On the intrinsic interface mobility for the austenite-ferrite and the ferrite-austenite phase transformation

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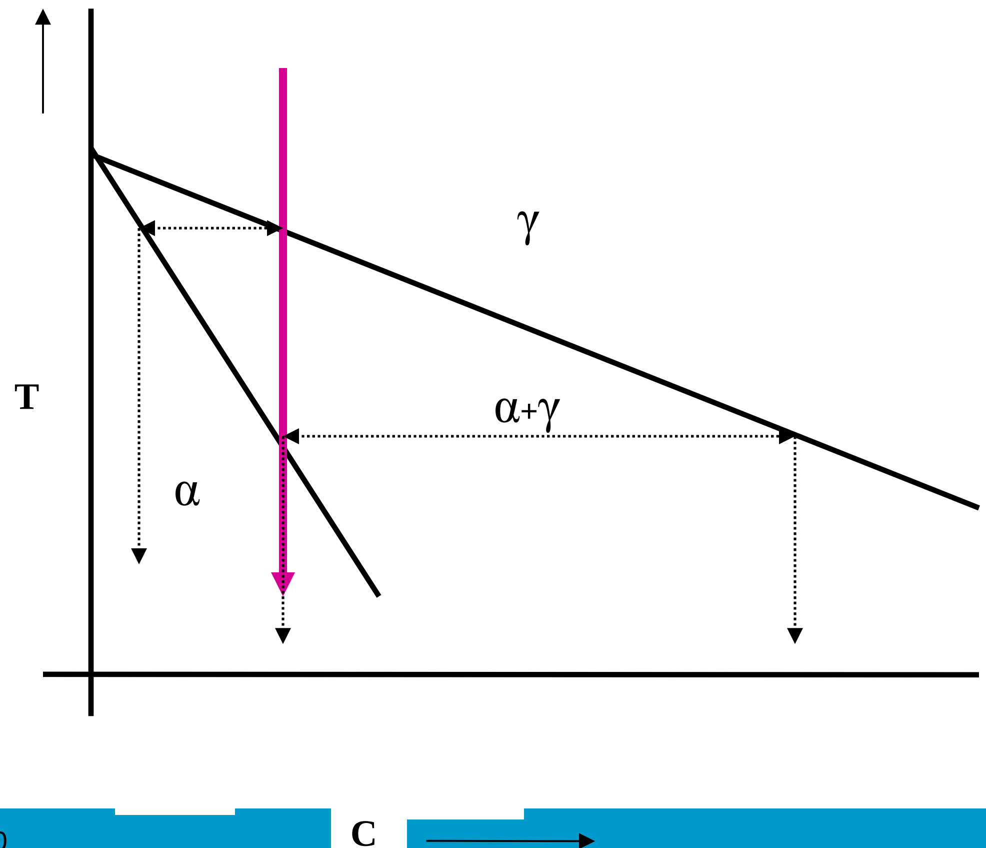
The famous austenite to ferrite phase transformation



The **famous** austenite-ferrite phase transformation

- .the growth is determined by solute partitioning
- .the growth is determined by the interface conditions
- .the growth might be also determined by **interface mobility**
- .the overall kinetics is determined by **nucleation** and growth
- .the overall kinetics is strongly affected by the **topology** (i.e. nucleation site spatial distribution)
- .the modelled kinetics always **deviate** from the experimental data
- .the discrepancy is generally attributed to nucleation distribution, morphology and soft impingements

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The mixed mode approach

1. The kinetics is determined by both the solute redistribution **and** the *effective* interface mobility
2. The interface concentrations change for an isothermal transformation and are not given by the equilibrium concentrations during isothermal cooling
3. The velocity of the interface is given by

   $\mathbf{v = M \times \Delta\mu_C}$ where M is the mobility
4. The mixed mode is also not capable of perfectly describing the transformation curve
5. Hence, the interface mobility is hard to determine with good accuracy

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The impact of nucleation on kinetics

- The number of (simultaneous) nucleation sites per grain affects the kinetics strongly *(van Leeuwen et al, Chen et al)*

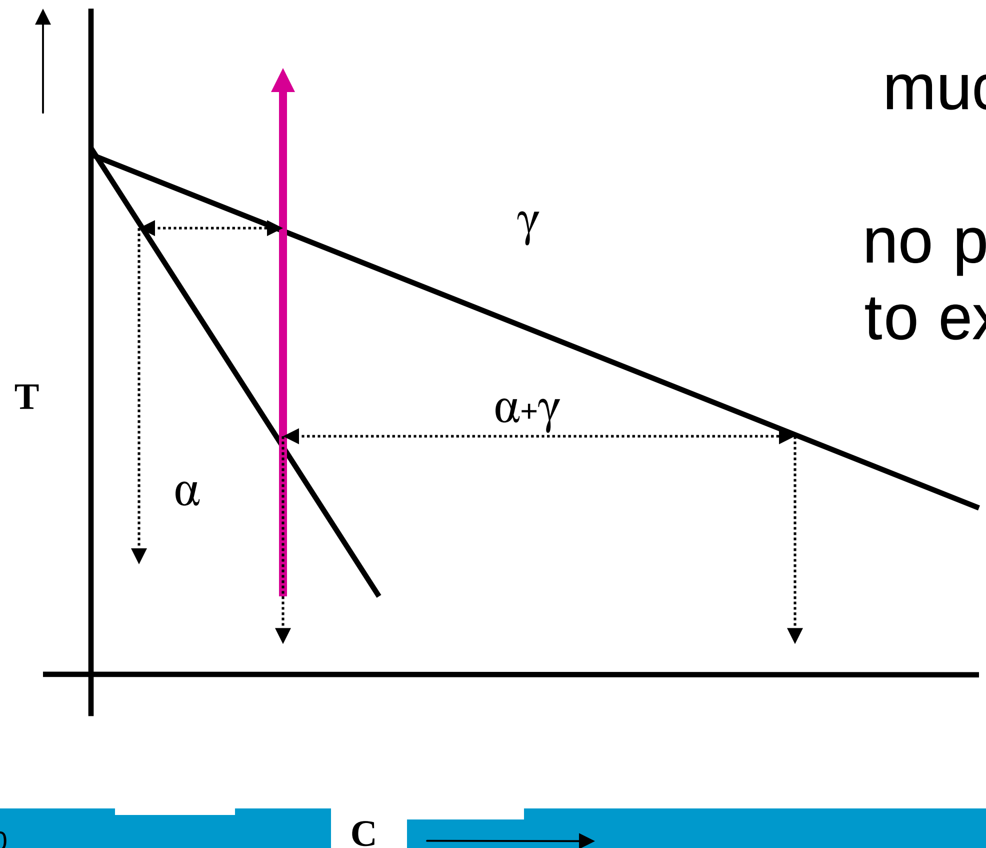
- Nucleation occurs over a significant temperature range *(Offerman et al)*

- Nucleation temperature range can be derived from the width of the grain size distribution *(Mecozzi ett al)*

Topology and transformation kinetics

- Initial austenite topology is generally only known implicitly
- Topology and topology development play an important role in kinetics
- Topological uncertainties make the determination of true transformation kinetics impossible

