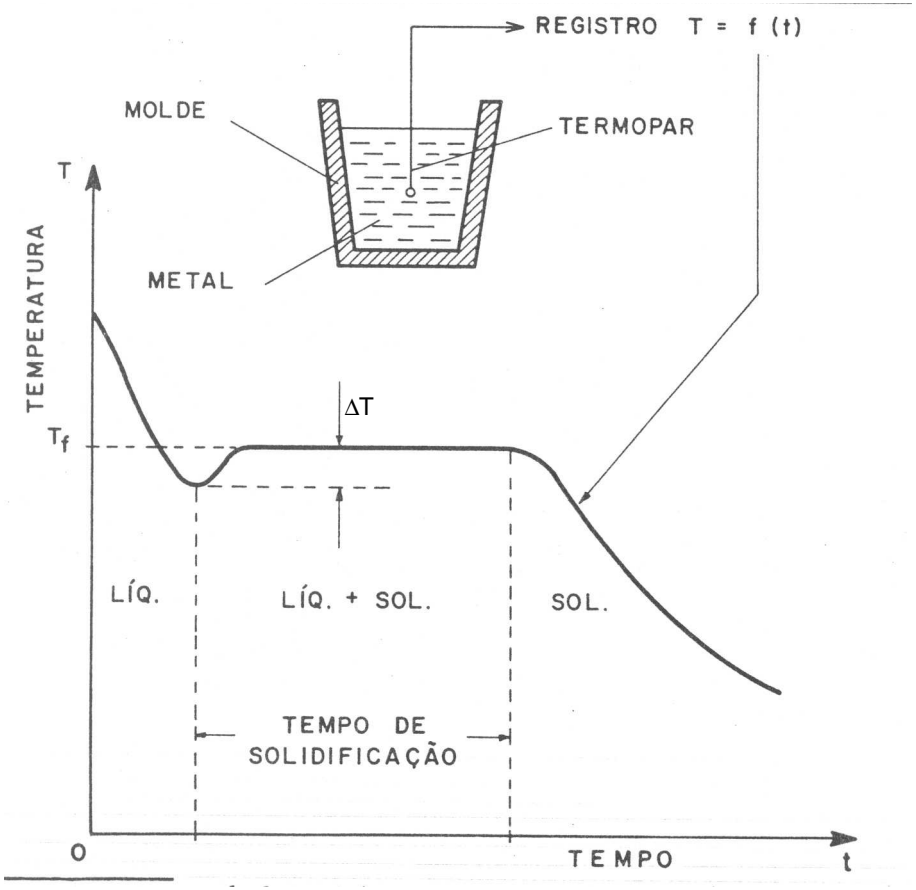
Transformações de Fases

Solidificação

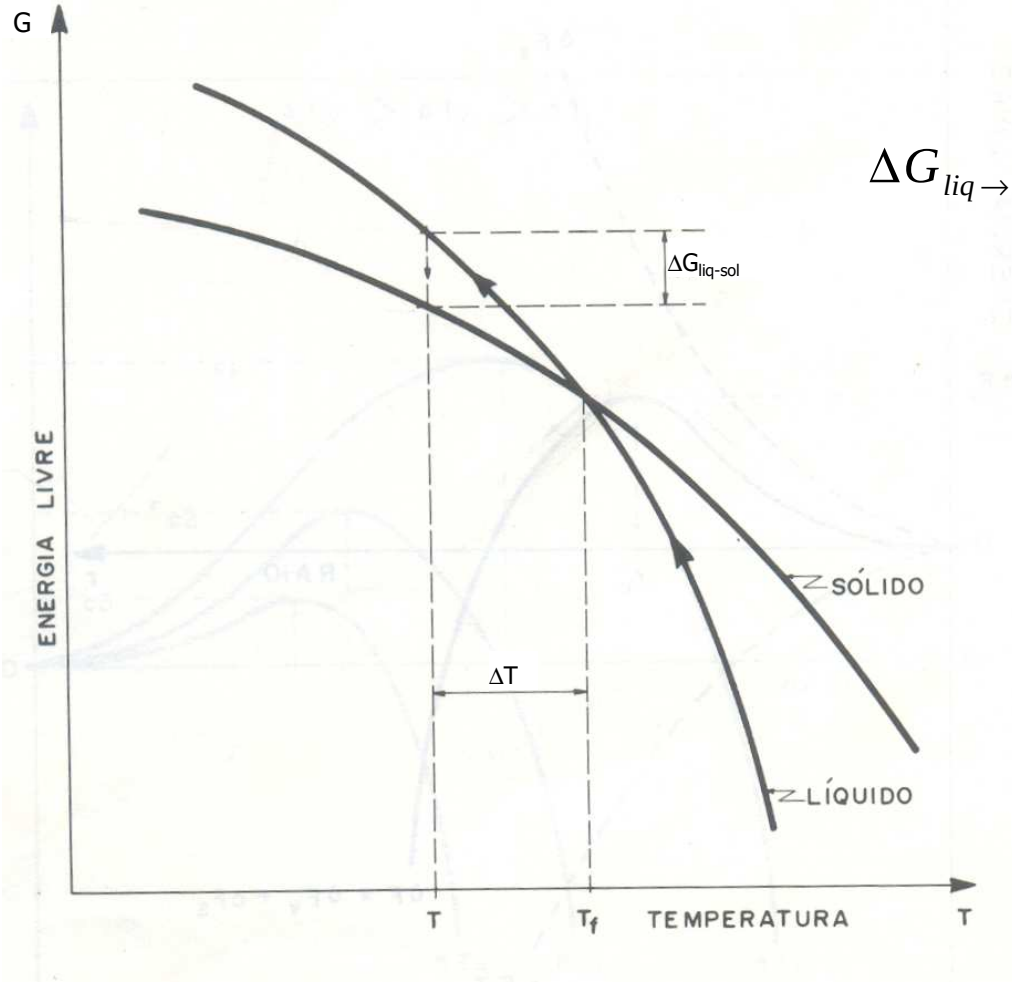
- Exemplo de Solidificação

Super-resfriamento Térmico



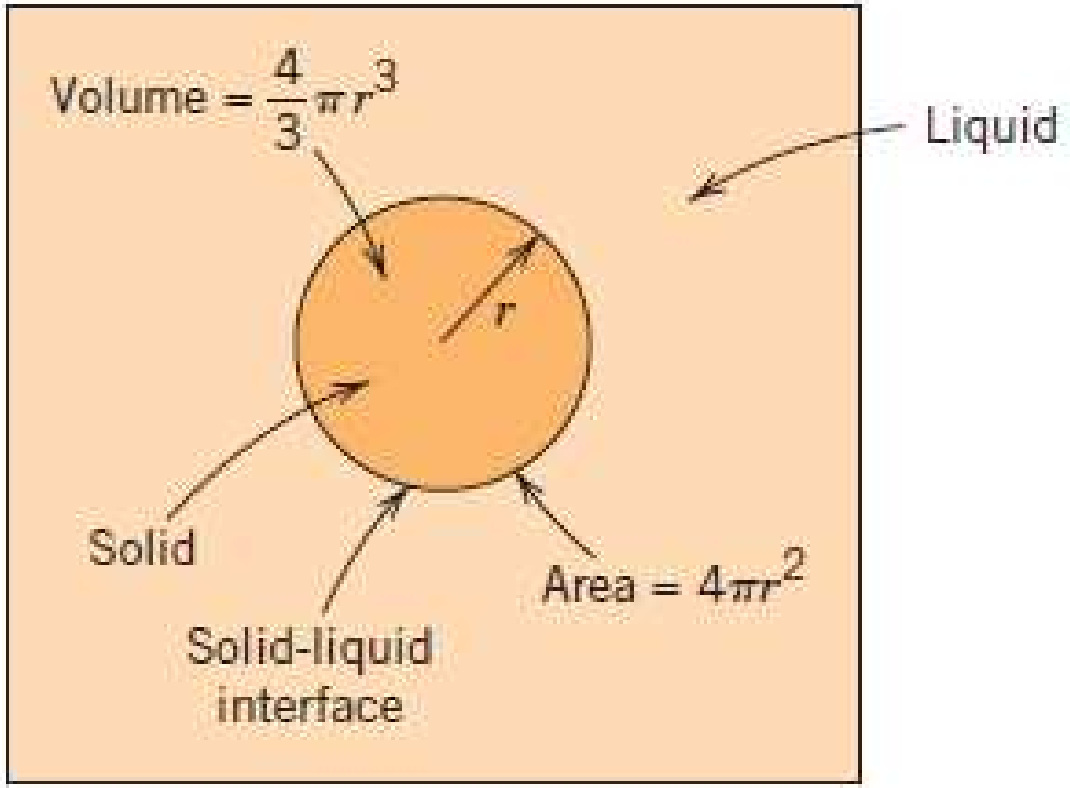
- Líquido super-resfriado 1
- Líquido super-resfriado 2

