Kinetics of the austenite-to-ferrite phase transformation - Interface mobility and solute drag

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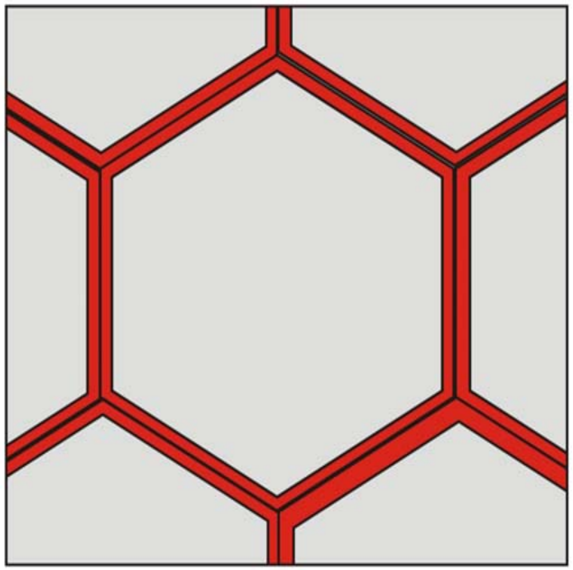
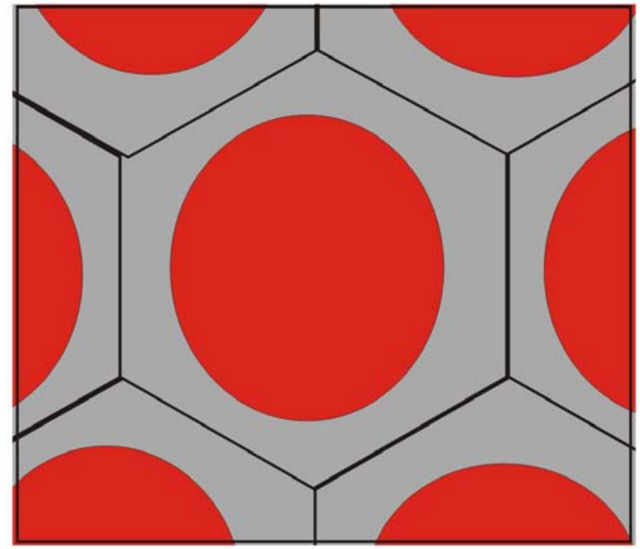
Contents and Structure

- **Introduction**
  - Austenite(γ)-to ferrite(α) transformation in low alloyed steels
    - Geometry of the γ/α phase arrangement (matrix/inclusion)
    - Interfacial reactions (finite mobility, solute drag)
    - Diffusion in the bulk material
- **Experiments and Modeling**
  - Transformation kinetics in low carbon steels
    - Two stage transformation kinetics
  - Ultra-low carbon steel
    - Hierarchical model
- **Results**
  - Explanation for the two stage transformation behavior
  - Intrinsic interface mobility
  - Evolution of the effective mobility during transformation

Matrix / Inclusion Topology
Extreme Cases





Red = ferrite; gray = austenite

Diffusion in low-alloyed steels
($\underline{Fe}$-C-X_1-X_2-…-X_n)

Péclet Number $Pe = \dfrac{l}{D/v}$

l ...relevant thickness
D … diffusivity
v … velocity

$Pe \ll 1$	$Pe \approx 1$		$Pe \gg 1$
C (interface)	X (interface)	C (γ–bulk)	X (bulk)
Pe $5\cdot10^{-4}$	1	1	10^3
local equilibrium	solute drag	C-diffusion in γ	immobile substitutional comp.

Dissipative processes

- Rearrangement of the lattice (negligible)
- Motion of the interface, Q_M $Q_M \sim v^2 / M$

- Solute drag, Q_{Sd} $Q_{Sd} \sim \sum_i j_i^2 / D_{i,\,int}$

- Bulk diffusion (Spike diffusion ?)

