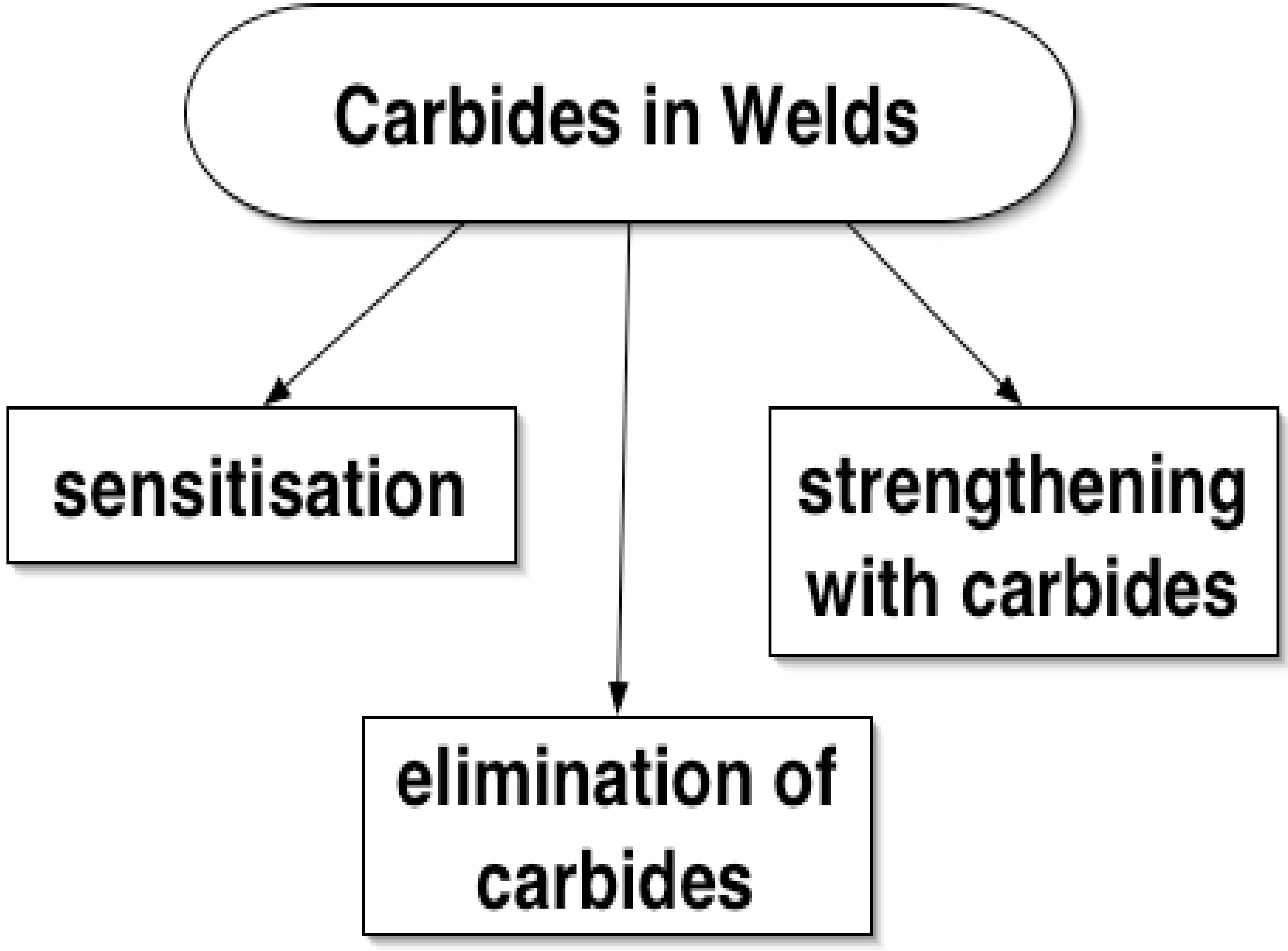
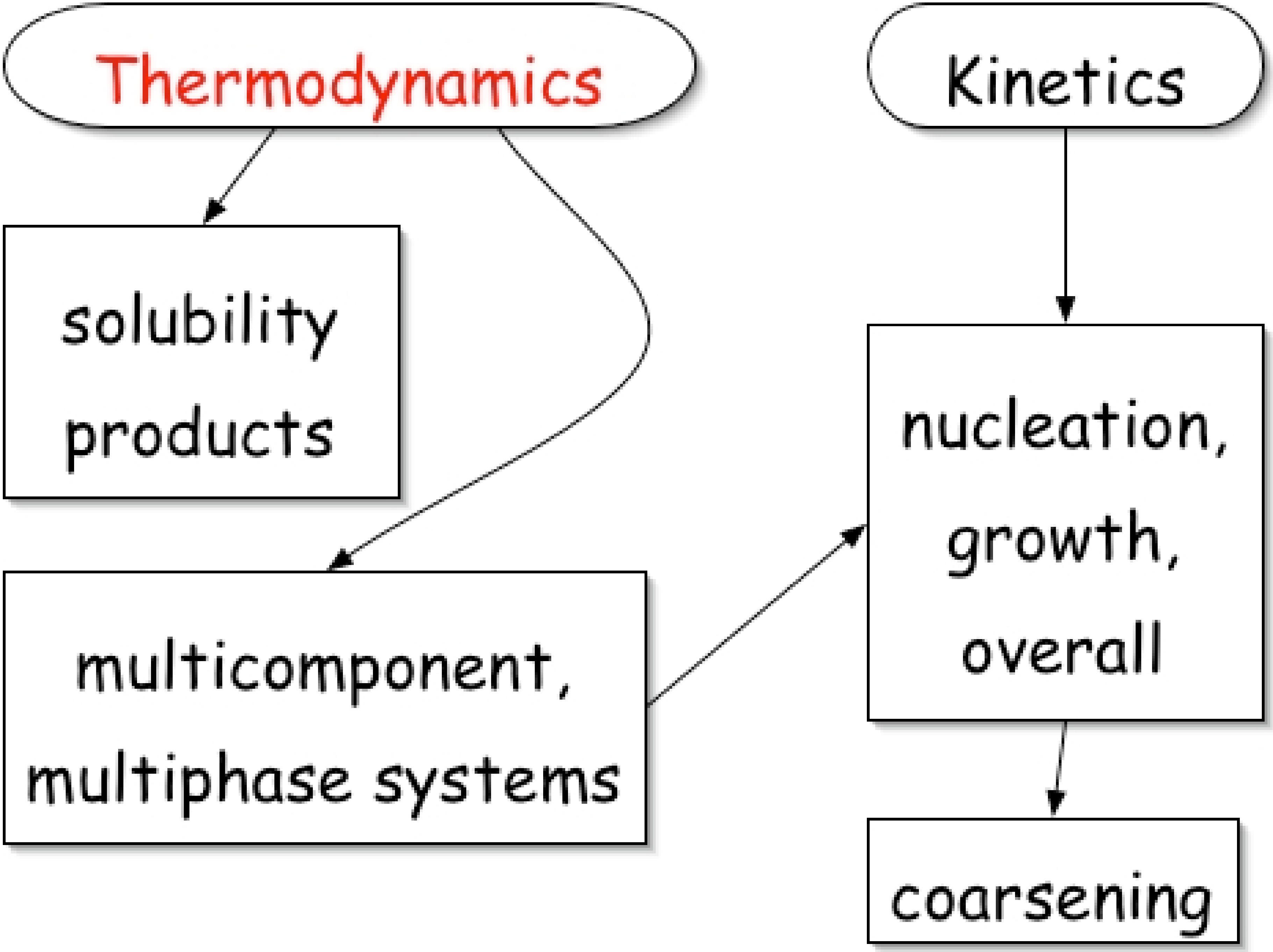
Carbide Precipitation in Steel Weld Metals

www.msm.cam.ac.uk/phase-trans

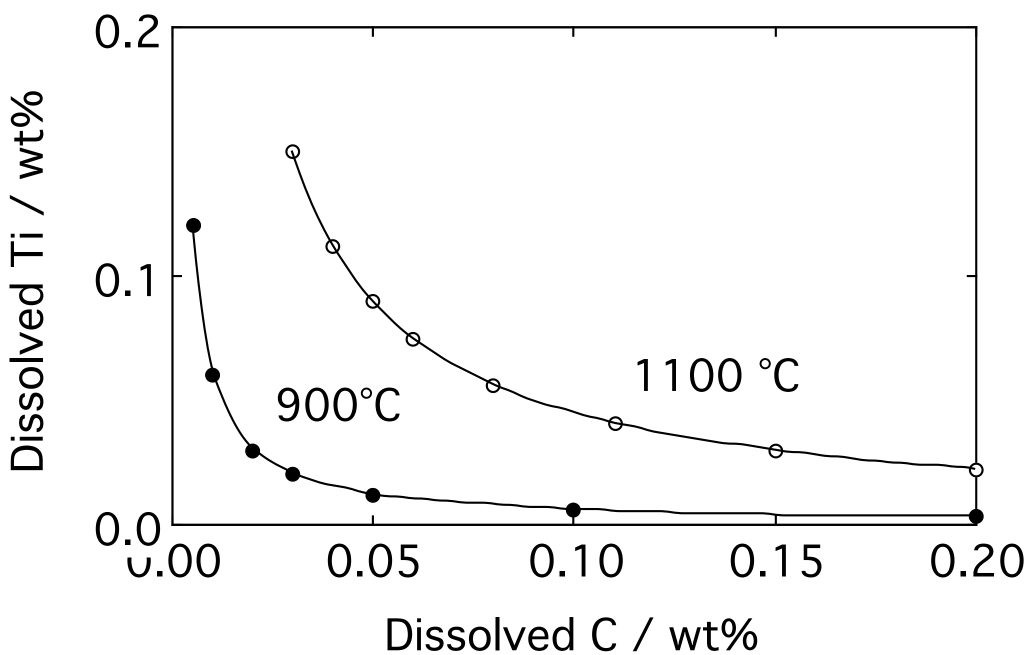
UNIVERSITY OF CAMBRIDGE


Carbides in Welds
sensitisation
elimination of carbides
strengthening with carbides


Thermodynamics
Kinetics
solubility products
multicomponent, multiphase systems
nucleation, growth, overall
coarsening

$$\mathrm{Ti}_\gamma + \mathrm{C}_\gamma \rightleftharpoons \mathrm{TiC}$$

$$\log\{\mathrm{w}_{\mathrm{Ti}_\gamma}\mathrm{w}_{\mathrm{C}_\gamma}\} = \frac{-7000}{T} + 2.35$$

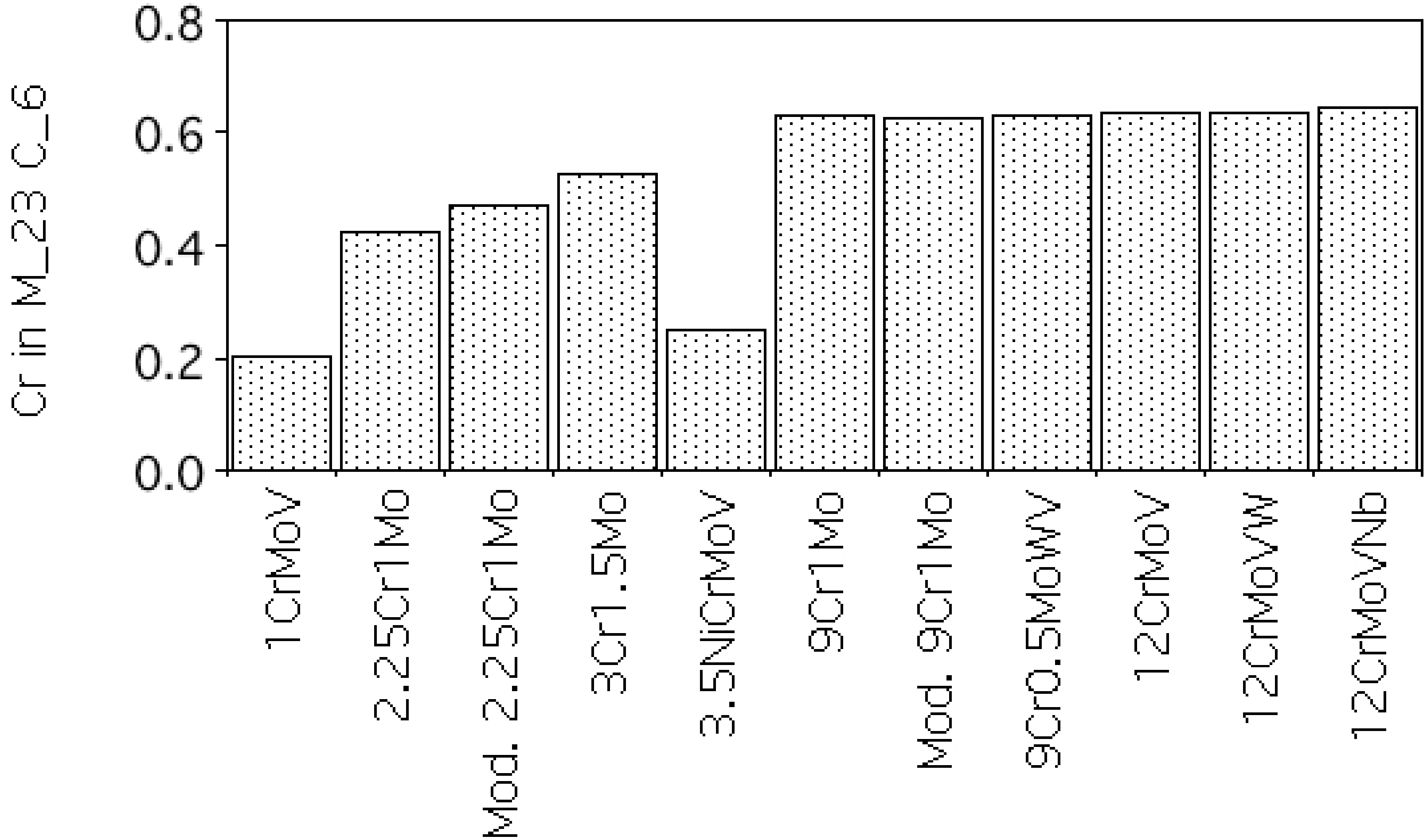


$$\Delta G = 0 = \Delta G^0 + RT \ln\left\{ \frac{a_{\mathrm{TiC}}}{a_{\mathrm{Ti}_\gamma} a_{\mathrm{C}_\gamma}} \right\}$$

