Grain boundary sliding and superplasticity

T.G. Nieh
Department of Materials Science and Engineering
University of Tennessee

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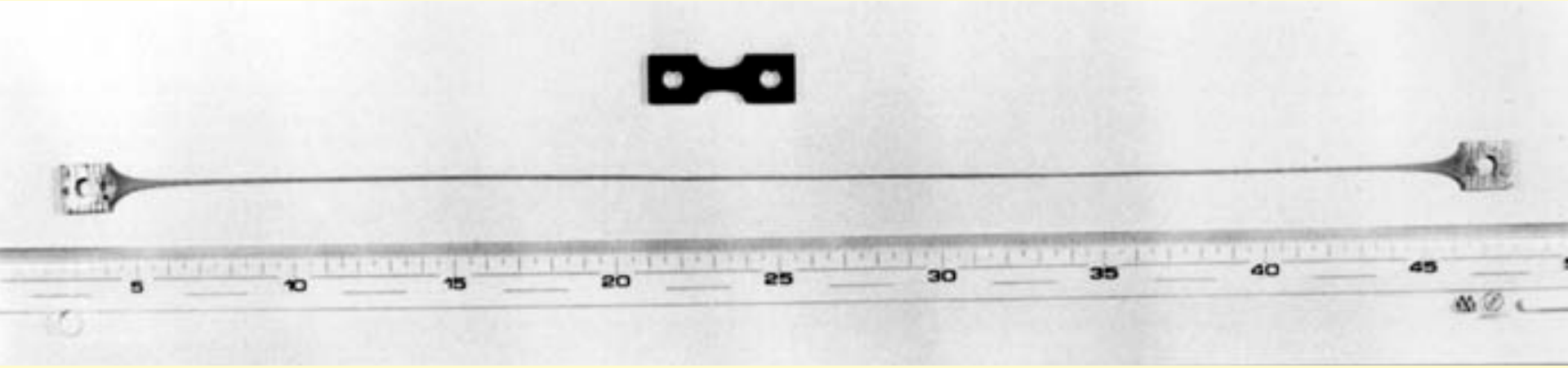
"Superplasticity is the ability of a polycrystalline solid to exhibit very high tensile elongation prior to failure."



extraordinary elongation (8000%) achieved in a fine-grained three-phase Cu-Al alloy by Higashi

Grain sizes of superplastic materials

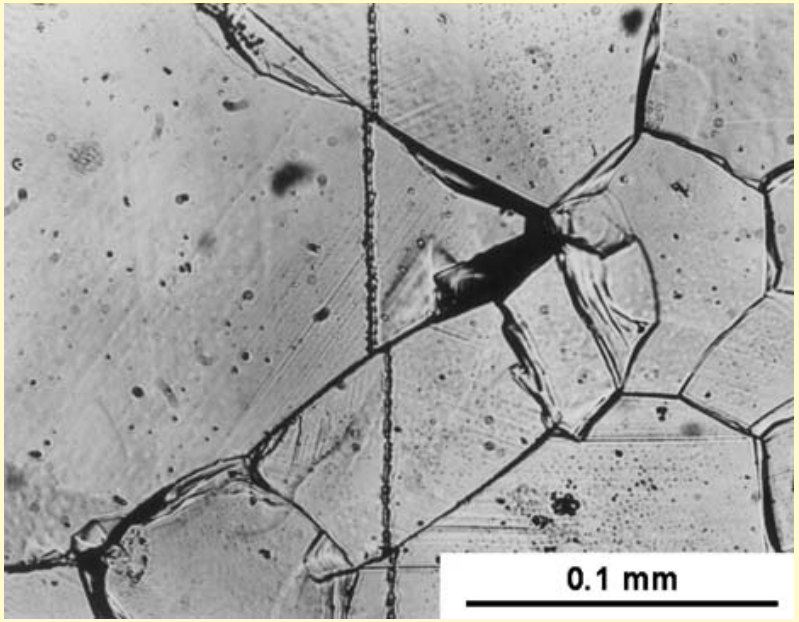
Metallics	< 10 μm
Ceramics	< 1 μm

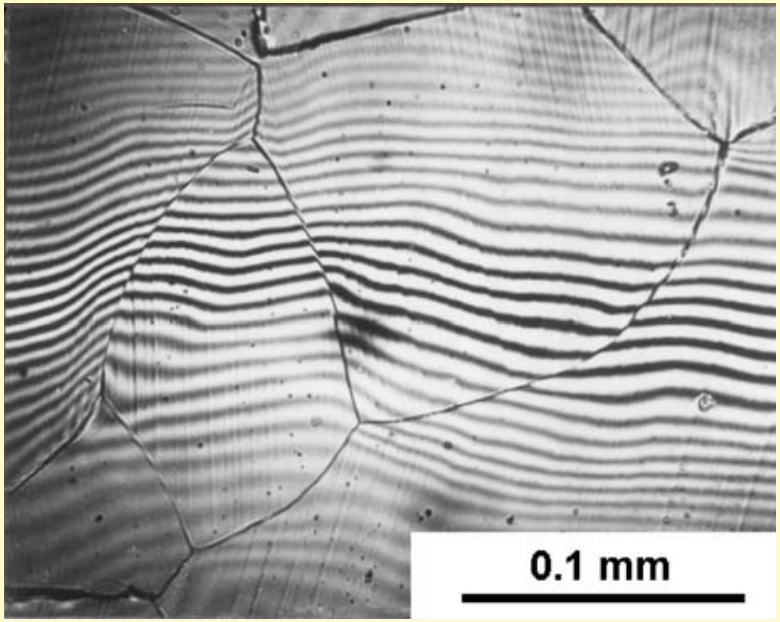
Grain size in conventional materials is typically about 100 μm.

