Dilatometric analysis of cementite dissolution in Cr-containing hyper-eutectoid steels

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POSTECH

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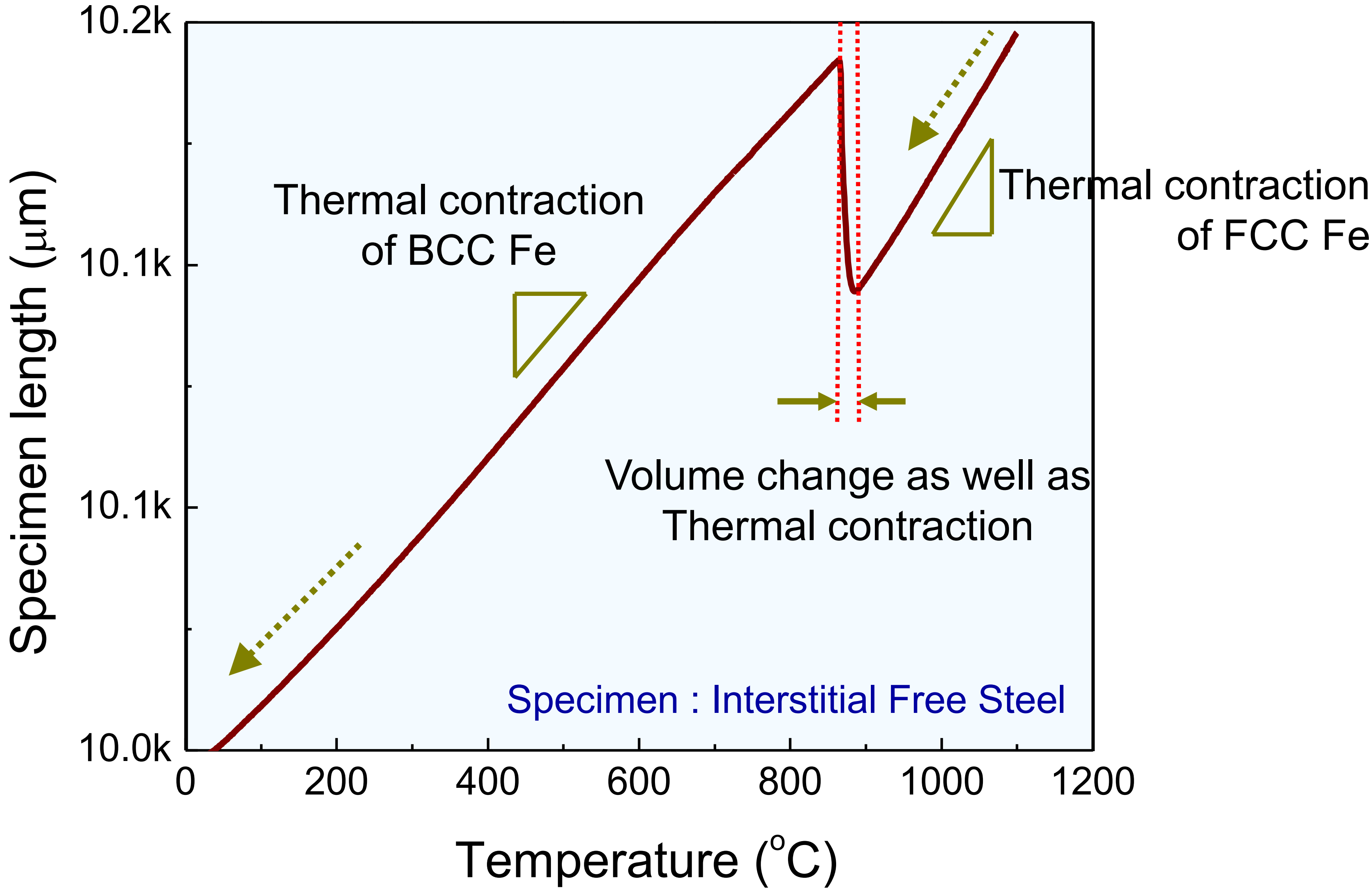
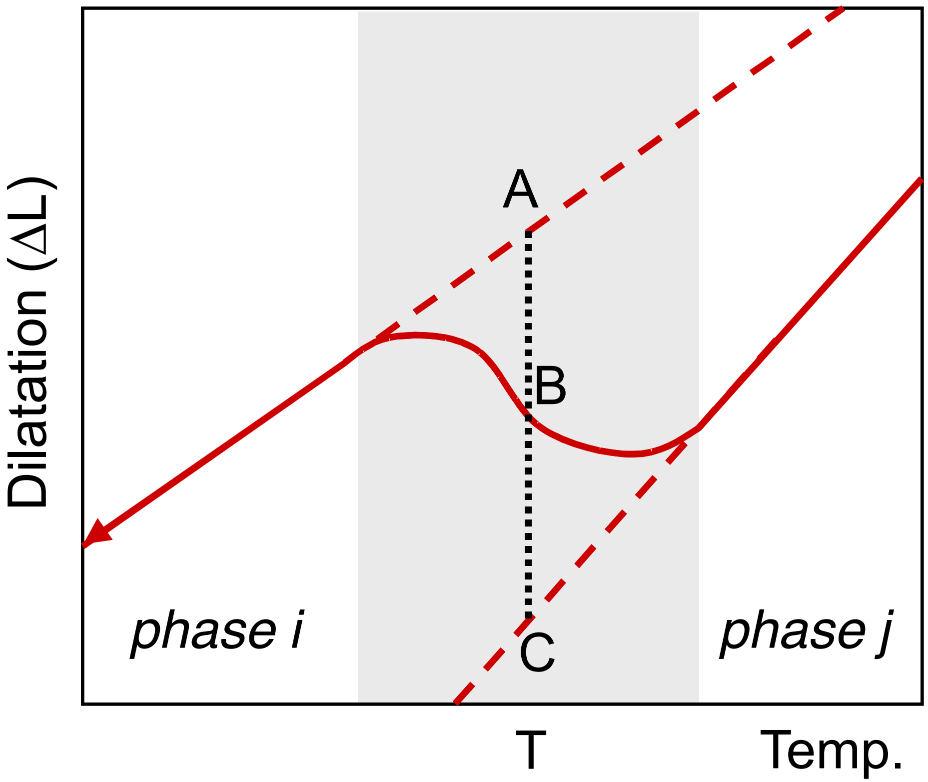
- General description of dilatometric analysis
- Application to cementite dissolution kinetics in Cr-containing hyper-eutectoid steels

Dilatometric curve



Lever rule

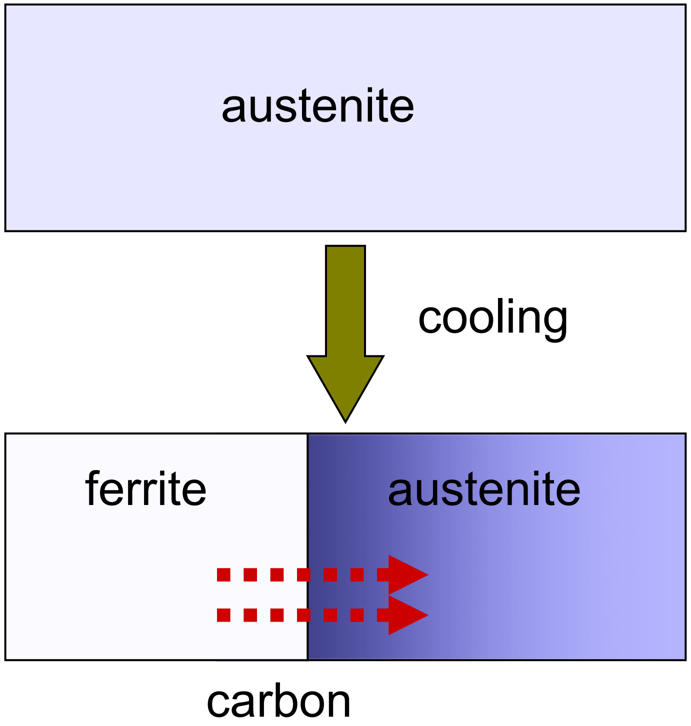


$$f_i(T) = \frac{V - V_j}{V_i - V_j}$$

$$= \frac{\overline{BC}}{\overline{AC}}$$

$$= \frac{\Delta L(T) - \Delta L_j(T, X_0)}{\Delta L_i(T, X_0) - \Delta L_j(T, X_0)}$$