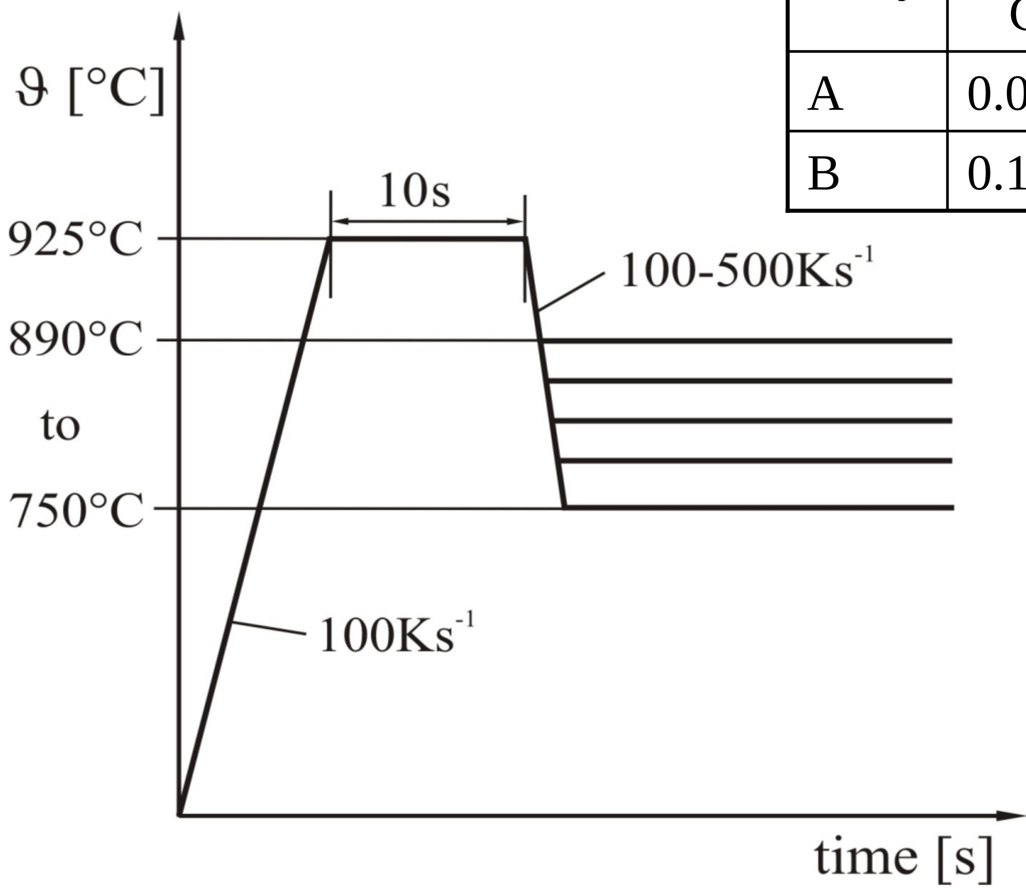
$$Q_{bulk} \sim \sum_i j_i^2 / D_i$$

$$\boxed{Q = Q_M + Q_{Sd} + Q_{bulk}}$$

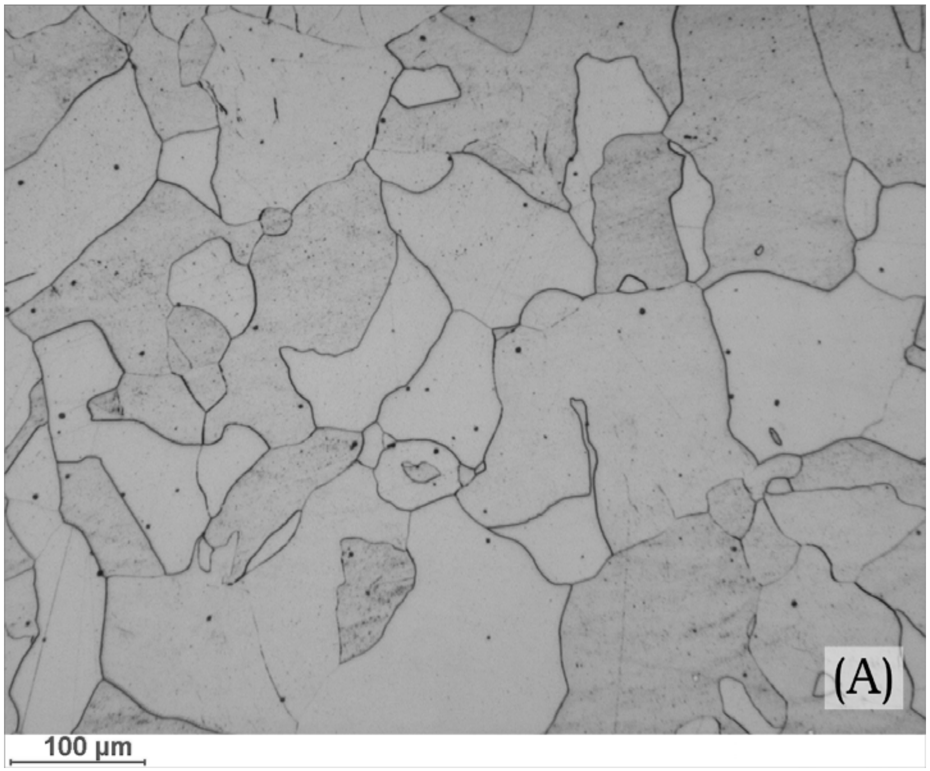
for $Q_{bulk} \approx 0 \longrightarrow \boxed{Q \sim v^2 / M_{eff}}$