Microstructural prerequisites for fine-structure superplasticity

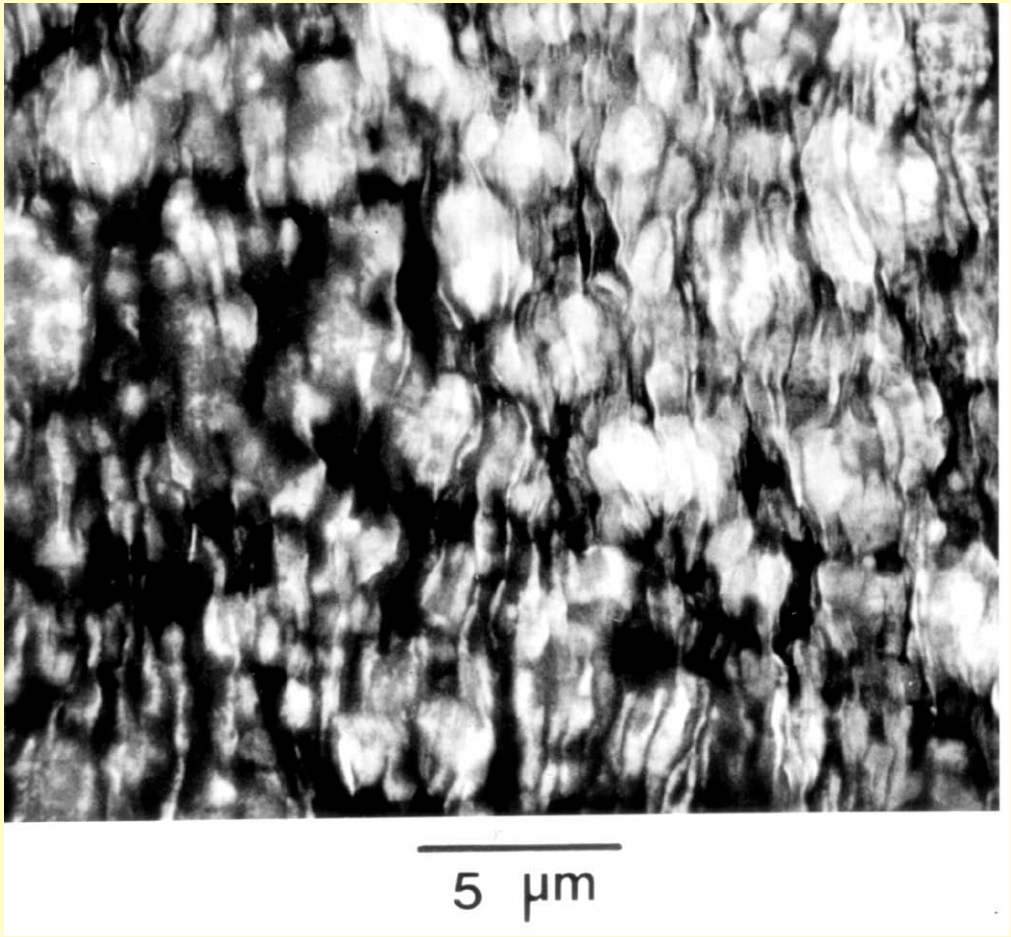
- Fine grain size
- Second phase particle
- Mobile grain boundary
- Equiaxed grains
- Grain boundary resists tensile separation