The less- famous ferrite to austenite phase transformation



much slower kinetics

no perfect fit of models to experimental data

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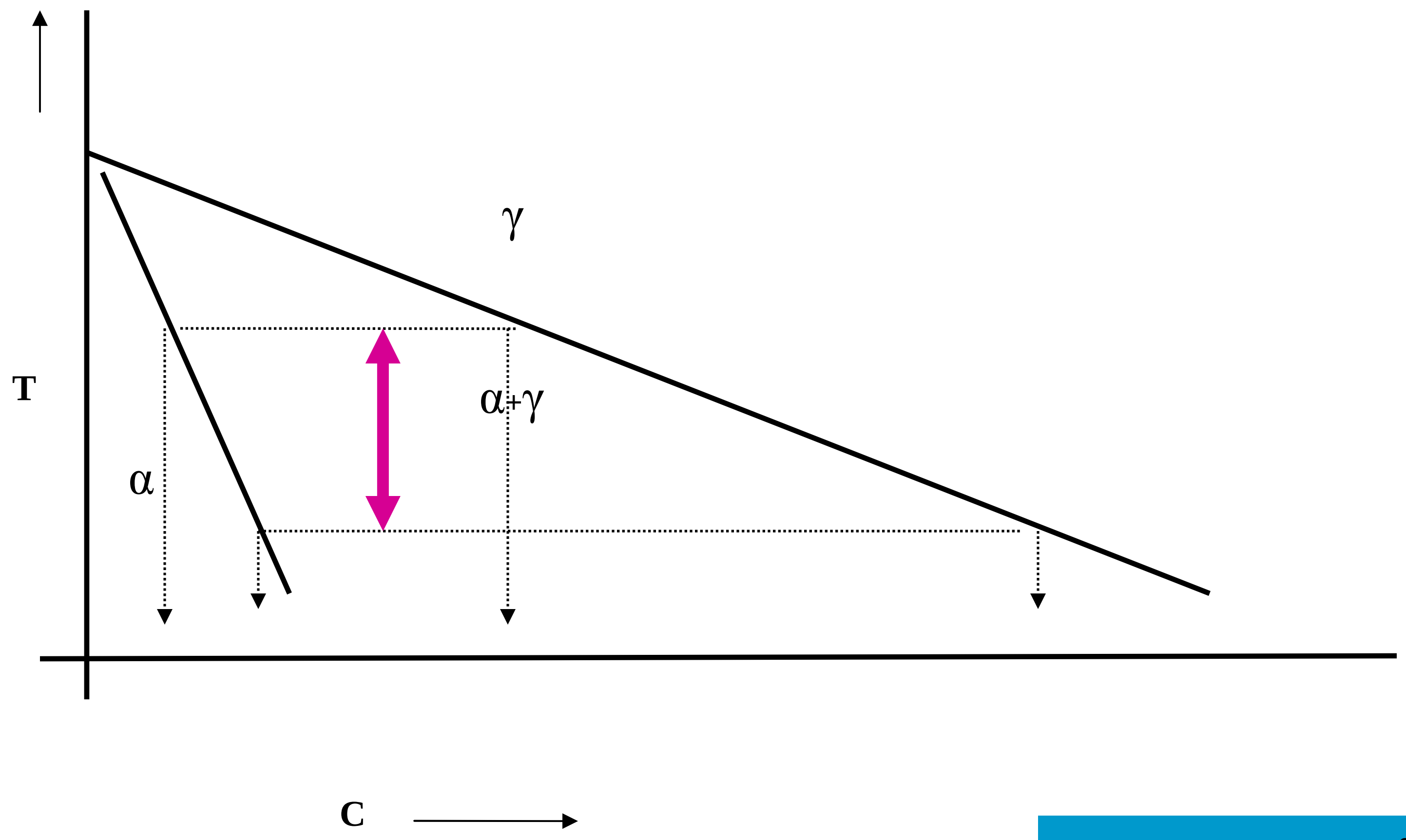
The challenge

- Design an experiment which would enable the determination of the interface mobility for the austenite-ferrite phase transformation

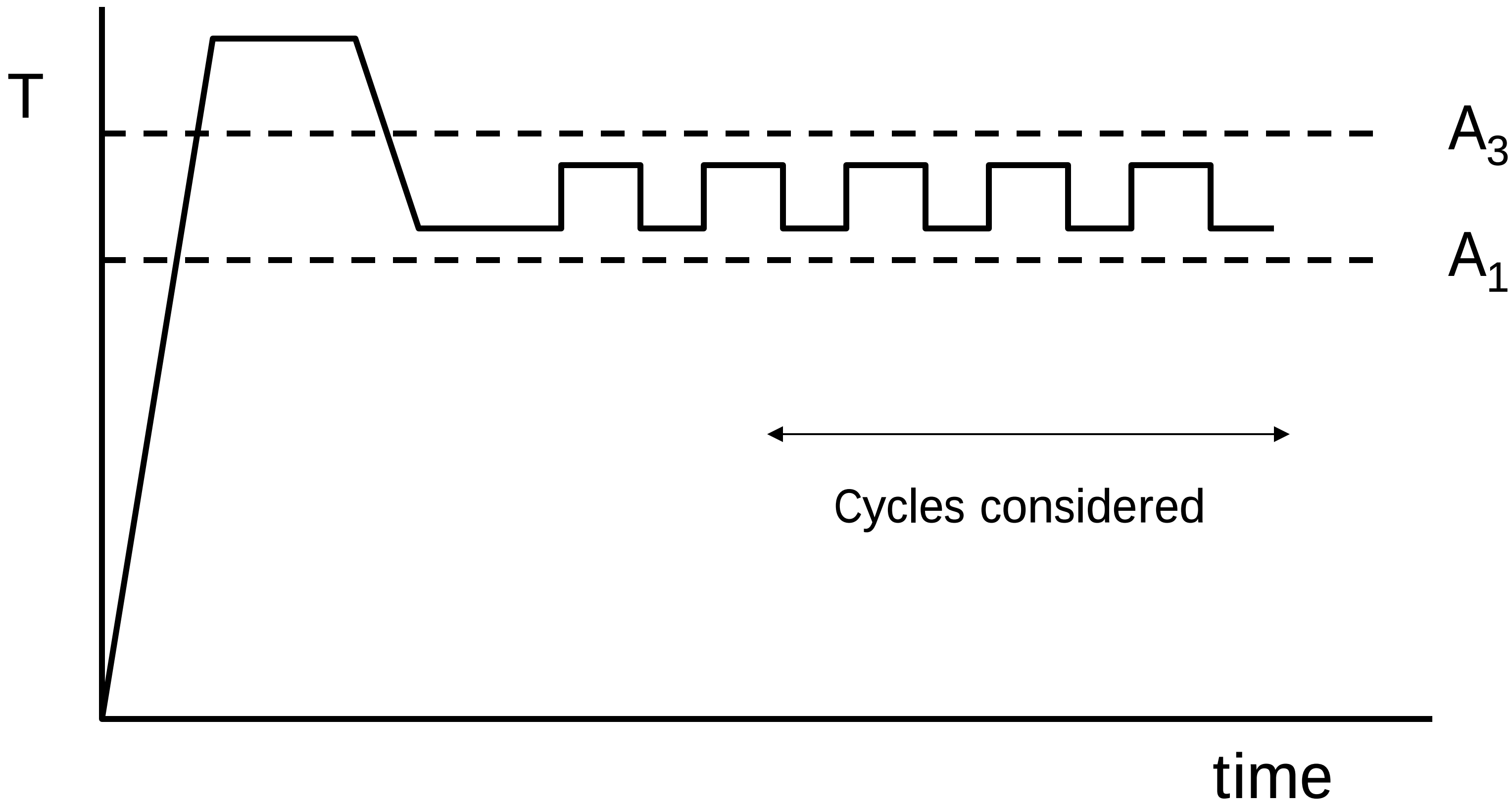
The infamous cyclic partial austenite-ferrite phase transformation