Variação da Energia Livre Líquido - Sólido



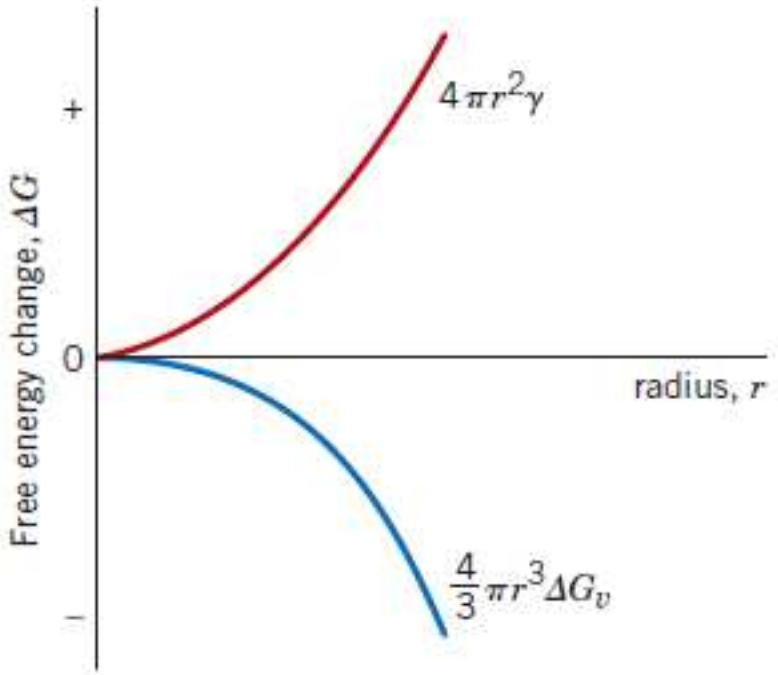
$$\Delta G_{liq \rightarrow sol} = -\frac{\Delta H_f \Delta T}{T_f}$$

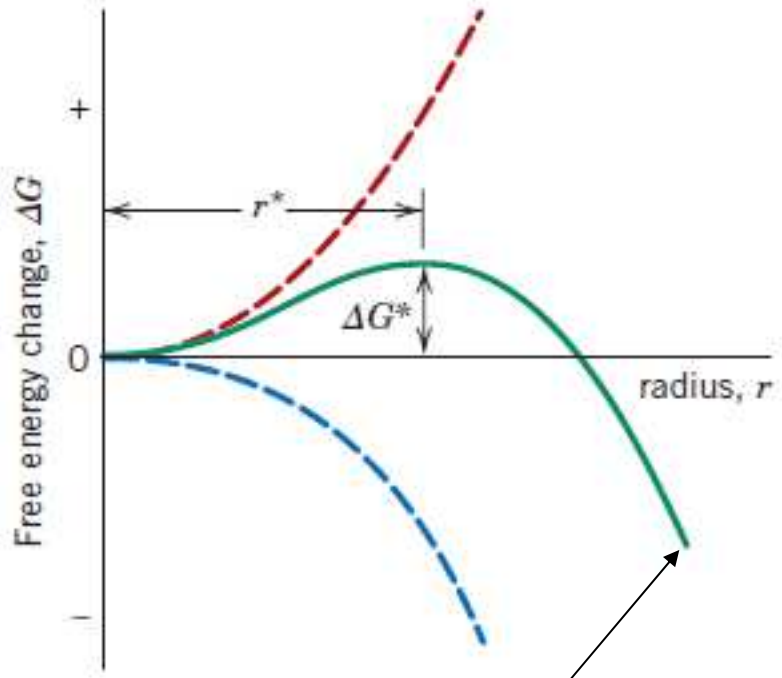
Nucleação Homogênea



Exemplo de tensão superficial

Nucleação Homogênea





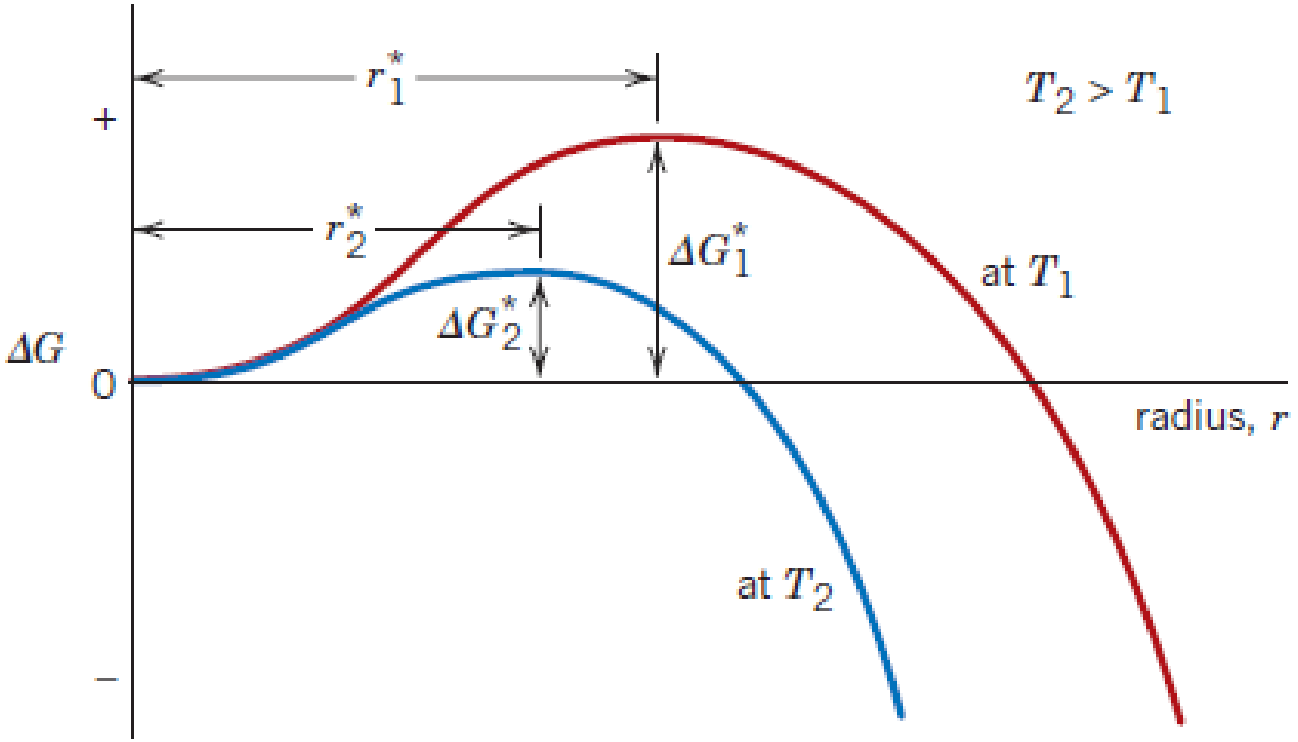
$$r^* = -\frac{2\gamma}{\Delta G_v}$$

$$\Delta G^* = \frac{16\pi\gamma^3}{3(\Delta G_v)^2}$$

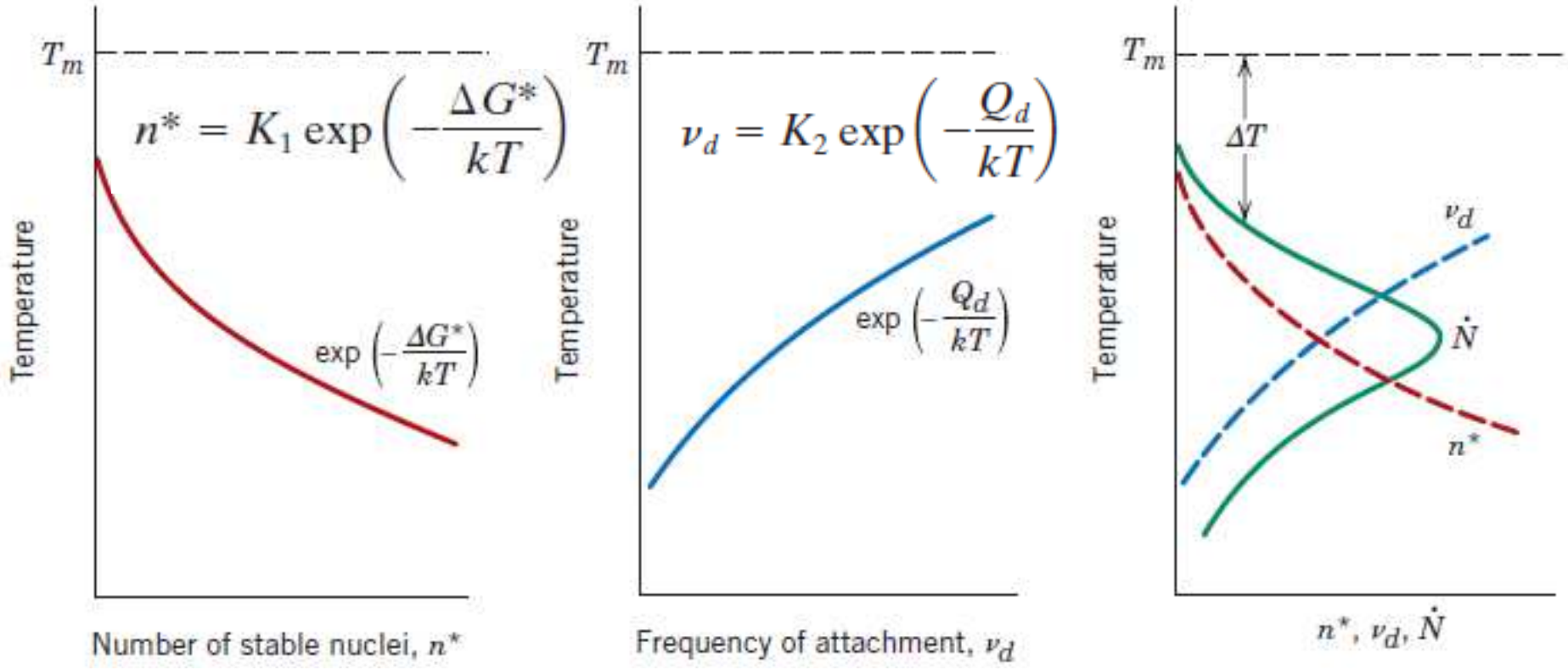
$$\Delta G_v = \frac{\Delta H_f(T_m - T)}{T_m}$$

