Modified Jogged-Screw Model for Creep

Michael J. Mills, The Ohio State University, DMR-0116126

"Moving Line source" results → "Critical Jog height" results

"Jog Spacing" results

"Dislocation density" results

Theory

Experiment

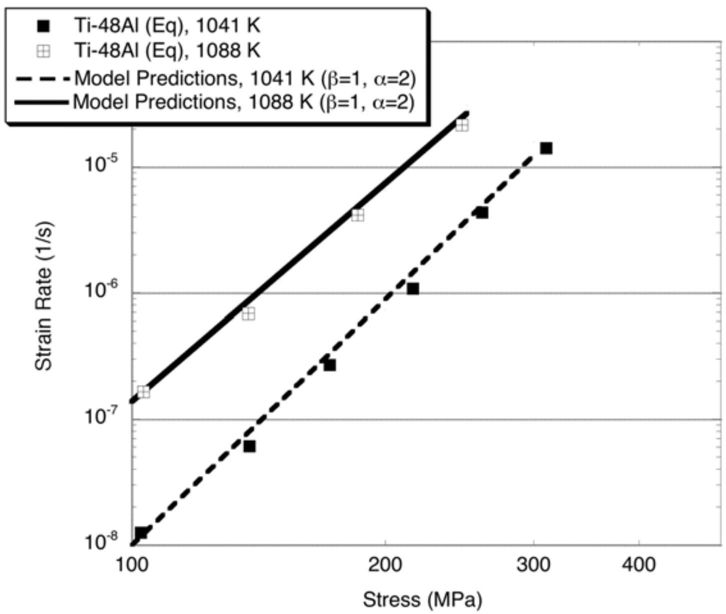
$h_d \propto \tau^{-2}$

$l \propto \tau^{-1}$

Taylor's Relation

Orowan's Equation

Property Prediction



Motivation:

Develop a predictive modeling capability for the high temperature deformation response of TiAl – an important new high temperature alloy system

Approach:

Detailed characterization of the deformation substructure has directed dislocation and continuum-level modeling, resulting in a new model for creep that is physically-based and relies on *no* fitting parameters for its accuracy.

The combination of light weight and good mechanical properties makes γ-TiAl based alloys ideal candidates for high temperature applications. Consequently, the creep deformation of these alloys has been of great interest. On the basis of microstructural observation of 1/2[110]-type jogged-screw dislocations, it is proposed that the creep deformation mechanism in equiaxed γ-Ti-48Al alloys is controlled by the non-conservative dragging of the numerous superjogs that pin screw dislocations. A previously proposed creep model based on these observations has now been ratified to include parametric stress dependencies of the various microstructural variables. The original solution has been reformulated to take into account the finite height of the moving jog. The jog is now treated as a line source/sink of vacancies instead of a point source/sink of vacancies. This is a better approximation of the tall jog that predicts that jog-dragging is easier than anticipated by the previous model. By accounting for the possibility of three competing mechanisms (jog dragging, dipole dragging and dipole bypass), we have arrived at a modified critical jog height beyond which the jog is not dragged. The critical jog height was found to be strongly stress-dependent. Dynamic simulation of the motion of these jogged-screw segments using line tension arguments suggests that jog spacing is inversely proportional to the applied stress (not assumed in the previous model). This relationship arises from a balance between a) coarsening of jog spacings due to conservative glide of jogs and b) refinement due to continued nucleation of fresh jog-pairs. This result is also confirmed by direct TEM measurements. Taylor's expression for dislocation density was also confirmed by actual density measurements on the TEM. The combination of these parameters and dependencies, derived both from experiment and theory, leads to an excellent prediction of creep rates and stress exponents. The absence of “fitting” parameters lends to the generality and rigidity of the model.

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Broad Impact:

The modified jogged-screw model also appears to be applicable to a wide range of technologically important metallic systems:

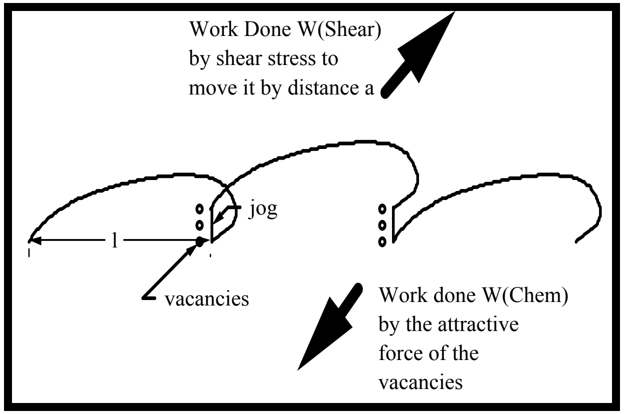
(1) γ-Ti-48%Al ($L1_0$ structure)
- **Equiaxed Structure**
- **Fully Lamellar Structure**
- **More complex alloys based on the Ti-Al system**

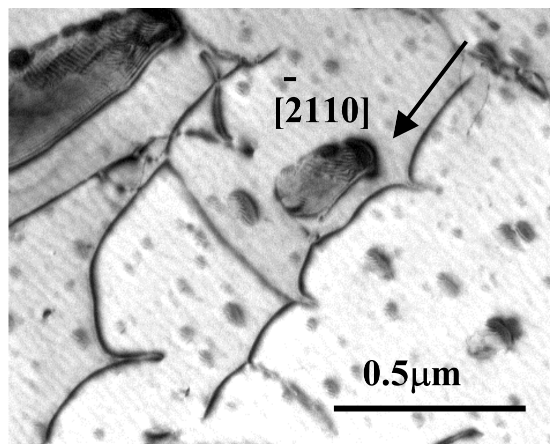
(2) α-Ti-6%Al (HCP structure)

(3) α-Phase of commercial α/β Ti alloys such as T-6242

(4) α-Zr-4%O alloy (Zircaloy-4)

The underlying physics of the model suggests that it may also be extendable to other BCC systems, such as α-Fe, Mo, Nb, and W alloys which is the subject of continued investigation.





Microstructure of crept Zicaloy-4 at 42MPa, 866*K*

Education:

- **This project has engaged two graduate students, Subramanian Karthikeyan (PhD in 2003) and Junho Moon as their thesis projects, and an undergraduate student, Erin Barry.**
- **In collaboration with Pratt&Whitney, the model is being integrated into a DARPA-funded effort on low and high temperature creep in Ti alloys.**
- **Bechtel-Bettis is interested in developing the model for Zr alloys use for nuclear fuel cladding.**

The ability to predict the life-limiting creep behavior is a major advance which should enable more rapid development and deployment of these materials