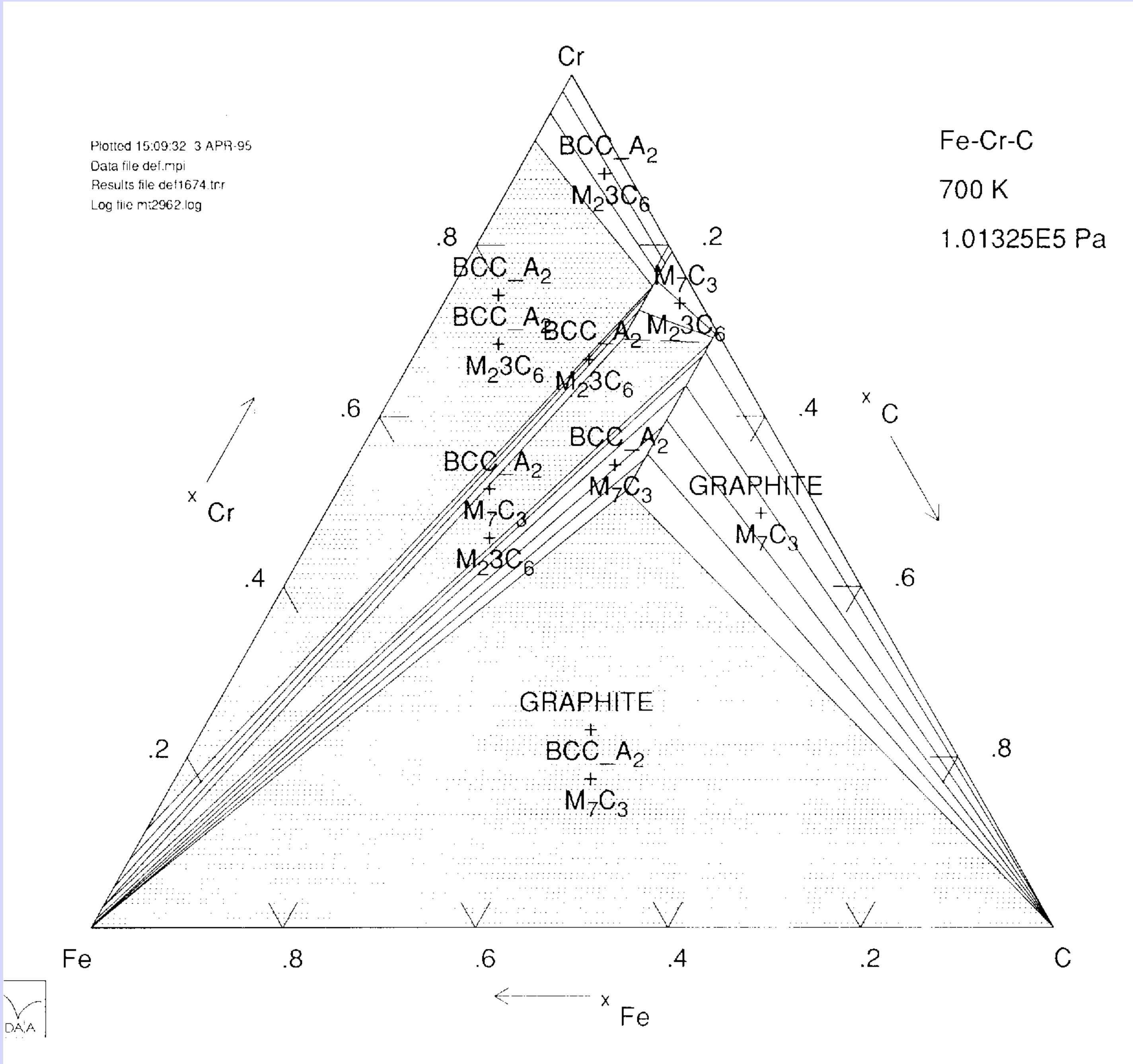
$$\Delta G^0 = \Delta H^0 - T\Delta S^0$$

$$\ln\{\mathrm{w}_{\mathrm{Ti}_\gamma} \mathrm{w}_{\mathrm{C}_\gamma}\} = \frac{-\Delta H^0}{RT} + \frac{\Delta S^0}{R}$$

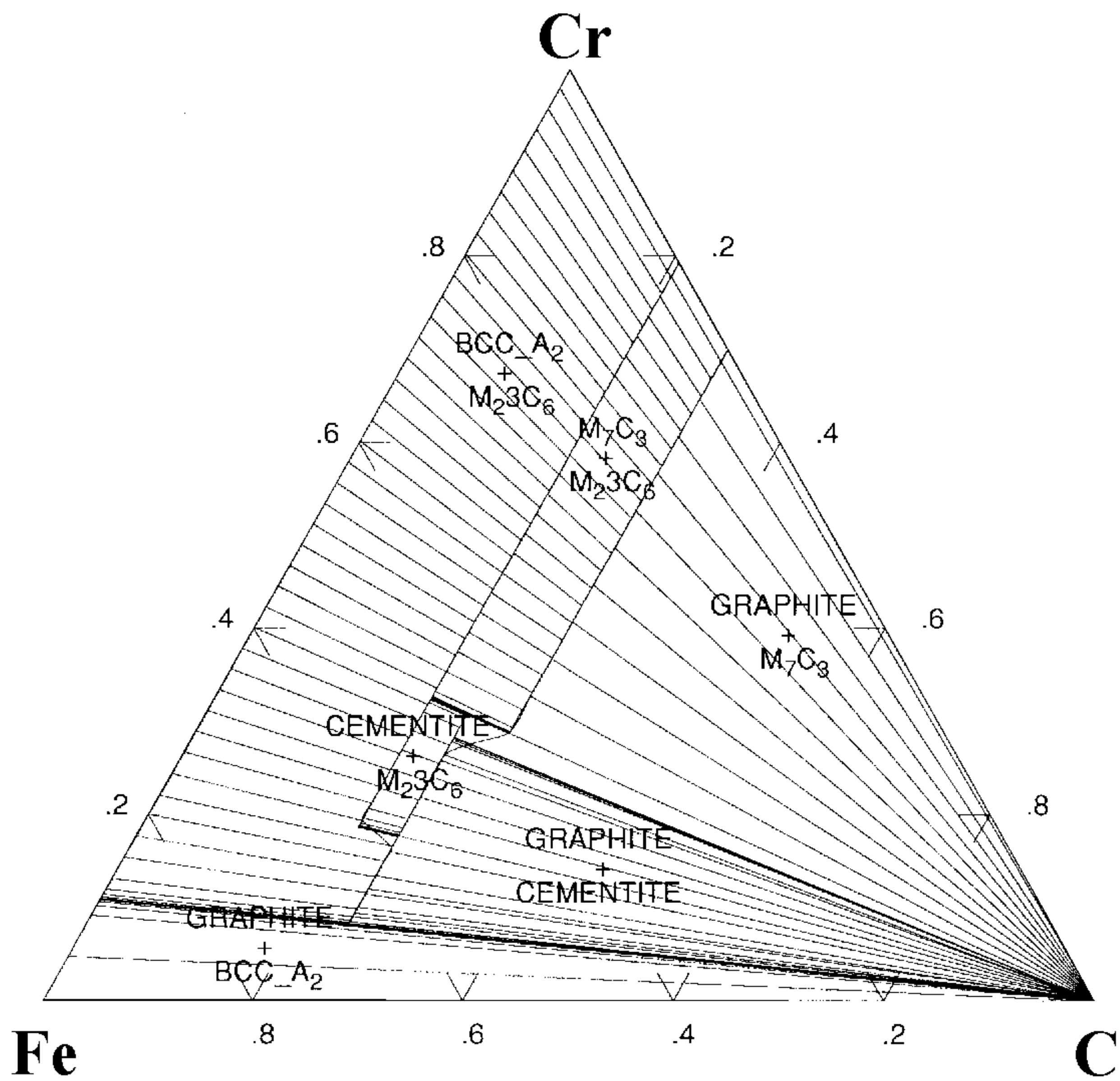
$$\log\{\mathrm{w}_{\mathrm{Ti}_\gamma} \mathrm{w}_{\mathrm{C}_\gamma}\} = \frac{-7000}{T} + 2.35$$



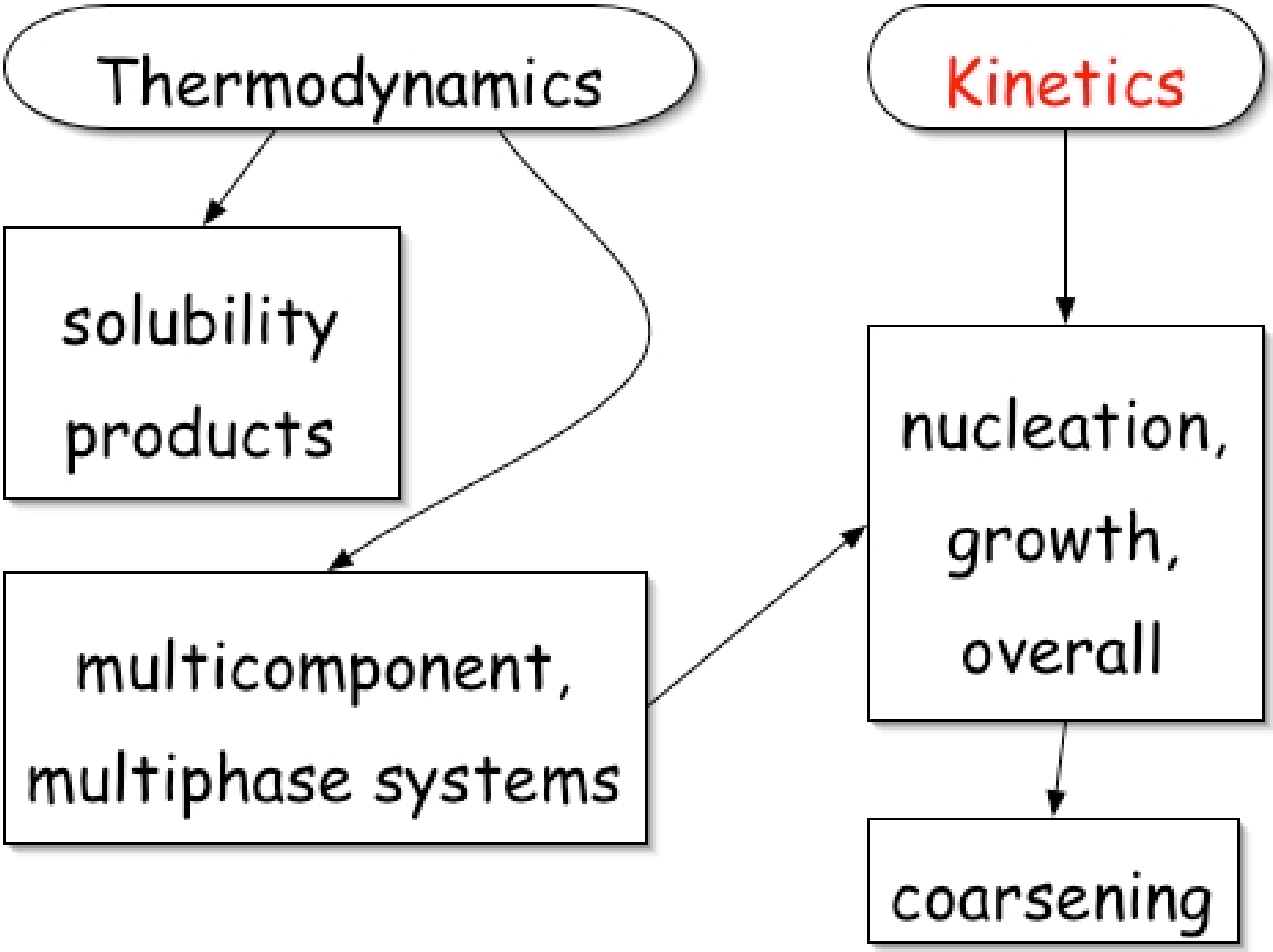
Cr in M_23 C_6
0.8
0.6
0.4
0.2
0.0
1CrMoV
2.25Cr1Mo
Mod. 2.25Cr1Mo
3Cr1.5Mo
3.5NiCrMoV
9Cr1Mo
Mod. 9Cr1Mo
9Cr0.5MoWV
12CrMoV
12CrMoVW
12CrMoVNb



Cr
Plotted 15:09:32 3 APR-95
Data file def.mpi
Results file def1674.tnr
Log file mt2962.log
Fe-Cr-C
700 K
1.01325E5 Pa
BCC_A2 + M23C6
BCC_A2 + BCC_A2 + M23C6
M7C3 + M23C6
BCC_A2 + M23C6
BCC_A2 + M7C3
BCC_A2 + M7C3 + M23C6
GRAPHITE + M7C3
GRAPHITE + BCC_A2 + M7C3
x Cr
x C
x Fe
Fe
C
.2
.4
.6
.8