$$\Delta G = \tfrac{4}{3}\pi r^3 \Delta G_v + 4\pi r^2\gamma$$

Nucleação Homogênea x ΔT

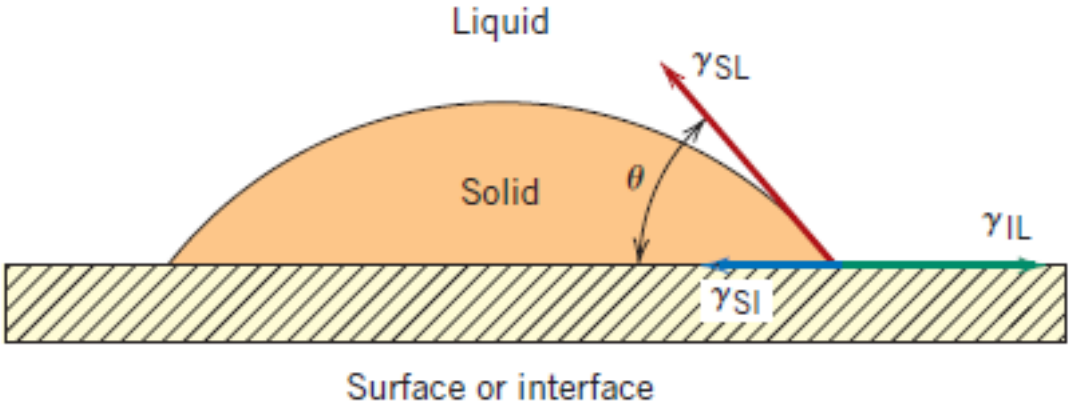


Taxa de Nucleação Homogênea



$$\dot{N} = K_3 n^* \nu_d = K_1 K_2 K_3 \left[\exp\left(-\frac{\Delta G^*}{kT}\right)\exp\left(-\frac{Q_d}{kT}\right)\right]$$