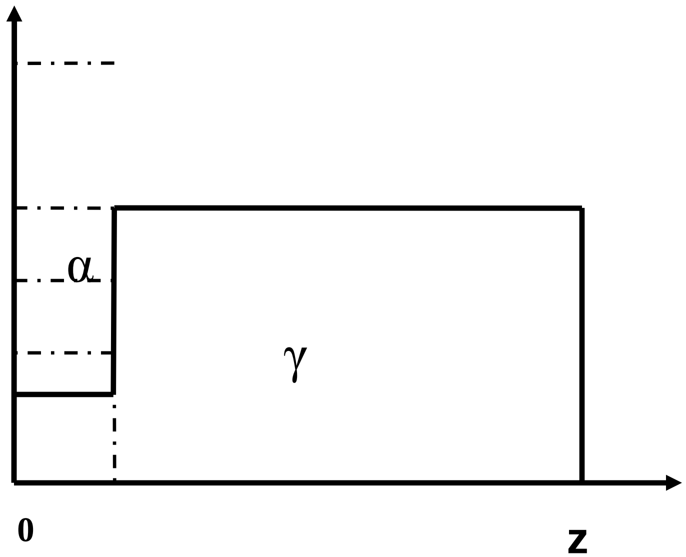
The advantages

1. The starting and final conditions are defined
2. Nucleation effects can be suppressed
3. The initial and final topology can be quantified
4. The thermal cycling conditions can be realised in a modern dilatometer
5. The interfacial mobility $M_{\gamma\alpha}$ and $M_{\alpha\gamma}$ may be determined (hopefully)

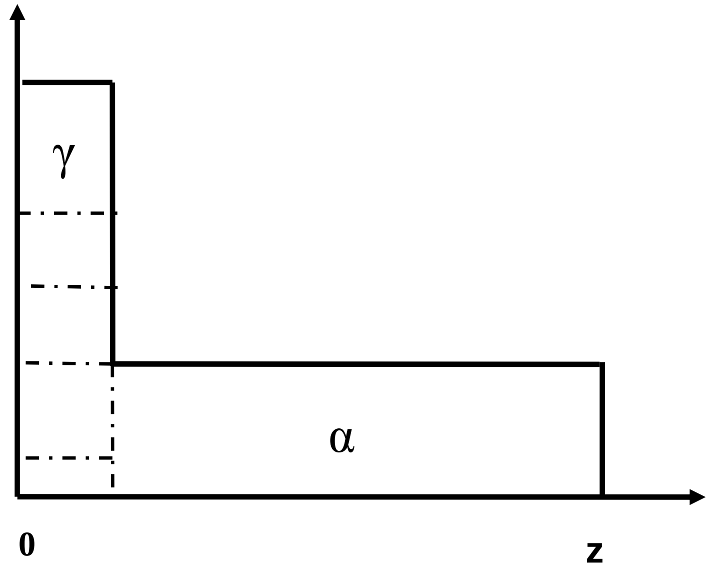
The experiment



The analysis



The starting state



The final state

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The kinetic equations

$$v_{\alpha\to\gamma} = M_{\alpha\to\gamma}\Delta G(c^{\alpha}) \qquad \Delta G(c^{\alpha}) = \chi_{\alpha\to\gamma}\left(c^{\alpha} - c_{eq}^{\alpha}(T_2)\right)$$

$$v_{\gamma\to\alpha} = M_{\gamma\to\alpha}\Delta G(c^{\gamma}) \qquad \Delta G(c^{\gamma}) = \chi_{\gamma\to\alpha}\left(c_{eq}^{\gamma}(T_2) - c^{\gamma}\right)$$

$$J_{\alpha\to\gamma}^{i} = D^{\alpha}\frac{\partial c_{\alpha}}{\partial z} - D^{\gamma}\frac{\partial c_{\gamma}}{\partial z} \qquad J_{\gamma\to\alpha}^{i} = D^{\alpha}\frac{\partial c_{\alpha}}{\partial z} - D^{\gamma}\frac{\partial c_{\gamma}}{\partial z}$$

$$M = M_0 \exp(-Q_G / RT)$$

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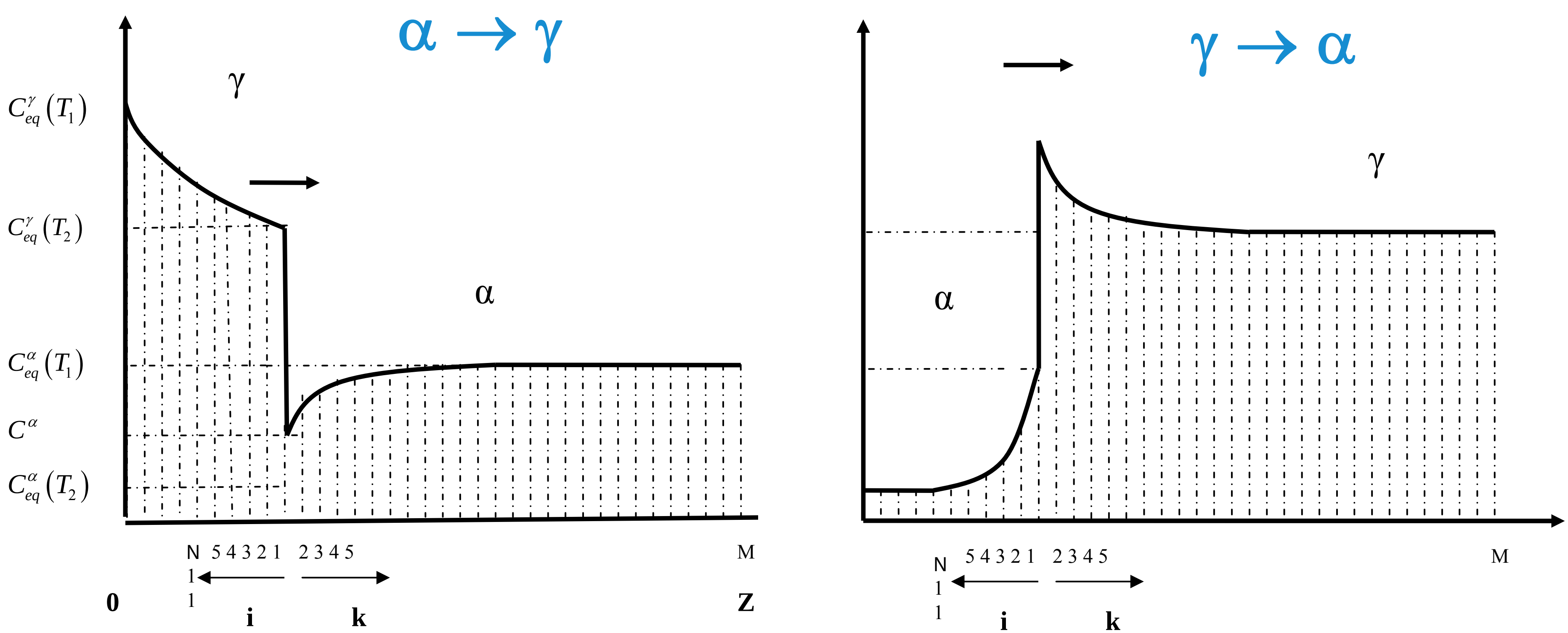
Interfacial concentrations

$$c^{\alpha} = \frac{\left[\left(c_{eq}^{\gamma}(T_2) + c_{eq}^{\alpha}(T_2)\right) + \frac{D^{\alpha}}{2M_{\alpha\to\gamma}\chi_{\alpha\to\gamma}\Delta x_{\alpha}}\right]}{2} - \frac{\left\{\left[\left(c_{eq}^{\gamma}(T_2) + c_{eq}^{\alpha}(T_2)\right) + \frac{D^{\alpha}}{2M_{\alpha\to\gamma}\chi_{\alpha\to\gamma}\Delta x_{\alpha}}\right]^2 - 4\left[D^{\gamma}\frac{c_1^{\gamma} - c_3^{\gamma}}{2M_{\alpha\to\gamma}\chi_{\alpha\to\gamma}\Delta x_{\gamma}} + c_{eq}^{\gamma}(T_2)\times c_{eq}^{\alpha}(T_2) + \frac{D^{\alpha}\times c_3^{\alpha}}{2M_{\alpha\to\gamma}\chi_{\alpha\to\gamma}\Delta x_{\alpha}}\right]\right\}^{1/2}}{2}$$

$$c^{\gamma} = \frac{\left[\left(c_{eq}^{\gamma}(T_1) + c_{eq}^{\alpha}(T_1)\right) - \frac{D^{\gamma}}{2M_{\gamma\to\alpha}\chi_{\gamma\to\alpha}\Delta x_{\gamma}}\right]}{2} + \frac{\left\{\left[\left(c_{eq}^{\gamma}(T_1) + c_{eq}^{\alpha}(T_1)\right) - \frac{D^{\gamma}}{2M_{\gamma\to\alpha}\chi_{\gamma\to\alpha}\Delta x_{\gamma}}\right]^2 - 4\left[D^{\alpha}\frac{c_1^{\alpha} - c_3^{\alpha}}{2M_{\gamma\to\alpha}\chi_{\gamma\to\alpha}\Delta x_{\alpha}} + c_{eq}^{\alpha}(T_1)\times c_{eq}^{\gamma}(T_1) - \frac{D^{\gamma}\times c_3^{\gamma}}{2M_{\gamma\to\alpha}\chi_{\gamma\to\alpha}\Delta x_{\gamma}}\right]\right\}^{1/2}}{2}$$