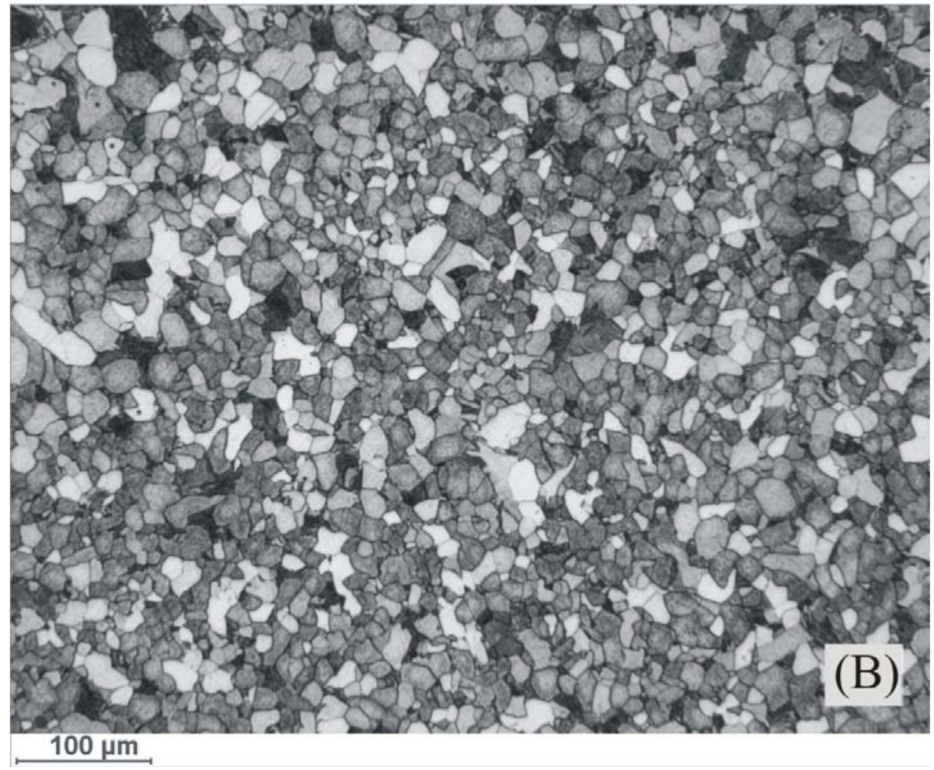
1. Experiment: Fe-low C-alloy

Alloy	$w \cdot 100$				
	C	Mn	Si	Cr	Ni
A	0.007	0.08	0.008	0.01	0.03
B	0.150				

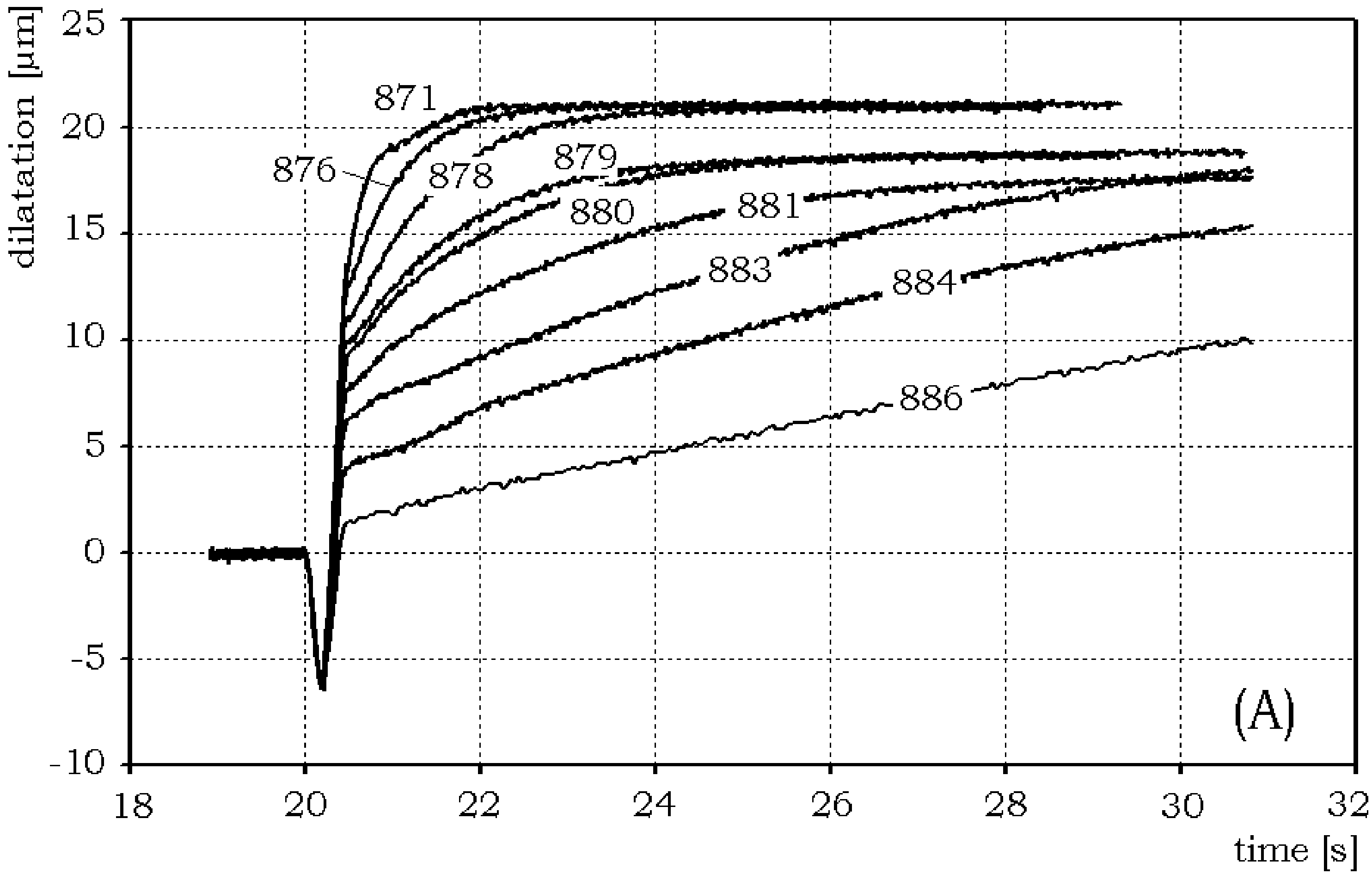