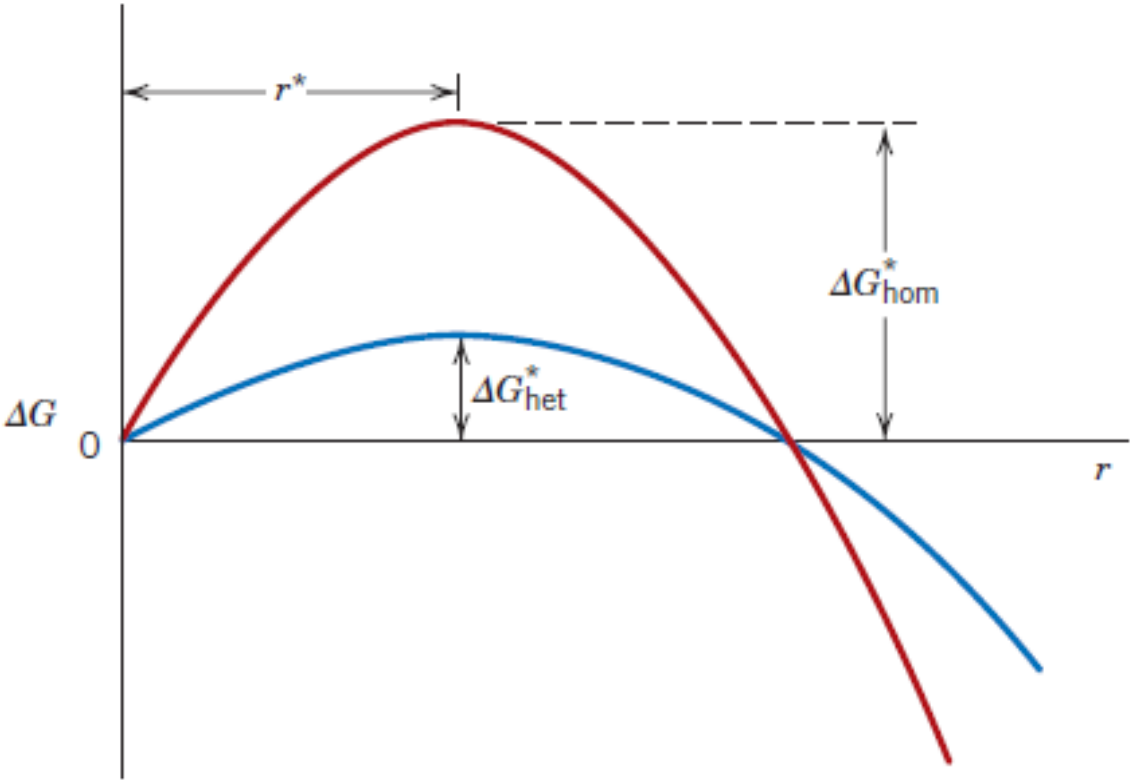
Nucleação Heterogênea

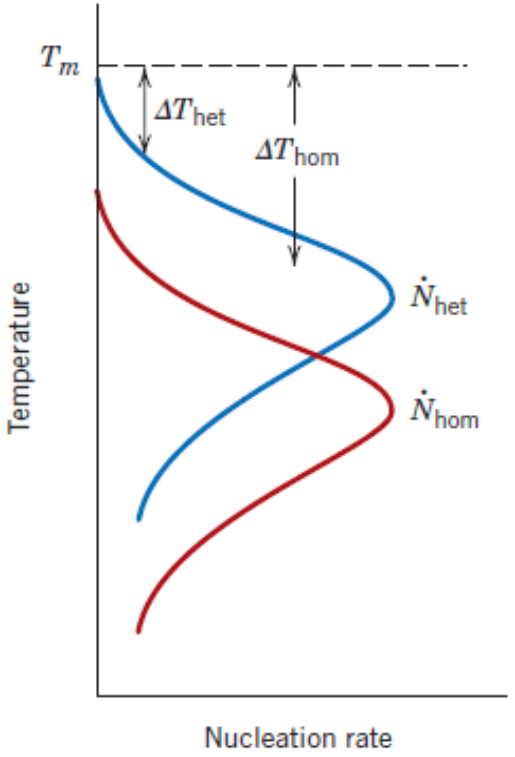


$$\gamma_{IL} = \gamma_{SI} + \gamma_{SL} \cos \theta$$

$$S(\theta) = \frac{(2 + \cos\theta)(1 - \cos\theta)^2}{4}$$

Heterogênea x Homogênea



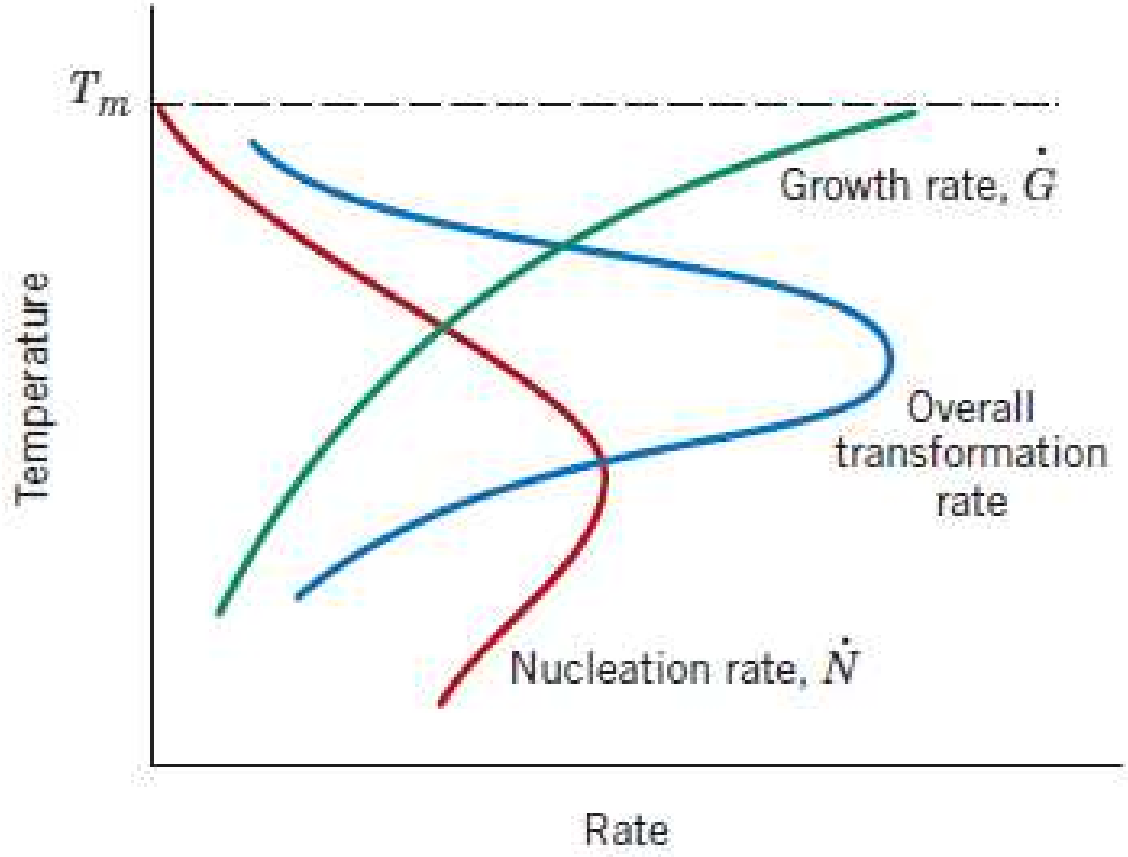


$$r^* = -\frac{2\gamma_{SL}}{\Delta G_v}$$

$$\Delta G^* = \left(\frac{16\pi\gamma_{SL}^3}{3\Delta G_v^2}\right) S(\theta)$$

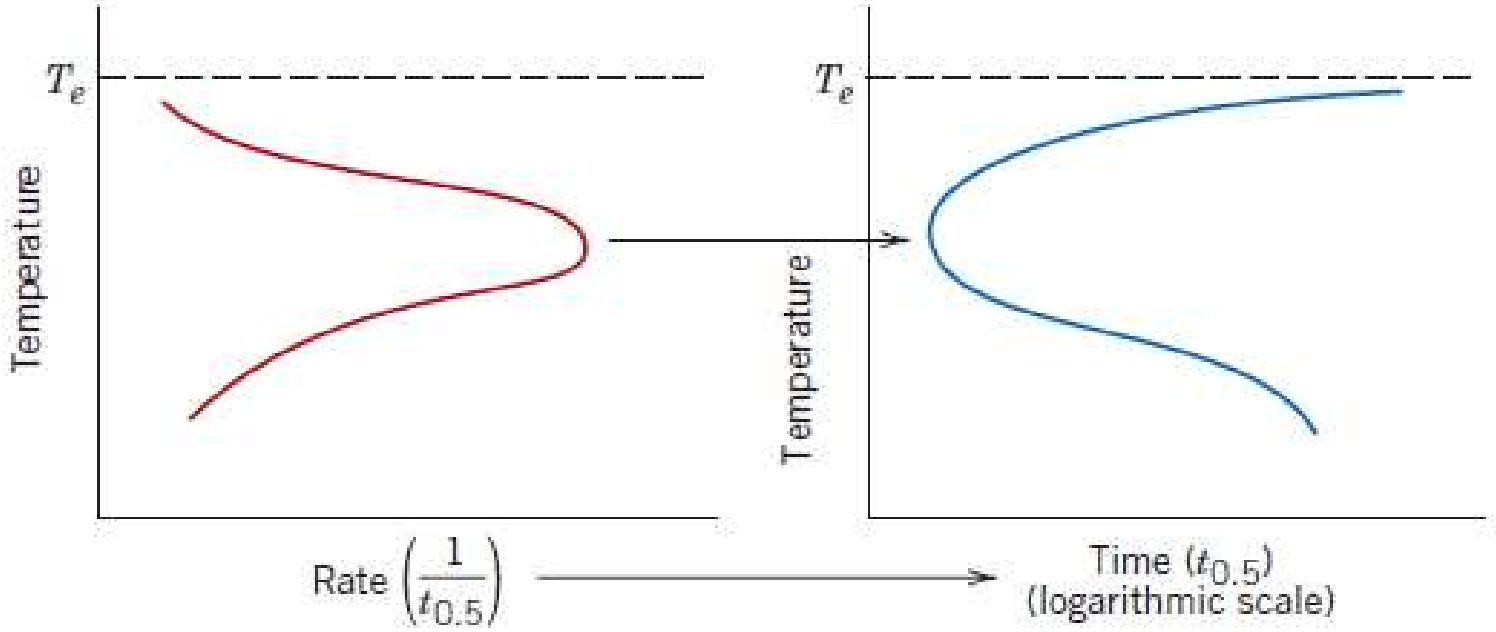
$$\Delta G^*_{het} = \Delta G^*_{hom} S(\theta)$$