Grain boundary offset caused by grain boundary sliding during creep

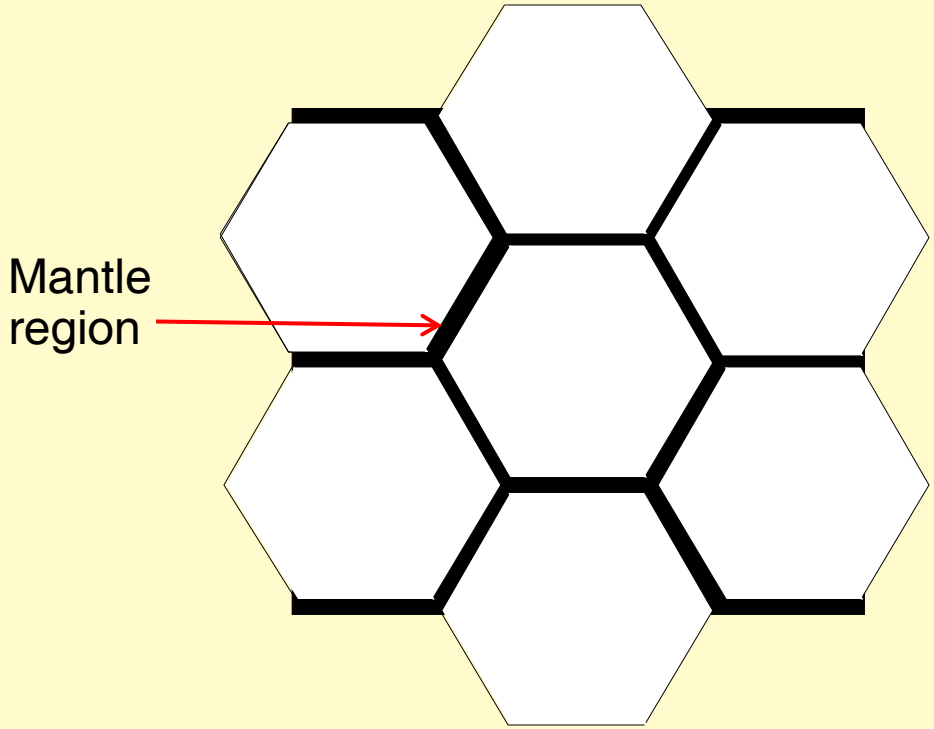




Severe grain boundary sliding in superplastic alloys

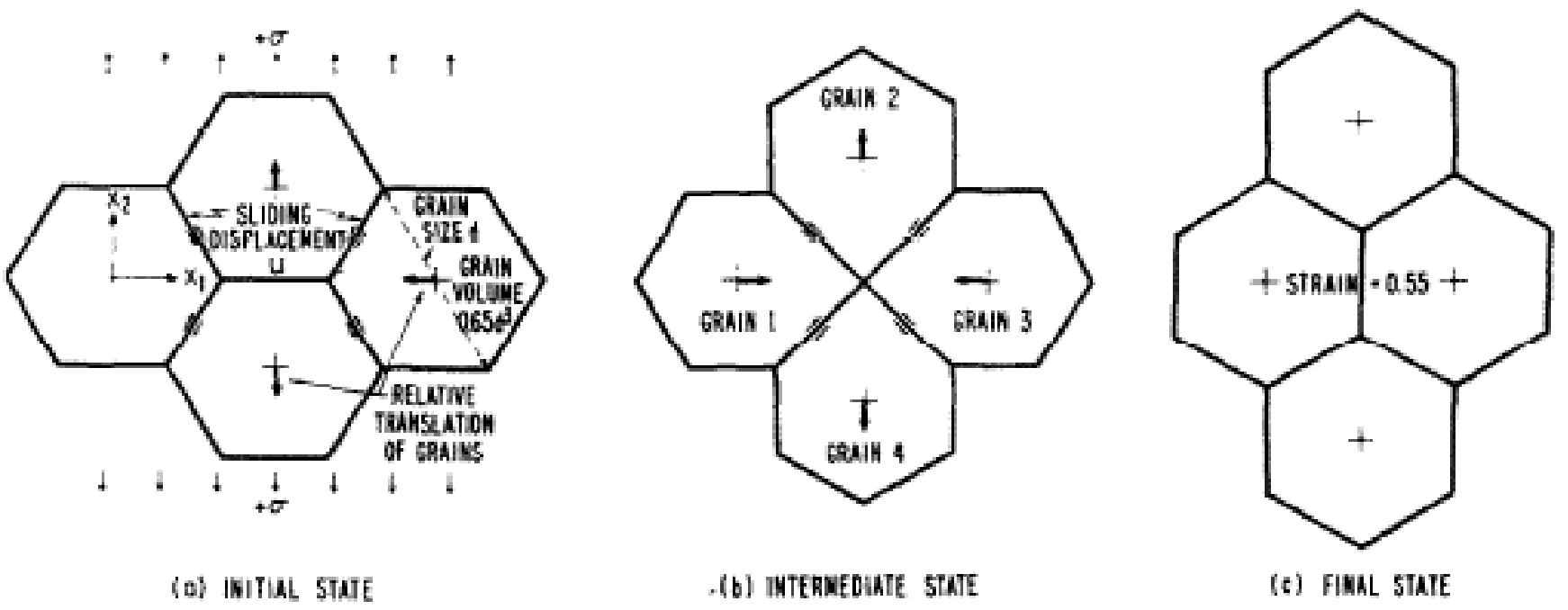


Gifkin (1976)