Redistribution of alloying element



$$f_i(T) = \frac{V - V_j}{V_i - V_j}$$

$$= \frac{\overline{V}_0\left(\frac{3 \cdot \Delta L_{iso}}{L_0} + 1\right) - \overline{V}_j(T, X_j^C)}{\overline{V}_i(T, X_i^C) - \overline{V}_j(T, X_j^C)}$$

$$X_0^C = f_i \cdot X_i^C + f_j \cdot X_j^C$$

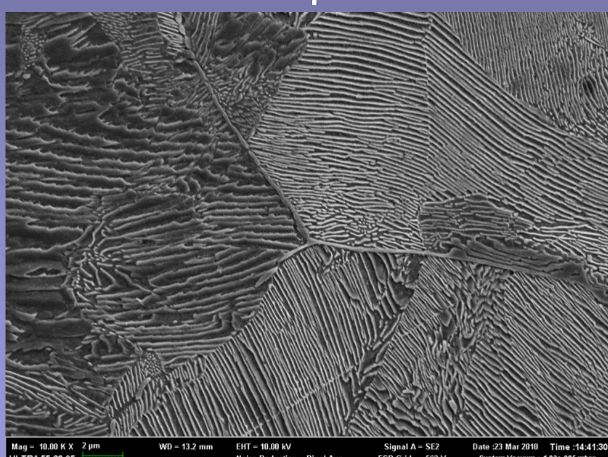
$$= f_i \cdot X_i^C + (1 - f_i) \cdot X_j^C$$

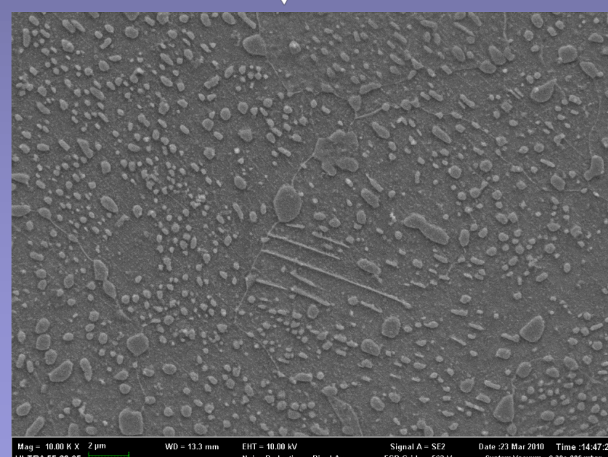
High Cr bearing steel (SAE 52100)

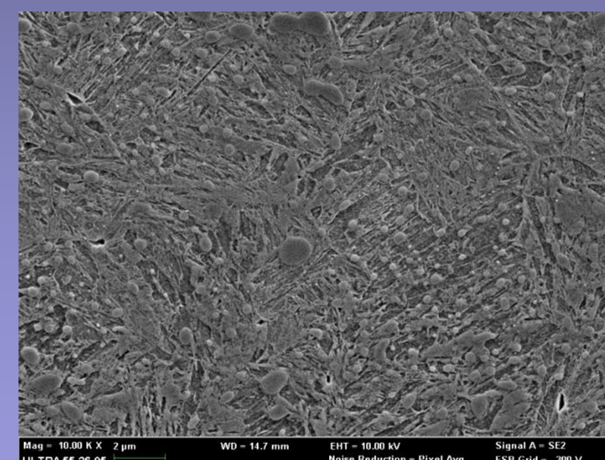
C	Mn	Si	Cr	Fe
0.95~1.1	0.2~0.45	0.25~0.35	1.3~1.6	Bal.

