TALAT Lecture 3802

Physical Mechanism of Superplasticity

7 pages, 8 figures

Advanced Level

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Objectives:

- to describe in general the physical mechanism of superplasticity and the microstructural changes which accompany superplastic forming

Prerequisites:

- General background in production engineering and material science

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3802 Physical Mechanism of Superplasticity

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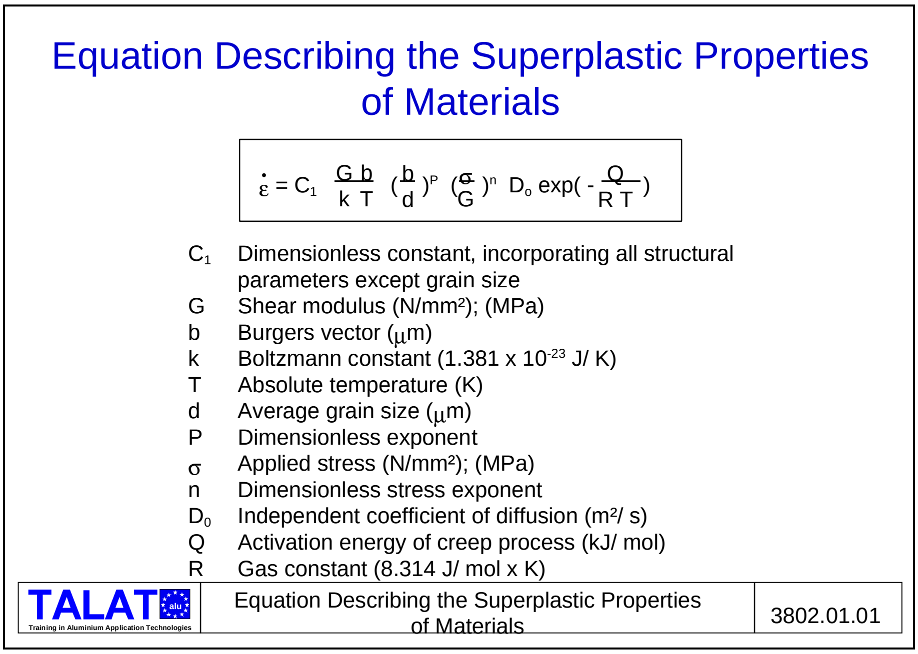
Note: Literature/References at the end of TALAT Lecture 3805.

Equation of Superplasticity

Figure 3802.01.01 gives the equation describing the superplastic properties of materials from the metallurgical point of view. The individual parameters are listed and described.



Equation Describing the Superplastic Properties of Materials

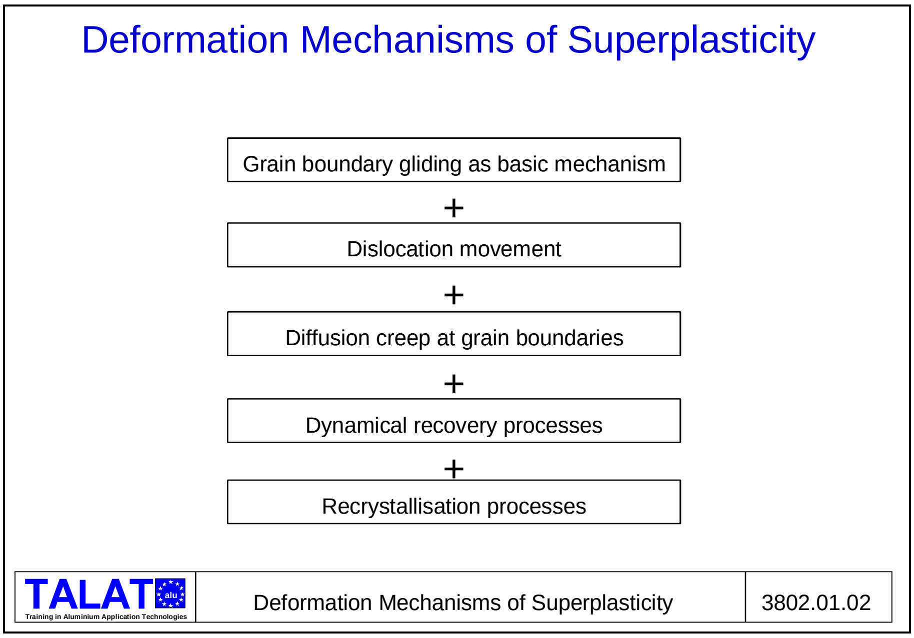
$$\dot{\varepsilon} = C_1 \frac{G\,b}{k\,T} \left(\frac{b}{d}\right)^P \left(\frac{\sigma}{G}\right)^n D_o \exp\left(-\frac{Q}{R\,T}\right)$$