Crescimento

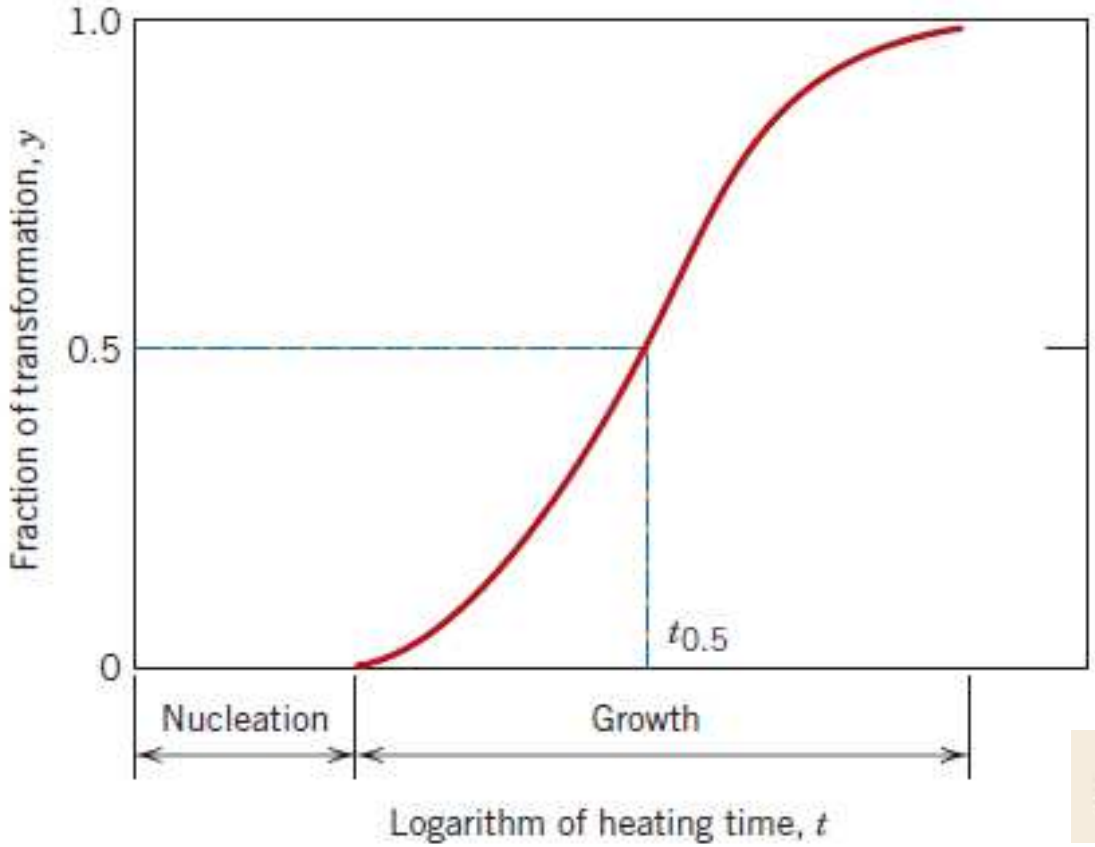


$$\dot{G} = C \exp\left(-\frac{Q}{kT}\right)$$

Diagrama TTT

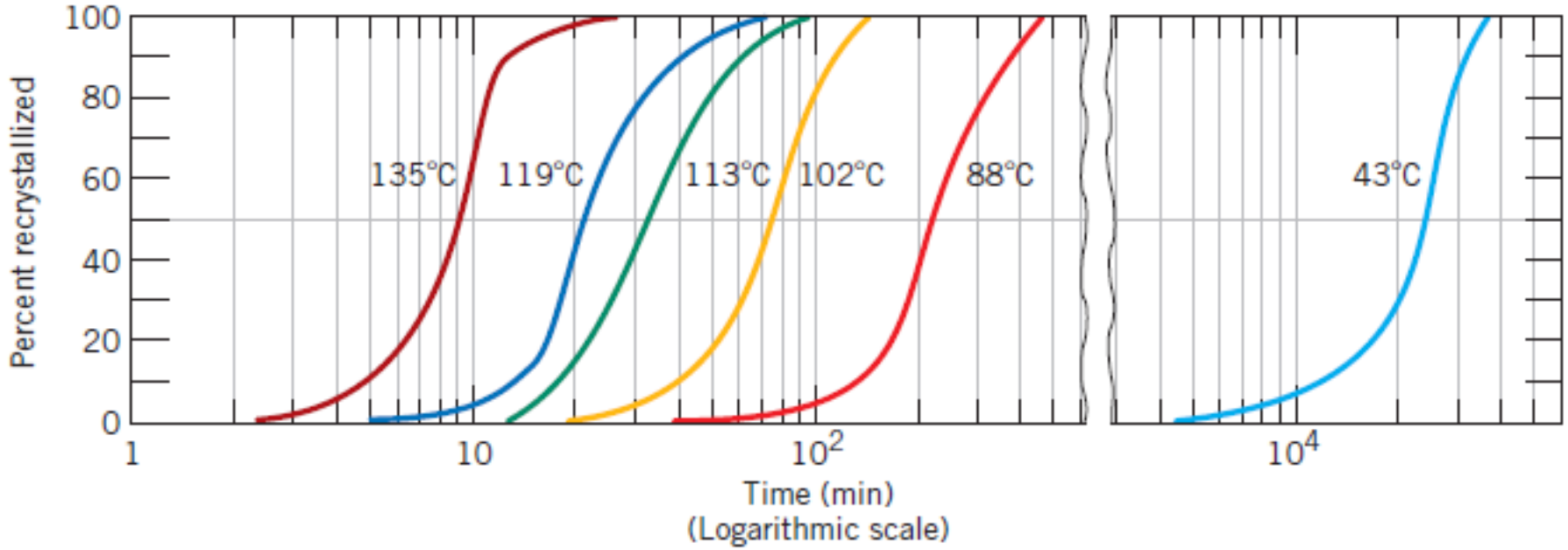


Fração transformada x Tempo