- HRC > 58
- Rolling contact fatigue property

spheroidizing

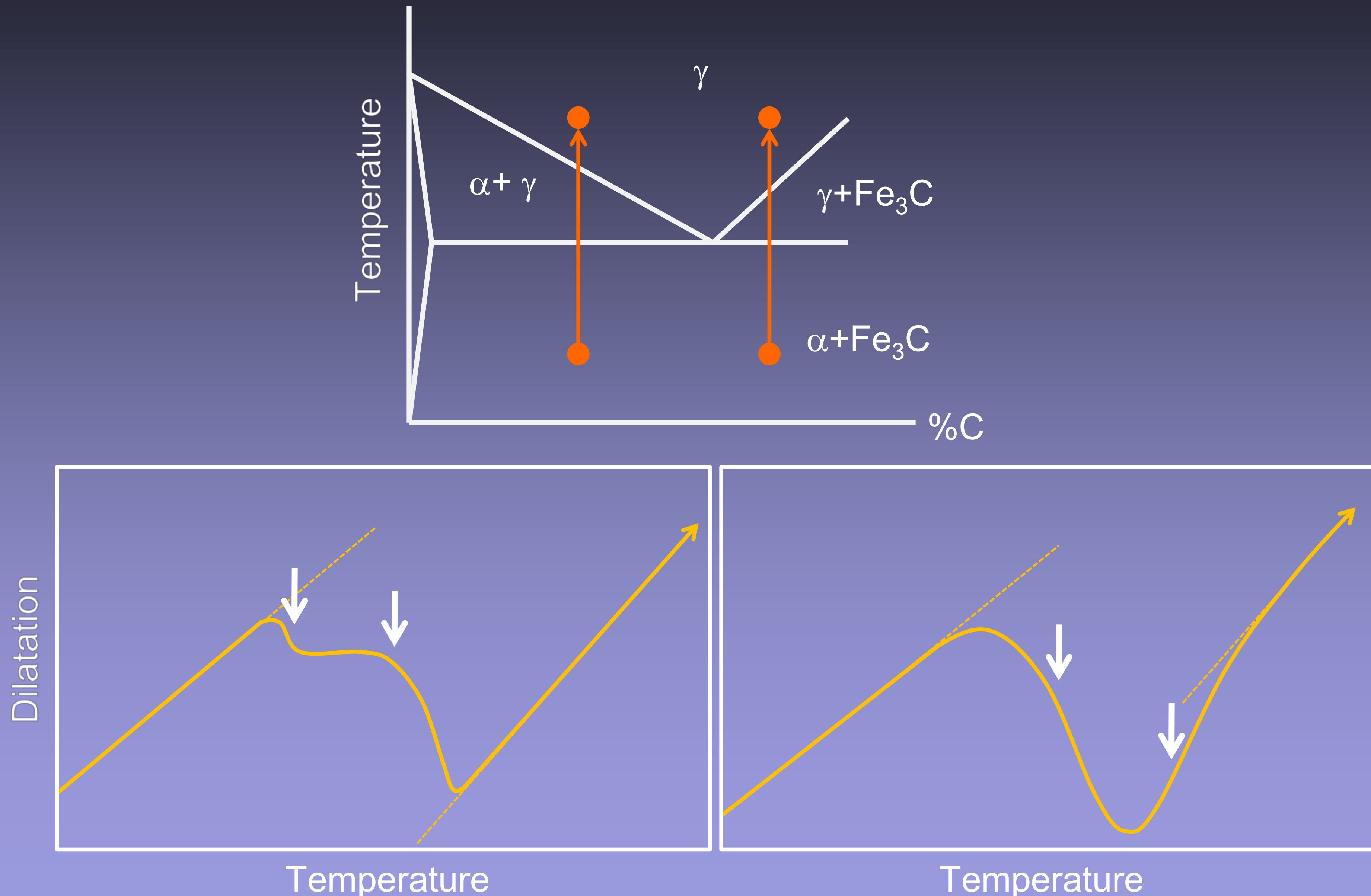




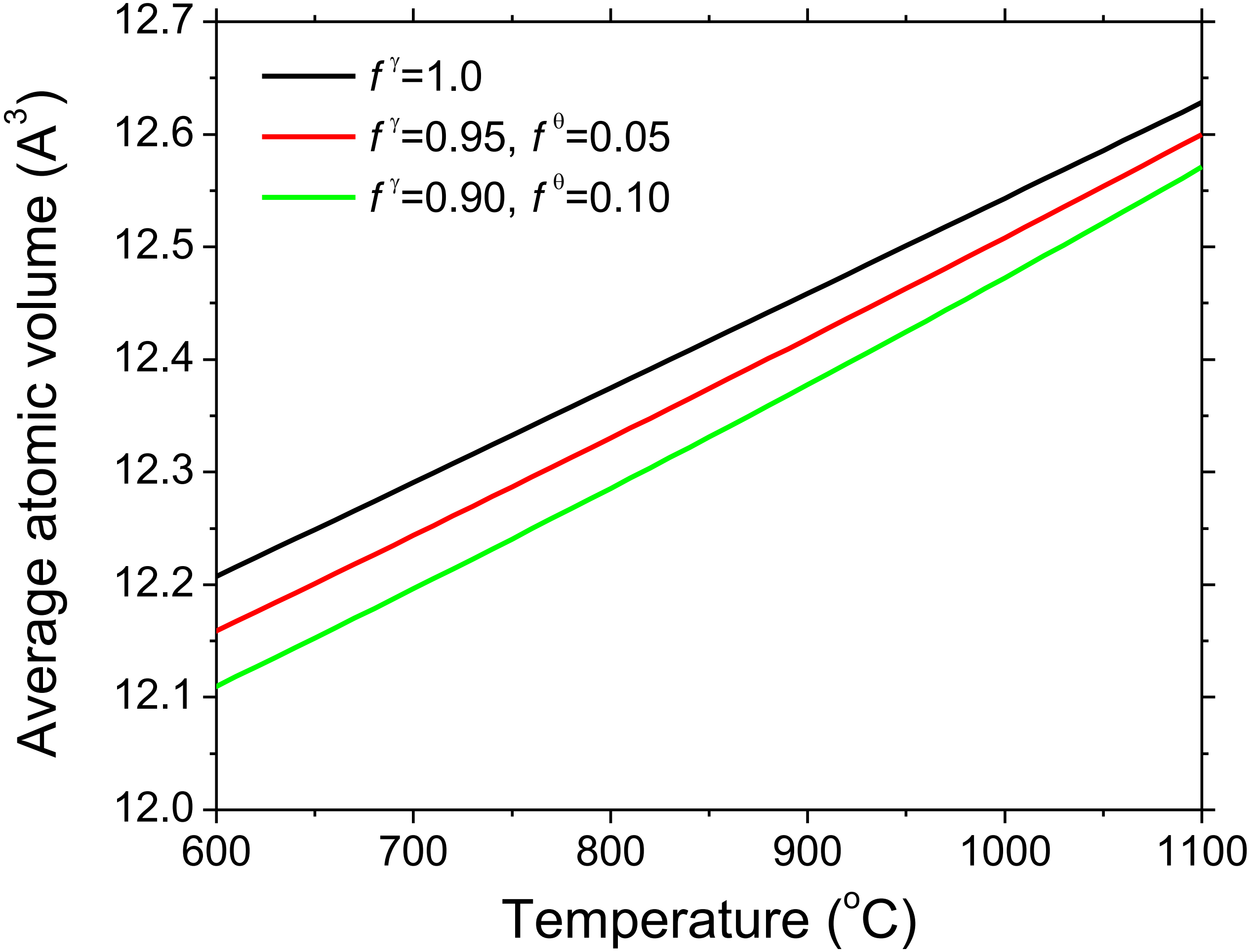


Quenching and tempering

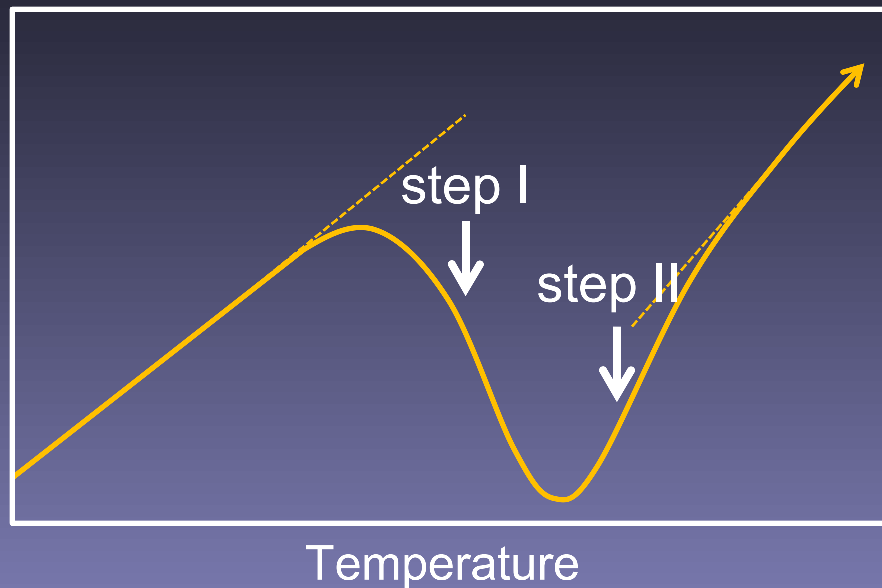
Ferrite+Cementite → Austenite

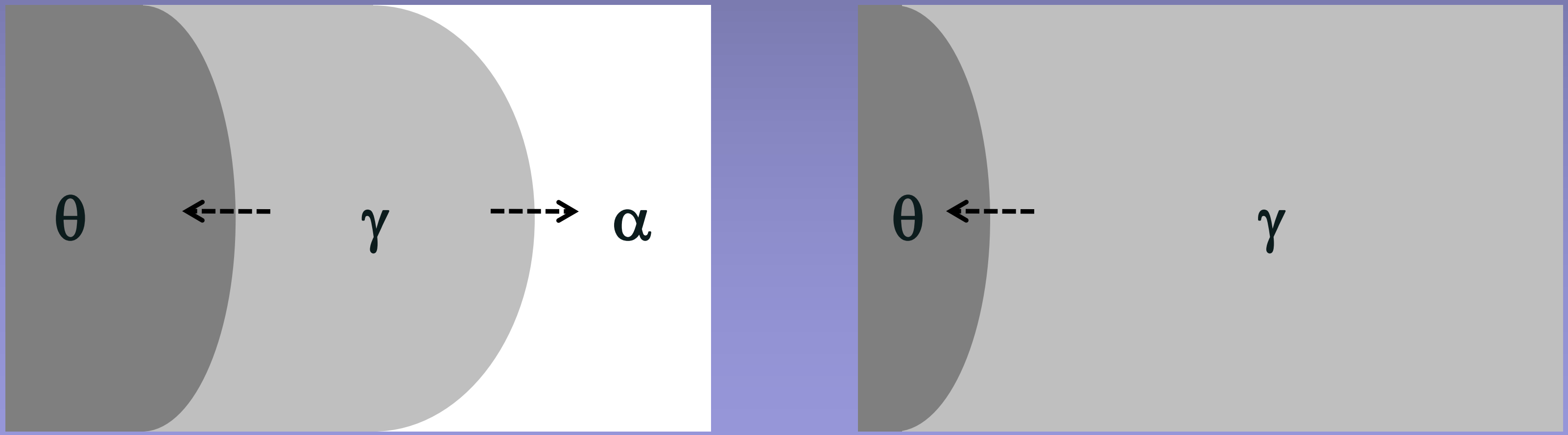


Cementite dissolution into austenite



Two step analysis





$\alpha + \theta \rightarrow \alpha + \gamma + \theta$

$\gamma + \theta \rightarrow \gamma$

Formulation in step I

$$V = f_\alpha \cdot V_\alpha + f_\theta \cdot V_\theta + f_\gamma \cdot V_\gamma$$
$$= (V_\alpha - V_\gamma) \cdot f_\alpha + (V_\theta - V_\gamma) \cdot f_\theta + V_\gamma$$

$$\begin{cases} V_\alpha(T) = \left(\frac{1}{2}\right) \cdot a_\alpha^3 \\ V_\theta(T) = \left(\frac{1}{12}\right) \cdot a_\theta \cdot b_\theta \cdot c_\theta \\ V_\gamma(T, C_\gamma) = \left(\frac{1}{4}\right) \cdot a_\gamma^3 \end{cases}$$