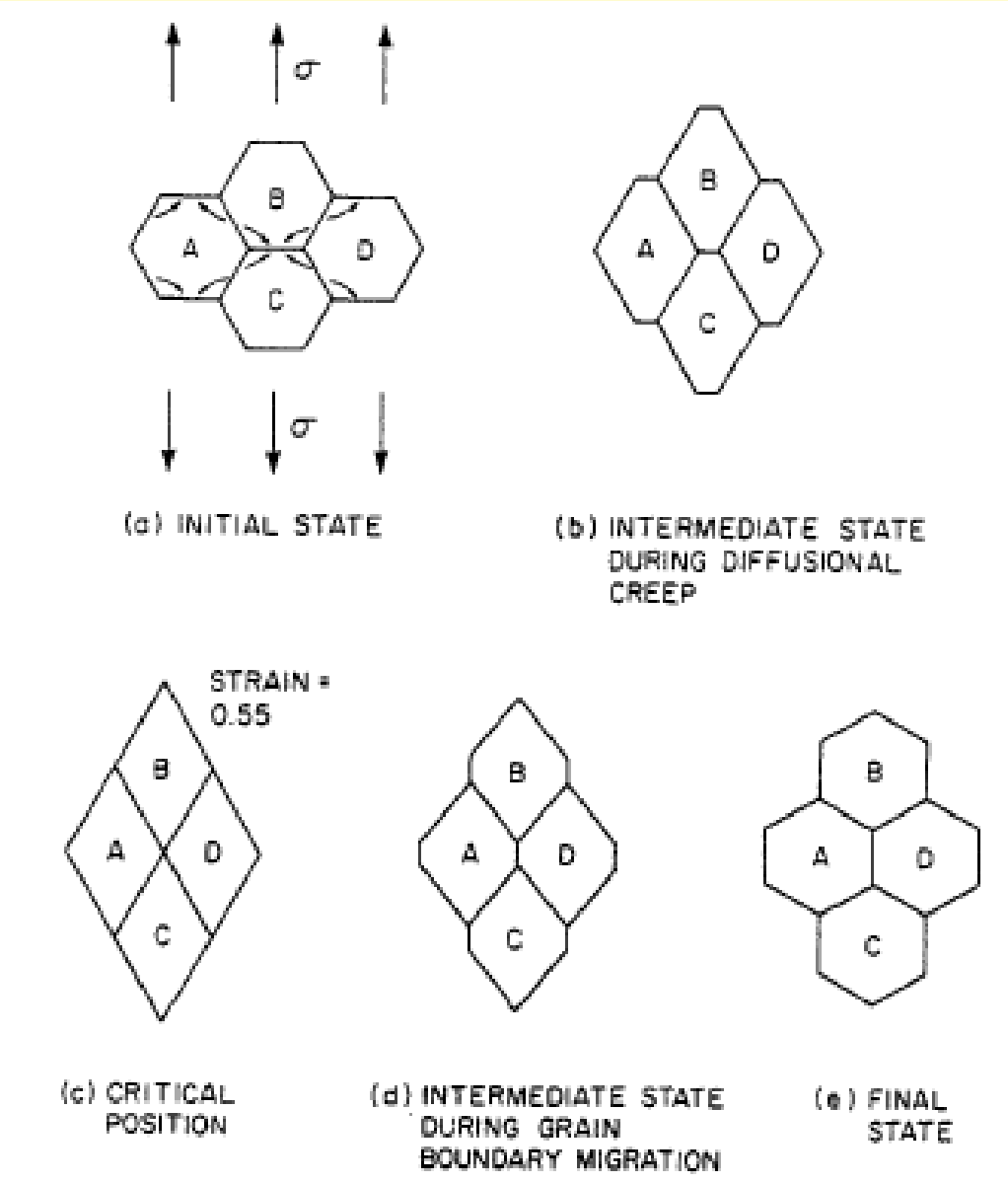


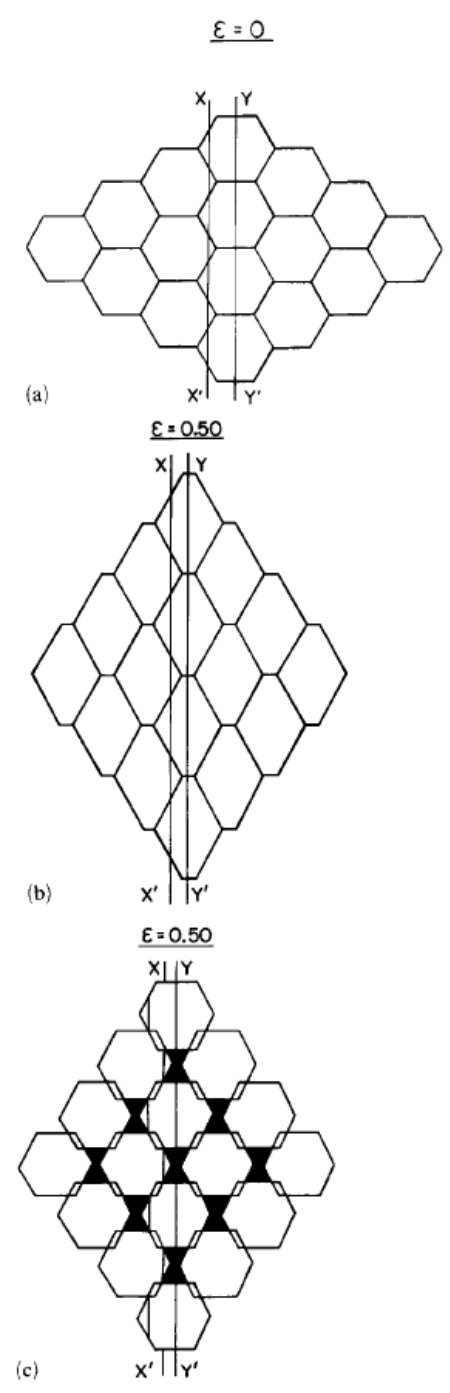
Grain boundary is like mantle region, easy to slide, especially at high temperatures