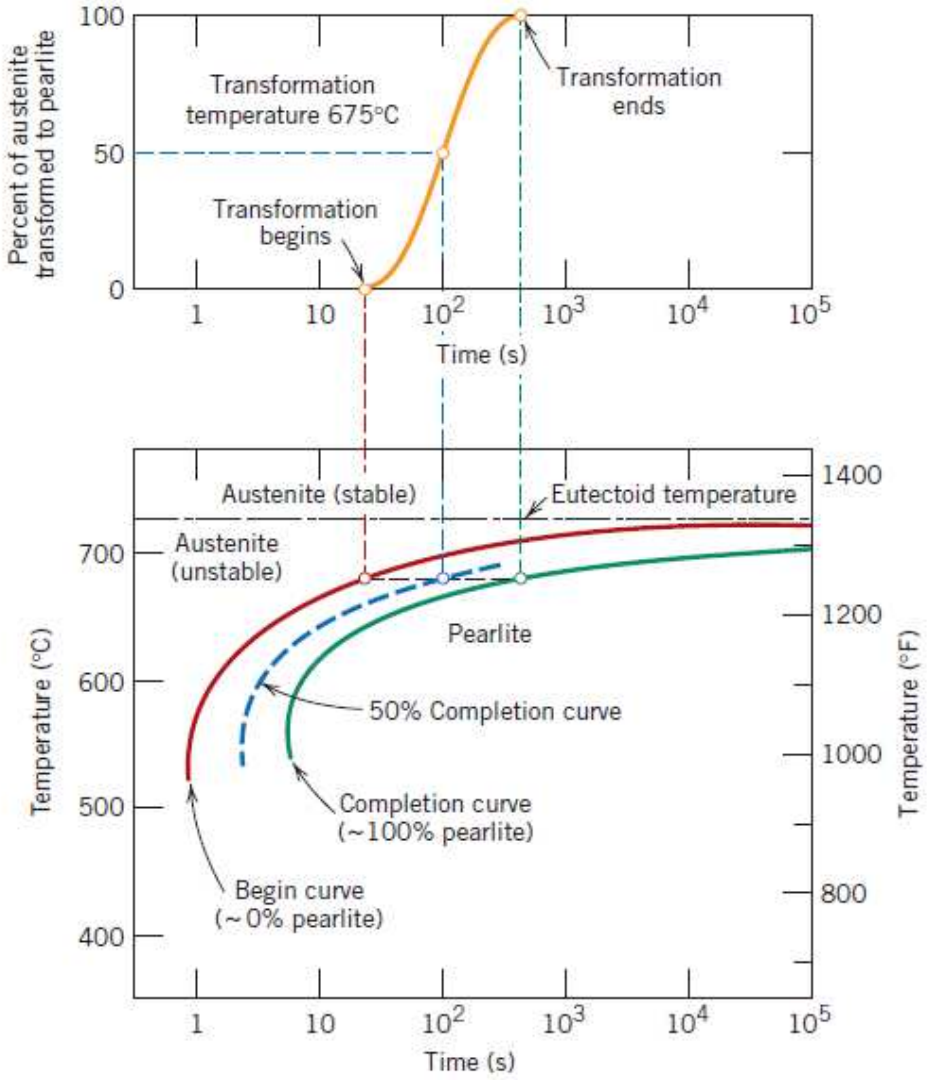


$$y = 1 - \exp(-kt^n)$$

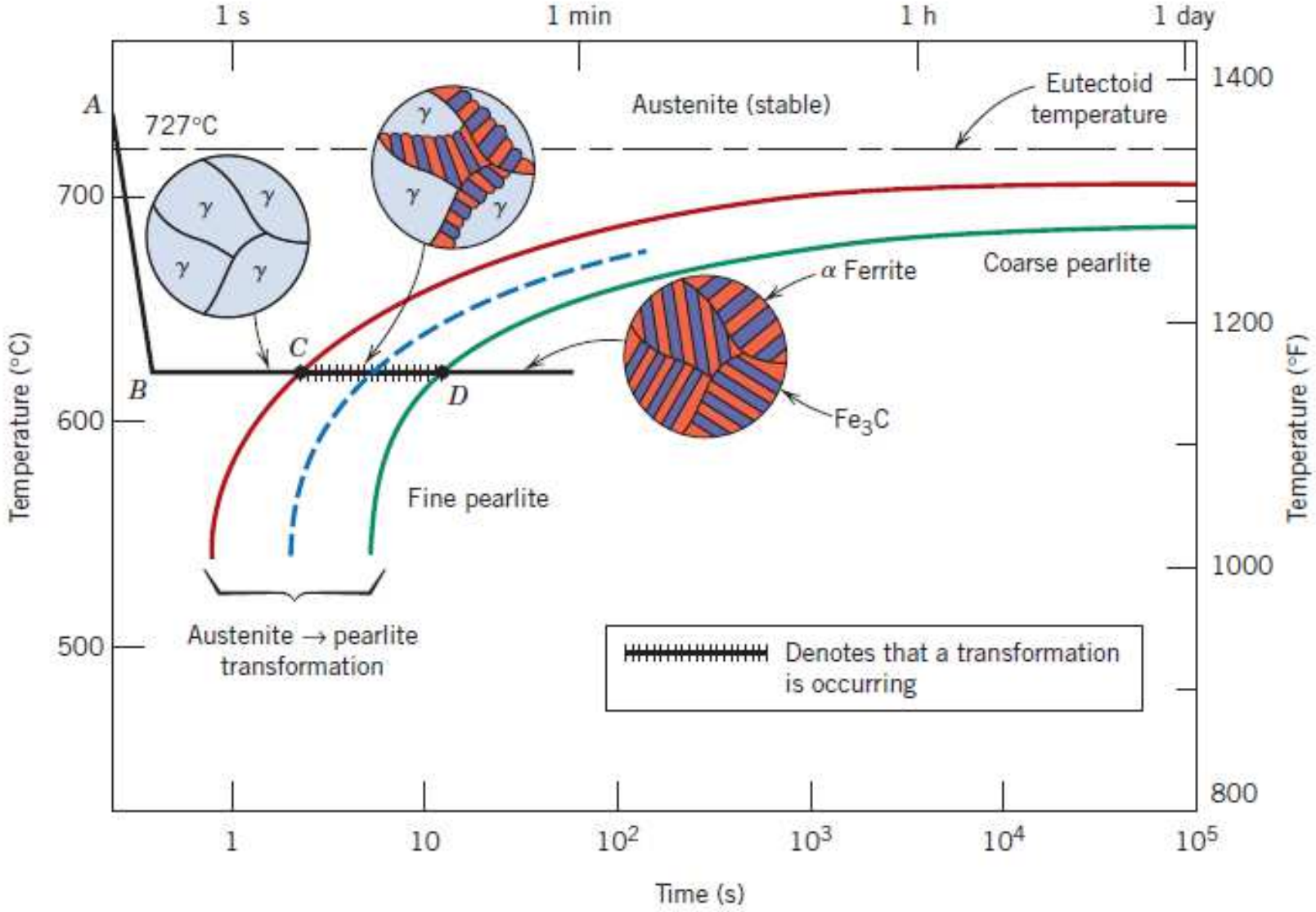
Efeito da temperatura



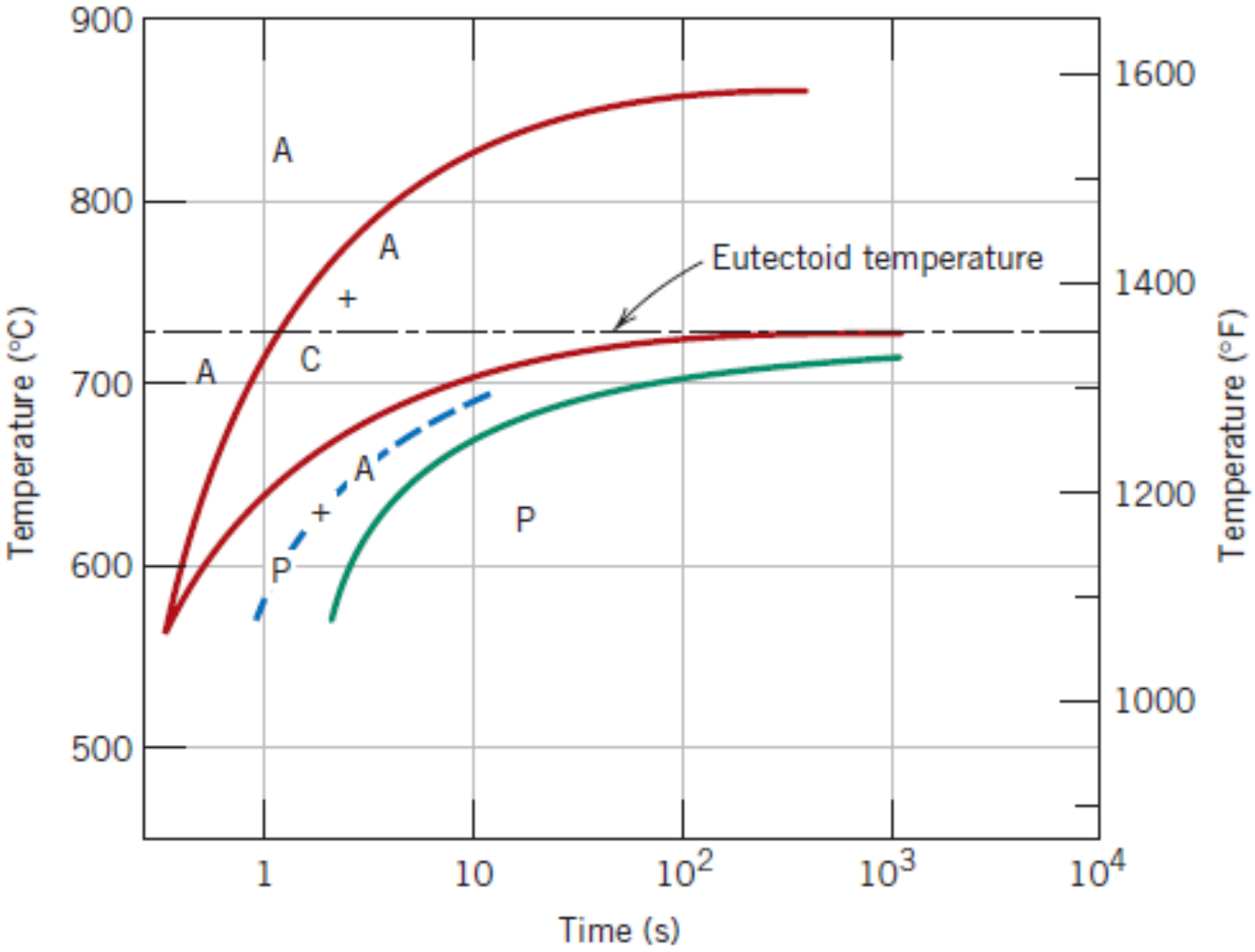
Exemplo de TTT (aço eutetóide)