Cr
Fe
C
.8
.6
.4
.2
BCC_A2 + M23C6
M7C3 + M23C6
GRAPHITE + M7C3
CEMENTITE + M23C6
GRAPHITE + CEMENTITE
GRAPHITE + BCC_A2


Thermodynamics
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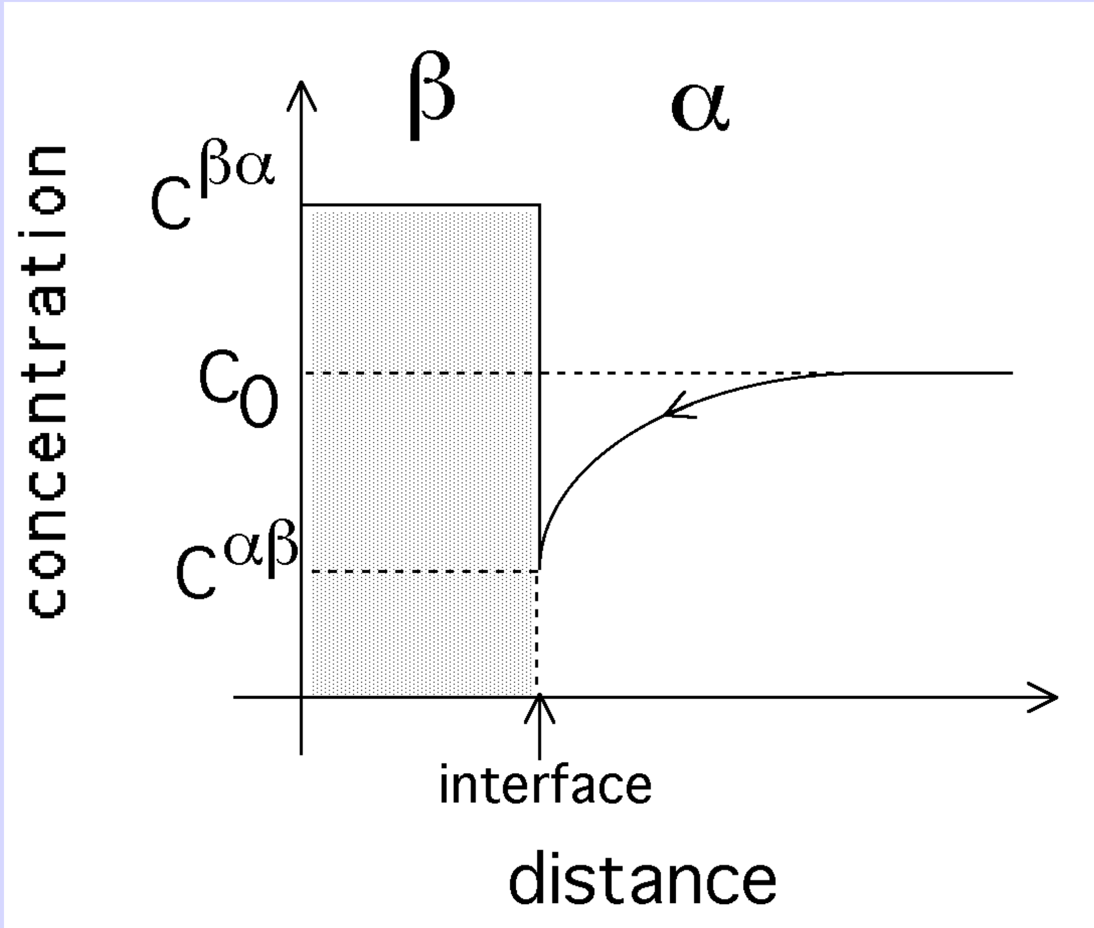
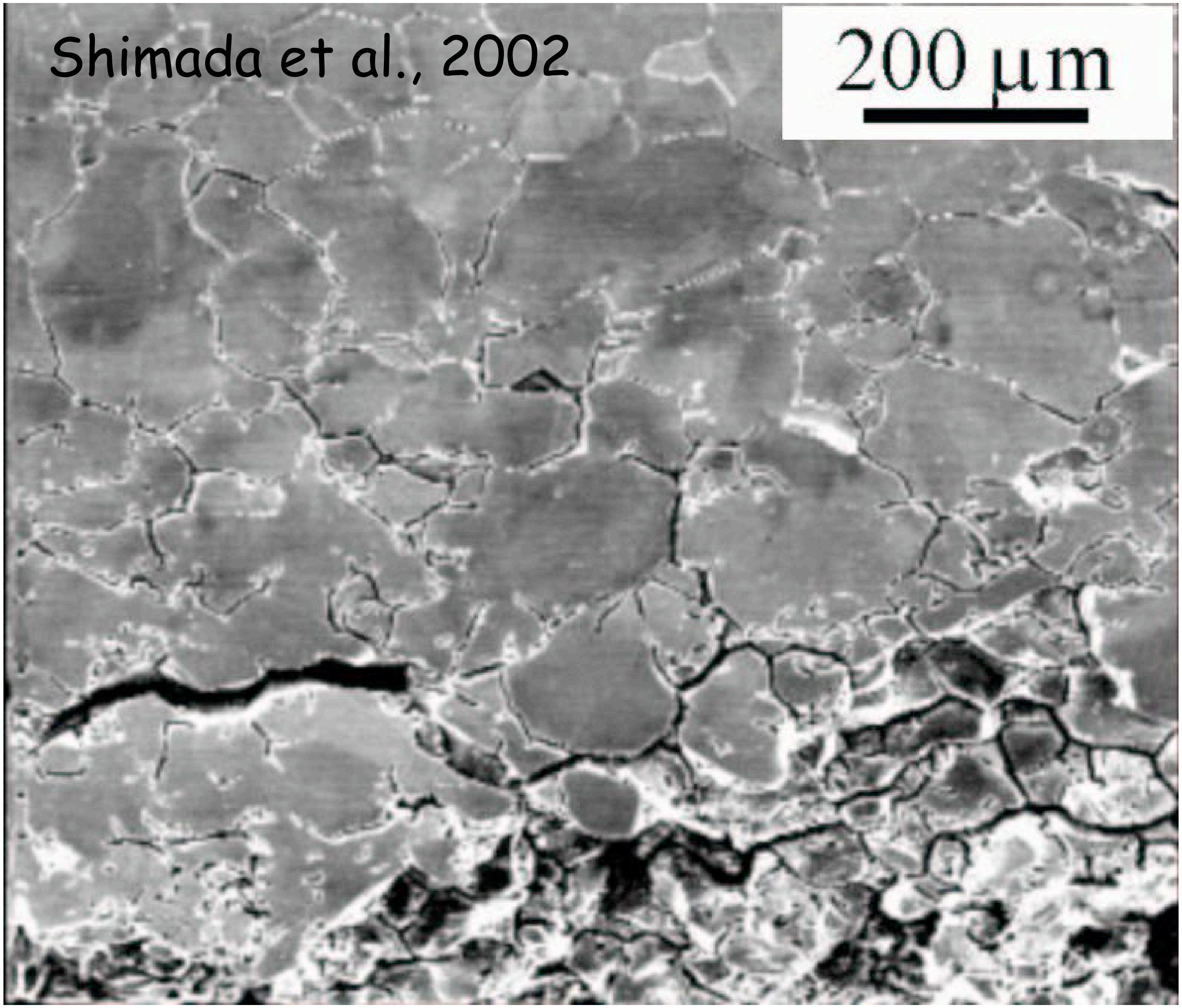


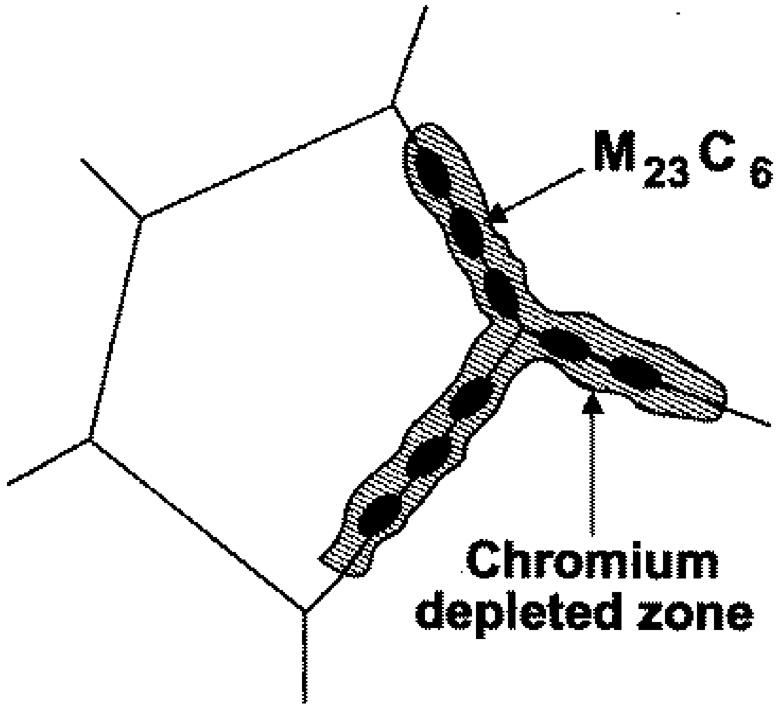
$$\underbrace{(C_\beta - C_\alpha)\frac{\partial x}{\partial t}}_{\text{rate solute absorbed}} = \underbrace{D\frac{\partial C}{\partial x}}_{\text{diffusion flux towards interface}}$$

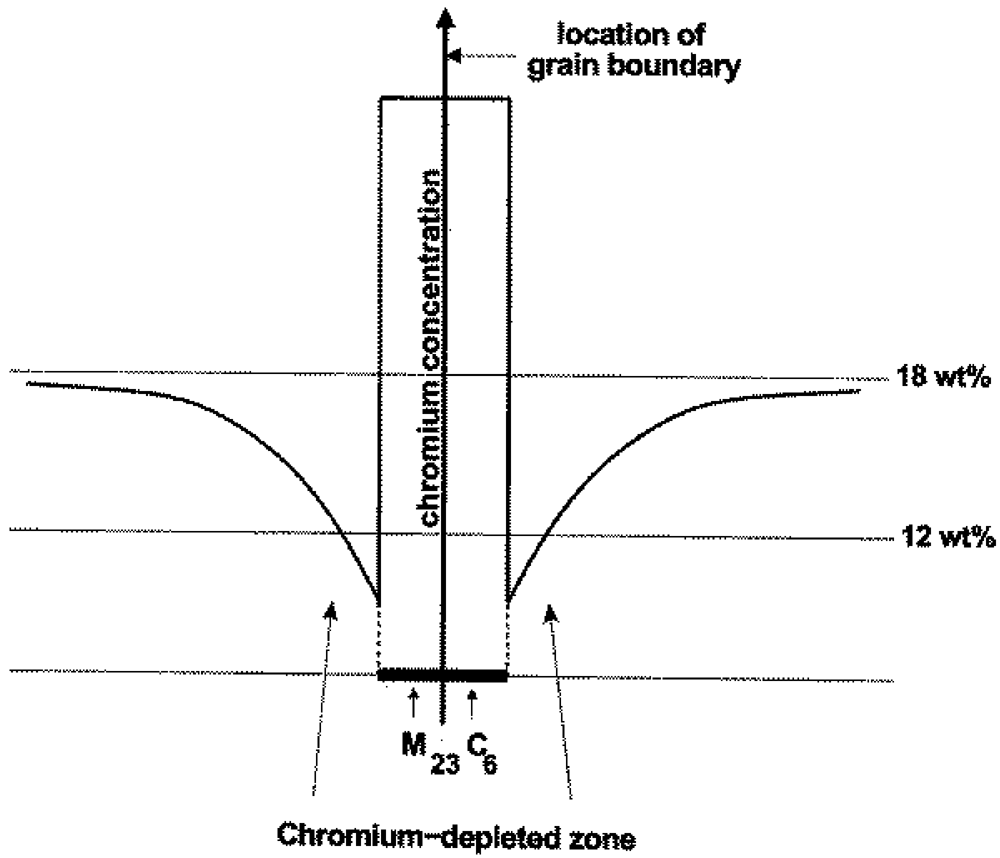
$$(C_{\mathrm{C}}^{\beta} - C_{\mathrm{C}}^{\alpha})\frac{\partial x}{\partial t} = D_{\mathrm{C}}\frac{\partial C_{\mathrm{C}}}{\partial x}$$

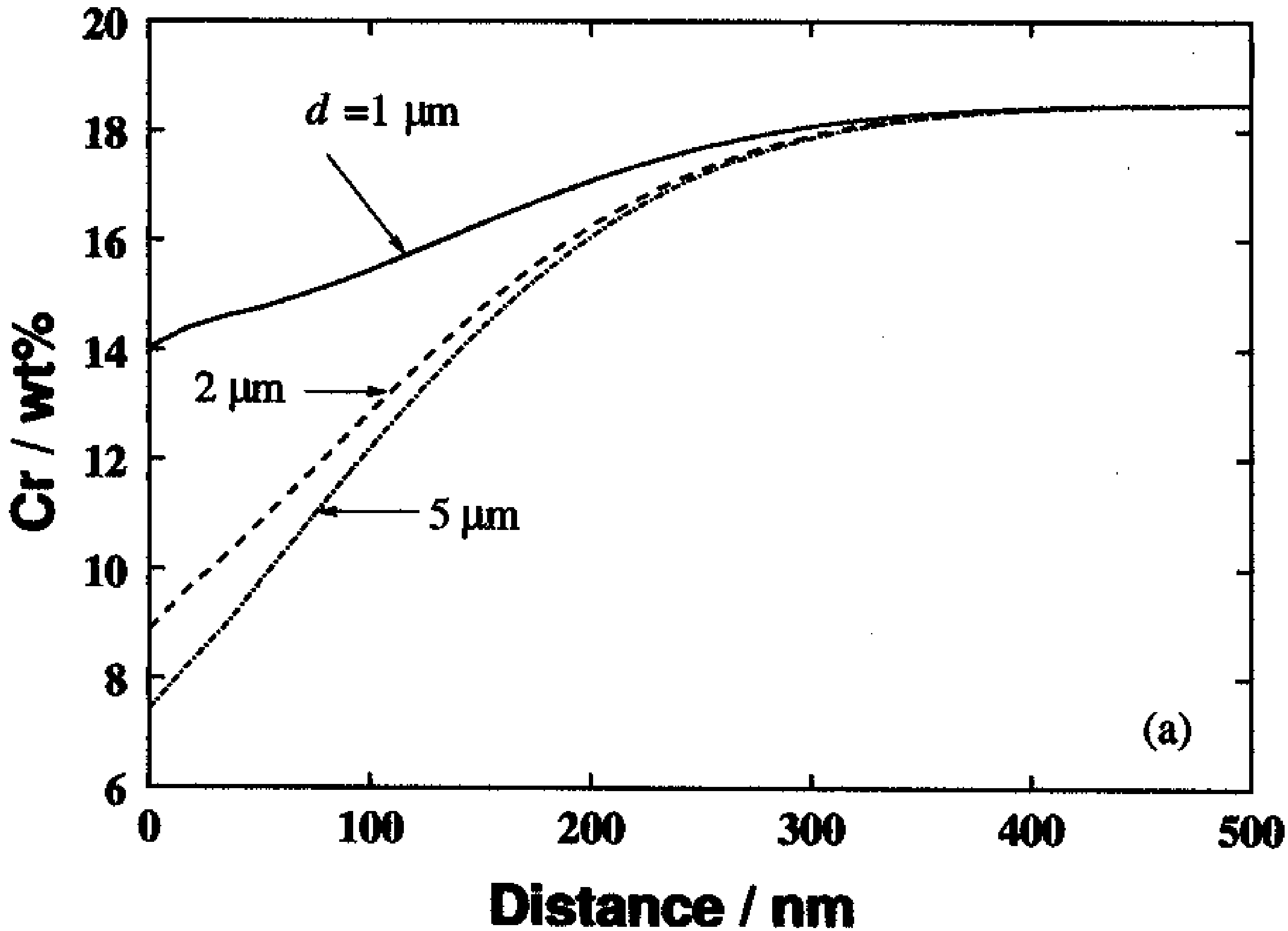
$$(C_{\mathrm{Cr}}^{\beta} - C_{\mathrm{Cr}}^{\alpha})\frac{\partial x}{\partial t} = D_{\mathrm{Cr}}\frac{\partial C_{\mathrm{Cr}}}{\partial x}$$

