Crystal Viscoplasticity of Ti-Al Alloy under High Temperature Condition

Helal Chowdhury, Institute for Mechanics, Faculty of Mechanical Engineering, Otto-von-Guericke-University Magdeburg
Prof. Dr.-Ing habil. Holm Altenbach, Institute for Mechanics, Faculty of Mechanical Engineering, Otto-von-Guericke-University Magdeburg
Prof. Dr.-Ing habil. Konstantin Naumenko, Institute for Mechanics, Faculty of Mechanical Engineering, Otto-von-Guericke-University Magdeburg
Prof. Dr.-Ing Manja Krüger, Institute for Material and Joining Technology, Faculty of Mechanical Engineering, Otto-von-Guericke-University Magdeburg

Introduction: Since late in the last century, the complex interaction among crystal dislocations and motion have been recognized for dominating macroscopic characteristics such as morphological, mechanical and thermodynamic properties of engineering materials**.** Therefore plasticity modeling is primarily concerns how good the accommodation of dislocation characteristics into the model. Crystal viscoplasticity model is highly useful tool for studying stress-strain, anomalous yielding behavior, the strain rate and the temperature dependence etc. It is quite capable of capturing first-order microstructural effects and failure criteria for various manufacturing processes as well.

Plasticity in Different Scales

❖ Molecular Dynamics (MD), Dislocation Dynamics (DD), grain scale and Continuum scale plasticity

❖ The deviations of the position of the atoms from the lattice sites implicitly represent the dislocations in MD. Only few dislocation lines are studied due to simulation size constraint.