Final Microstructures: Alloy A and alloy B

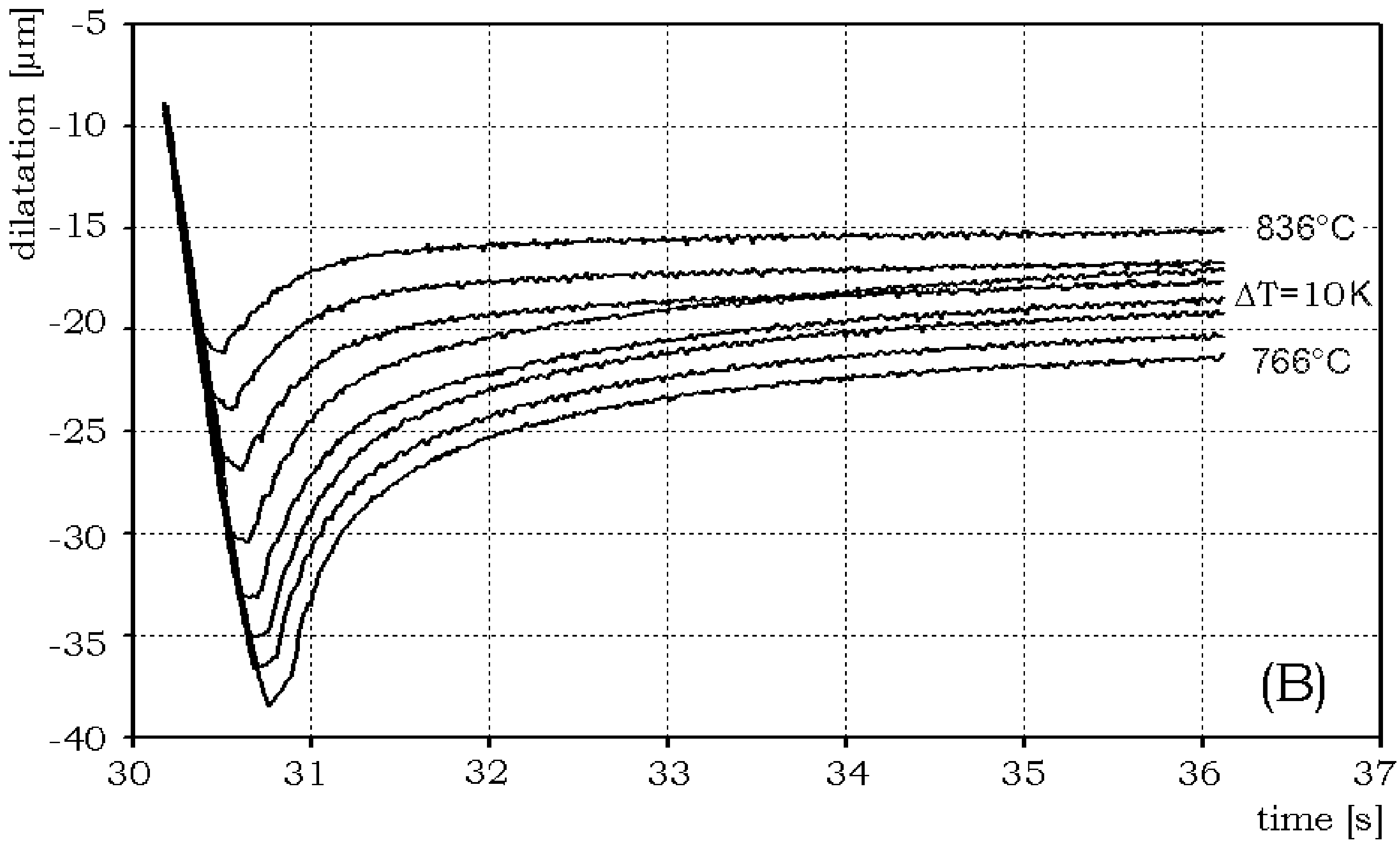




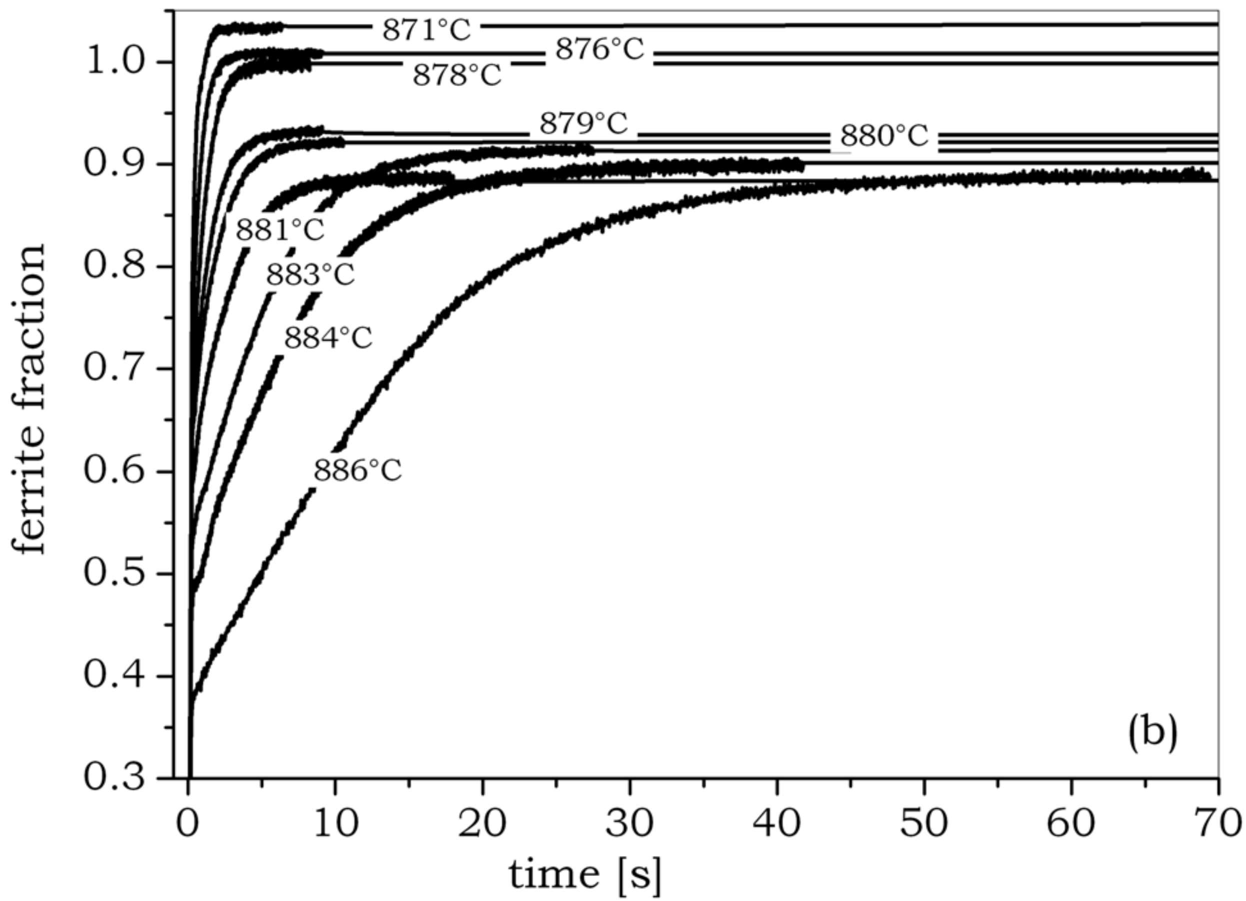
Dilatometersignals for alloy A



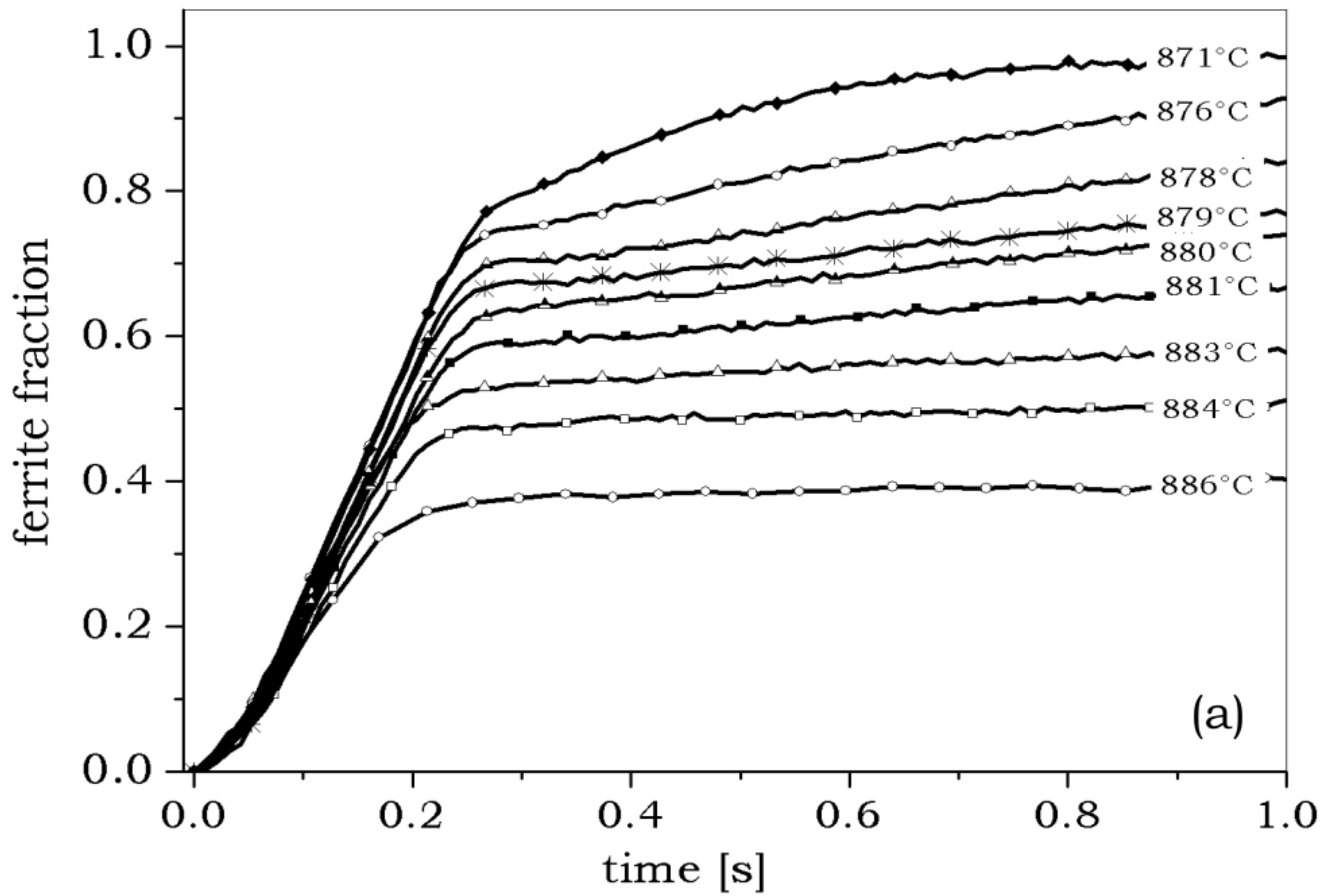
Dilatometersignals for alloy B