$C_{eq}^{\gamma}(T_1)$

Early stage of transformation (mixed mode model)



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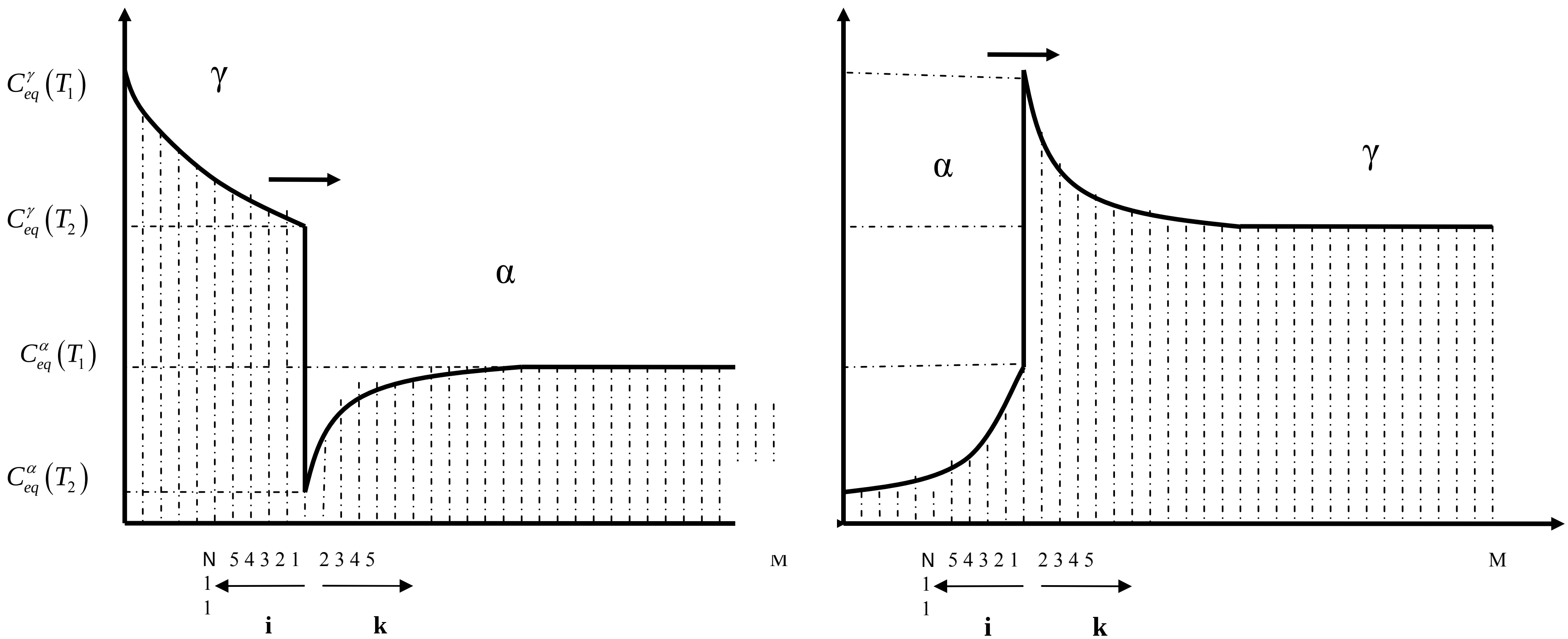
Early stage of transformation
Diffusional model



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Parameter values

Binary Fe - 0.3 a% C alloy

parameter	1050 K	1100 K
$D_{C,\gamma}$ m^2/s	1.10^{-12}	$4.\ 10^{-12}$
$D_{C,\ \alpha,}$ m^2/s	$1.\ 10^{-10}$	$4.\ 10^{-10}$
M_0 mol.m/J.s	0.5	0.5
Q, kJ/mol	140	140