❖ DD based on force on each dislocation segment and its mobility function

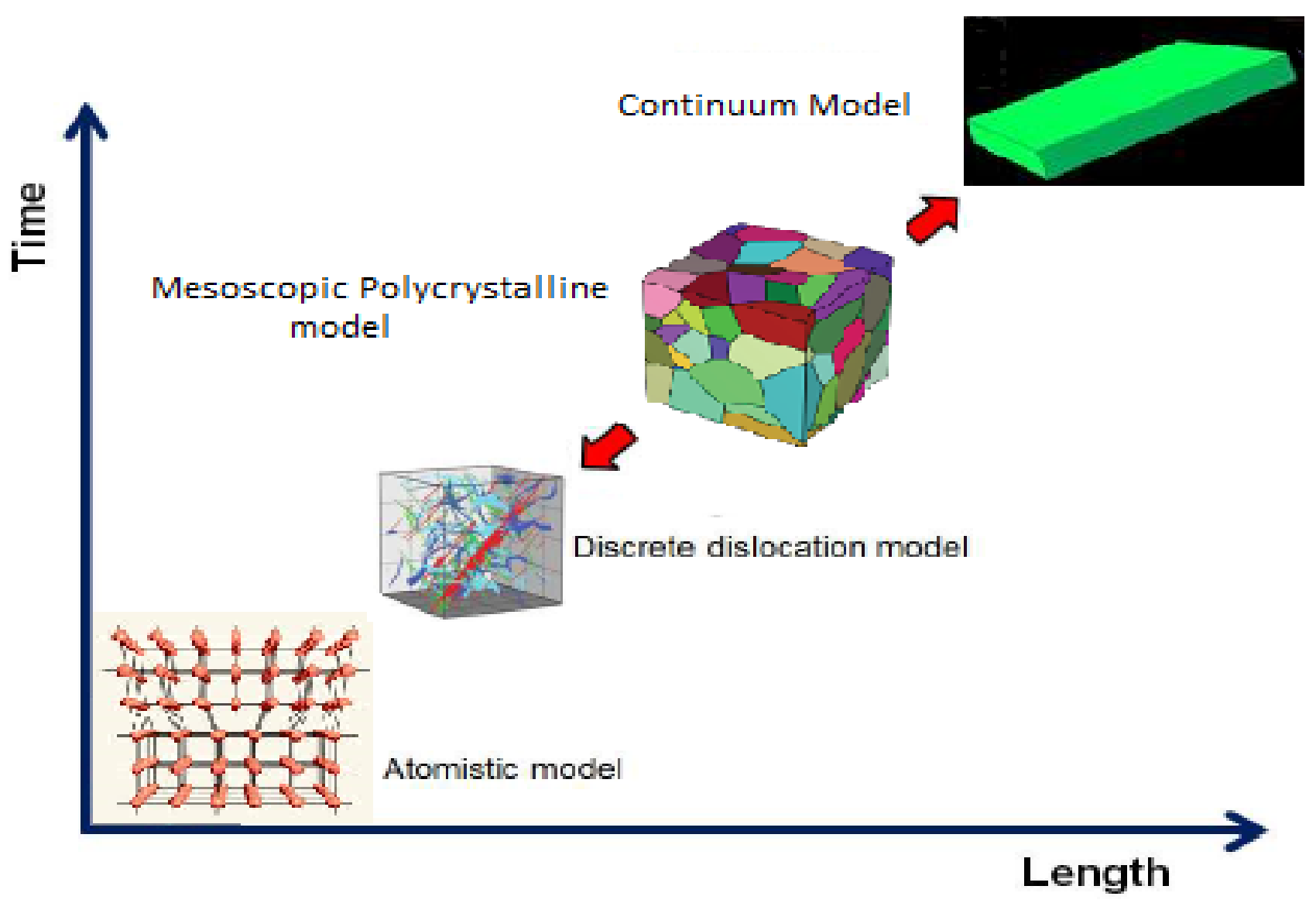


Figure 1: Mesoscopic grained model bridges scales

❖In mesoscopic grain scale, dislocations are accommodated by plastic slip of each slip system, it bridges macroscale and DD

❖In continuum plasticity, rheological models are used using basic mechanical elements like spring, dashpot and friction element

Plasticity in General

General Theory of Plasticity requires:

❖ A yield criterion: like von Mises and Tresca

❖ A hardening rule: e.g Isotropic or kinematic: power-law hardening

❖ A flow rule: e.g Levy-Mises or Prandtal-Reuss

Phase System of Ti-Al Alloy

❖ widely recognized as a possible basis for lightweight alloys for high temperature structural applications.

❖ exhibits high strength, fracture toughness, corrosive resistance, low density and high melting temperature.