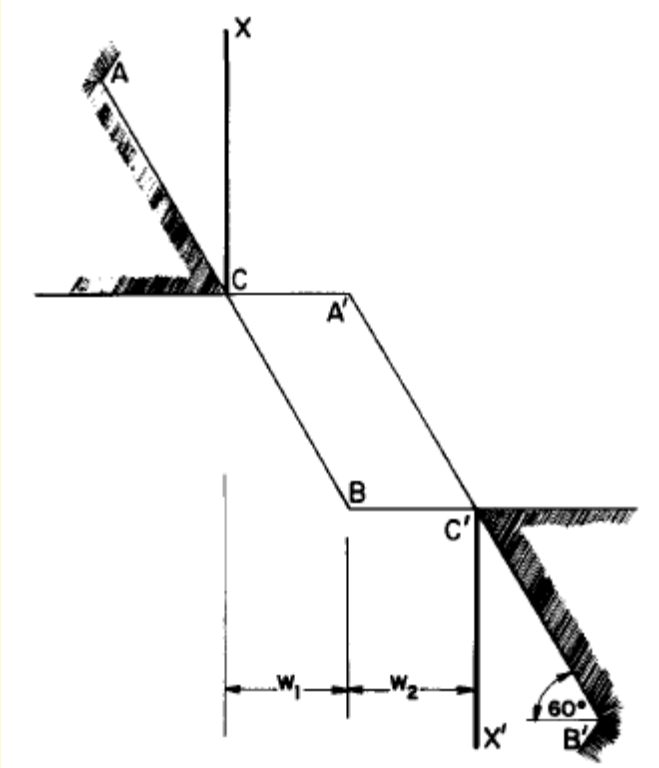
Ashby & Verral's grain switching (1983)



Spingarn & Nix's modification (1978)