CASE 1: Sensitisation

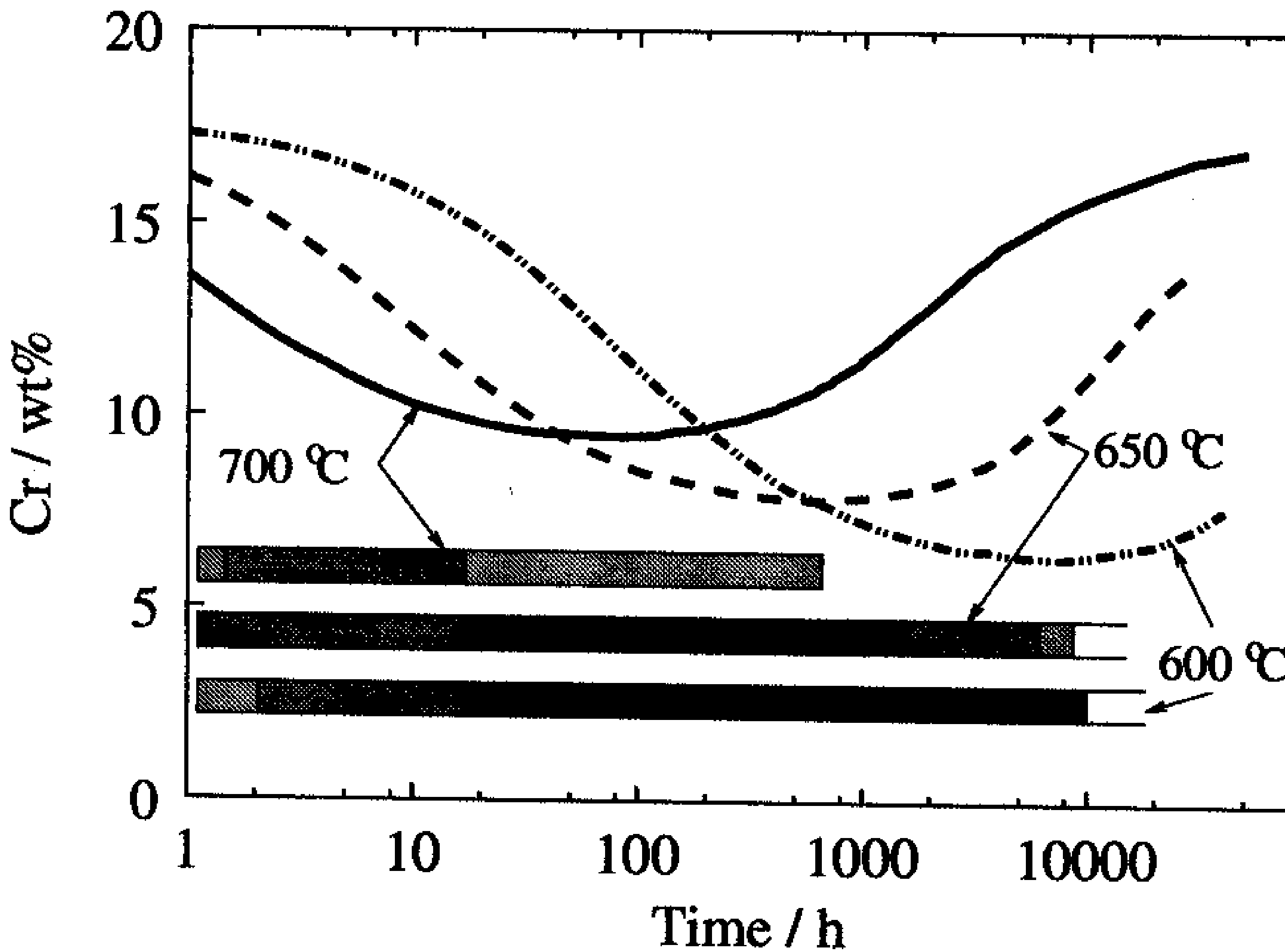



M23C6
Chromium depleted zone

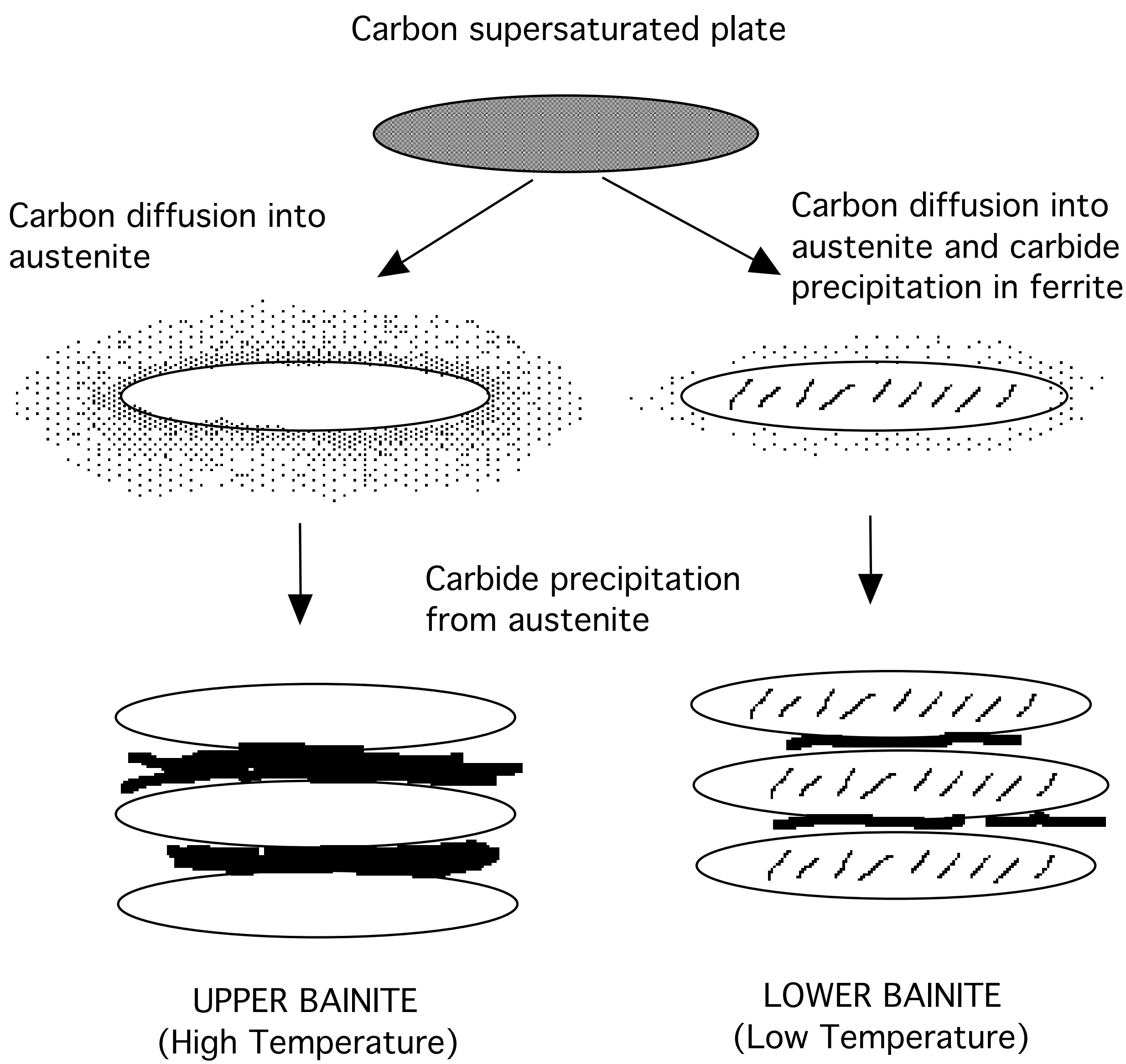

location of grain boundary
chromium concentration
18 wt%
12 wt%
M23C6
Chromium–depleted zone