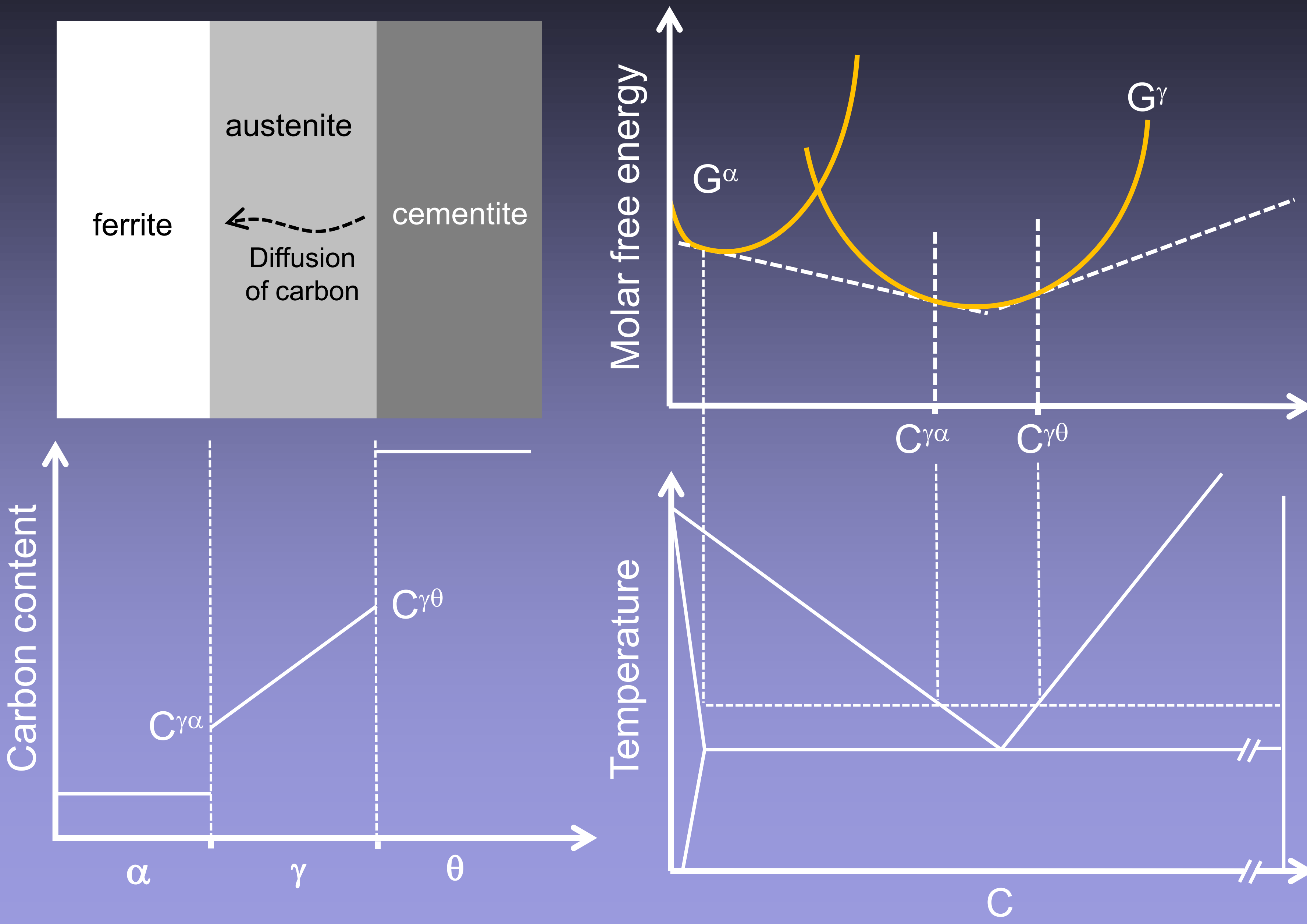
$$C_0 = \frac{C_\theta \cdot \rho_\theta \cdot f_\theta + C_\gamma \cdot \rho_\gamma \cdot f_\gamma}{\rho_\alpha \cdot f_\alpha + \rho_\theta \cdot f_\theta + \rho_\gamma \cdot f_\gamma}$$

$$\begin{cases} \rho_\alpha = \frac{M_{Fe}}{V_\alpha} \\ \rho_\theta = \frac{12 \cdot M_{Fe} + 4 \cdot M_c}{12 \cdot V_\theta} \\ \rho_\gamma = \frac{M_{Fe} + \left(\frac{X_c}{1 - Xc}\right) \cdot M_c}{V_\gamma} \end{cases}$$

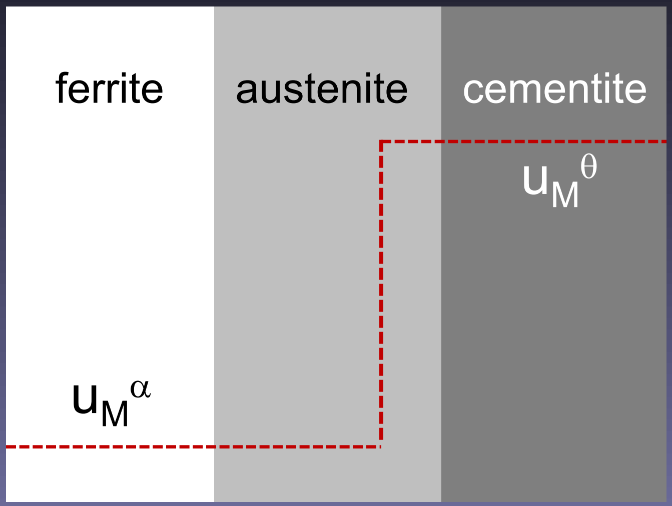
Missing equation ?

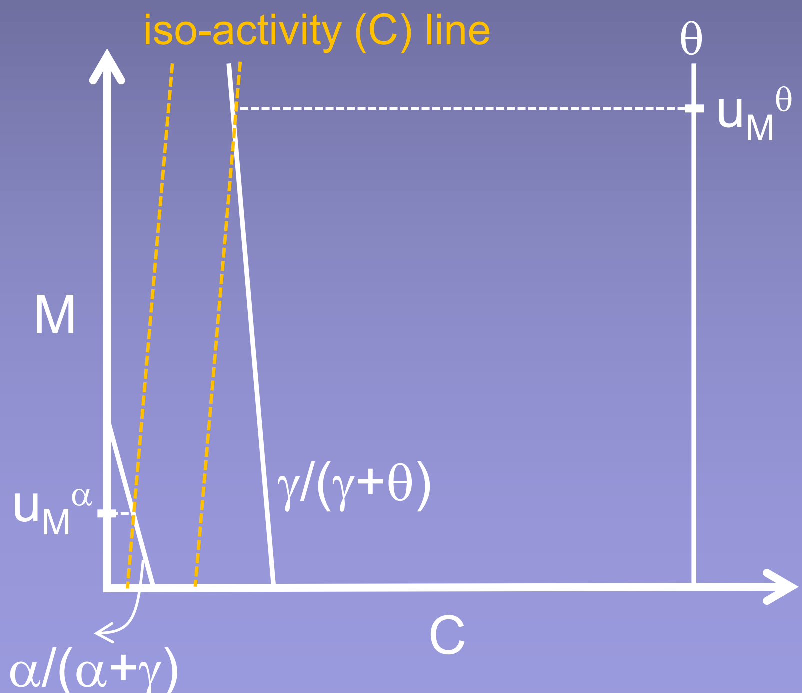
- Three unknowns, two equations
- No more deterministic relation