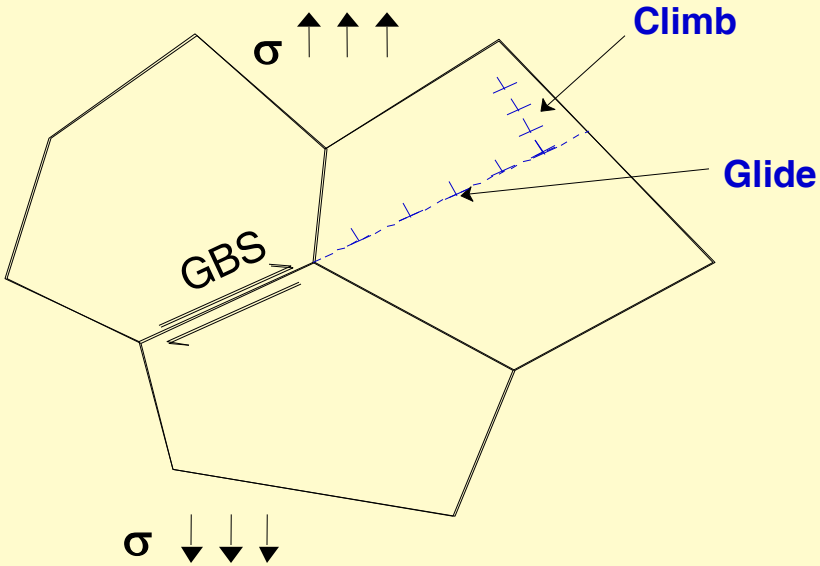


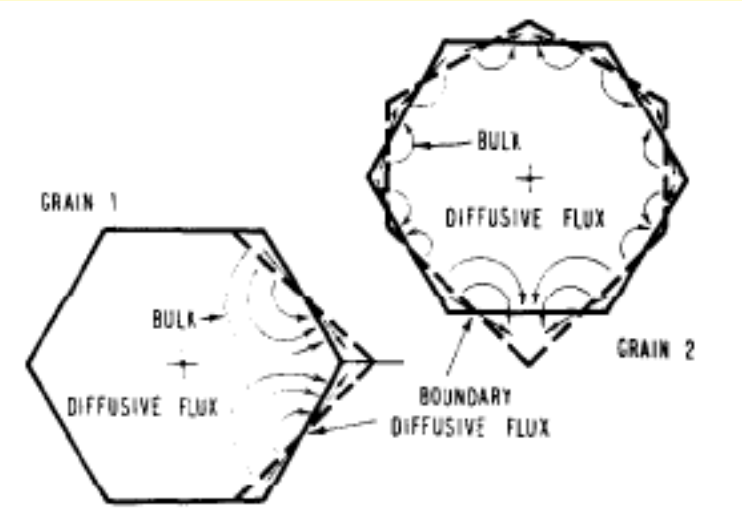


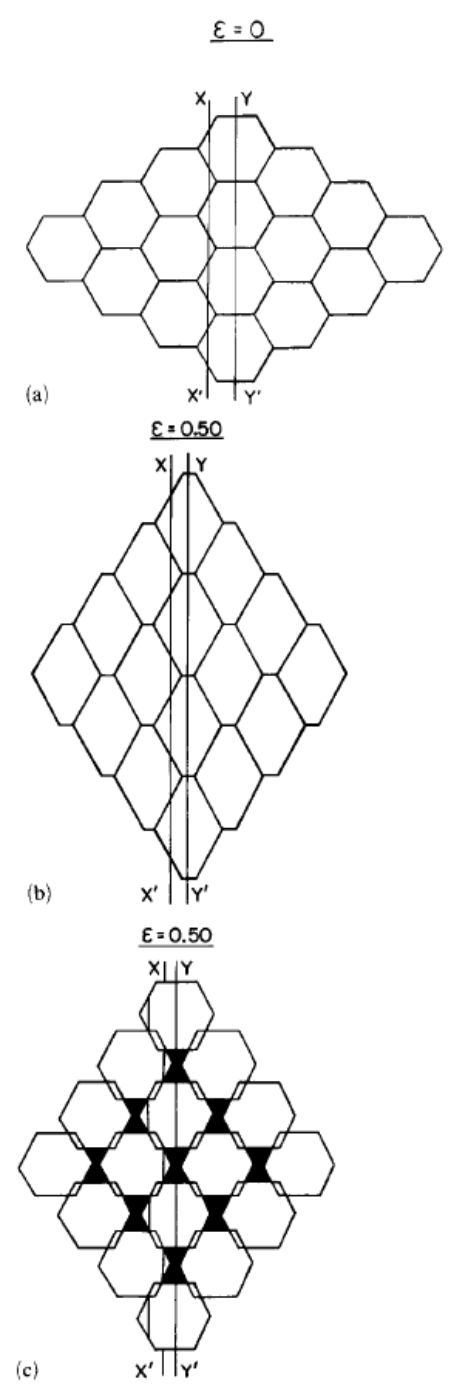
Mass must flow to accommodate strain

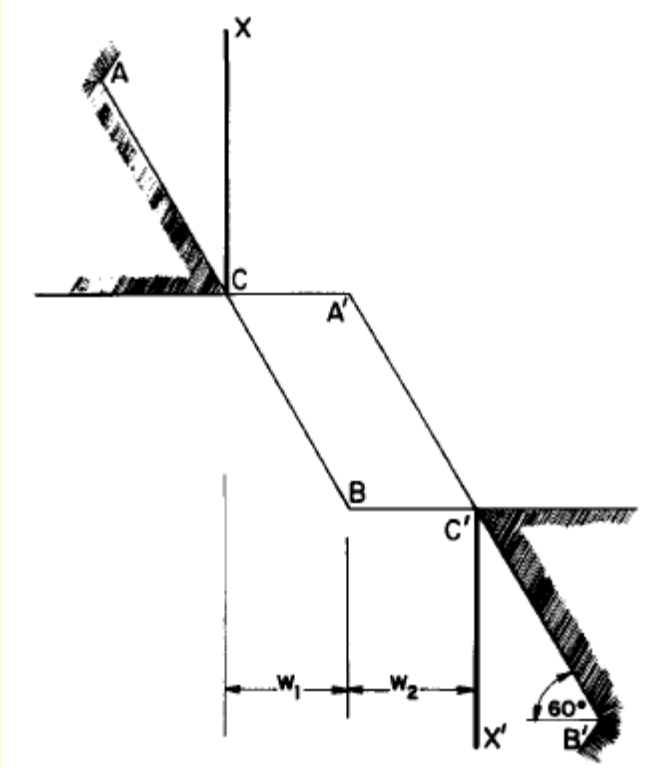
Strain accommodated by intragranular dislocation slip (*Rachinger sliding*)

diffusive mass flow to rearrange grains (*Lifshitz sliding*)









Sliding measurements on the surface can only count a part of (~ 50%) the total strain (Langdon, 1994)

Constitutive equations for superplasticity

$$\dot{\varepsilon} = 6 \times 10^8 \left(\frac{b}{d}\right)^3 \frac{D_{gb}}{b^2} \left(\frac{\sigma}{E}\right)^2$$

$$\dot{\varepsilon} = 2 \times 10^9 \left(\frac{b}{d}\right)^2 \frac{D_L}{b^2} \left(\frac{\sigma}{E}\right)^2$$