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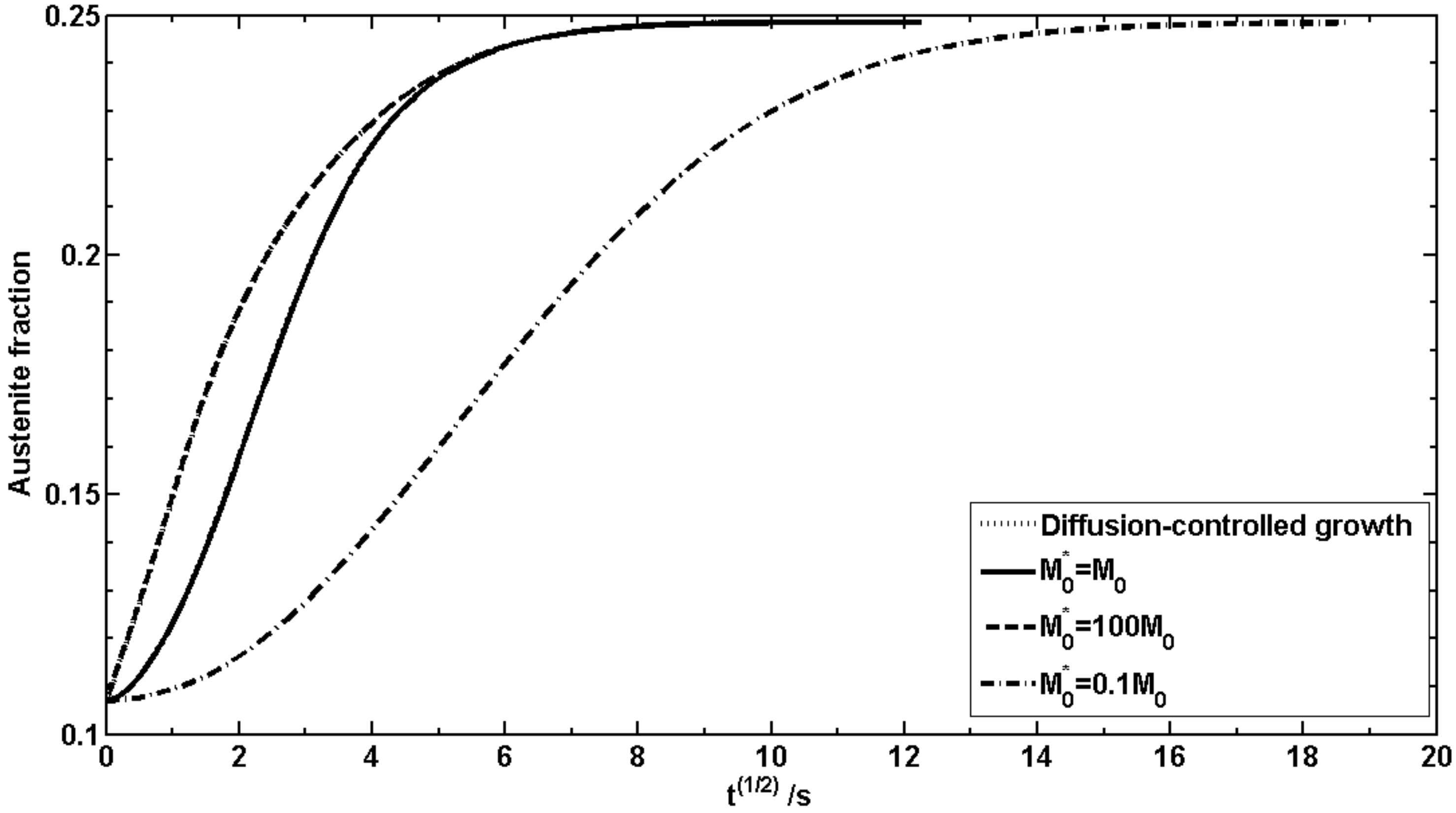
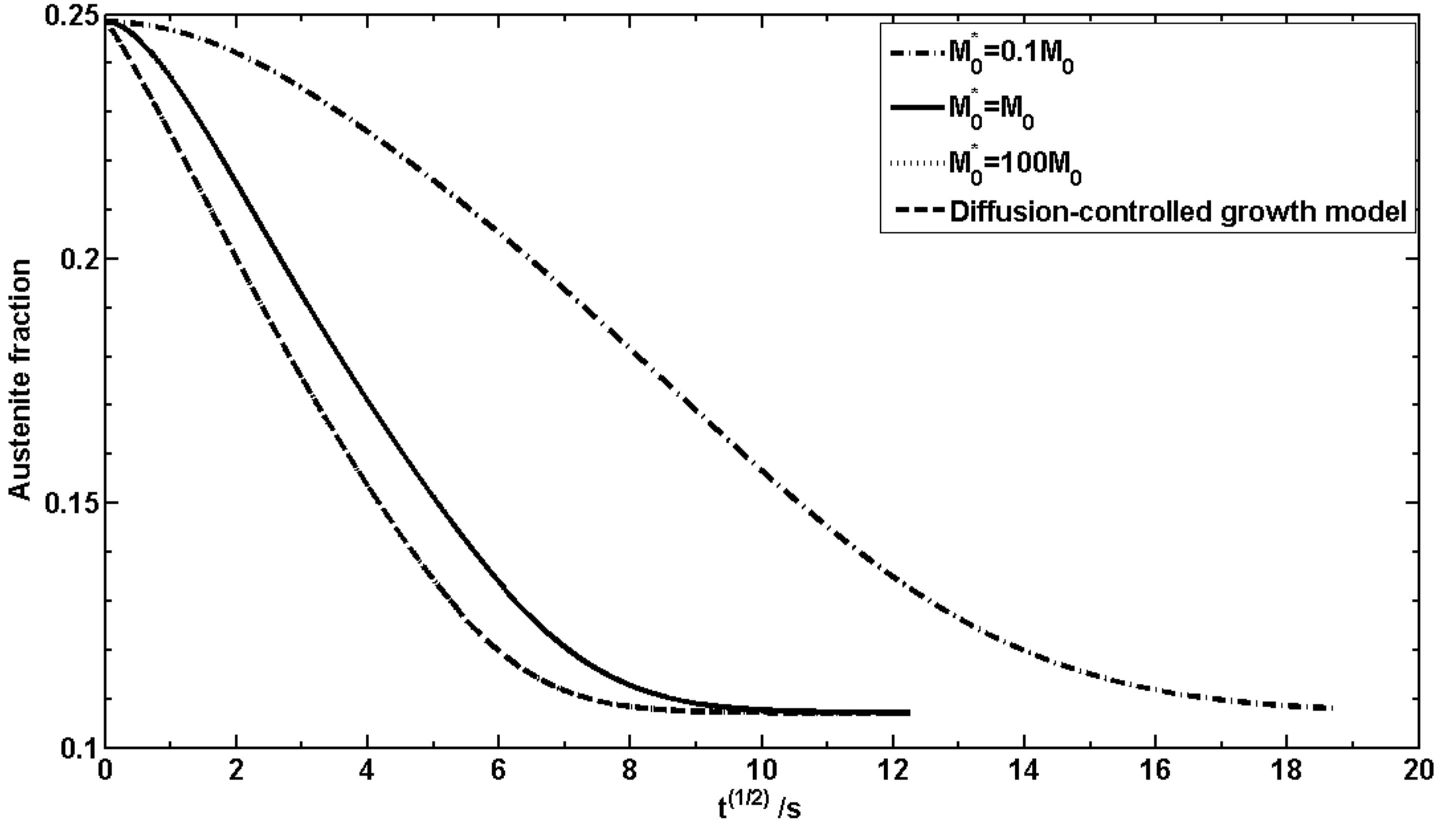
Ferrite to Austenite heating



Austenite to ferrite cooling



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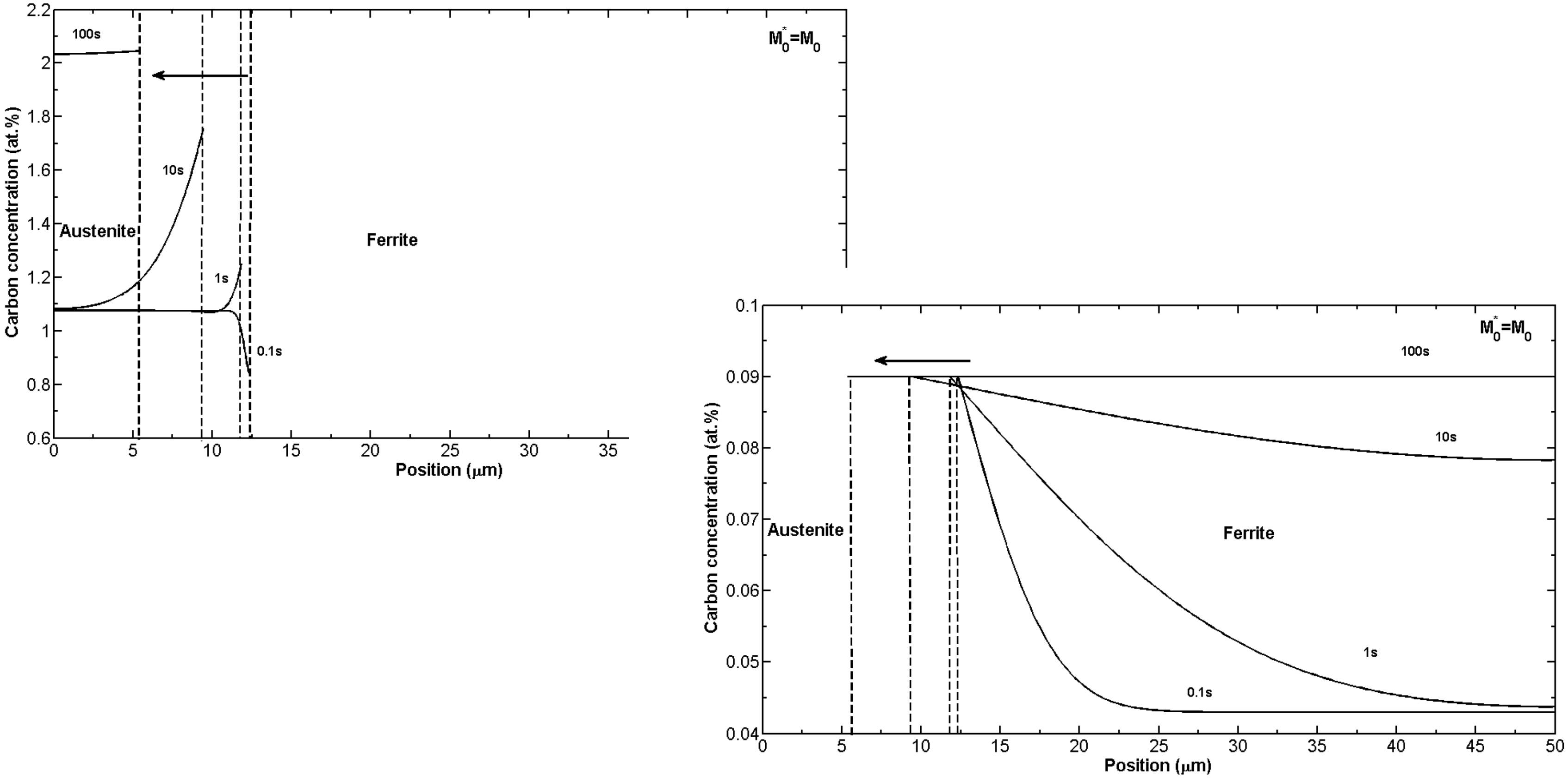
Carbon profile in austenite and ferrite during annealing at 1050 K