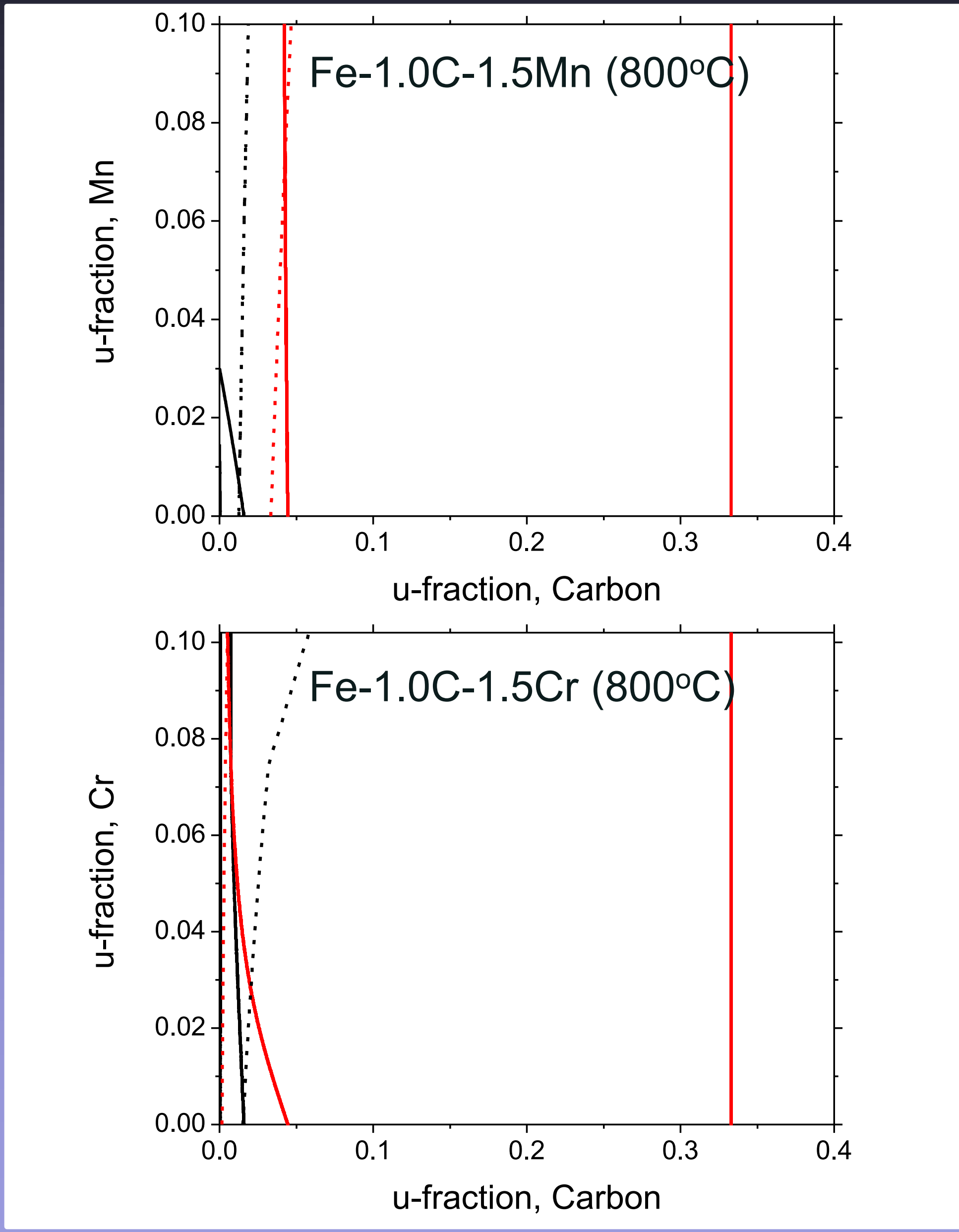
Local equilibrium at interface



Effect of alloying elements

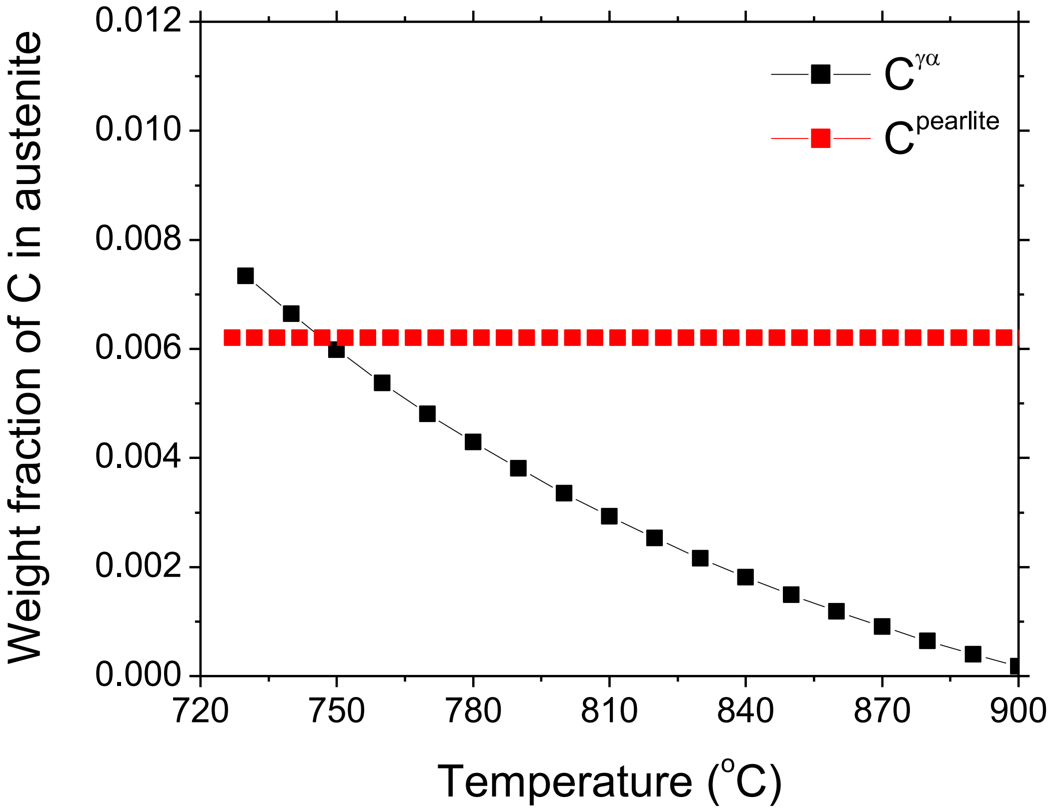






Carbon concentration in austenite

- Carbon content of austenite in local equilibrium with ferrite, $C^{\gamma/\alpha}$
- Carbon content of austenite inheriting carbon concentration of pearlite, $C^{pearlite}$



Formulation in step II

$$V = f_\theta \cdot V_\theta + f_\gamma \cdot V_\gamma$$
$$= V_\theta + (V_\gamma - V_\theta) \cdot f_\gamma$$

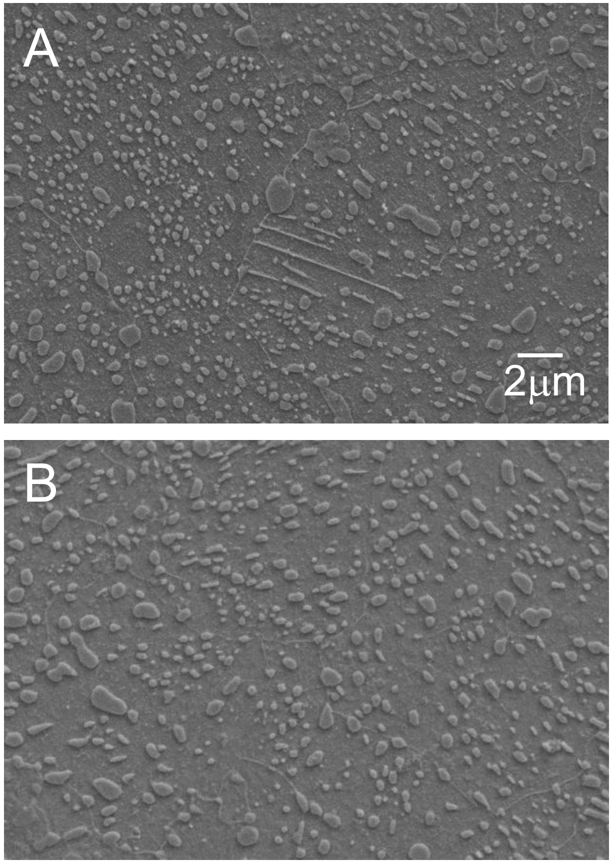
$$\begin{cases} V_\alpha(T) = \left(\frac{1}{2}\right) \cdot a_\alpha^3 \\ V_\theta(T) = \left(\frac{1}{12}\right) \cdot a_\theta \cdot b_\theta \cdot c_\theta \\ V_\gamma(T, C_\gamma) = \left(\frac{1}{4}\right) \cdot a_\gamma^3 \end{cases}$$