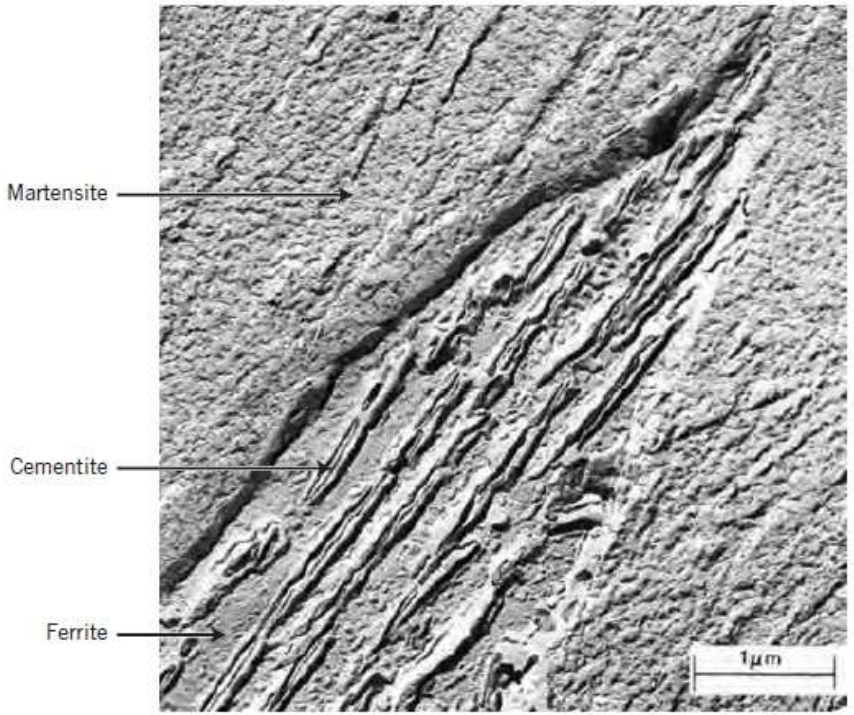
Evolucão da microestrutura



Outro exemplo: aço hipereutetóide

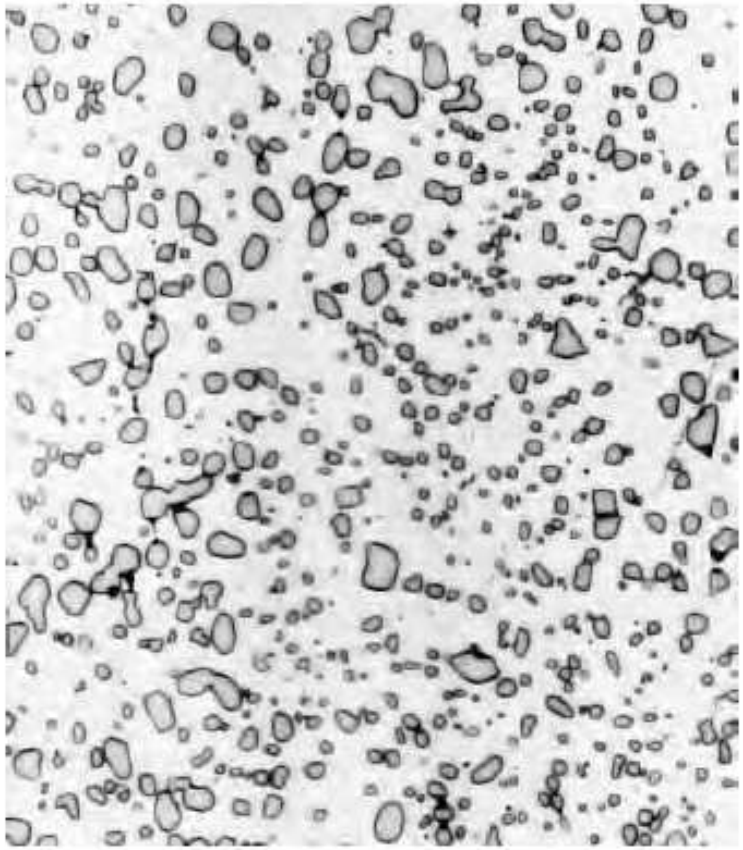


Perlita Grossa, Perlita Fina e Bainita

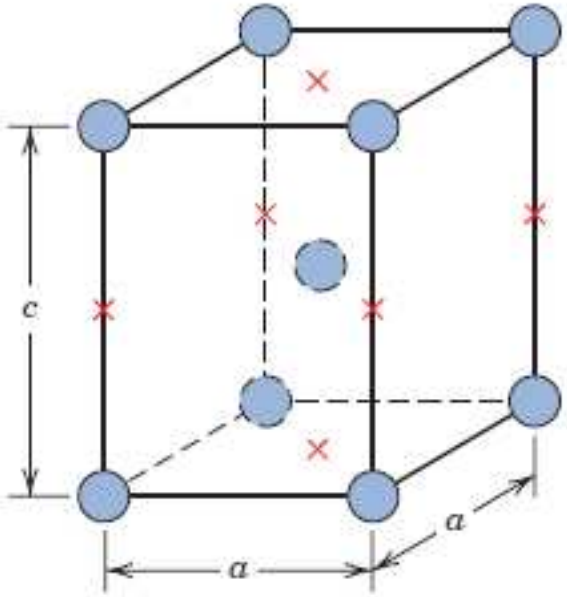


Esferoidita

- Redução da superfície específica (G menor, mais próxima do equilíbrio)