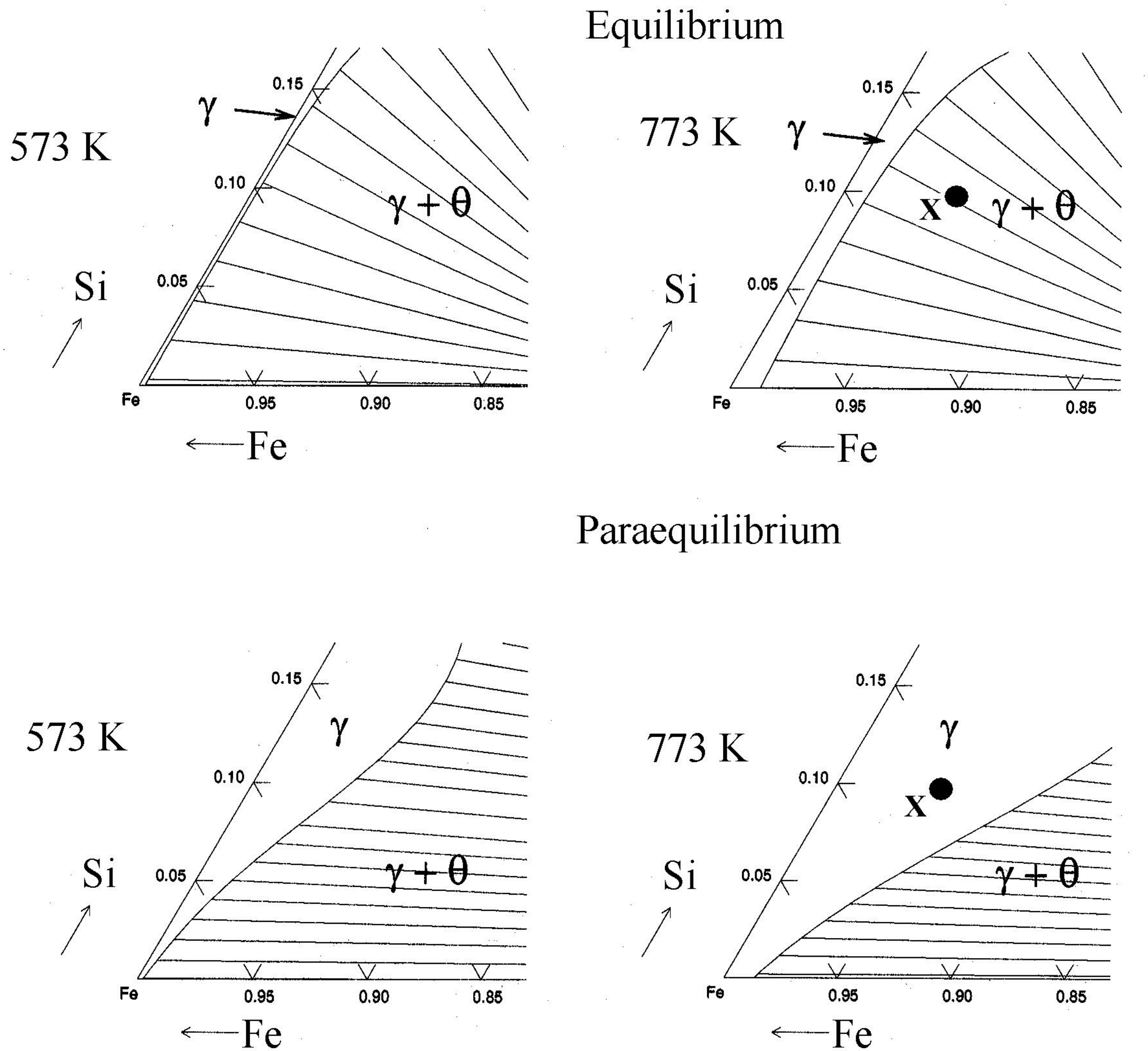
Sourmail, Too, Bhadeshia, 2003

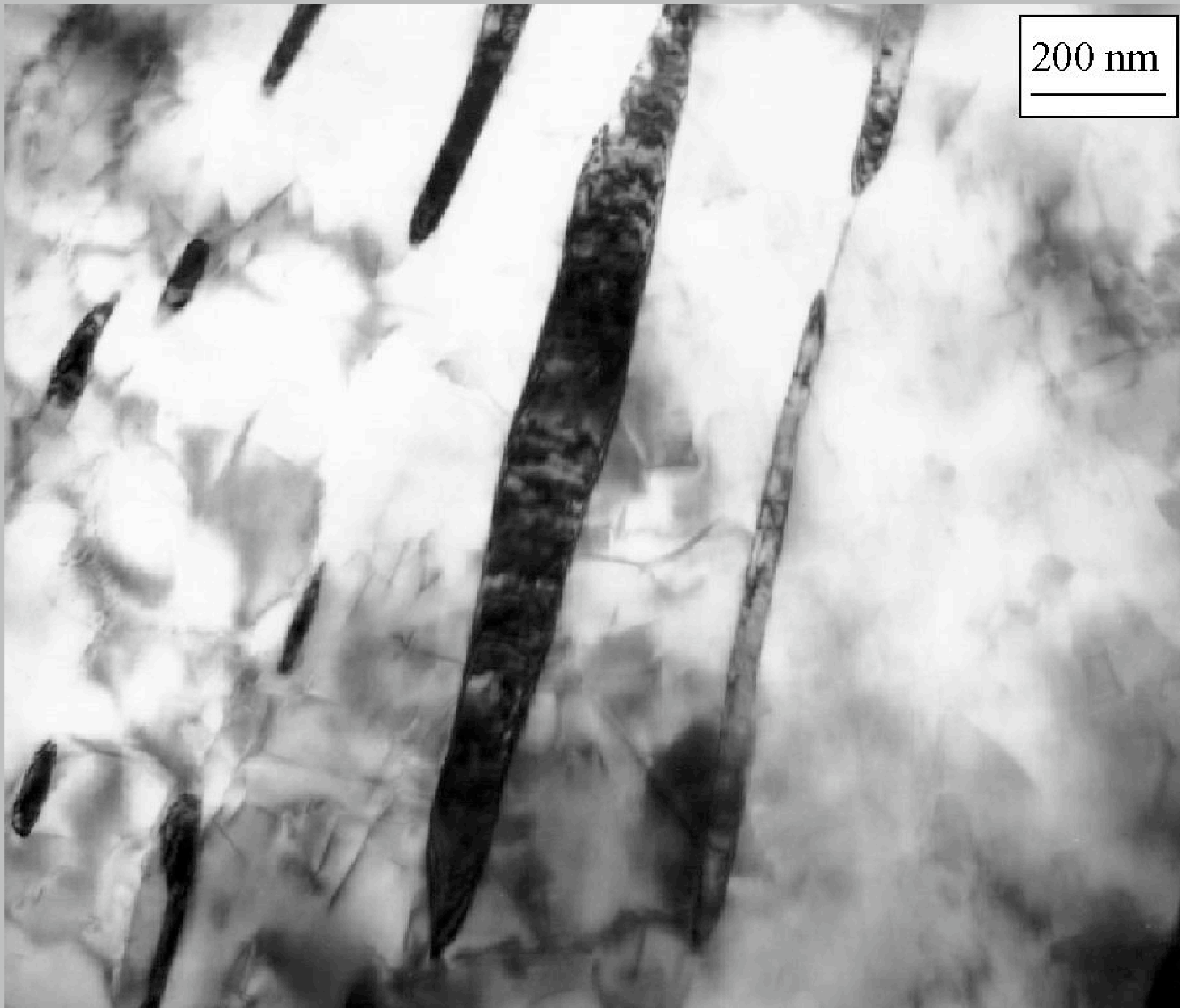


Sourmail, Too, Bhadeshia, 2003

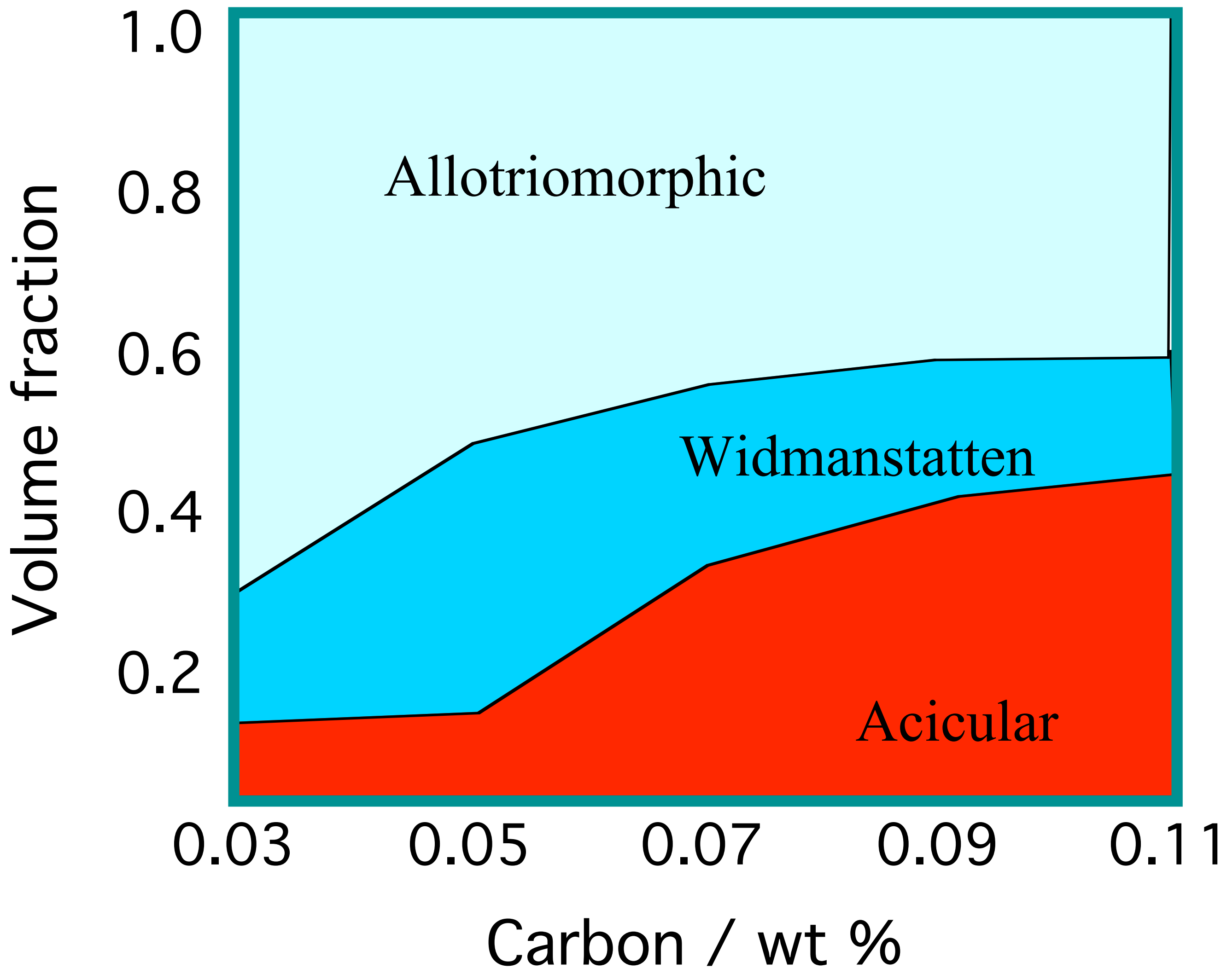


CASE 2: elimination of carbides


Equilibrium
573 K
γ
0.15
0.10
0.05
γ + θ
Si
Fe
0.95
0.90
0.85
Fe
773 K
γ
0.15
0.10
0.05
x
γ + θ
Si
Fe
0.95
0.90
0.85
Fe
Paraequilibrium
573 K
γ
0.15
0.10
0.05
γ + θ
Si
Fe
0.95
0.90
0.85
Fe
773 K
γ
0.15
0.10
0.05
x
γ + θ
Si
Fe
0.95
0.90
0.85
Fe


200 nm

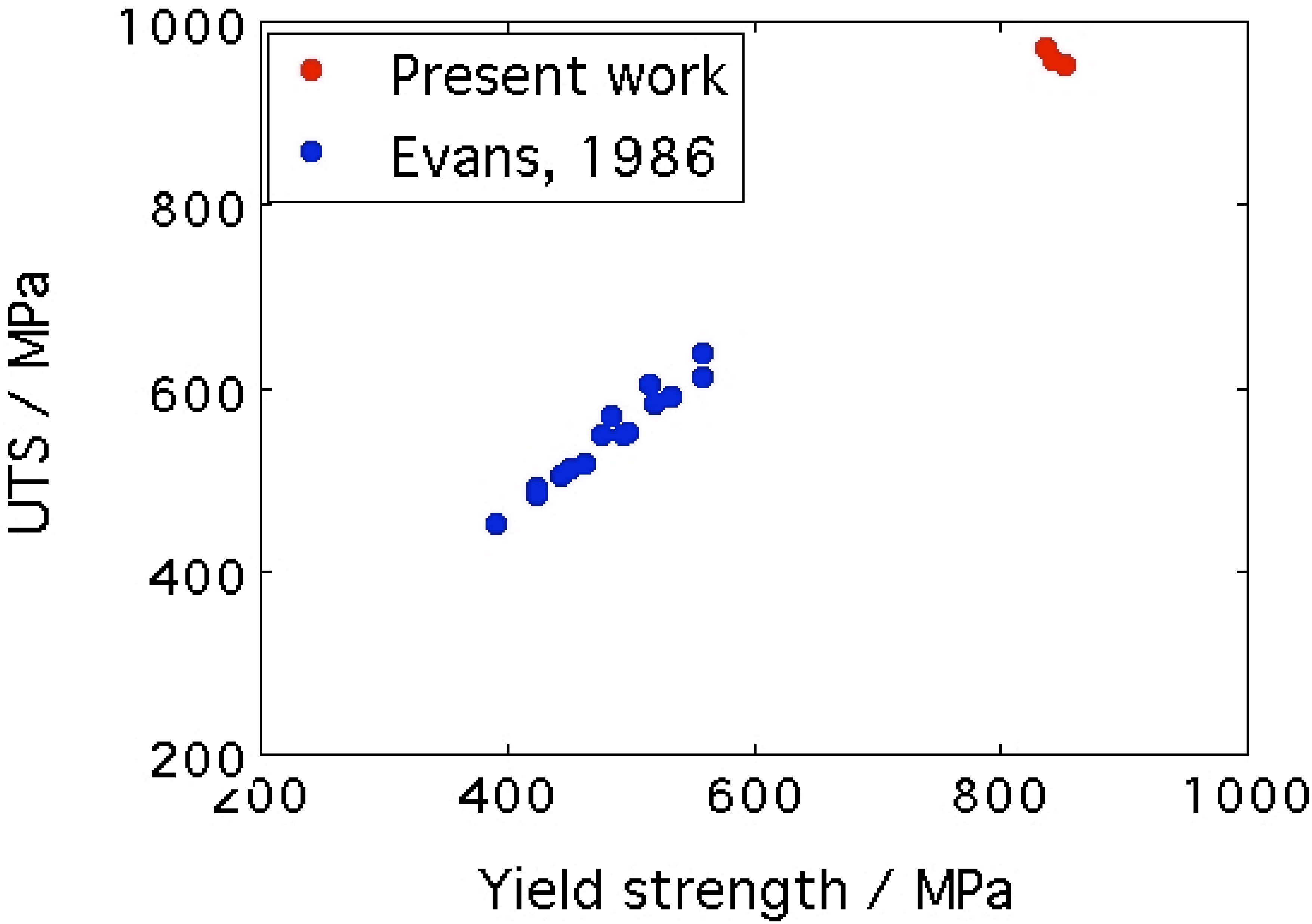
Fe-1Mn-C wt % manual metal arc welds

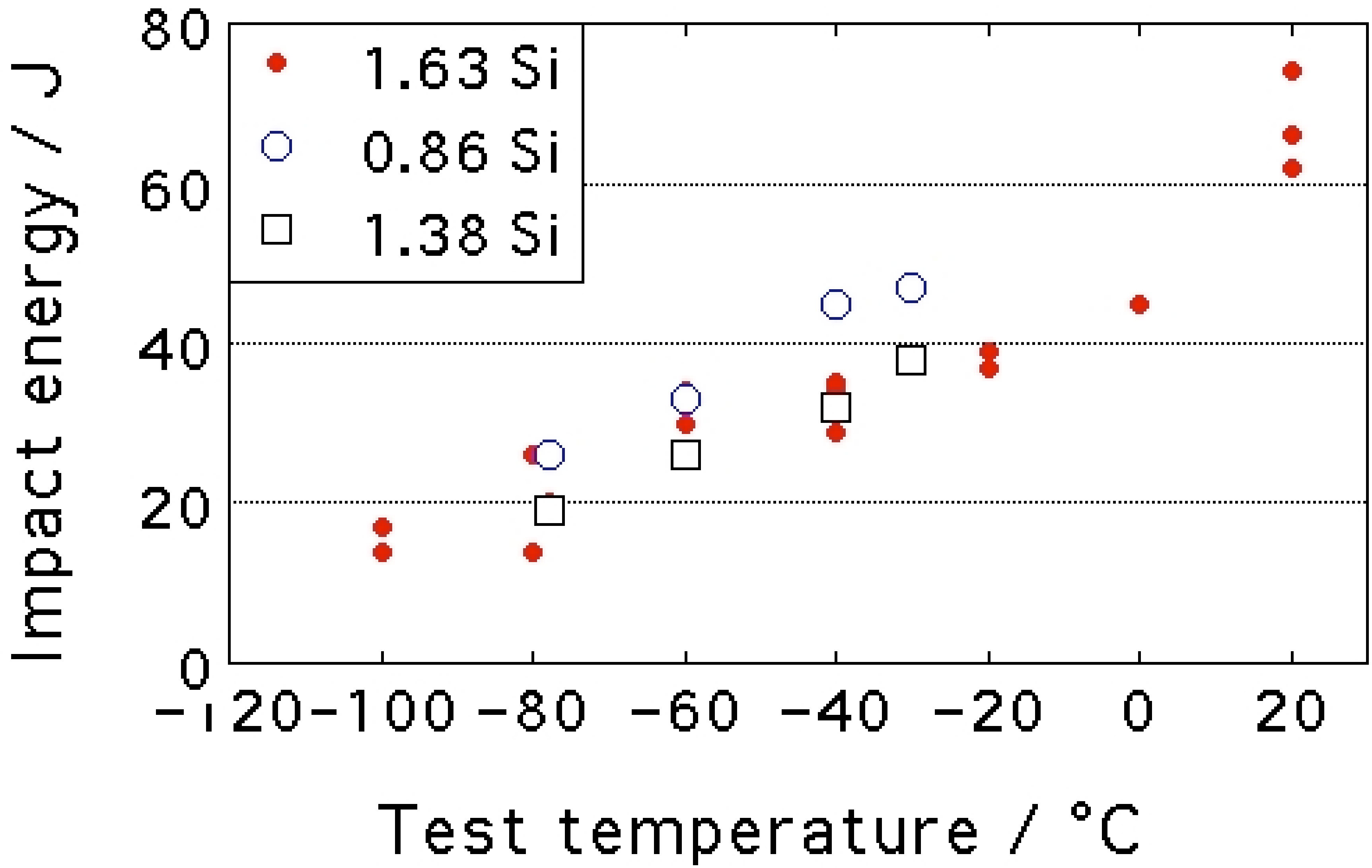


C	Mn	Ni	V_α	$V_{\alpha W}$
0.10	2.18	2.07	0.00	0.00
0.10	**1.00**	2.07	0.18	0.04
0.10	**1.00**	**1.00**	0.27	0.07
0.05	1.00	1.00	0.46	0.23

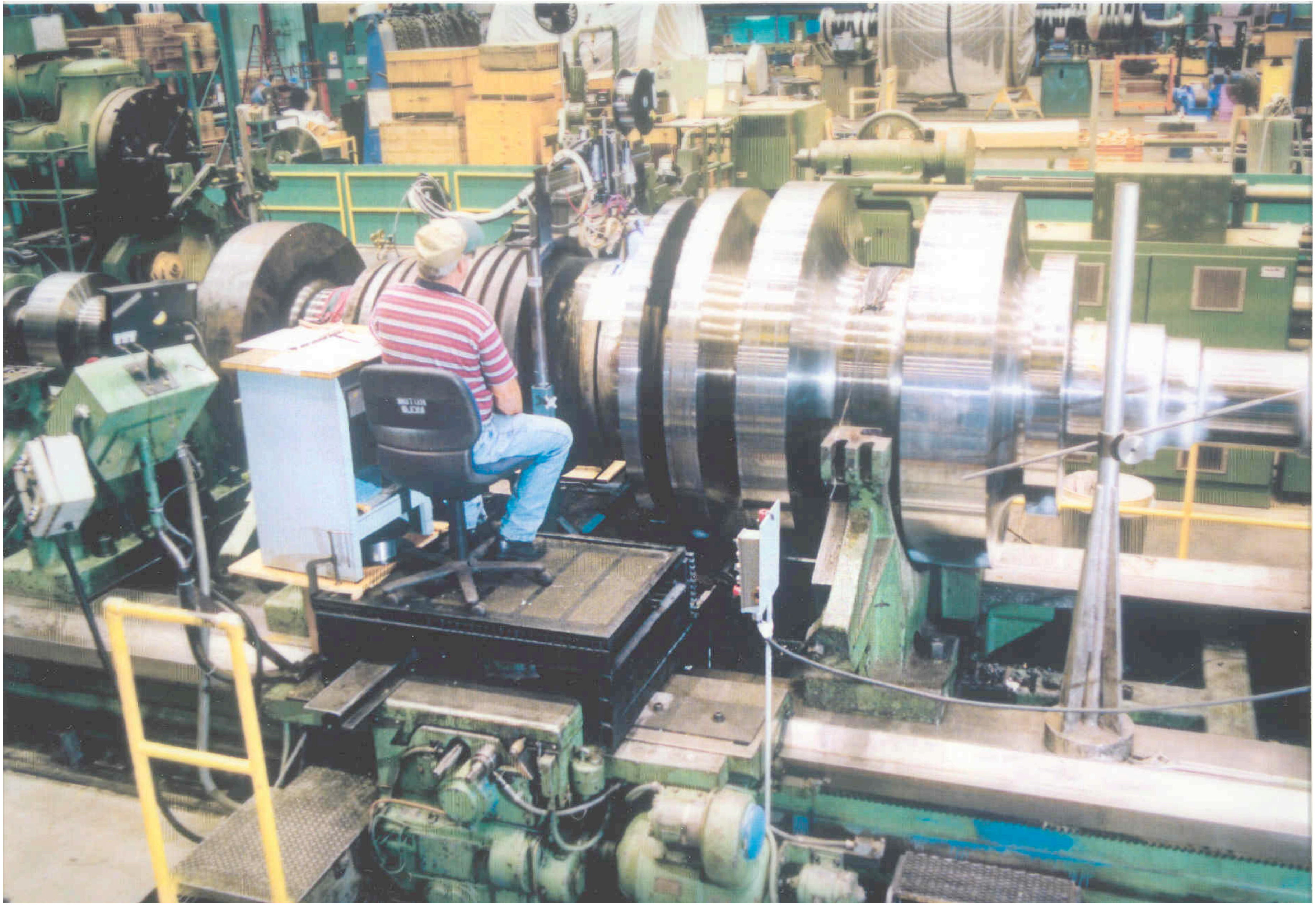
Weld	C	Mn	Si	Ni	Mo	O
A	0.10	2.24	**0.86**	2.11	0.21	**0.025**
B	0.12	2.30	**1.38**	2.12	0.21	**0.026**
C	0.10	2.18	**1.63**	2.07	0.23	**0.021**