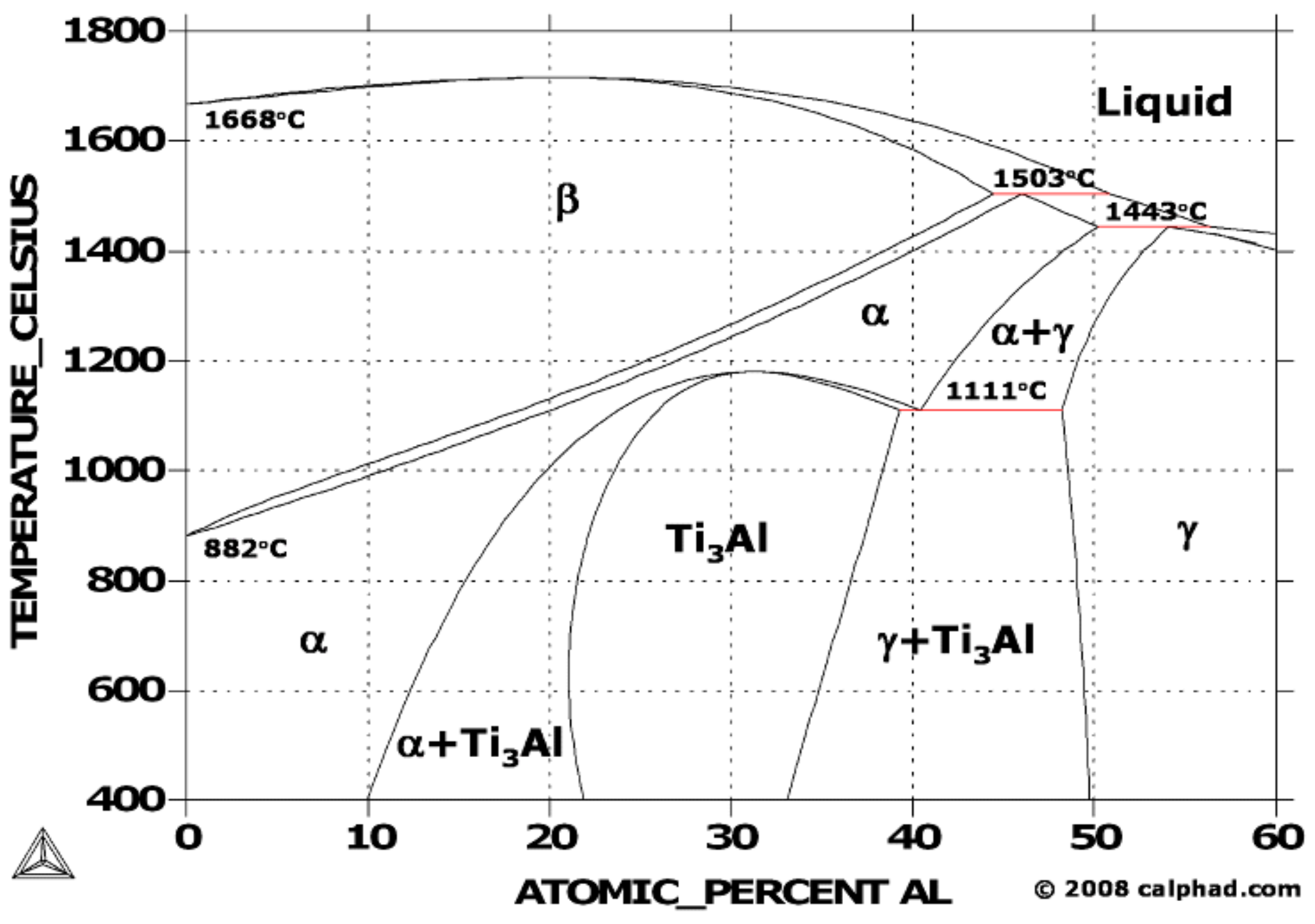


Figure 2: Phase diagram of Ti-Al alloy

❖ γ-TiAl type (with FCC structure) and α2-TiAl (with CPH structure) alloys show superior properties, while the best one is γ -TiAl phase strengthened by minor fractions of the hexagonal α2-TiAl phase.

❖ Application: automotive industry, power plant turbines, and aircraft engines, low pressure turbine blades, high pressure compressor blades, vanes, casings and tiles etc.

Objective

Studying inelastic behaviors like yielding, hardening, creep etc. of high performance Ti-Al alloy mainly in grain scale under high temperature condition