$\dot{\varepsilon}$: Strain rate

b : Burgers vector

d : Grain size,

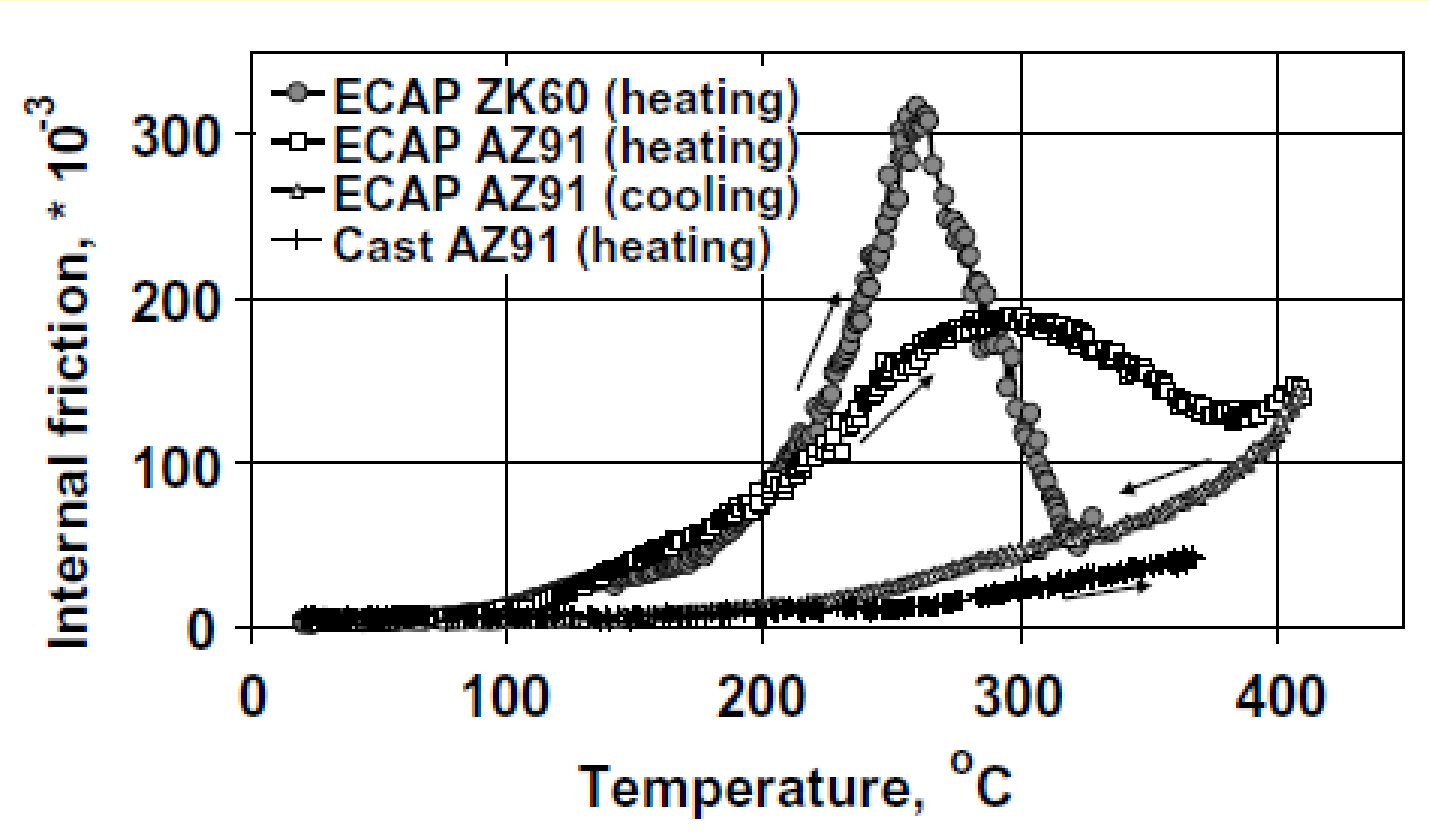
D_L and D_{gb} : lattice and grain boundary diffusivities

σ : Stress

E : Young's modulus

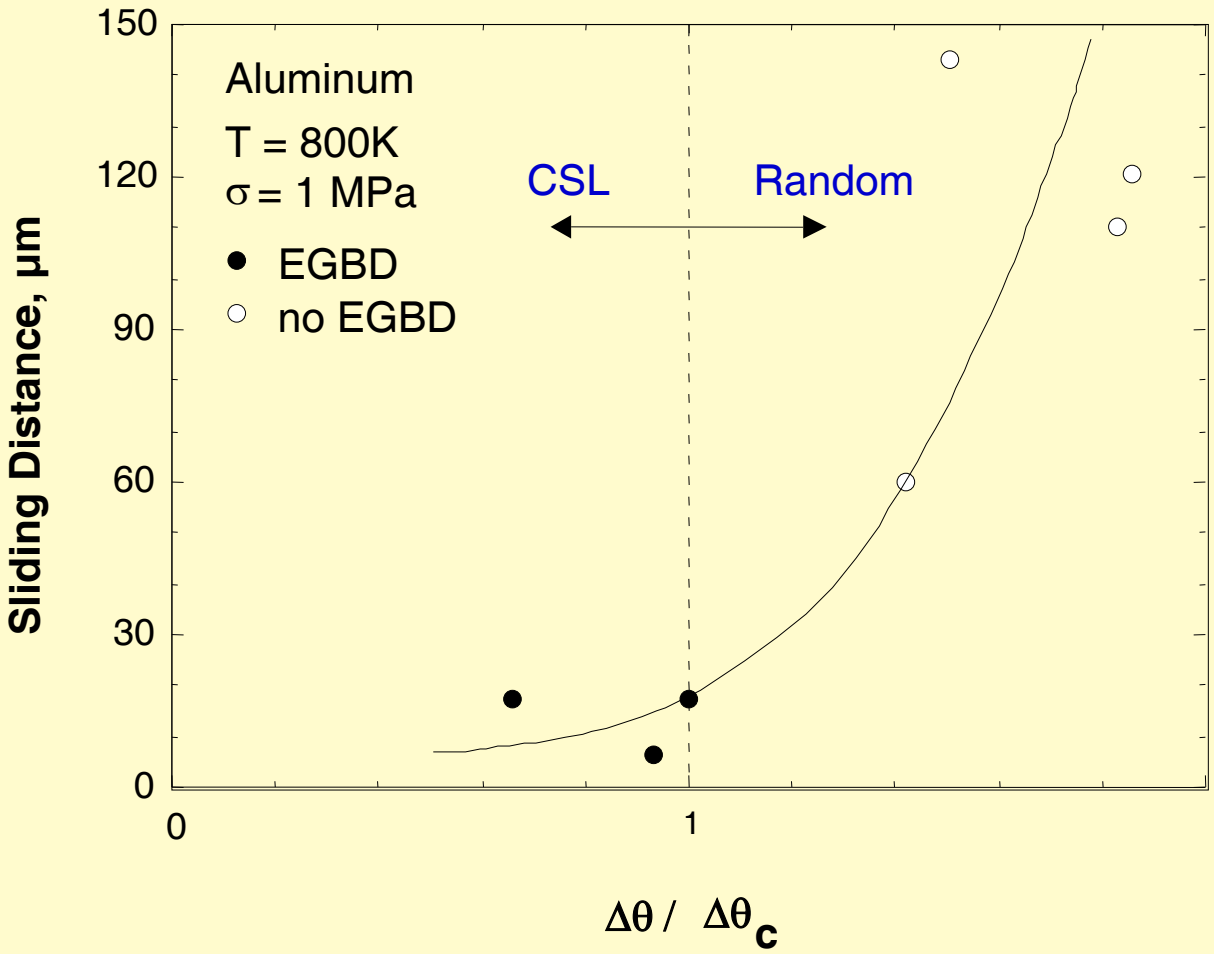
Issue: direct evidence of GBS from in situ measurements (VULCAN)