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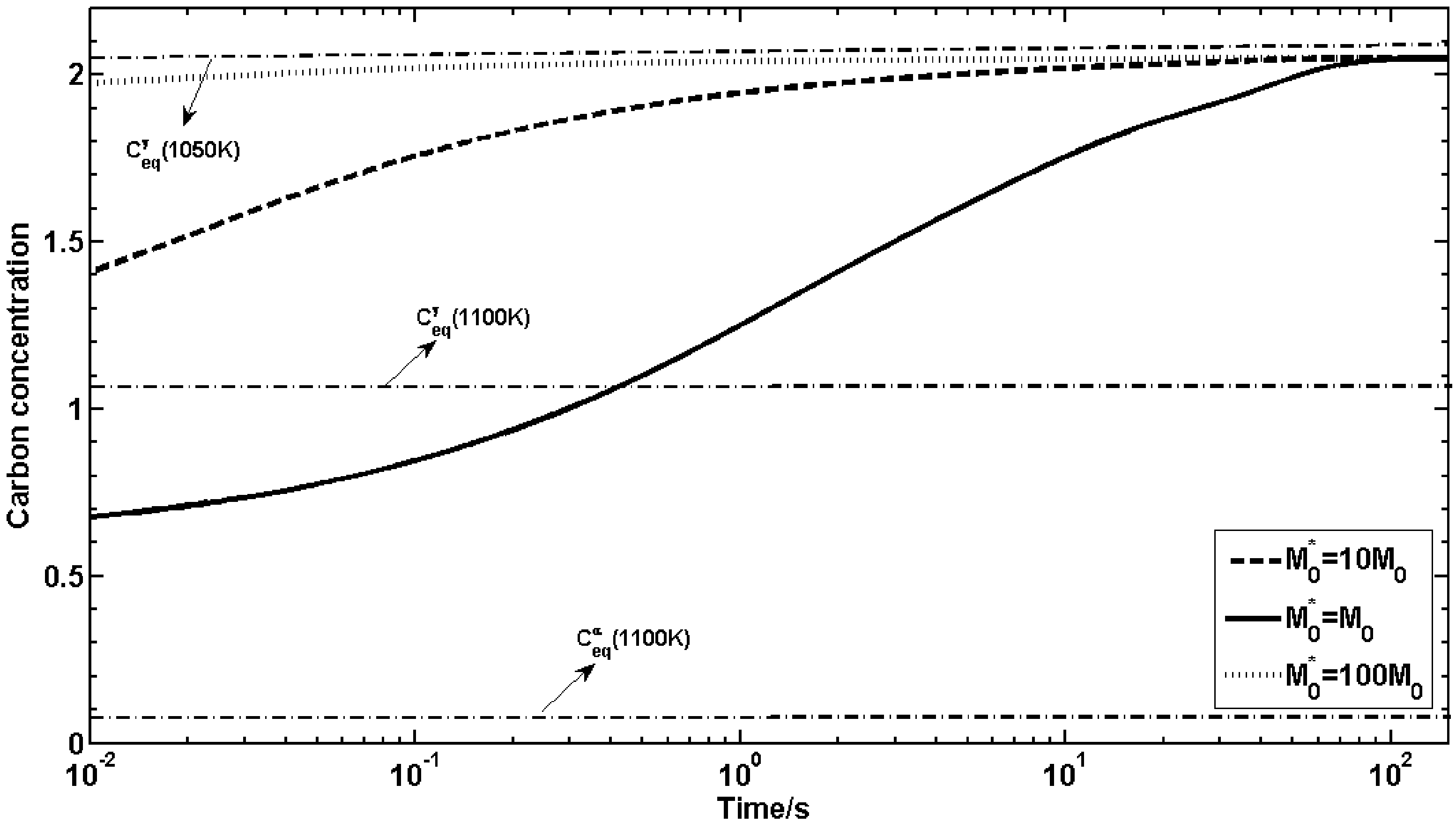
Carbon concentration
Time/s
C^{γ}_{eq}(1050K)
C^{γ}_{eq}(1100K)
C^{α}_{eq}(1100K)
$M_0^*=10M_0$
$M_0^*=M_0$
$M_0^*=100M_0$

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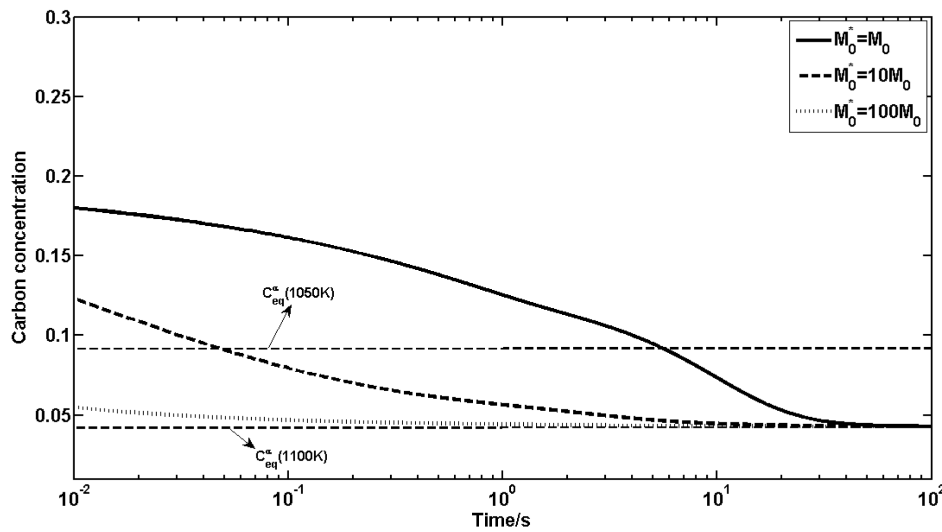
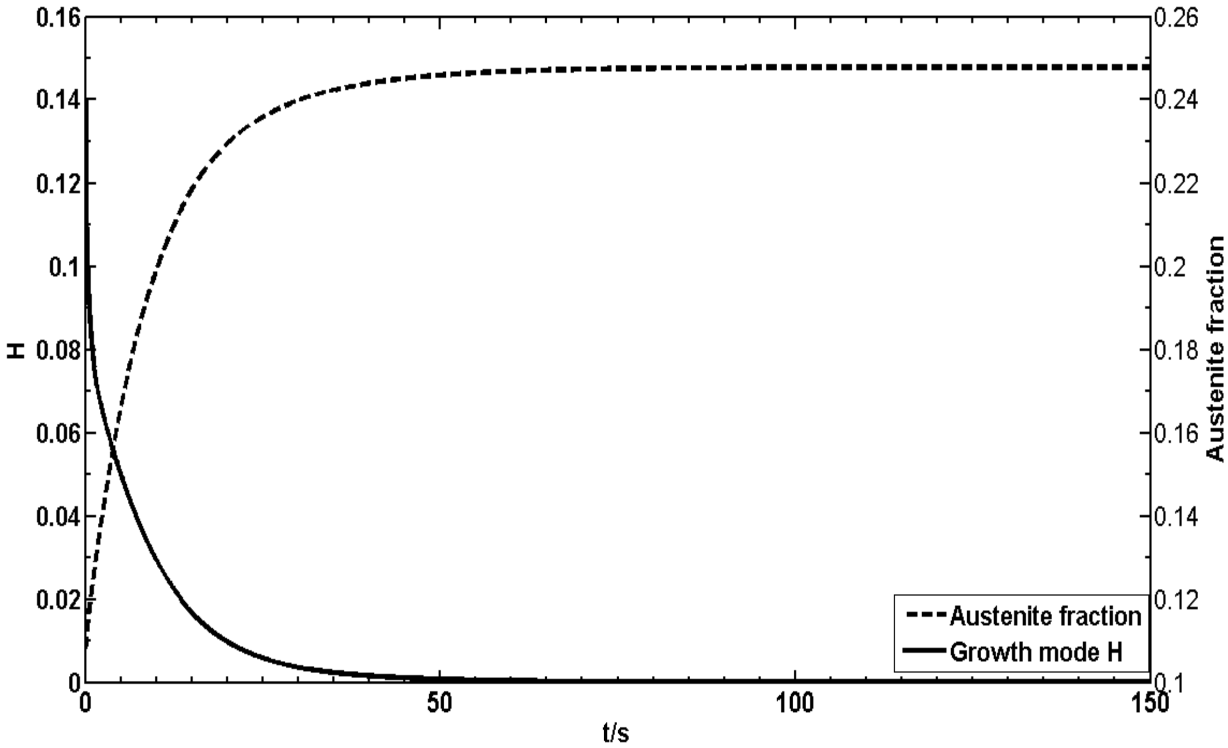