Cooperation

1. Mr. Oleksandr Prygorniev
2. Mr. Adili Maimaiti

Crystal Structure and Slip System

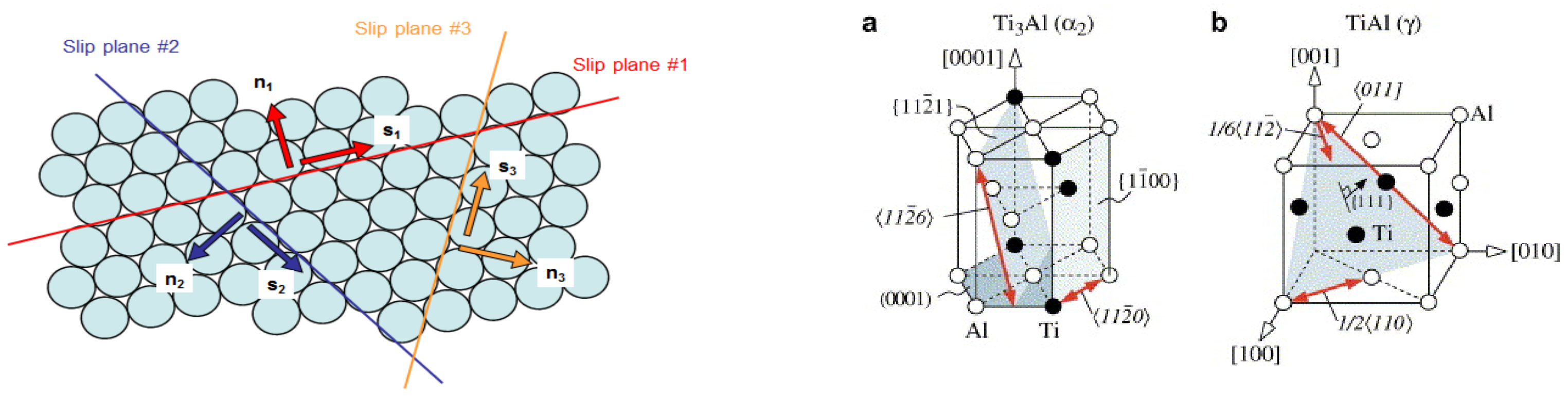


Figure 3: (a) Typical slip planes in 2D case (b)CPH, FCC crystal structures

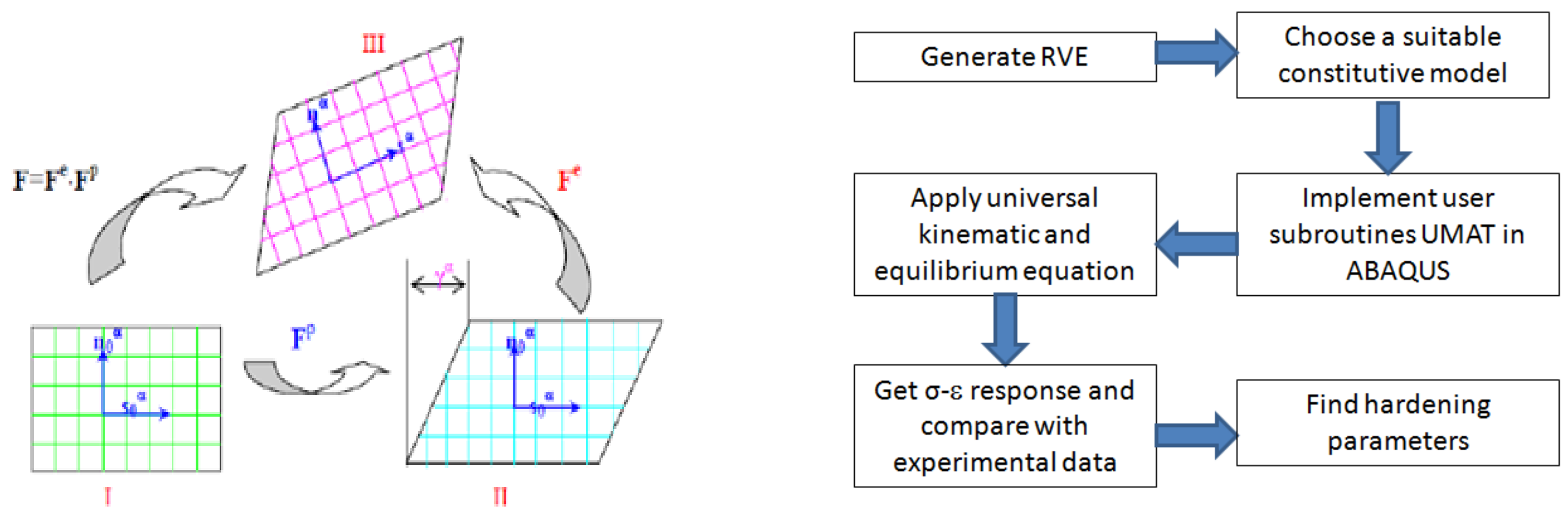
❖ Two phase γ -TiAl+α2-TiAl is also with FCC structure with 12 slip systems

Typical Crystal Plasticity Model

1. Resolved shear stress on α-th slip plane: $$\tau^{(\alpha)} = \sigma_{ij}\mu_{ij}^{(\alpha)}$$
2. Schmidt factor on α-th slip plane: $$\mu_{ij}^{(\alpha)} = \frac{1}{2}\left(s_i^{(\alpha)} n_j^{(\alpha)} + s_j^{(\alpha)} n_i^{(\alpha)}\right)$$
3. Plastic strain rate: $$\dot{\varepsilon}_{ij}^{p} = \sum \mu_{ij}^{(\alpha)}\dot{\gamma}^{(\alpha)}$$
4. Stress rate: $$\dot{\sigma}_{ij} = C_{ijkl}\dot{\varepsilon}_{kl}^{e} = C_{ijkl}\left(\dot{\varepsilon}_{kl} - \dot{\varepsilon}_{kl}^{p}\right)$$
5. Shear strain rate (power law): $$\dot{\gamma}^{(\alpha)} = \dot{\gamma}_o^{(\alpha)}\,\mathrm{sgn}\left(\tau^{(\alpha)}\right)\left|\frac{\tau^{(\alpha)}}{g^{(\alpha)}}\right|^{m}$$
6. Current strenth: $$\dot{g}^{(\alpha)} = \sum_{\beta=1}^{N} h_{\alpha\beta}\dot{\gamma}^{(\alpha)}$$
7. Hardening model (Peirce, Asaro and Needleman): $$h_{\alpha\alpha} = h(\gamma) = h_o \sec h^2\left|\frac{h_o\gamma}{\tau_s - \tau_o}\right|$$ $$h_{\alpha\beta} = qh(\gamma) \qquad (\alpha \neq \beta)$$