wt%

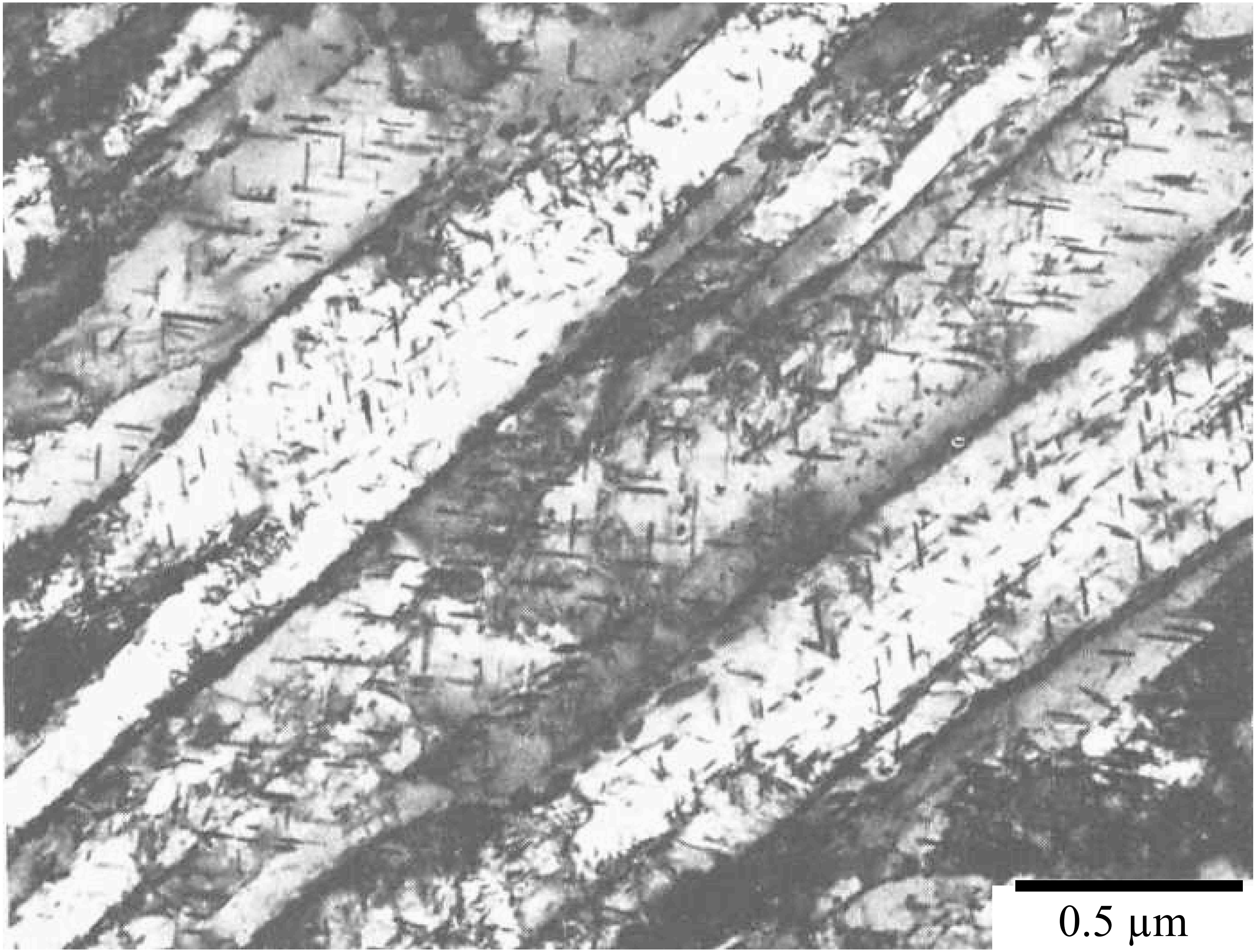

Present work
Evans, 1986
1000
800
600
400
200
UTS / MPa
200
400
600
800
1000
Yield strength / MPa

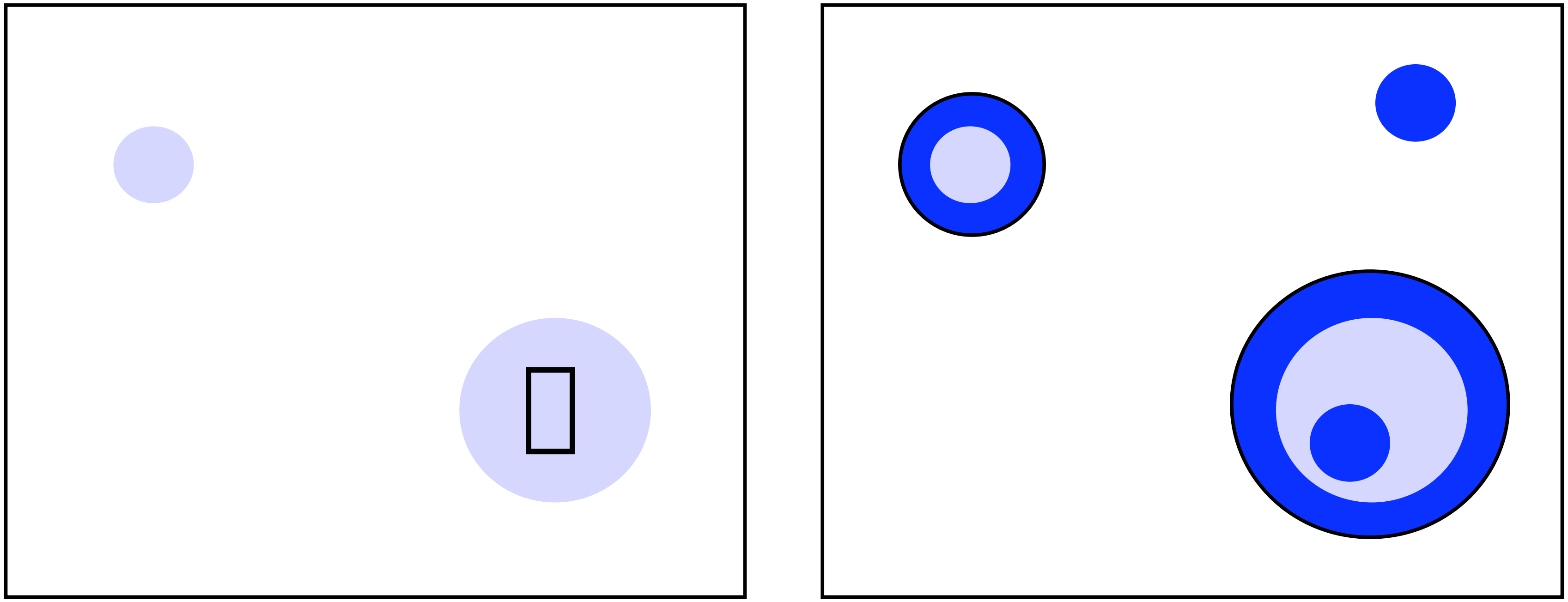


Impact energy / J
Test temperature / °C
1.63 Si
0.86 Si
1.38 Si
0
20
40
60
80
-120
-100
-80
-60
-40
-20
0
20



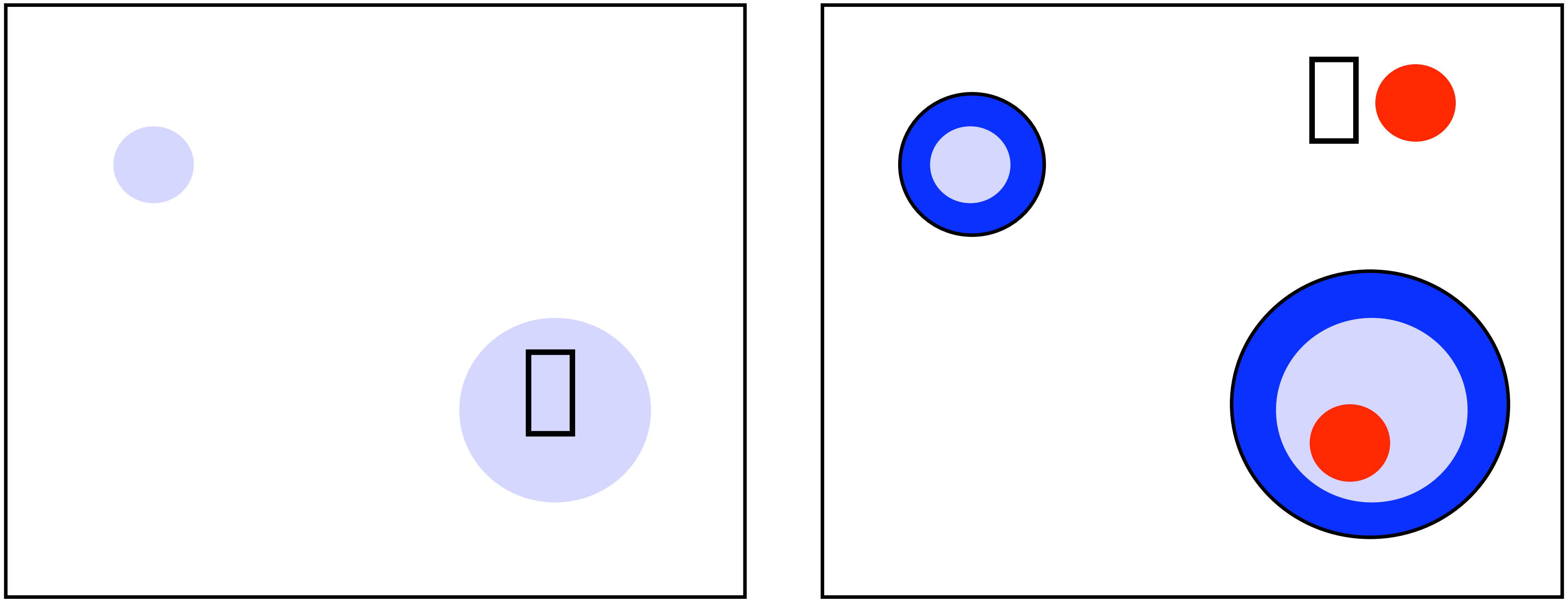
CASE 3: carbide strengthening


0.5 μm



time = t　　　time = t+Δt

$$dV^{\alpha} = \left(1 - \frac{V^{\alpha}}{V}\right) dV_e^{\alpha}$$



time = t

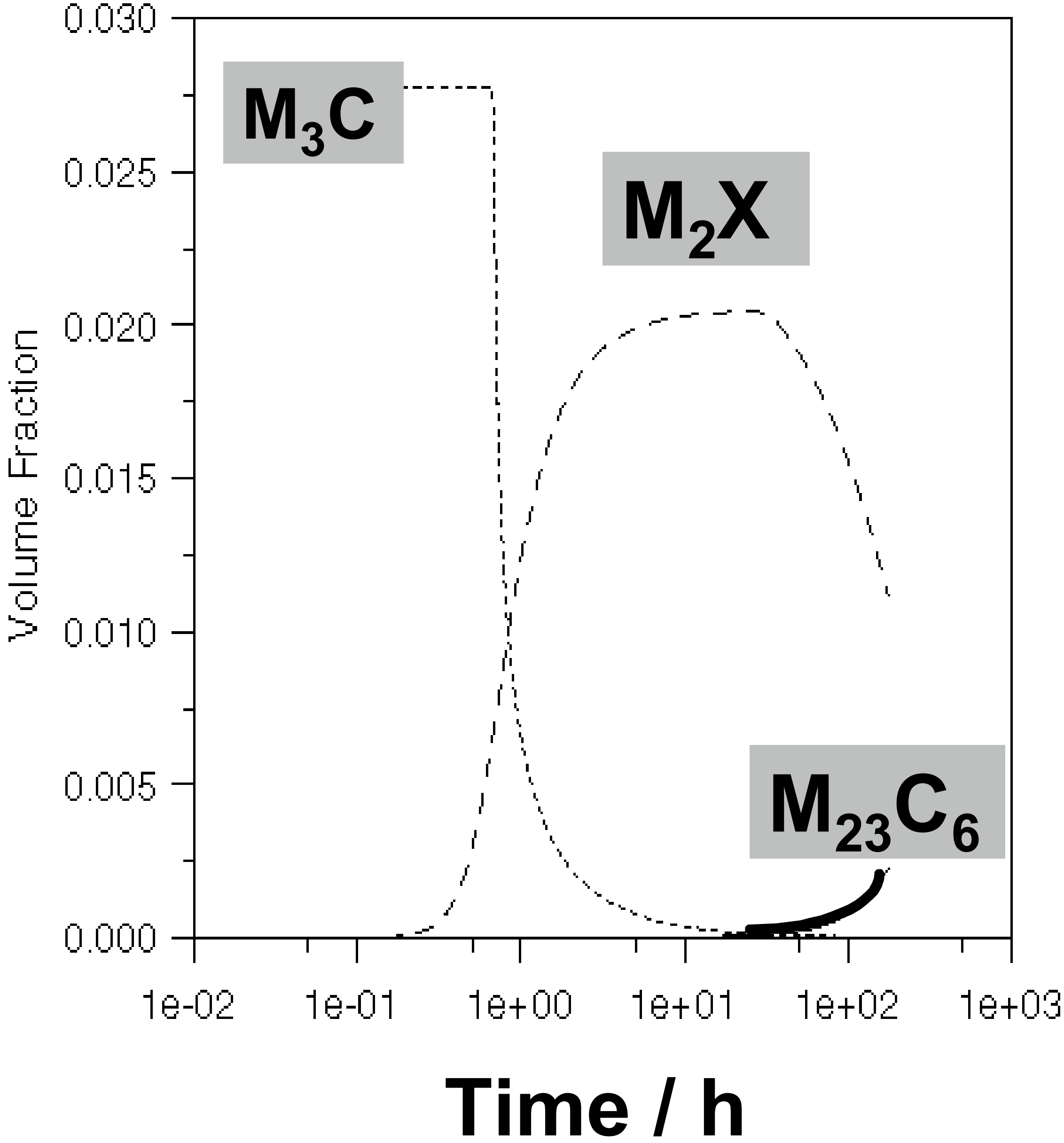
time = t+Δt

$$dV^{\alpha} = \left(1 - \frac{V^{\alpha} + V^{\beta}}{V}\right) dV_e^{\alpha}$$