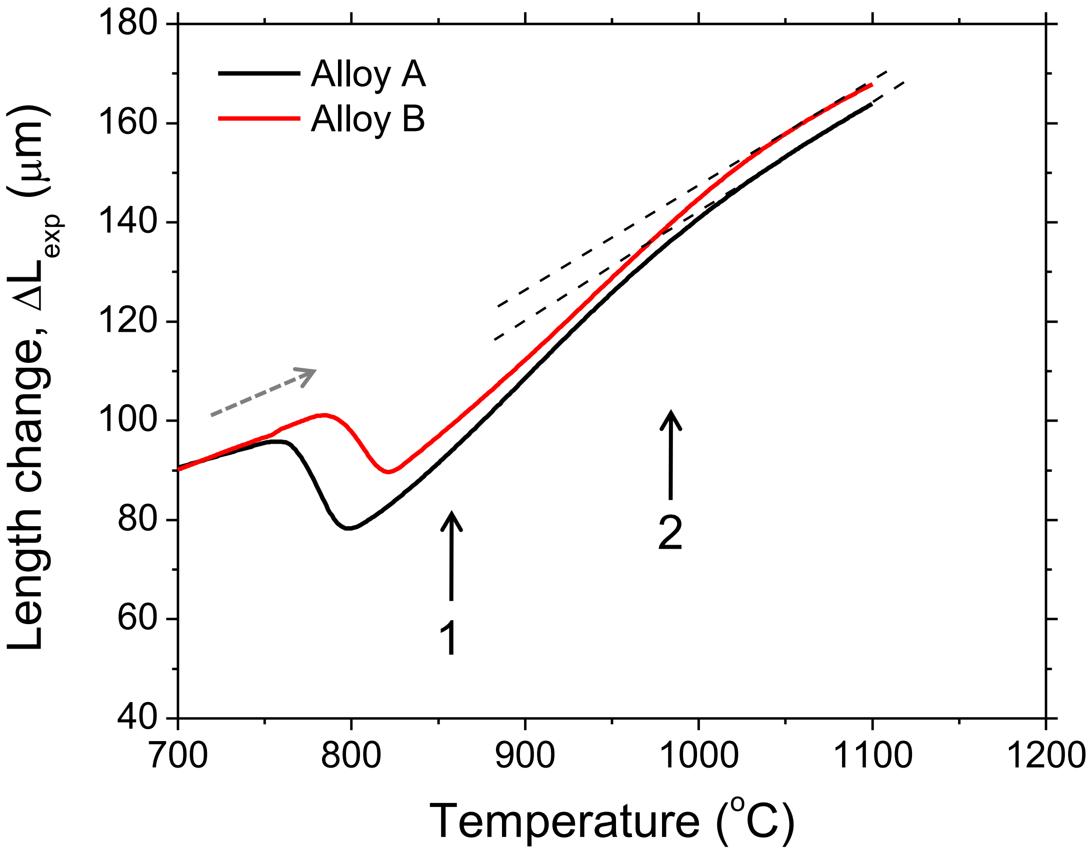
$$f_\gamma = \frac{(C_\theta - C_0) \cdot \rho_\theta}{[(C_0 - C_\gamma) \cdot \rho_\gamma - (C_0 - C_\theta) \cdot \rho_\theta]}$$

$$\begin{cases} \rho_\alpha = \frac{M_{Fe}}{V_\alpha} \\ \rho_\theta = \frac{12 \cdot M_{Fe} + 4 \cdot M_c}{12 \cdot V_\theta} \\ \rho_\gamma = \frac{M_{Fe} + \left(\frac{X_c}{1 - Xc}\right) \cdot M_c}{V_\gamma} \end{cases}$$

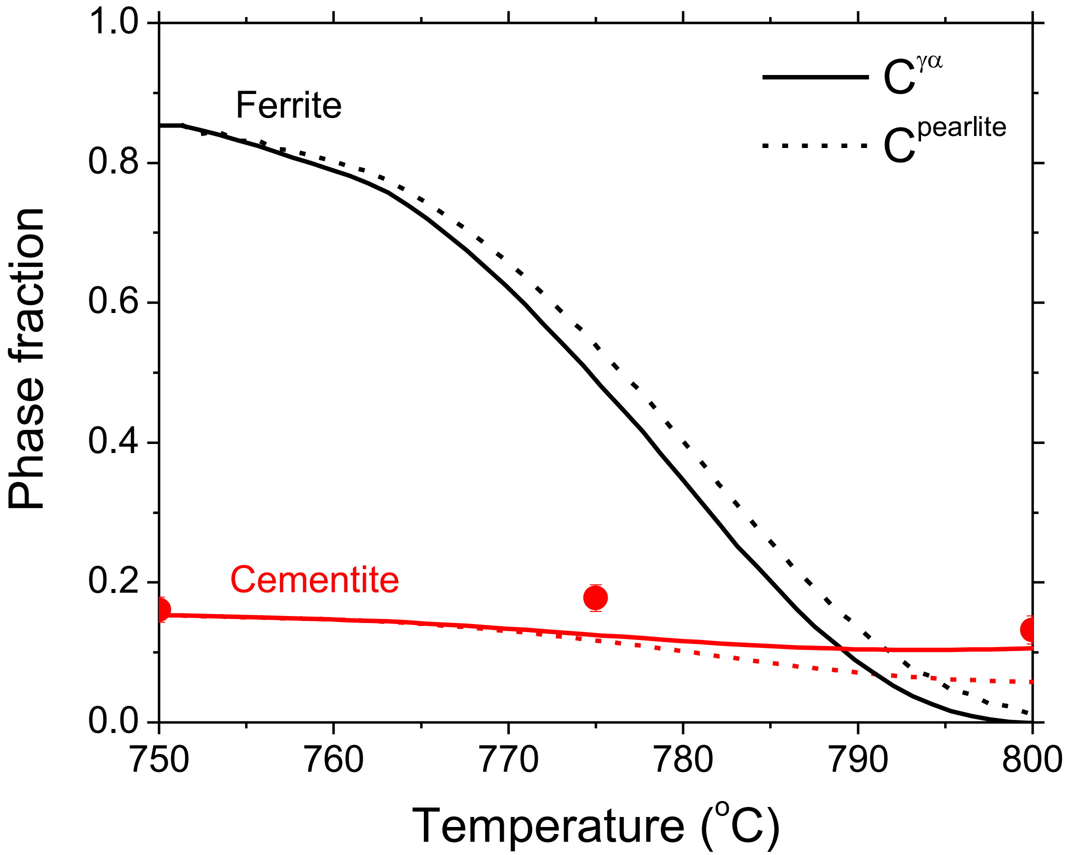
Dilatometric curves

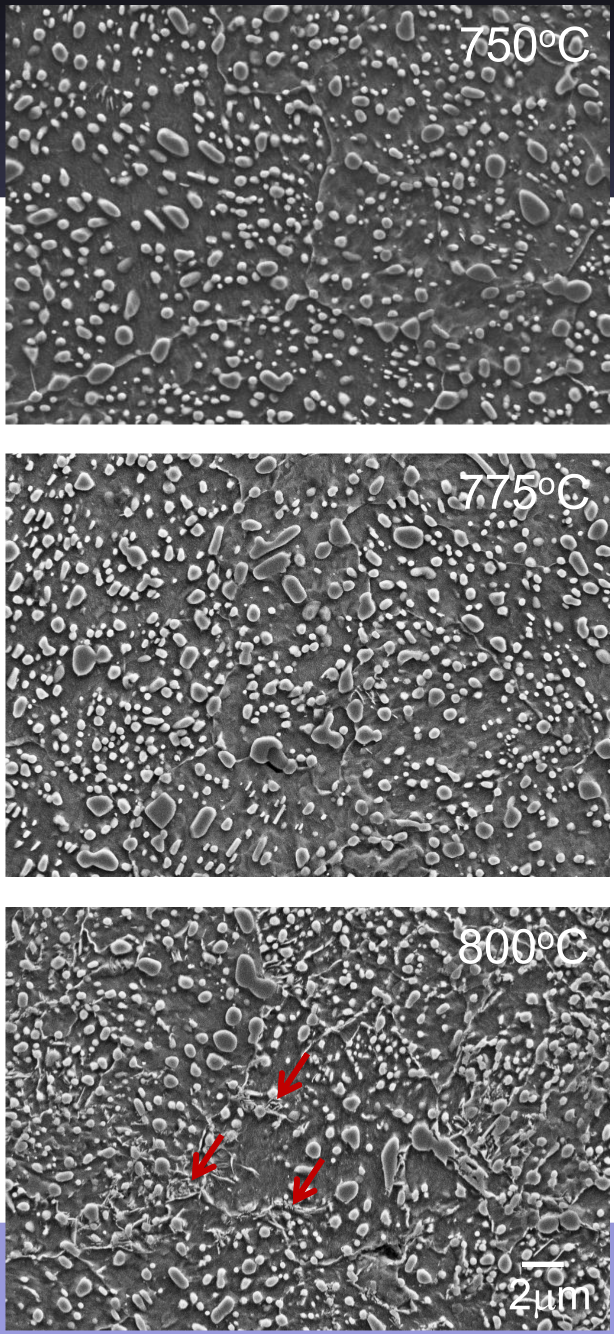
- Hyper-eutectoid steels
- Steel A : 1.0C-0.35Mn-0.25Si-1.4Cr
- Steel B : 1.0C-0.35Mn-1.25Si-1.4Cr