Where, $h_{\alpha\beta}$: hardening modulus
$h_{\alpha\alpha}$: self hardening parameter

Finding Hardening Parameter



Generate RVE → Choose a suitable constitutive model → Implement user subroutines UMAT in ABAQUS → Apply universal kinematic and equilibrium equation → Get σ-ε response and compare with experimental data → Find hardening parameters

Figure 4: (a) Splitting deformation gradient into elastic and plastic part, (b) Simple block diagram showing steps to find hardening parameters

Typical Figure for Viscoplasticity

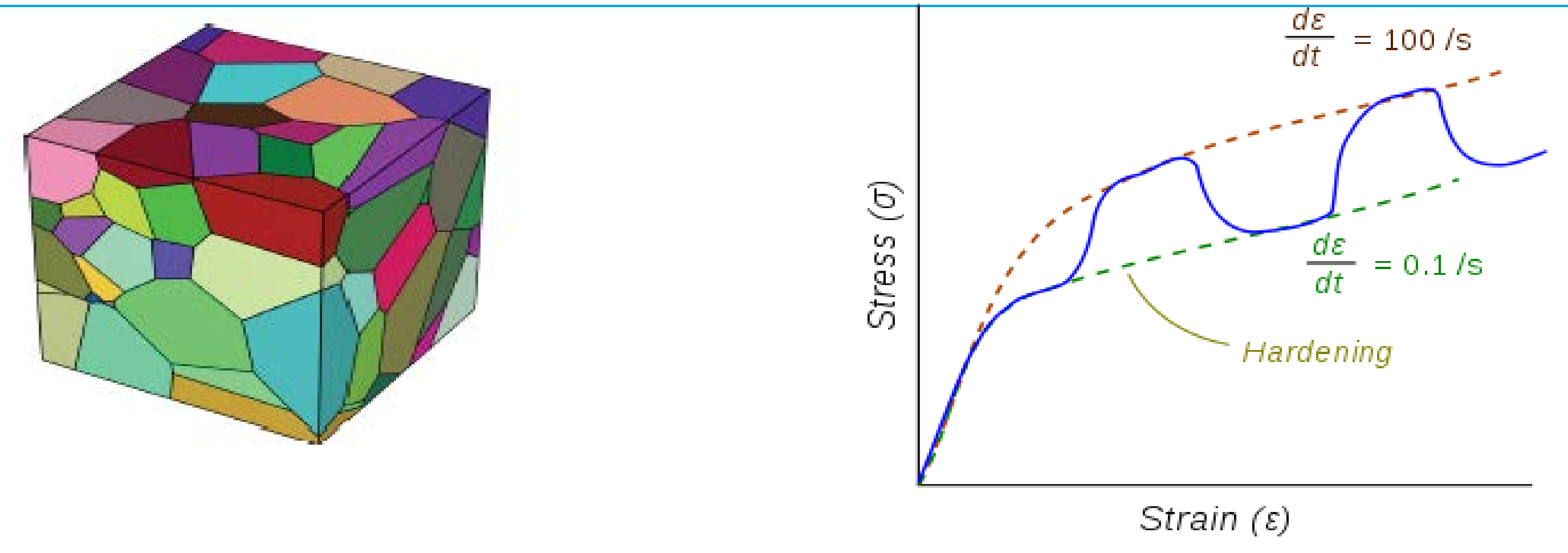


Figure 5: (a) Typical representative volume element (RVE) showing grains, (b) σ-ε response for viscoplastic material, dotted lines for constant rate, blue line for response when strain rate changes suddenly

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