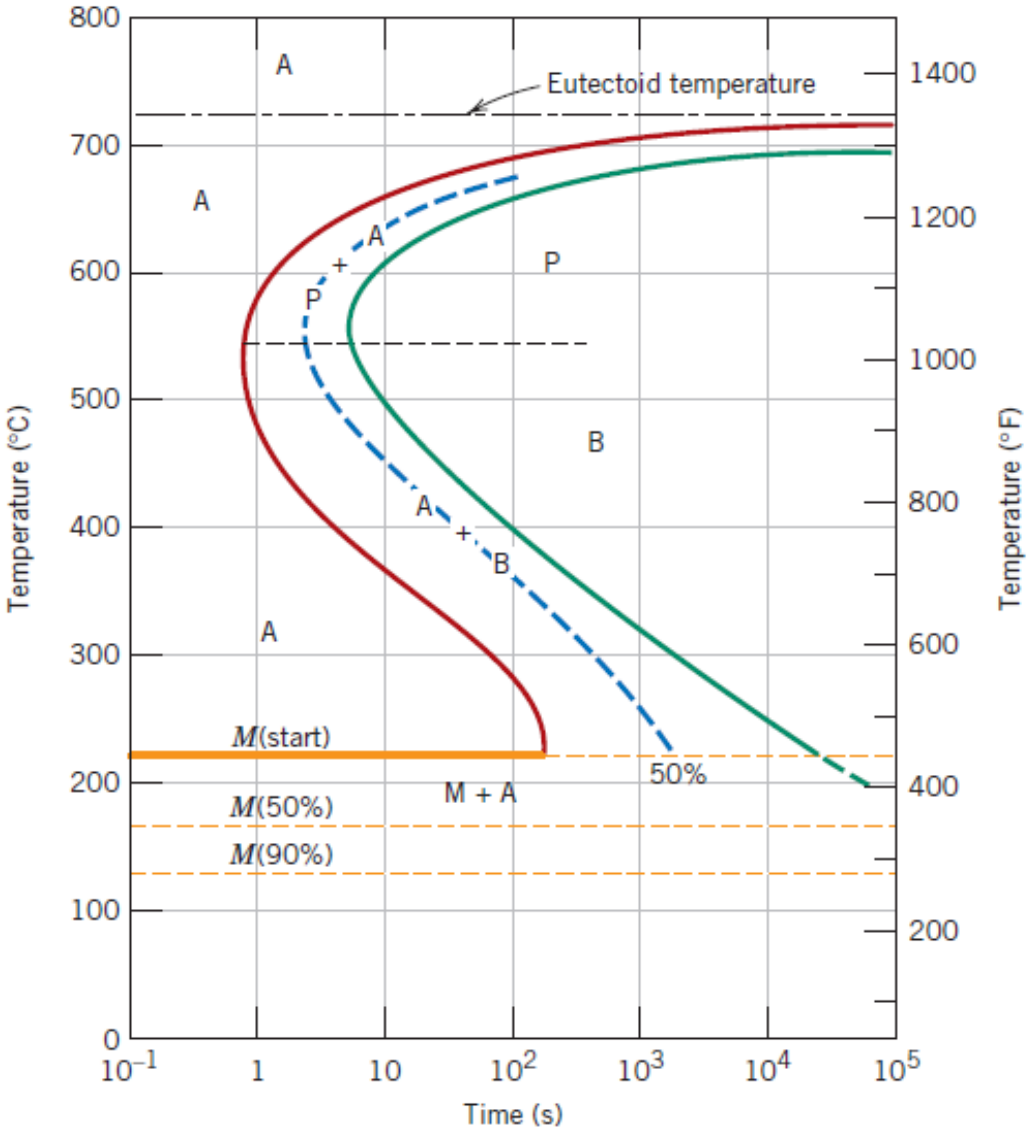


Exemplo de fase metaestável: Martensita



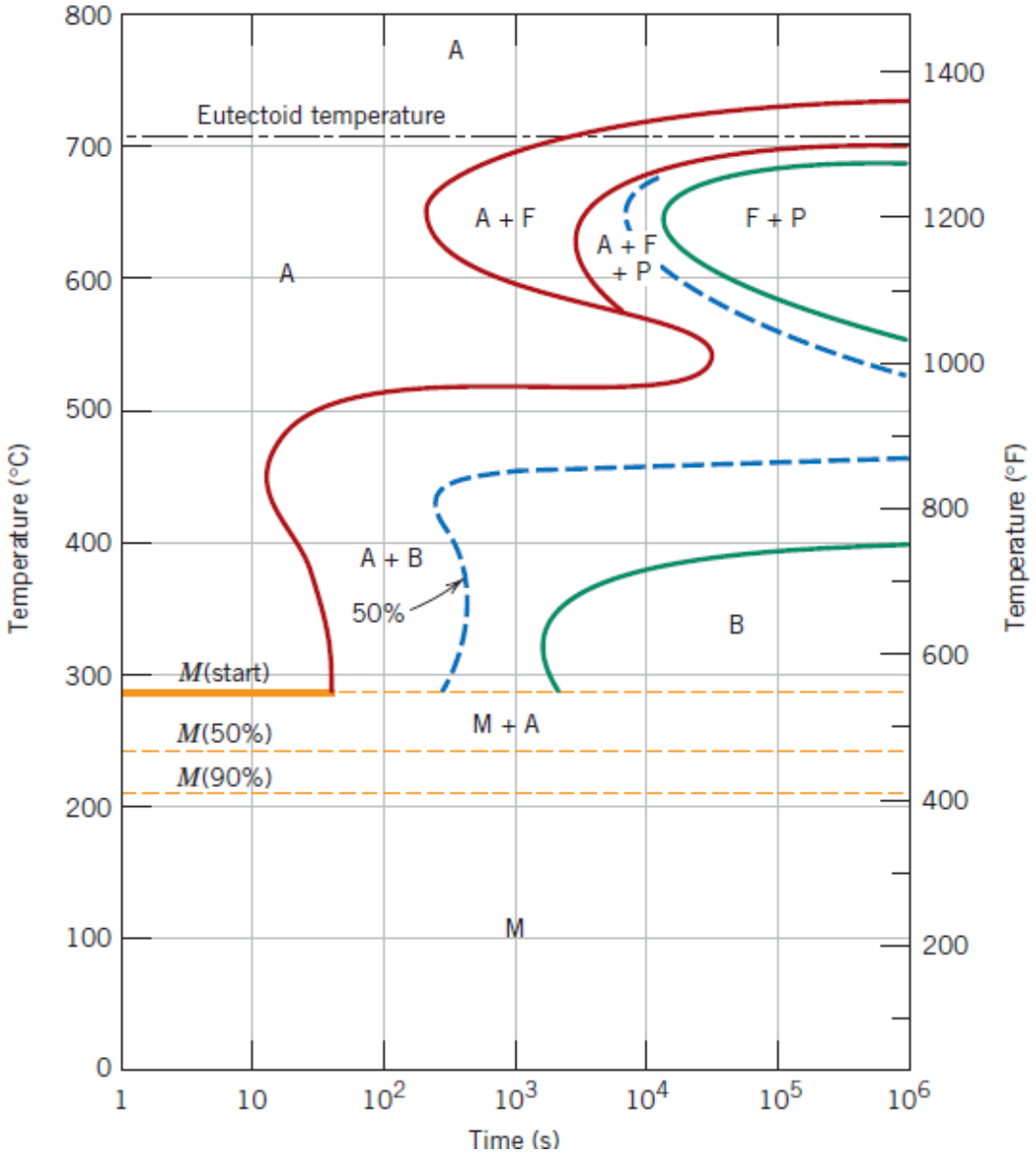
Exemplo de TTT

Aço AISI 1080

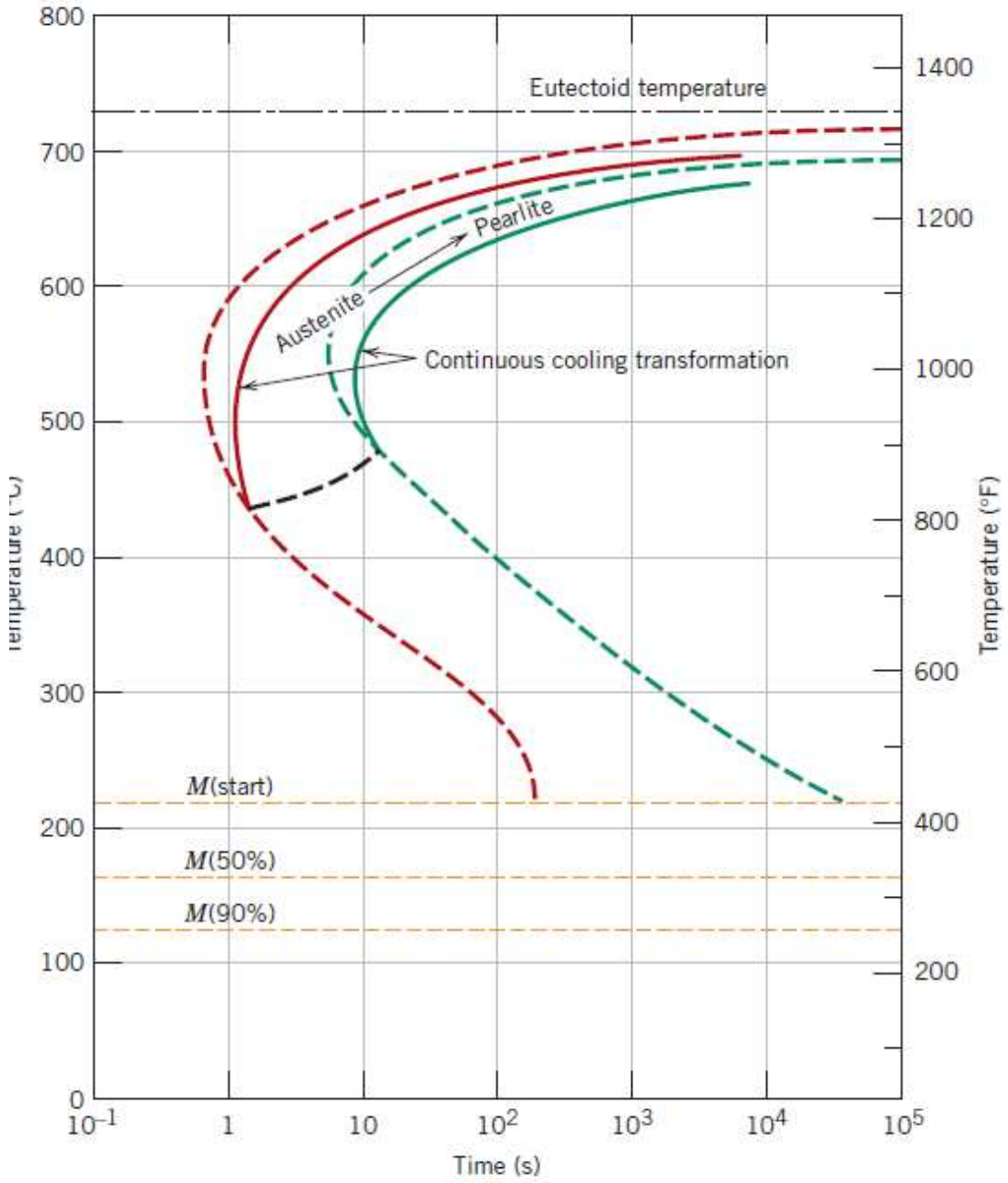


Outro exemplo

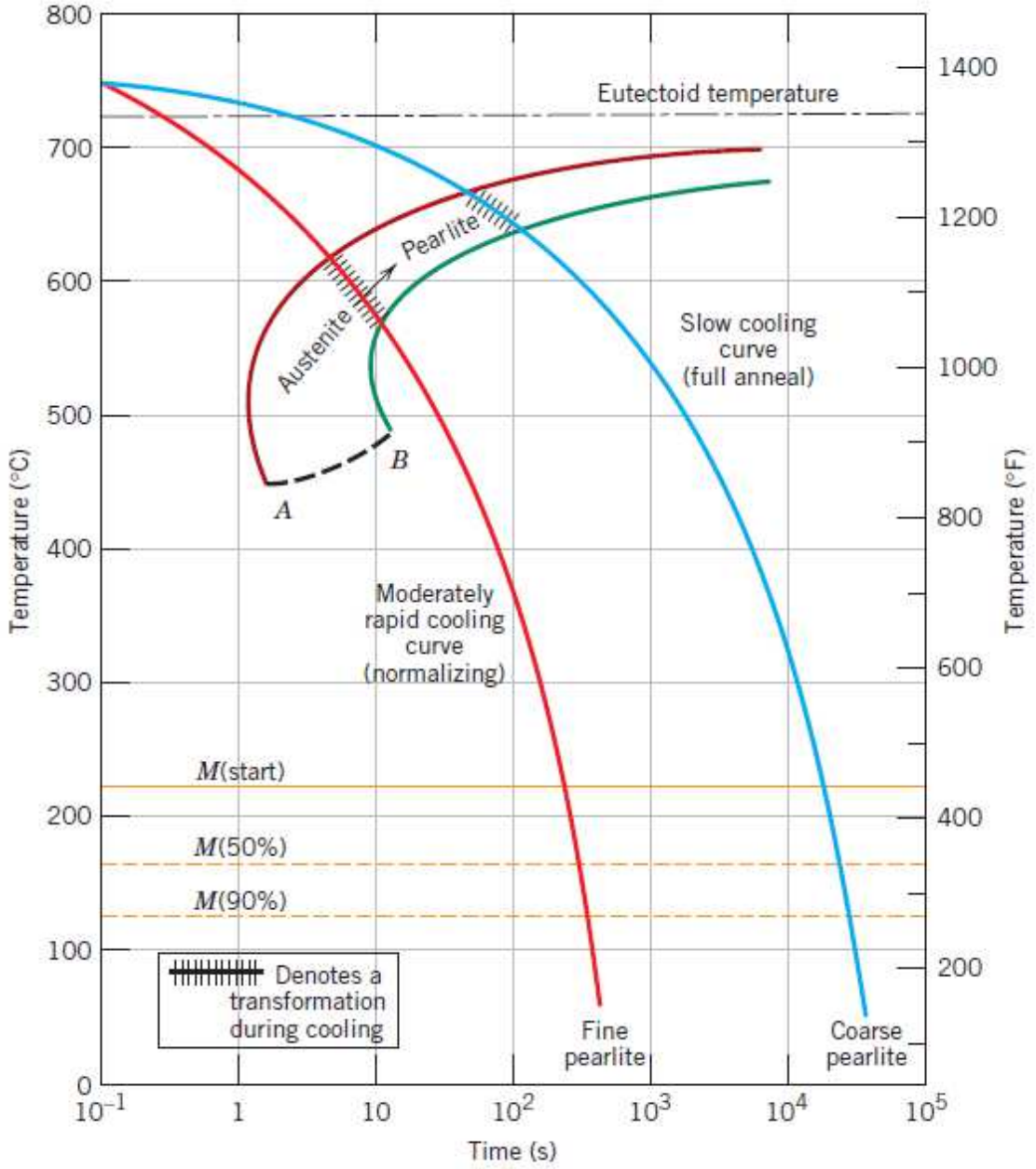
Aço AISI 4340



CCT


Eutectoid temperature
Pearlite
Austenite
Continuous cooling transformation
M(start)
M(50%)
M(90%)
Temperature (°C)
Temperature (°F)
Time (s)
800
700
600
500
400
300
200
100
0
1400
1200
1000
800
600
400
200
10⁻¹
1
10
10²
10³
10⁴
10⁵

CCT


Eutectoid temperature
Austenite
Pearlite
A
B
Slow cooling curve (full anneal)
Moderately rapid cooling curve (normalizing)
M(start)
M(50%)
M(90%)
Denotes a transformation during cooling
Fine pearlite
Coarse pearlite
Temperature (°C)
Temperature (°F)
Time (s)
800
700
600
500
400
300
200
100
0
1400
1200
1000
800
600
400
200
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}

CCT

Aço AISI 4340