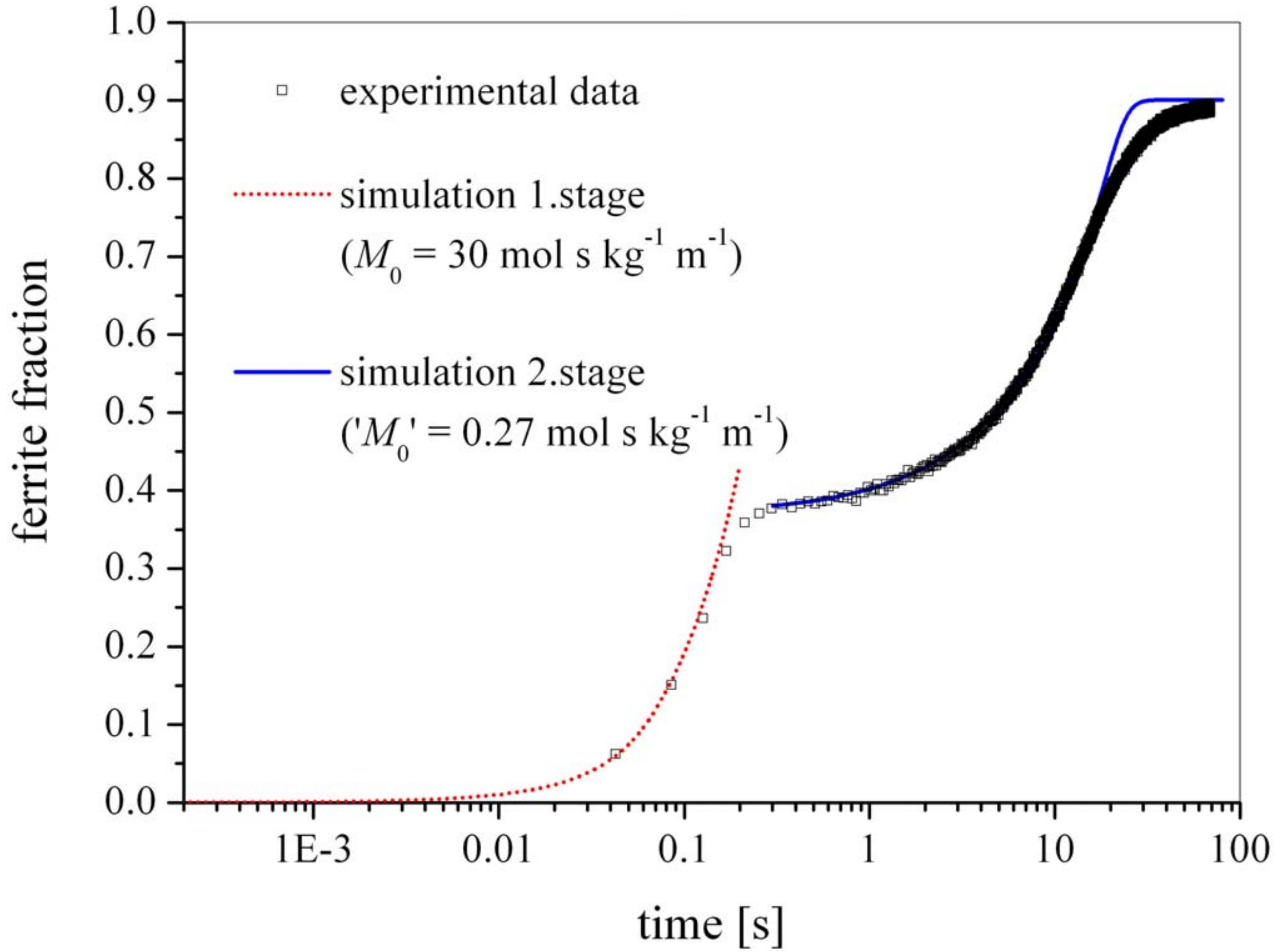
Evolution of ferrite fraction
Overall kinetics …



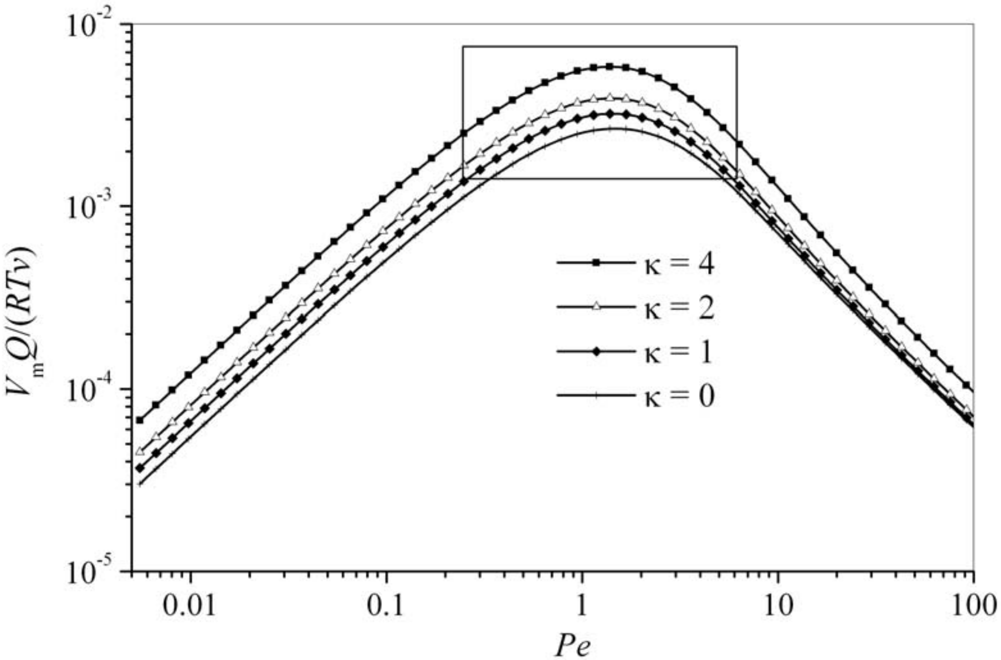
Evolution of ferrite fraction
… *and in the first second*



