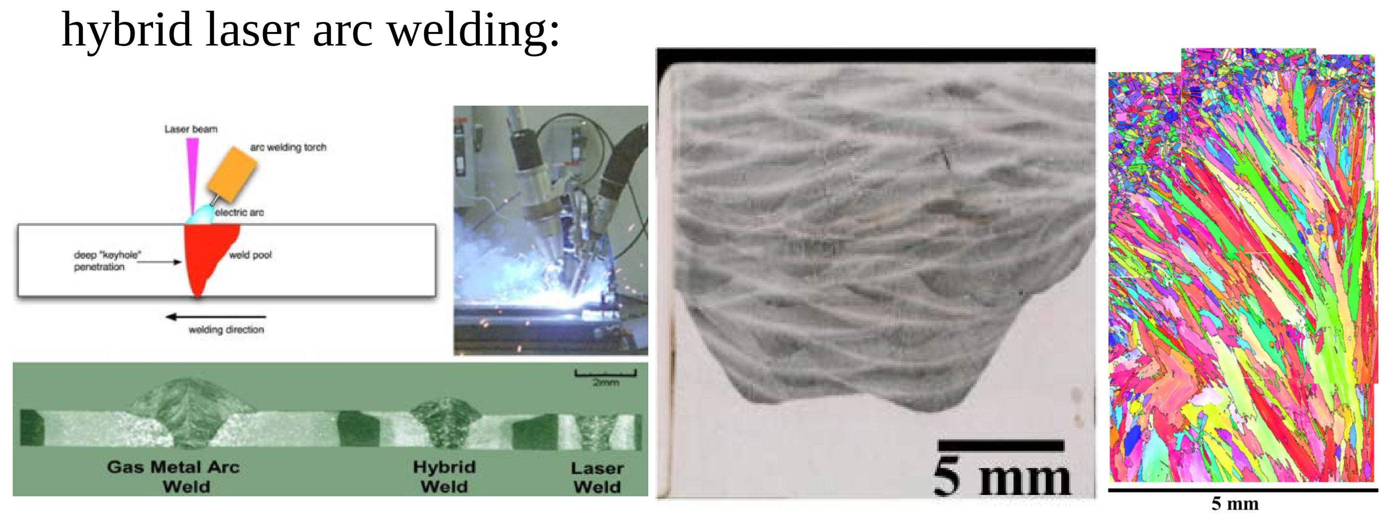
First Euler angle (98 grains)



Stress at t=500 hours (T=750°C, loading 305MPa)

Future work

- Additional calibration using all-weld metal data
- Transition to tertiary creep
- Calibration and modeling of Alloy 740H cross weld creep tests
- Model validation using long-term (4000-11,000 hr) creep tests on cross weld specimens
- Application of the model to microstructures that develop during hybrid laser arc welding:



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