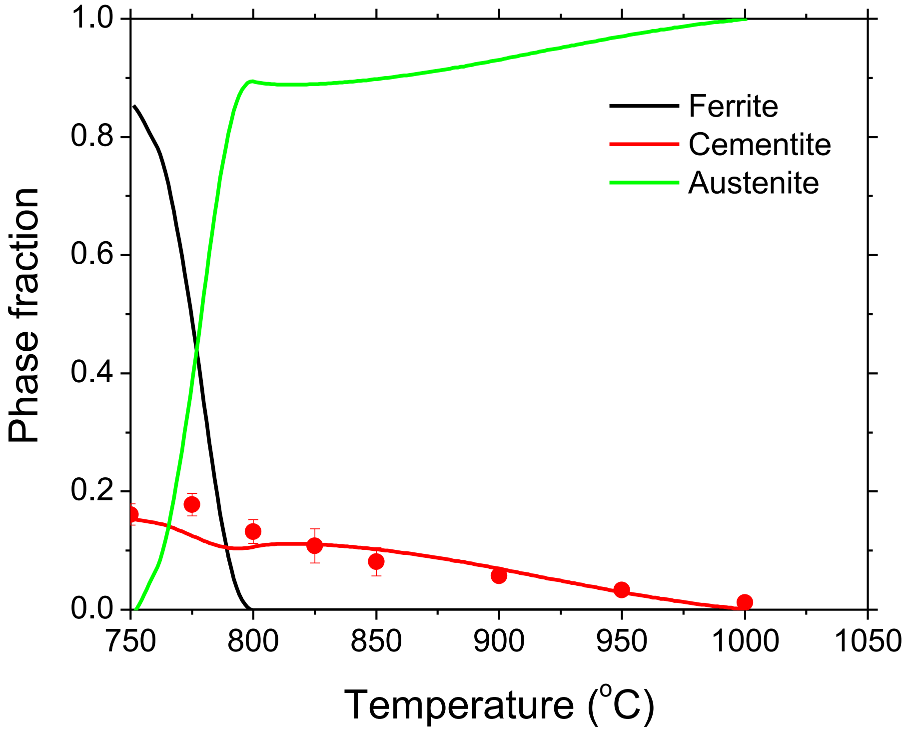


Stage I (Alloy A)