C_1	Dimensionless constant, incorporating all structural parameters except grain size
G	Shear modulus (N/mm²); (MPa)
b	Burgers vector (μm)
k	Boltzmann constant (1.381×10^{-23} J/ K)
T	Absolute temperature (K)
d	Average grain size (μm)
P	Dimensionless exponent
σ	Applied stress (N/mm²); (MPa)
n	Dimensionless stress exponent
D_0	Independent coefficient of diffusion (m²/ s)
Q	Activation energy of creep process (kJ/ mol)
R	Gas constant (8.314 J/ mol x K)

TALAT Training in Aluminium Application Technologies | Equation Describing the Superplastic Properties of Materials | 3802.01.01

Deformation mechanisms during superplastic forming

Figure 3802.01.02 lists the deformation mechanisms during superplastic forming. In principle, the same mechanisms are valid for both superplastic forming and classical creep of metals. These include grain boundary sliding and dislocation movement as well as dynamic recovery and recrystallisation processes. The individual mechanisms will be explained in the following overheads.



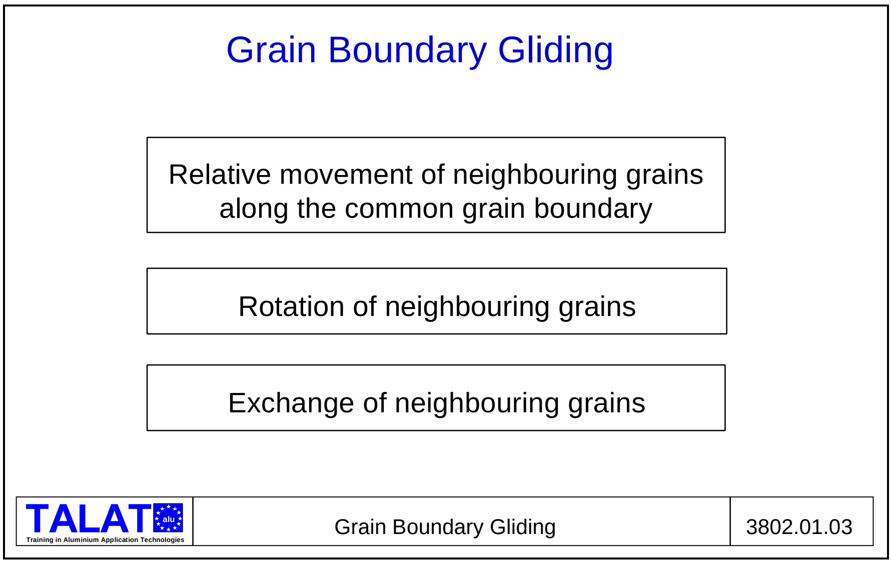
Deformation Mechanisms of Superplasticity

Grain boundary gliding as basic mechanism
+
Dislocation movement
+
Diffusion creep at grain boundaries
+
Dynamical recovery processes
+
Recrystallisation processes

TALAT Training in Aluminium Application Technologies | Deformation Mechanisms of Superplasticity | 3802.01.02

Grain boundary gliding

Figure 3802.01.03 defines the term grain boundary gliding. The characteristics for superplastic forming have been experimentally determined for various grain boundary gliding situations. These include the relative movement of neighbouring grains along the common grain boundary, the rotation of neighbouring grains and the exchange mechanism of neighbouring crystals. The individual mechanisms will be explained, based on models, in the following overheads.