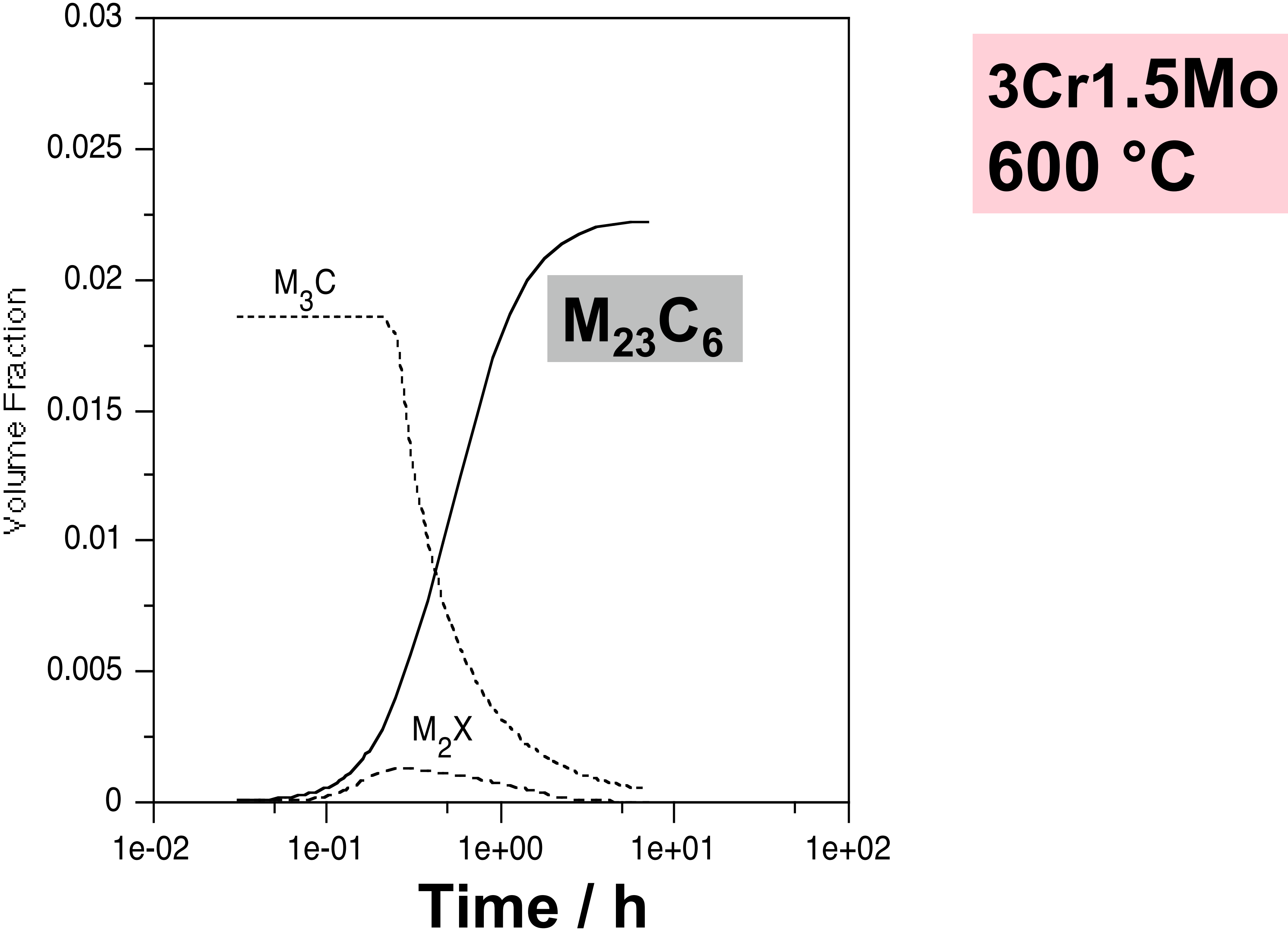
$$dV^{\alpha} = \left(1 - \frac{V^{\alpha} + V^{\beta}}{V}\right) dV_e^{\alpha}$$

$$dV^{\beta} = \left(1 - \frac{V^{\alpha} + V^{\beta}}{V}\right) dV_e^{\beta}$$

2.25Cr1Mo
600 °C

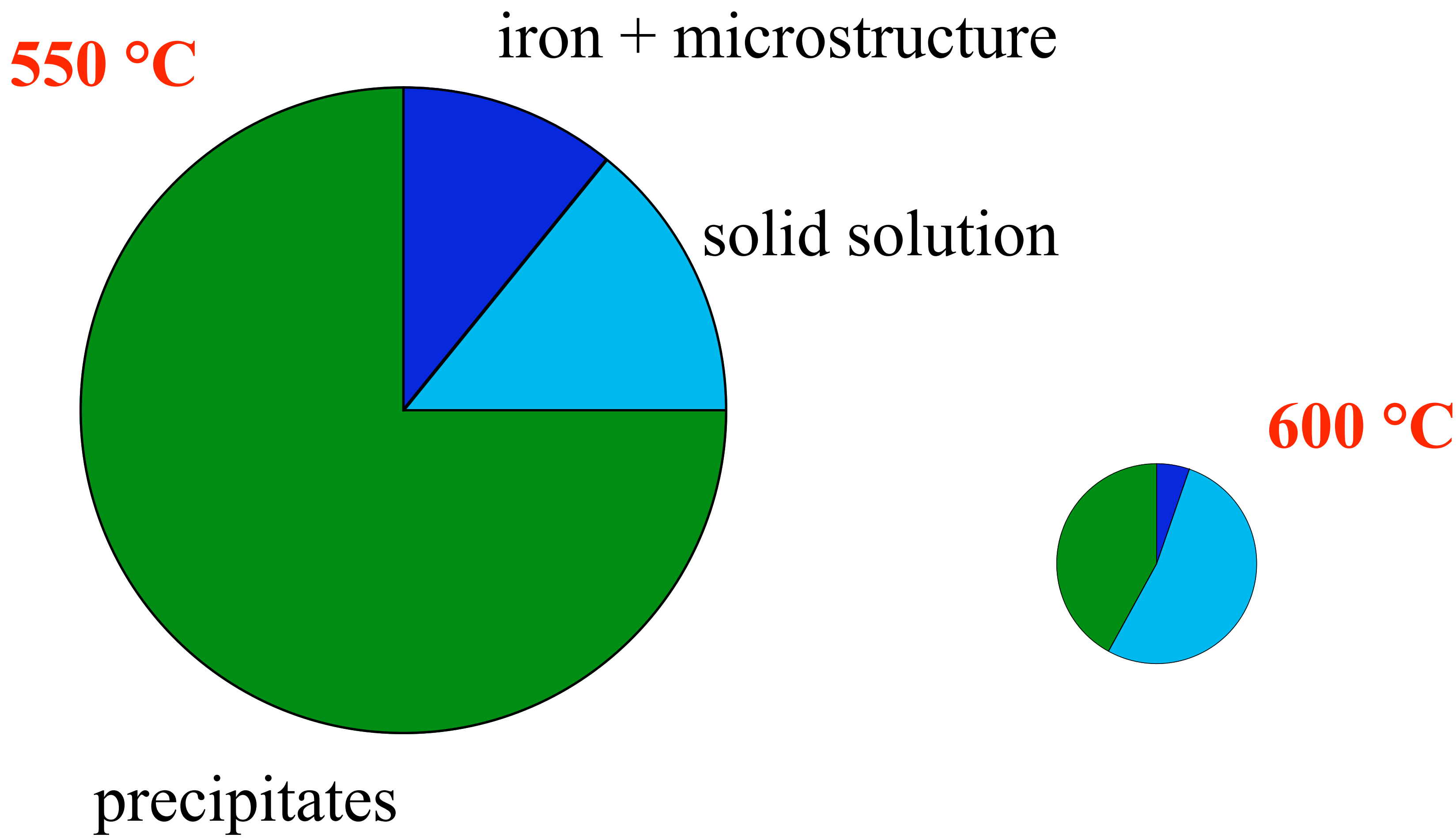


1000 h

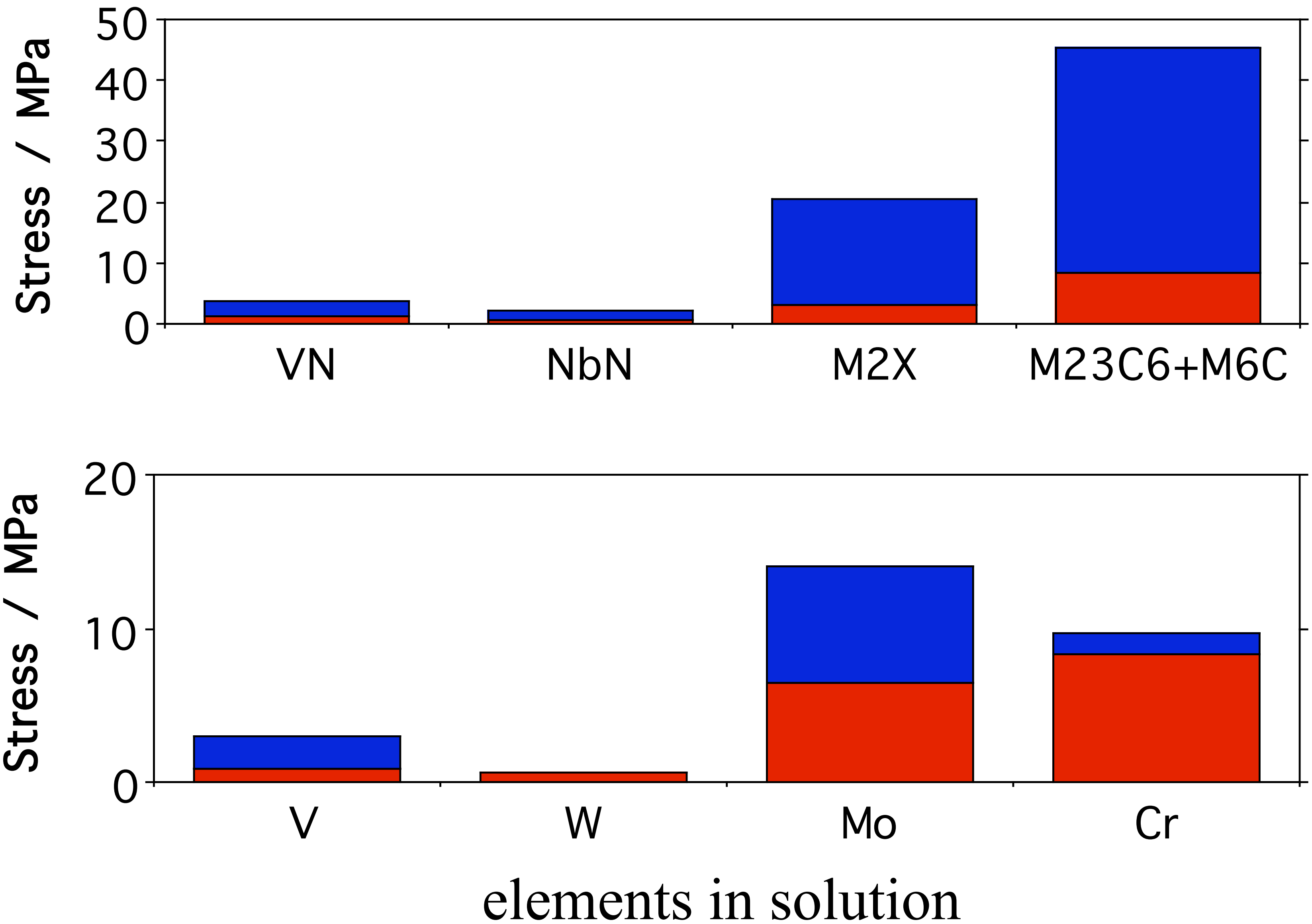


3Cr1.5Mo
600 °C
$M_{23}C_6$
M_3C
M_2X
Volume Fraction
0.03
0.025
0.02
0.015
0.01
0.005
0
1e-02
1e-01
1e+00
1e+01
1e+02
Time / h