Numerical calculations
1. stage and 2. stage



Solute drag simulation



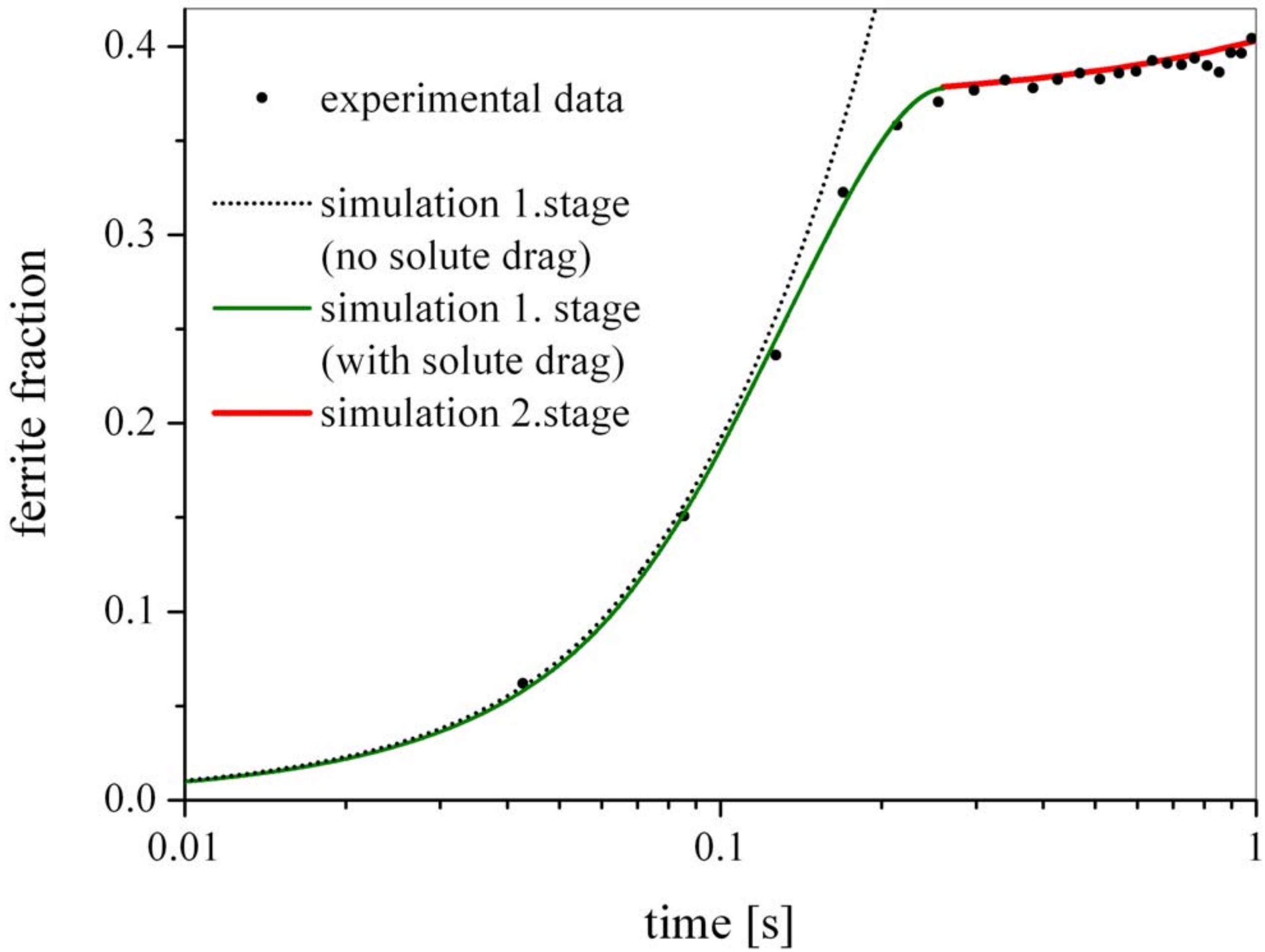
From: J. Svoboda, F. D. Fischer, E. Gamsjäger, "Influence of solute segregation and drag on properties of migrating interfaces", *Acta mater.*, **50**, 967-977, 2002.

$$M_{\mathrm{eff}} = \left(\frac{1}{M_{\mathrm{intr}}} + \frac{Q_{\mathrm{sd}}}{v^2} \right)^{-1}, \quad \frac{Q_{\mathrm{sd}}}{v} = \text{const.} \Rightarrow$$

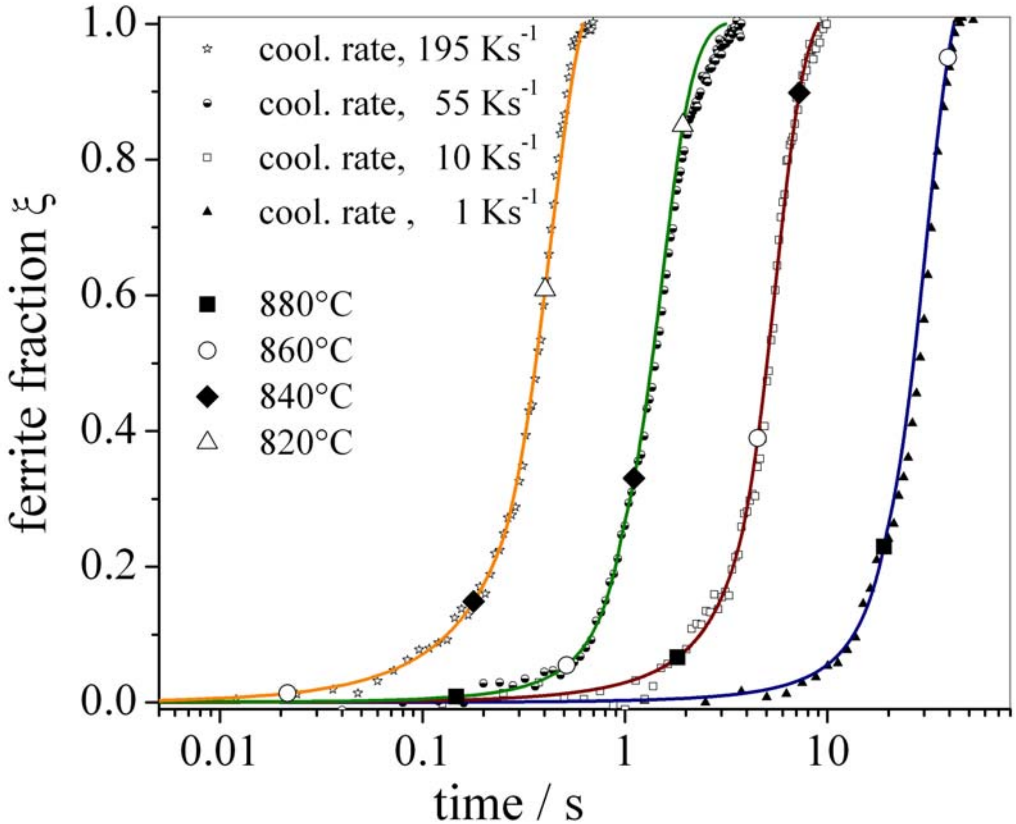
$$M_{\mathrm{eff}} = \left(\frac{1}{M_{\mathrm{intr}}} + \frac{C}{v} \right)^{-1}$$