Grain Boundary Gliding

Relative movement of neighbouring grains along the common grain boundary

Rotation of neighbouring grains

Exchange of neighbouring grains

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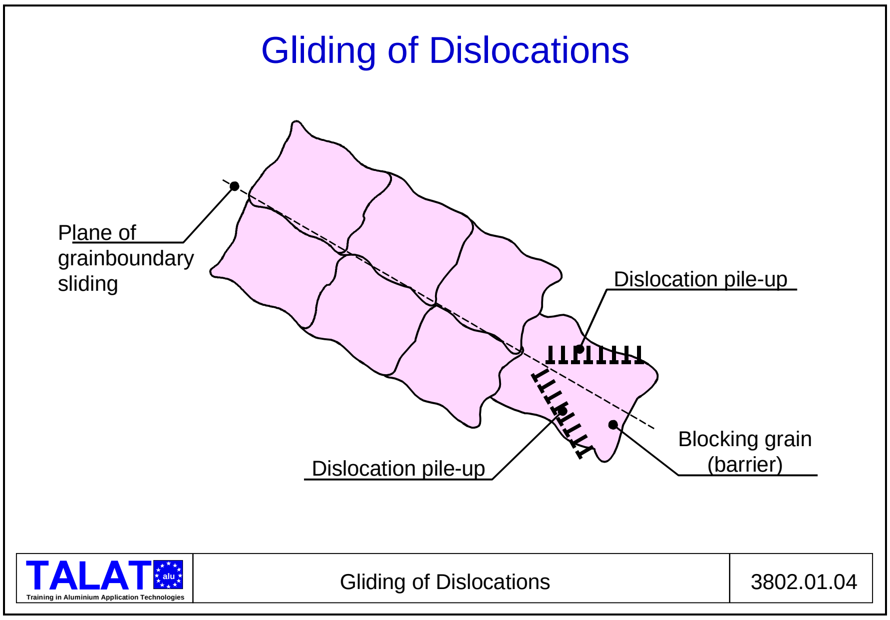
Gliding of dislocations

Gliding of dislocations is depicted schematically in **Figure 3802.01.04.** A group of grains with a favourable orientation moves as a block relative to its neighbours. The stress concentration in the grain in which the slip plane exists and acts as a slip barrier, produces new dislocations which once again cause a slip through the grain, stopping at the next grain boundary and leading to a dislocation pile-up. The stress rise then causes slip to initiate and proceed through the blocking grain. Furthermore, the mobility of dislocations increases by the mechanism of climb.



Gliding of Dislocations

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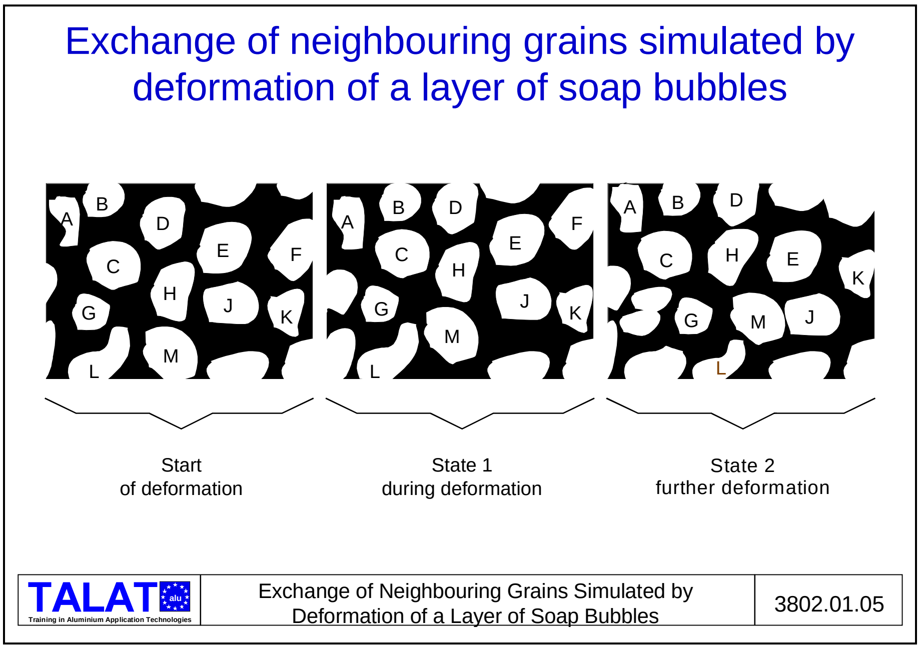
Exchange mechanism

Figure 3802.01.05 illustrates the exchange mechanism of grains in superplastic forming processes with the aid of a deformed layer of soap bubbles. The exchange between neighbours can be divided into two groups. In the permutation model, the grains in a layer rearrange themselves without any increase in the layer surface area. In the displacement model, a grain from the neighbourhood is inserted between the individual grains, so that the surface area of the layer is increased. The permutation model is based on observations of the behaviour of soap bubbles between two glass surfaces. With increasing deformation, the soap bubbles exchange their neighbours.