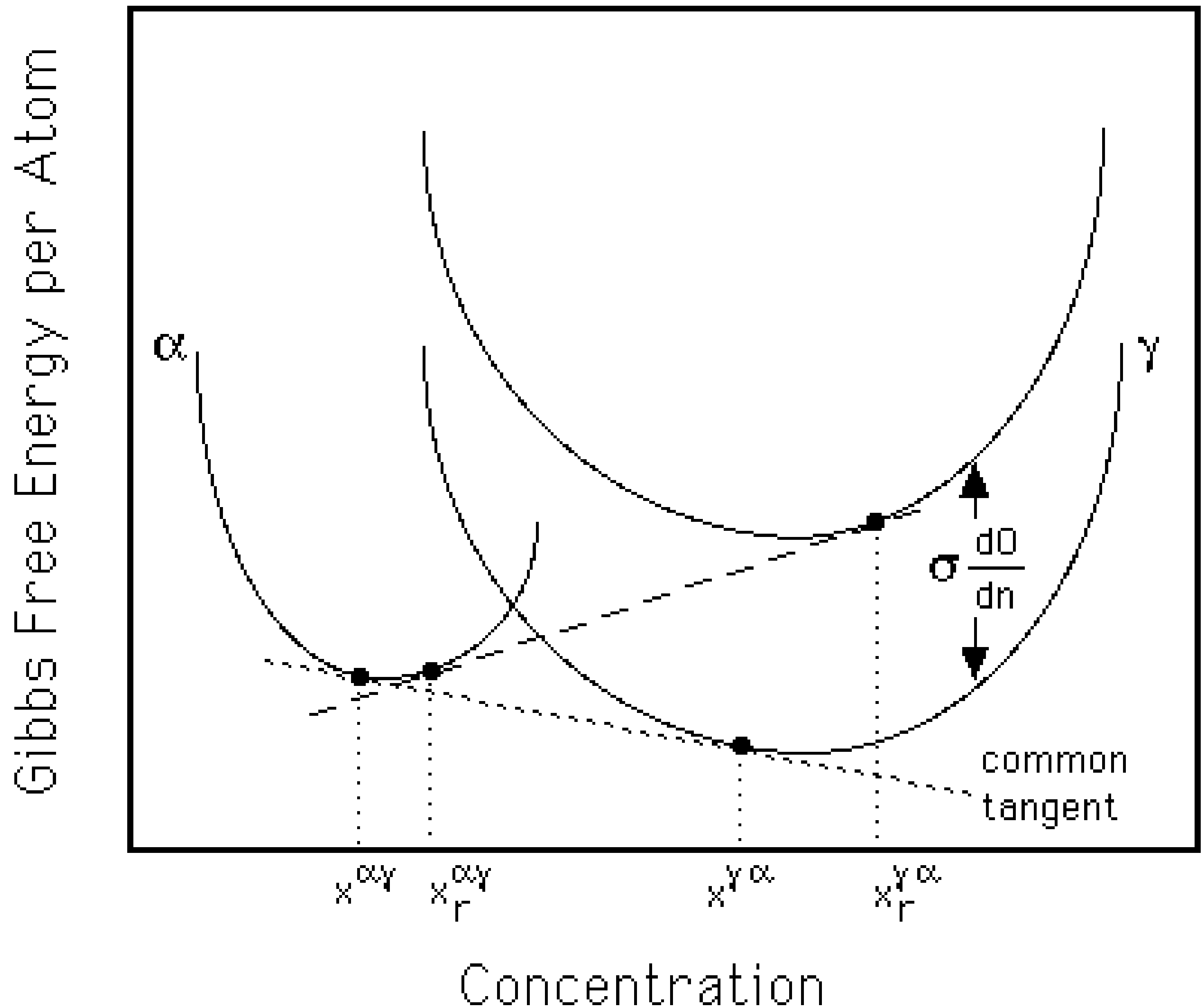
Components of Creep Strength, 2.25Cr1Mo



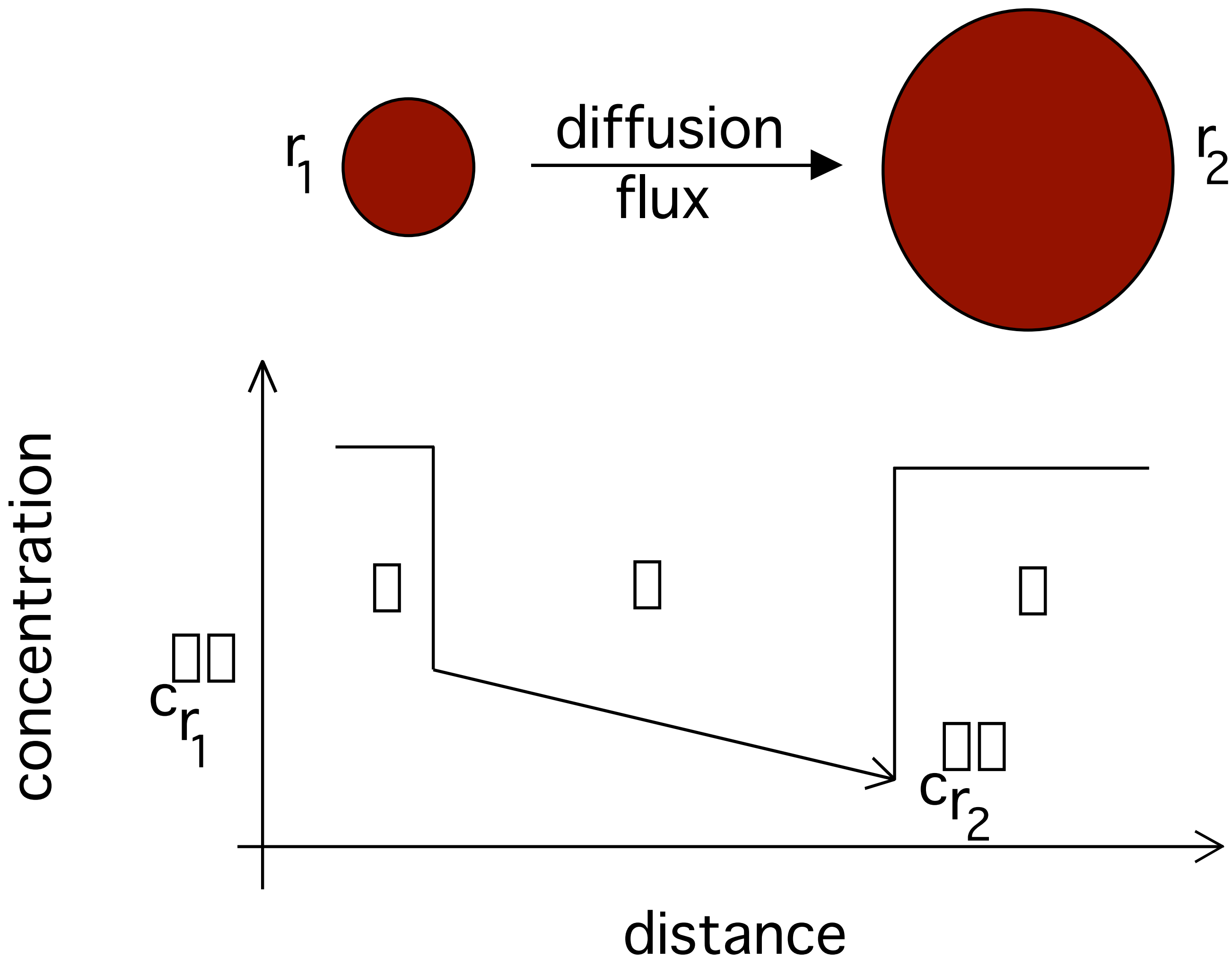
Murugananth & Bhadeshia, 2001

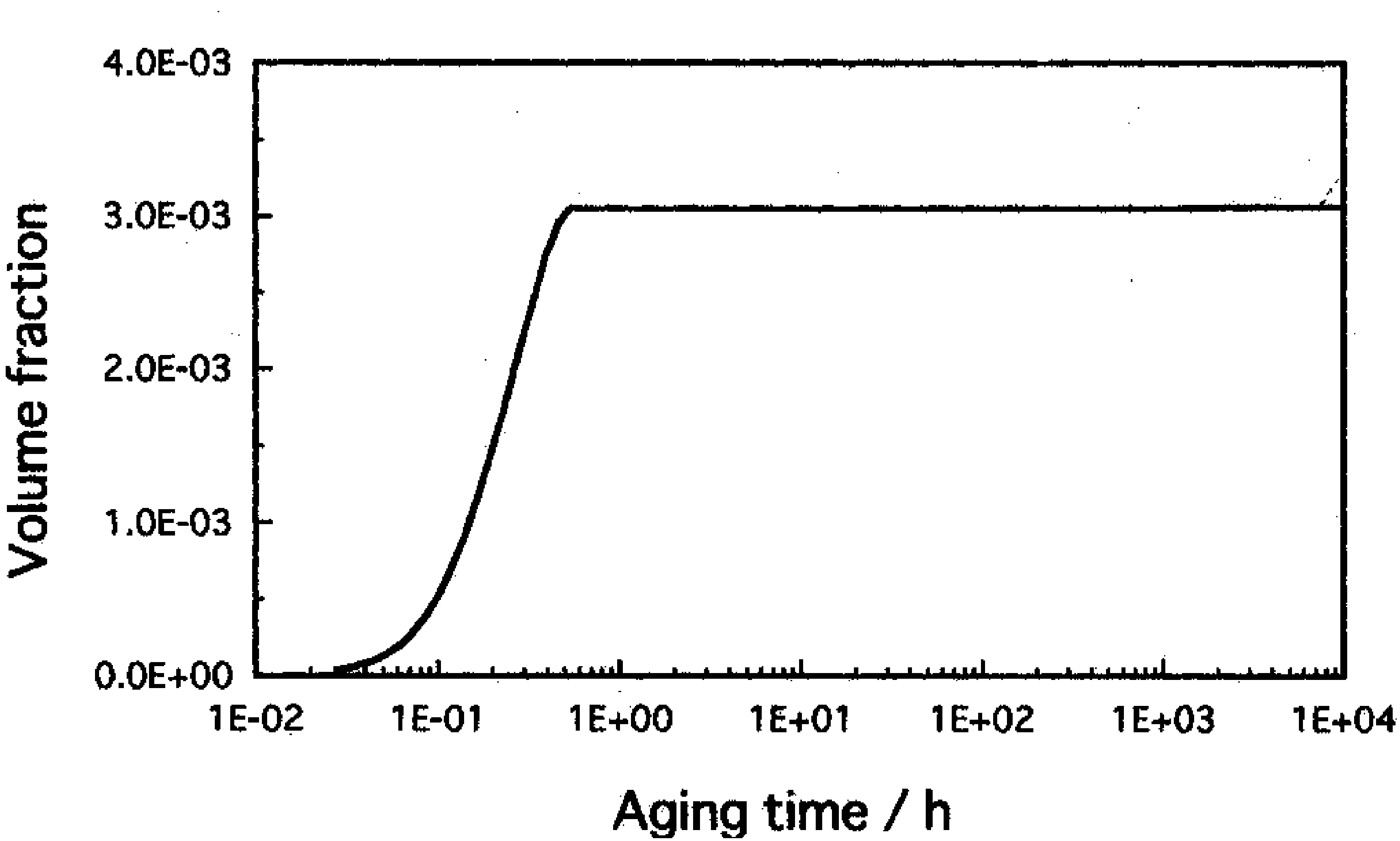


Murugananth & Bhadeshia, 2001

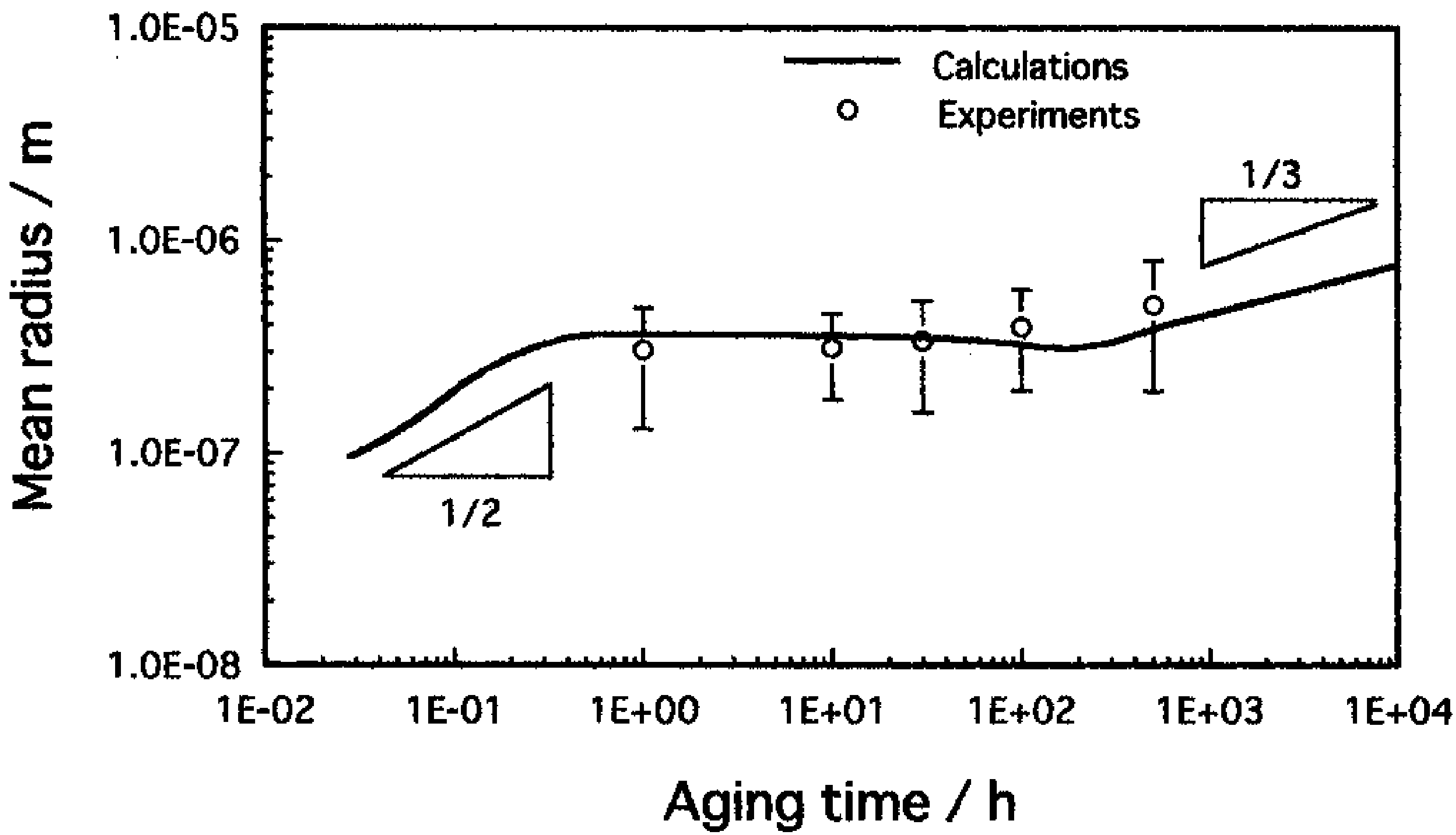

Gibbs Free Energy per Atom
α
γ
σ dO/dn
common tangent
$x^{\alpha\gamma}$
$x_r^{\alpha\gamma}$
$x^{\gamma\alpha}$
$x_r^{\gamma\alpha}$
Concentration

Coarsening

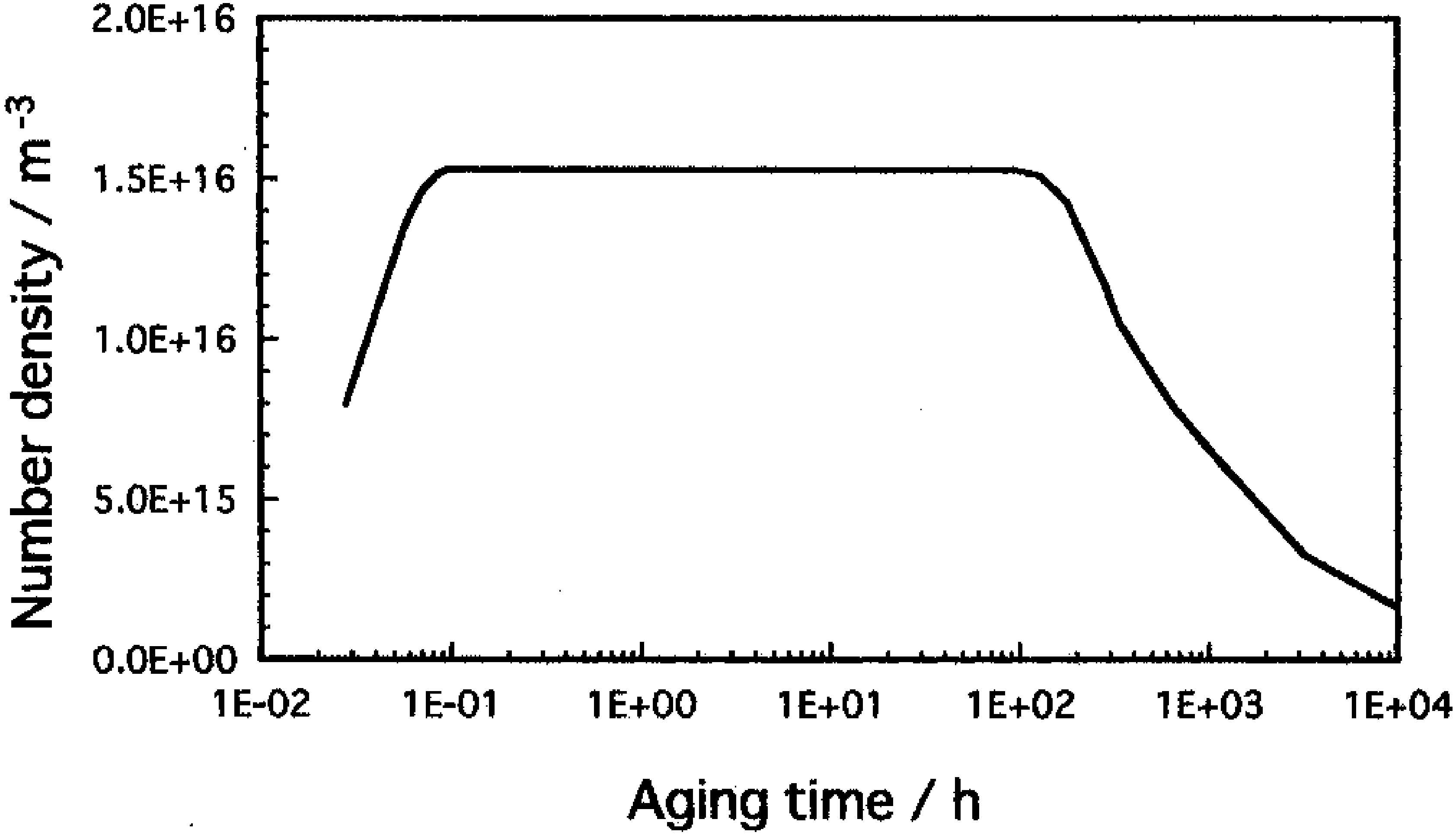




Fujita and Bhadeshia, 2002



Fujita and Bhadeshia, 2002



Fujita and Bhadeshia, 2002

Summary

- Significant advances in theory
- Can model diffusion-controlled growth, coarsening
- Elimination of cementite
- Long-term microstructural stability can be estimated

Conclusions