C depends linearly on time

Numerical calculations
1. stage influenced by solute drag



2. Experiment: Ultra low C-steel



$$w_C = 20\text{ppm}$$
$$w_{Mn} = 0.11\%$$

$$\xi(t) = \frac{a}{1 + b\exp(-ct)}$$

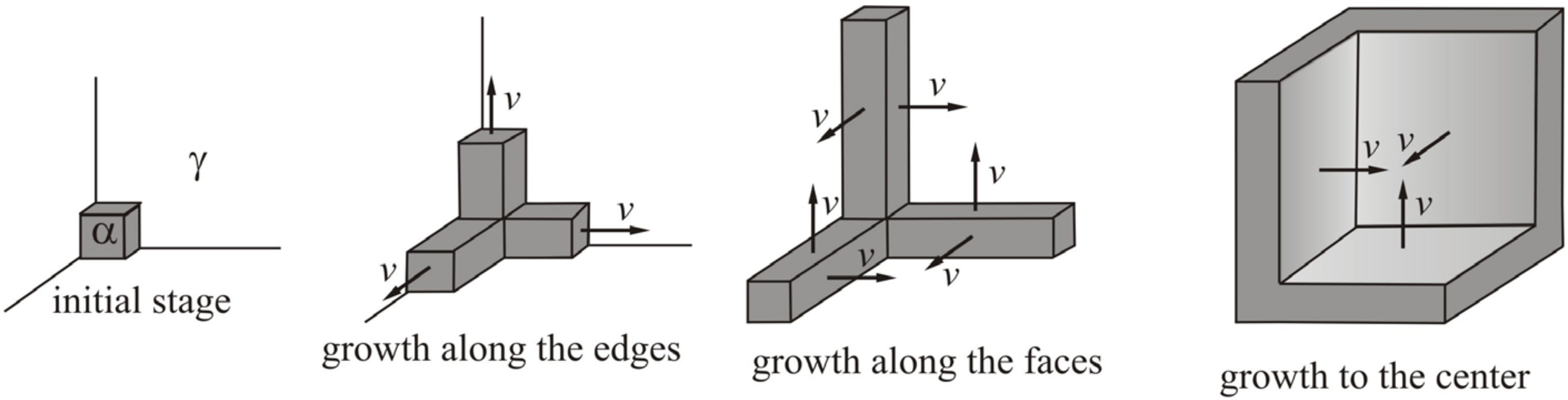
$$\frac{d\xi}{ds} \cdot \frac{ds}{dt} = \frac{d\xi}{ds}(\text{geometry}) \cdot \frac{ds}{dt}$$

$$v = M_{\text{eff}} \cdot \Delta G$$

M. Militzer, Austenite decomposition kinetics in advanced low carbon steels, Solid Phase Transformations 99, eds. M. Koiwa, K. Otsuka and T. Miyazaki, JIM, Sendai (1999) 1521-1524.

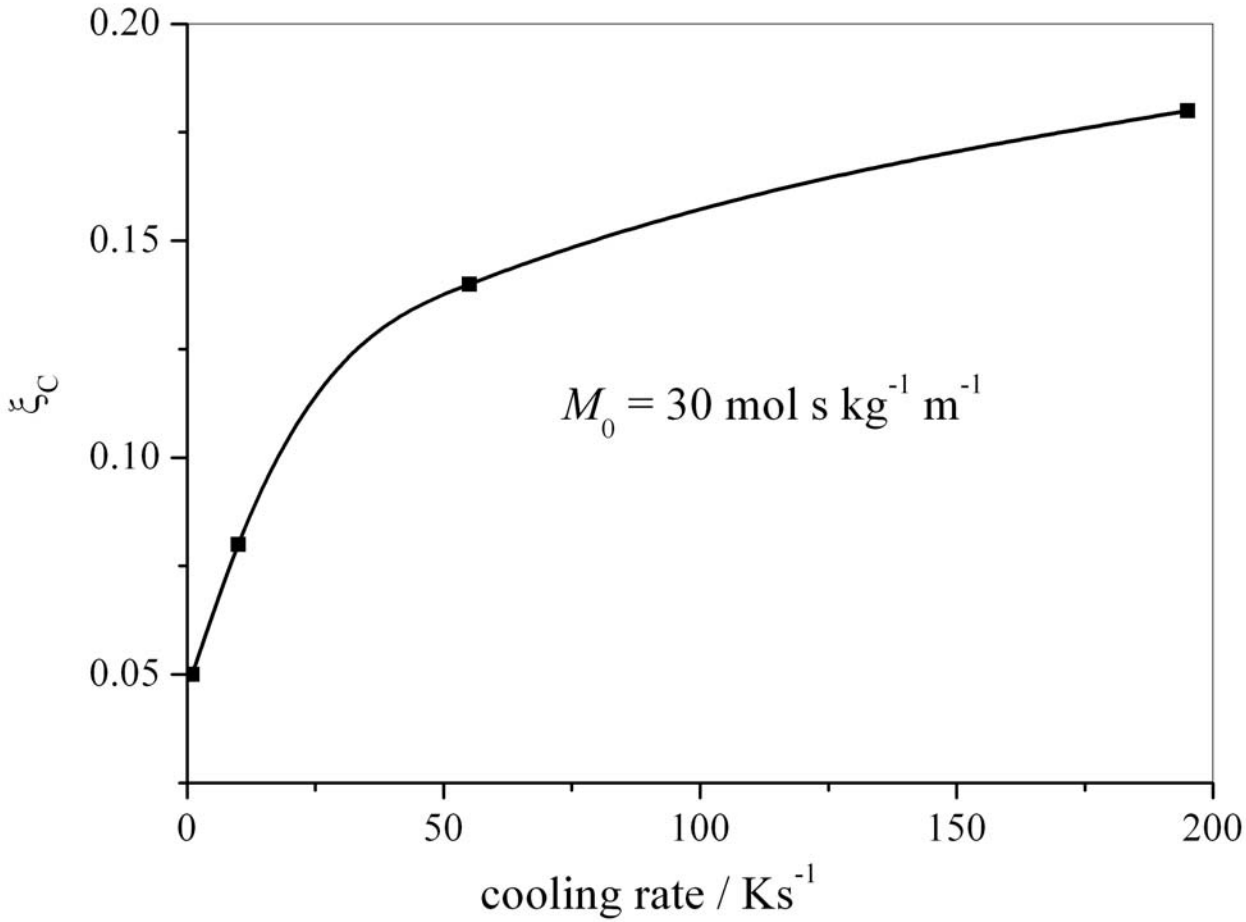
E. Gamsjäger, M. Militzer, F. Fazeli, J. Svoboda, F. D. Fischer: "Interface mobility in case of the austenite-to-ferrite phase transformation“, (*Comp. Mat. Sci*, 2006, in press).

Hierarchical model
(a quarter of a cubic grain)