Exchange of neighbouring grains simulated by deformation of a layer of soap bubbles

Start of deformation

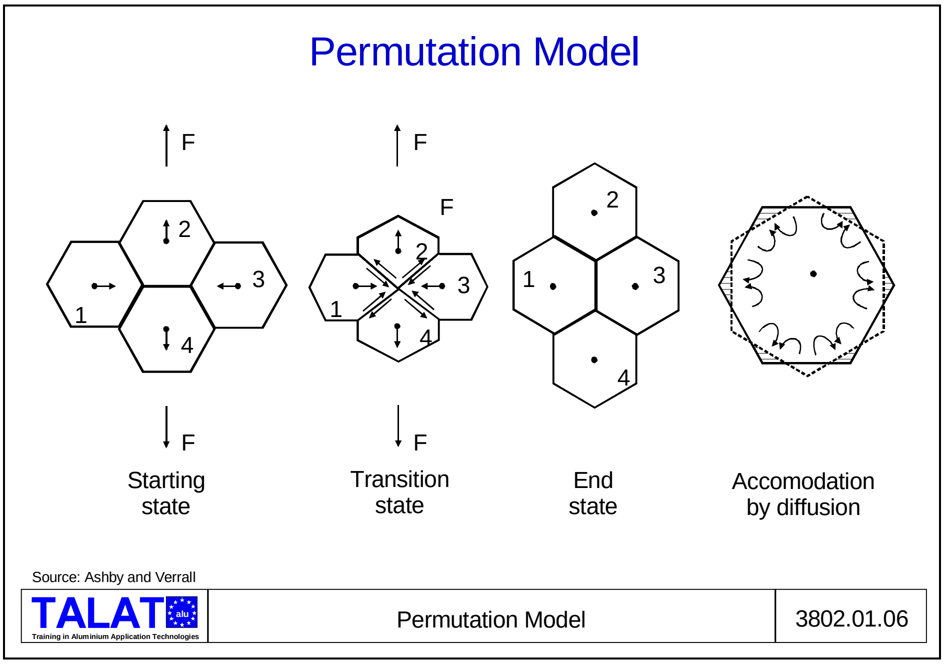
State 1 during deformation

State 2 further deformation

TALAT Training in Aluminium Application Technologies | Exchange of Neighbouring Grains Simulated by Deformation of a Layer of Soap Bubbles | 3802.01.05

Permutation Model

Figure 3802.01.06 describes the Permutation Model. According to Ashy and Verrall, grain boundary slip is a result of the diffusion controlled mass transport along the grain boundary or through the volume of the grain.



Permutation Model

Starting state

Transition state

End state

Accomodation by diffusion

Source: Ashby and Verrall

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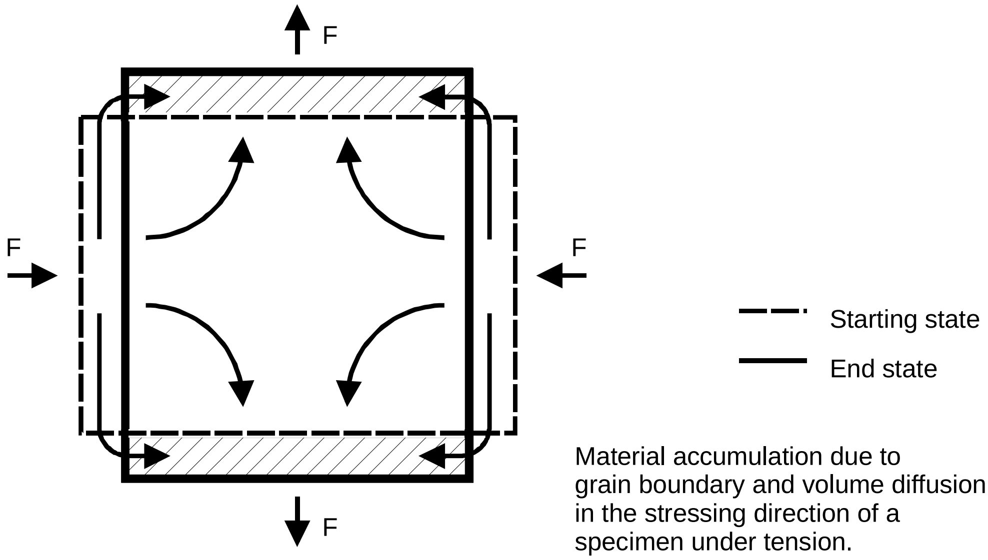
Mechanism of creep