0.3
0.25
0.2
0.15
0.1
0.05
Carbon concentration
$M_0^*=M_0$
$M_0^*=10M_0$
$M_0^*=100M_0$
$C_{eq}^{\alpha}(1050K)$
$C_{eq}^{\alpha}(1100K)$
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Time/s

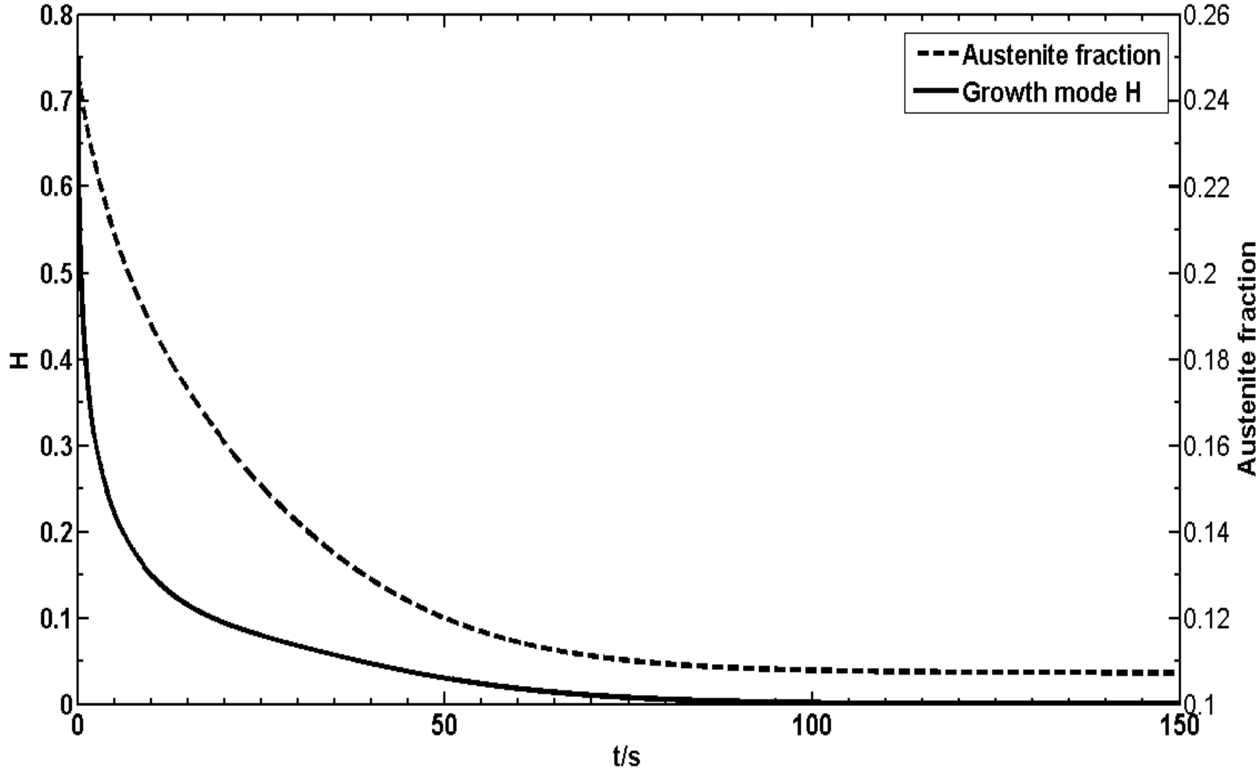
Character of the interface motion during ferrite to austenite growth



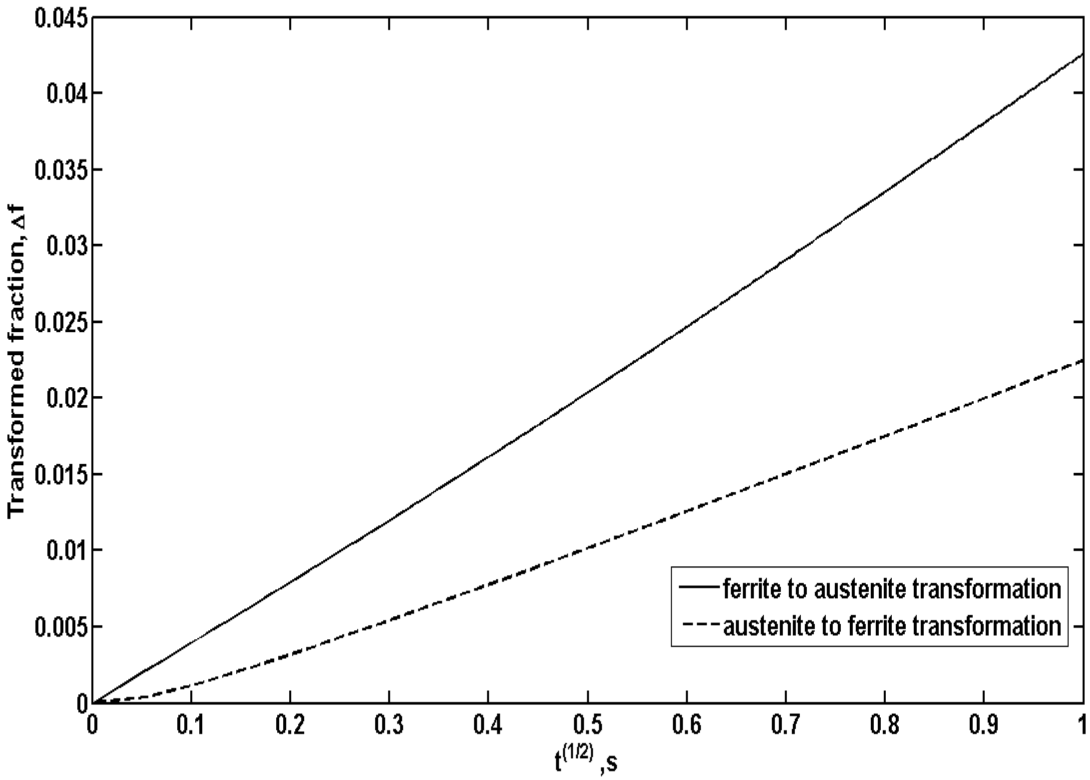
$$H_{\gamma\to\alpha} = \frac{C^{\gamma}_{eq} - C^{\gamma}}{C^{\gamma}_{eq} - C^{\alpha}_{eq}}$$