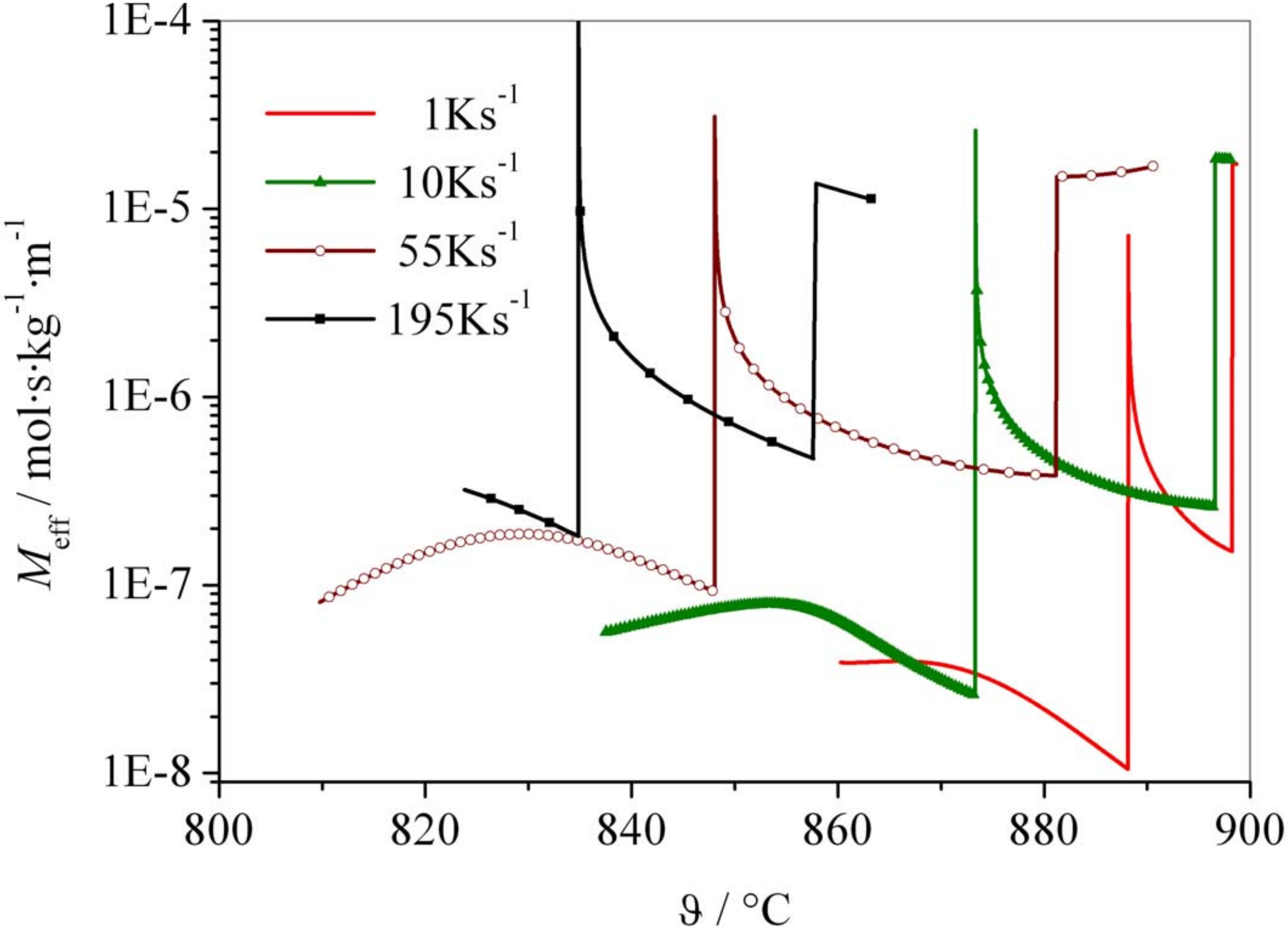


Parameter ξ_C: Minimum ferrite fraction for covered cube faces

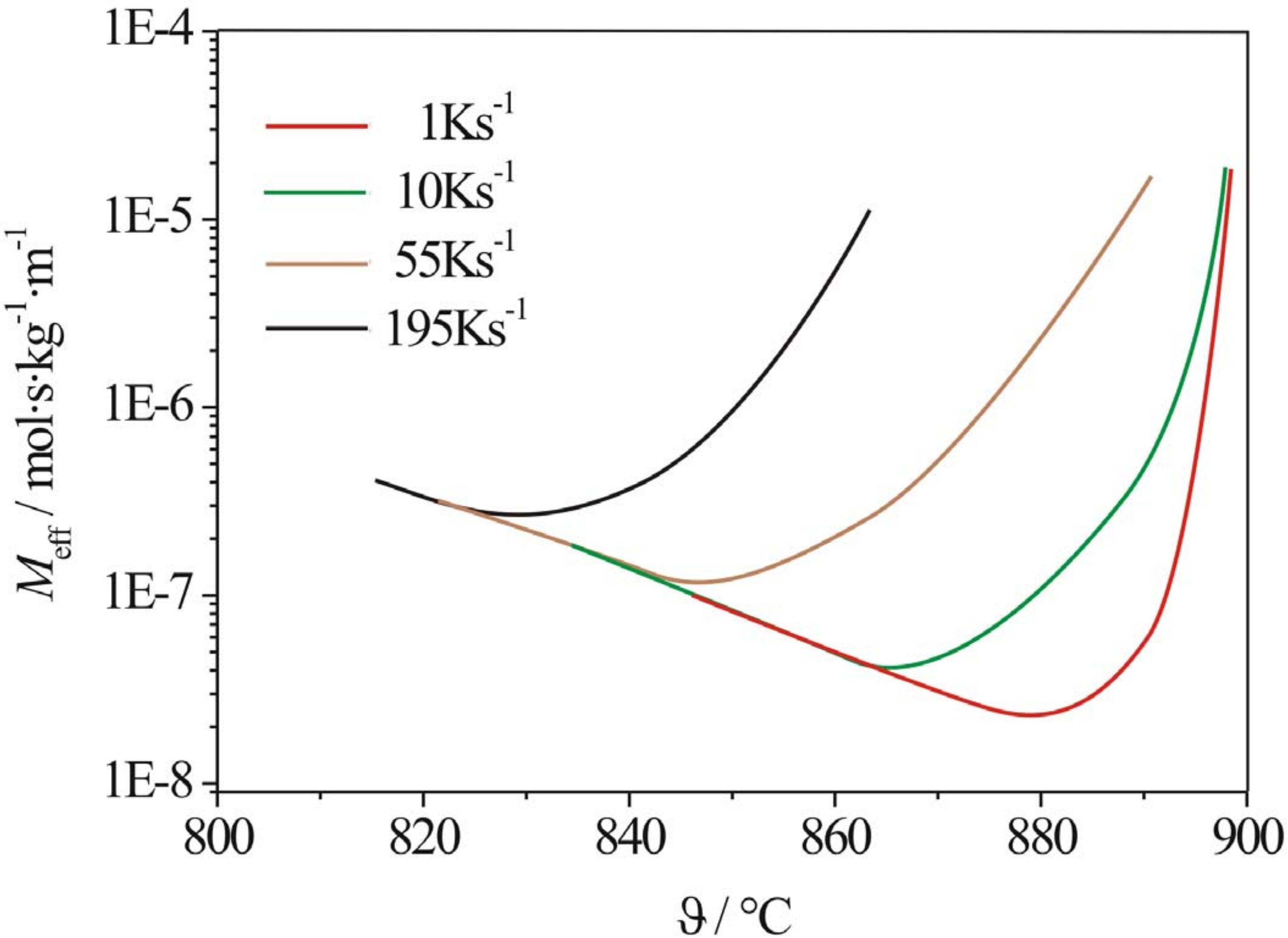
Minimum ferrite fraction for covered cube faces versus cooling rate



Effective mobility obtained by the hierarchical model



Effective mobility for the hierarchical model (interpreted curves)



Conclusions and Outlook

- ➔ **Austenite-to-ferrite transformation in low-alloyed steels**
  - **Two stages transformation kinetics**
  - **Solute drag, effective mobility**
  - **Hierarchical model**
  - **Direct estimation of the pre-exponential factor M_0**

- ➔ **<u>Next steps:</u>**
  - **Solute-interface interaction in more detail**
    - Thermodynamic extremal principal
    - Transformation studies with a systematic change in composition