The mechanism of creep by stress induced, oriented diffusion is illustrated in **Figure 3802.01.07.** Grain boundaries subjected to a tensile stress σ, require an energy which is lower by the amount σ·Ω (Ω = atomic volume), for vacancy formation. Consequently, the concentration of vacancies is higher than in regions subjected to a compressive stress. In compression stress regions, the energy for vacancy formation is increased by the same amount. The resulting gradient of the vacancy concentration causes an oriented movement of the defects. At the same time, the compressed zone acts as an atom donator or vacancy acceptor, so that a mass movement occurs in the opposite direction to the vacancy movement. The increase of material in the tensile force direction is shown as a hatched area. This leads to an elongation of the grain in the tensile direction and a narrowing in the plane normal to the tensile axis. The combined result leads to an elongation of the polycrystalline specimen in the tensile stress direction.

Creep by Oriented Diffusion



Material accumulation due to grain boundary and volume diffusion in the stressing direction of a specimen under tension.

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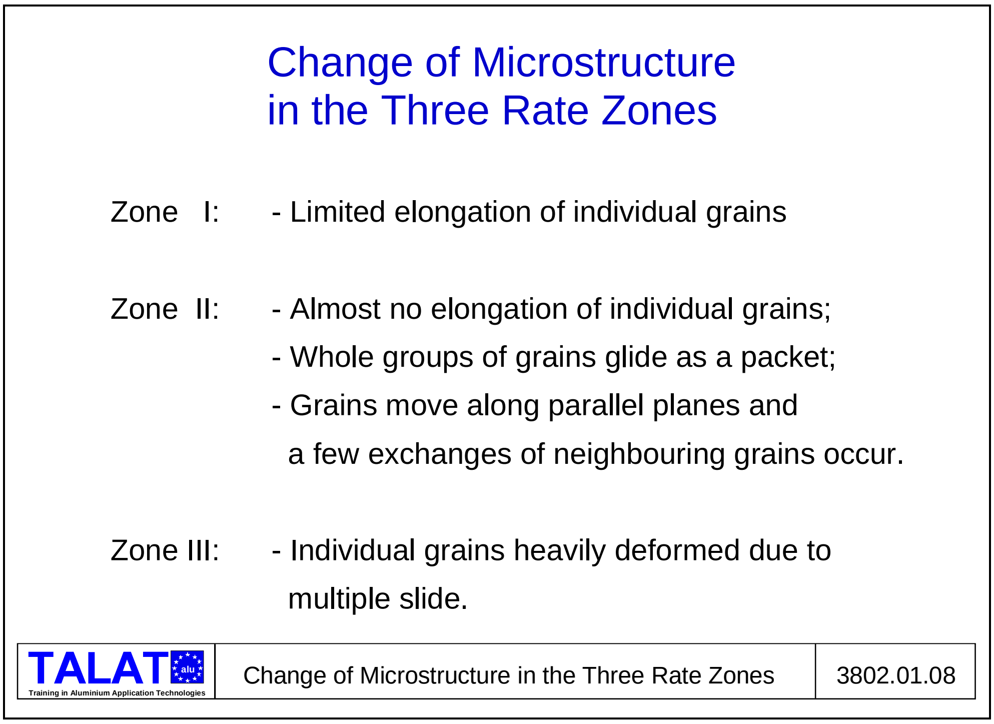
The three strain rate zones depicted in **Figure 3801.01.18** are characterized essentially by three different microstructural changes, as described **Figure 3802.01.08**. Zone II is markedly different than both the bordering zones I and III. In zone I, deformation is mainly a result of the increase in length of the individual grains. In zone III, the grain deformation is caused by multiple slide. In zone II, the individual grains are hardly elongated. Whole groups of grains glide as a packet. The grains move along parallel planes. A few location exchanges also occur.



Change of Microstructure in the Three Rate Zones

Zone I: - Limited elongation of individual grains

Zone II: - Almost no elongation of individual grains;
- Whole groups of grains glide as a packet;
- Grains move along parallel planes and a few exchanges of neighbouring grains occur.

Zone III: - Individual grains heavily deformed due to multiple slide.

TALAT Training in Aluminium Application Technologies | Change of Microstructure in the Three Rate Zones | 3802.01.08

Note: Literature/References at the end of TALAT Lecture 3805.

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