H = 0 is diffusional;
H = 1 is pure interface

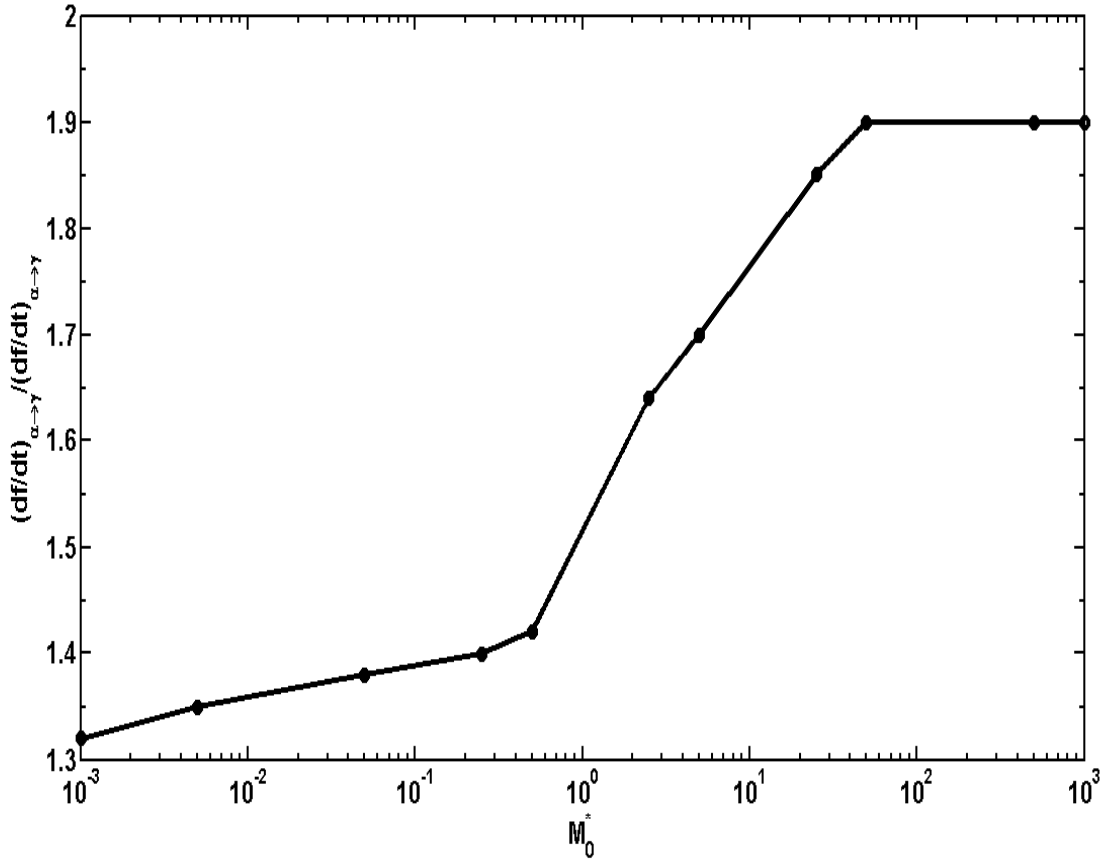
Character of the interface motion during the austenite to ferrite growth



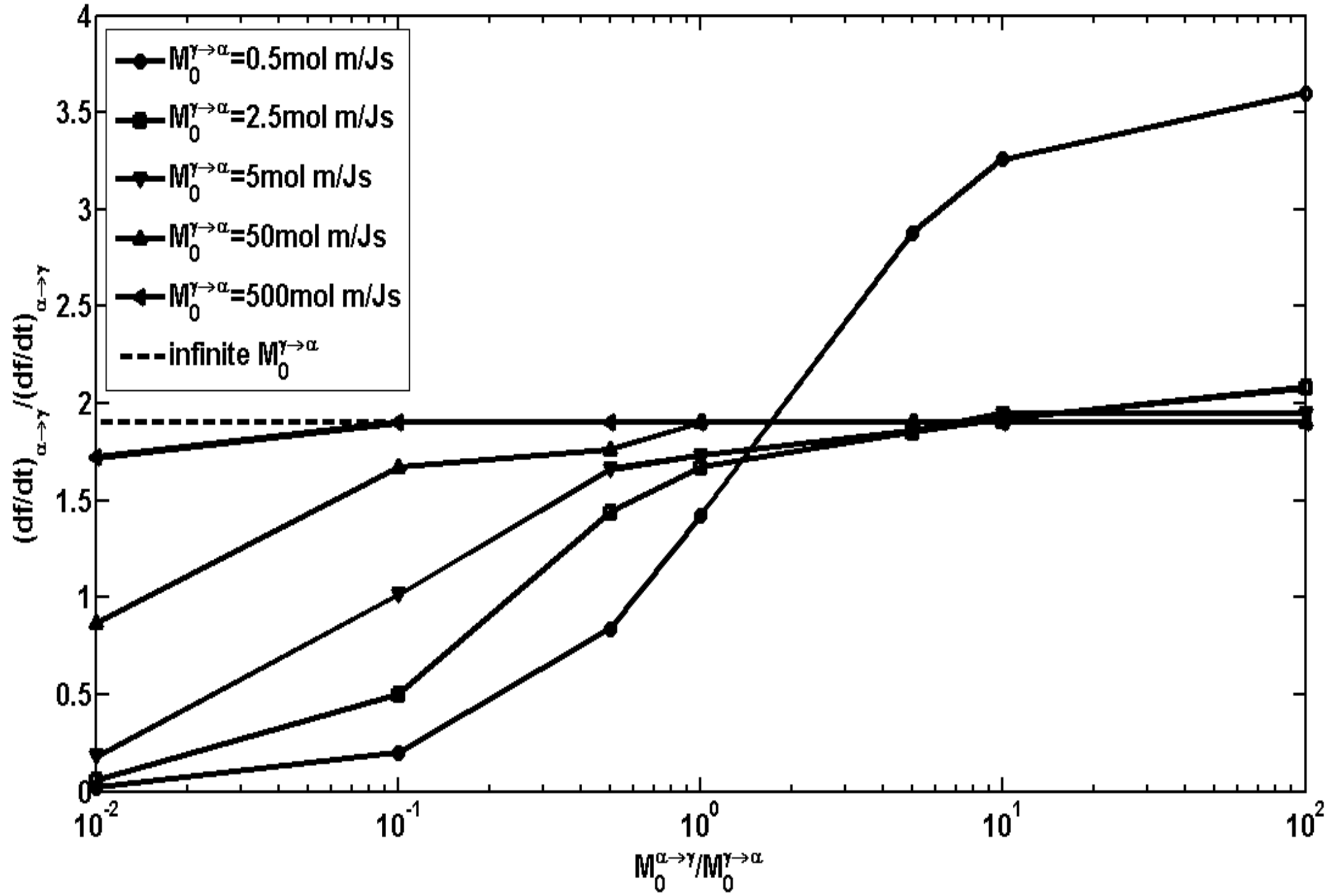
Relative transformation rates (taking $M_{\gamma \rightarrow \alpha} = M_{\alpha \rightarrow \gamma}$)



Relative rates as a function of M_0 (taking $M_{\gamma\rightarrow\alpha} = M_{\alpha\rightarrow\gamma}$)



Relative transformation rates
(taking $M_{\gamma\rightarrow\alpha} \neq M_{\alpha\rightarrow\gamma}$)



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Conclusions

1. Cyclic partial transformations offer interesting options to derive more accurate transformation insight

2. Mixed mode character should manifest itself in the early stages of each cycle

3. Relative transformation ratio’s leads to information on relative interface mobilities for both transformations

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