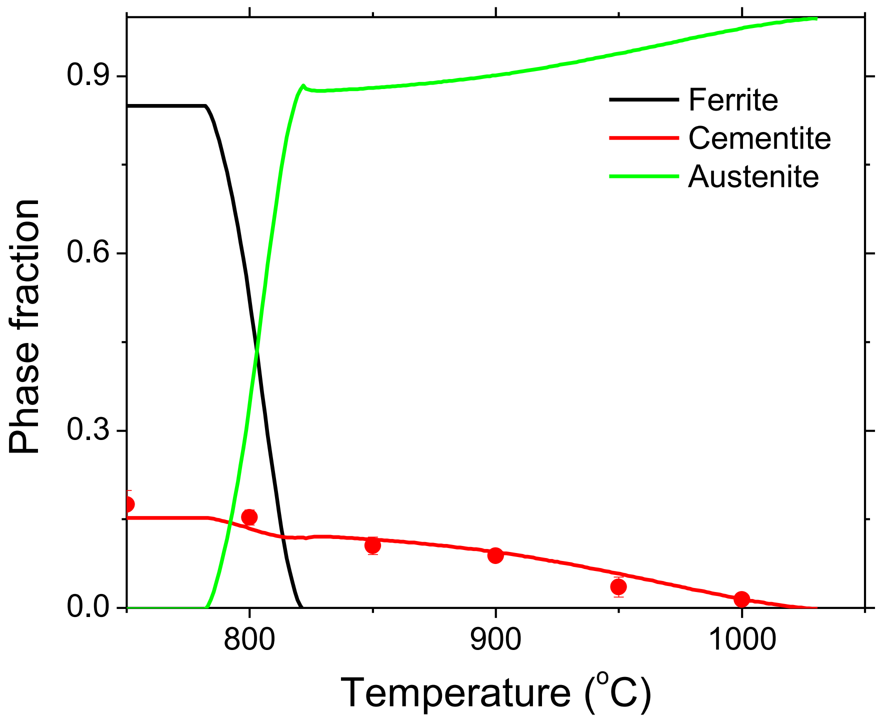




Overall analysis

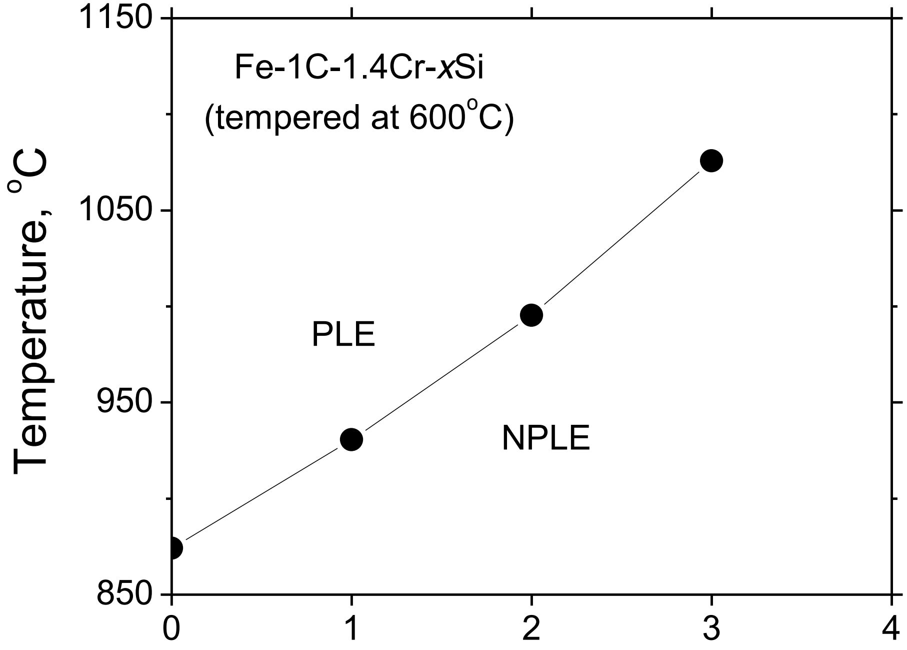


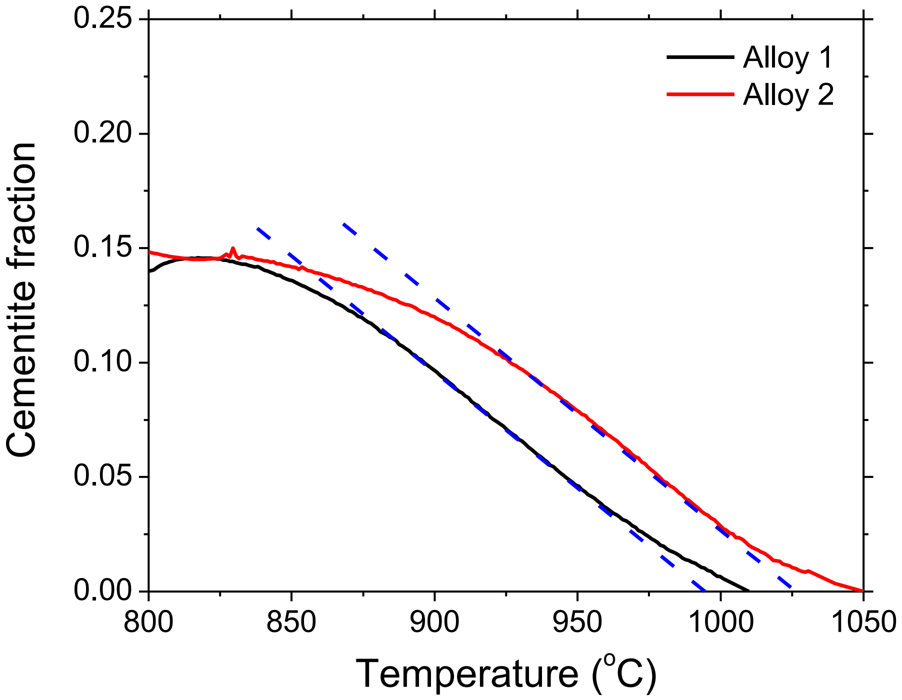
Alloy A



Alloy B

Cementite dissolution kinetics

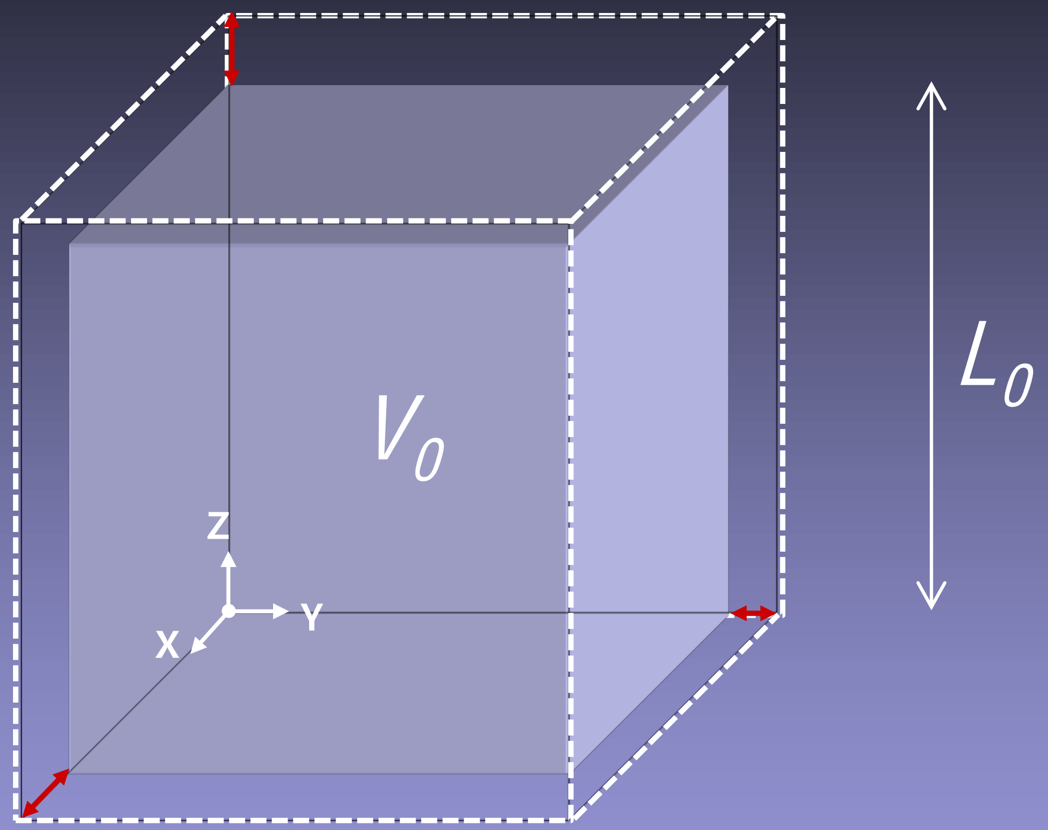




Summary

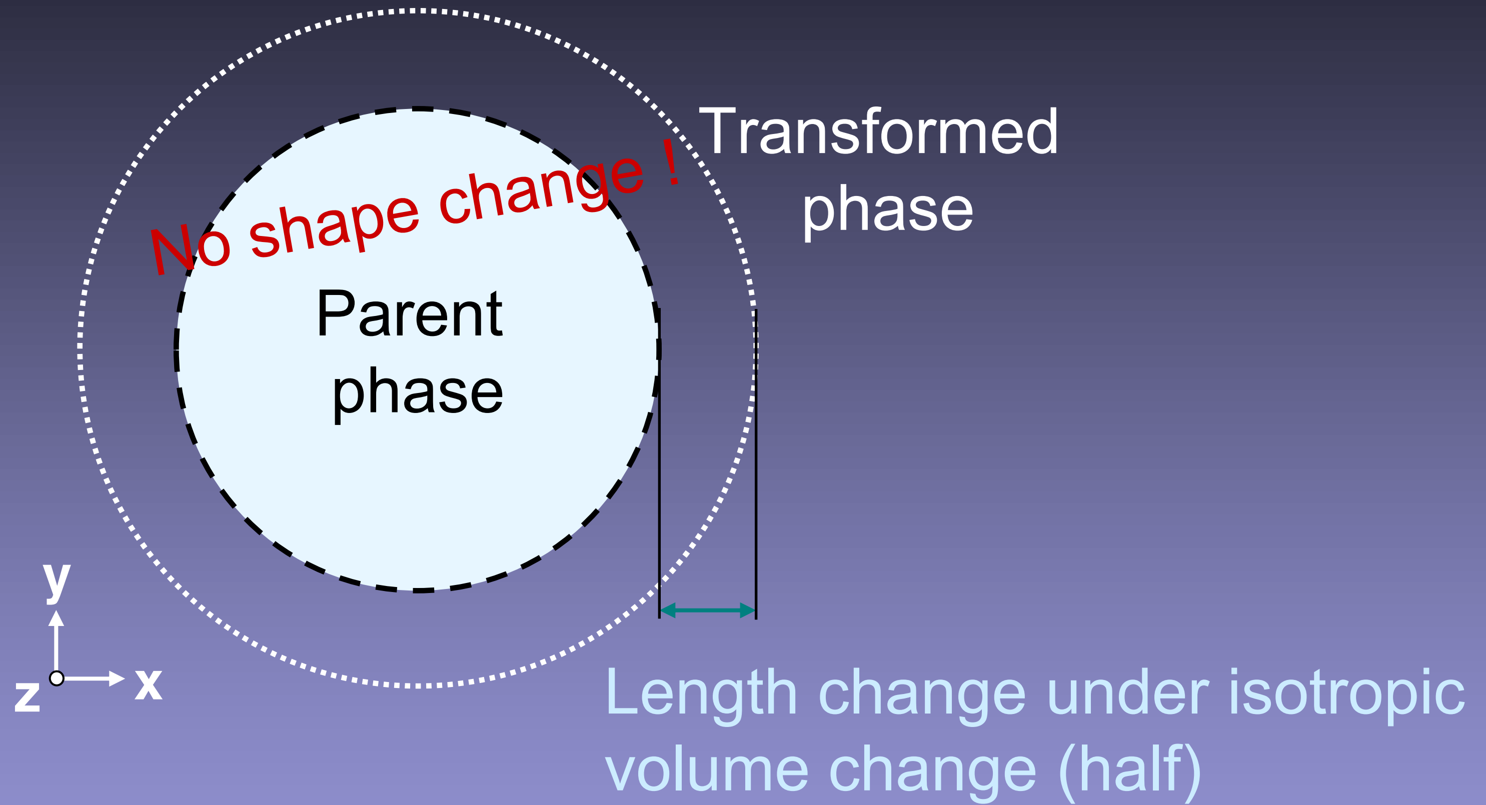
- Dilatometric analysis procedure is suggested for hypereutectoid steels on heating
- Partitioning of substitutional alloying elements is considered to estimate the carbon content in austenite
- Analysis results show reasonable agreement with metallographic one

Monitoring volume change



$$\frac{V - V_0}{V_0} \approx \frac{\Delta x + \Delta y + \Delta z}{L_0} \quad \left(\Delta x, \Delta y, \Delta z << L_0\right)$$

Length change to volume change



$$\frac{\Delta L_{iso}}{L_0} \approx \frac{1}{3} \cdot \left(\frac{V - V_0}{V_0} \right)$$