grain boundary sliding (mobility) is associated with internal friction

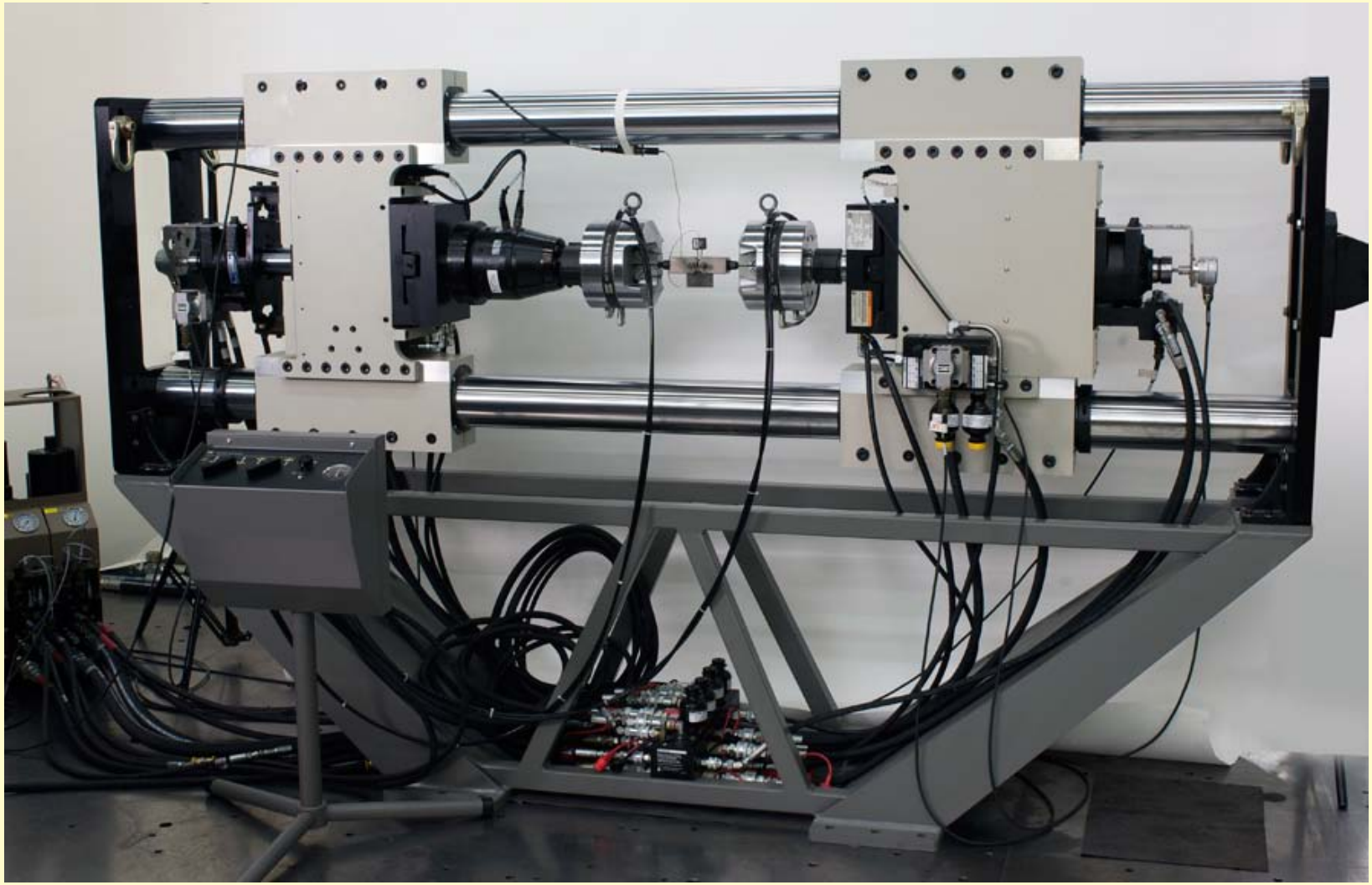


effects of grain size and temperature (Chuvil'deev, 2004)

grain boundary sliding mobility (Kokawa, 1981)



Issue: grain boundary mobility as a function of temperature, type of boundary, grain size (VULCAN)



Perspectives

We have reasonable understandings on the superplasticity of structural materials and it is generally believed that grain boundary sliding is the dominant mechanism for deformation.

What is exactly the atomic processes of grain boundary sliding?

VULCAN can provide direct measurements and shed lights on the atomistic nature of grain boundary sliding.