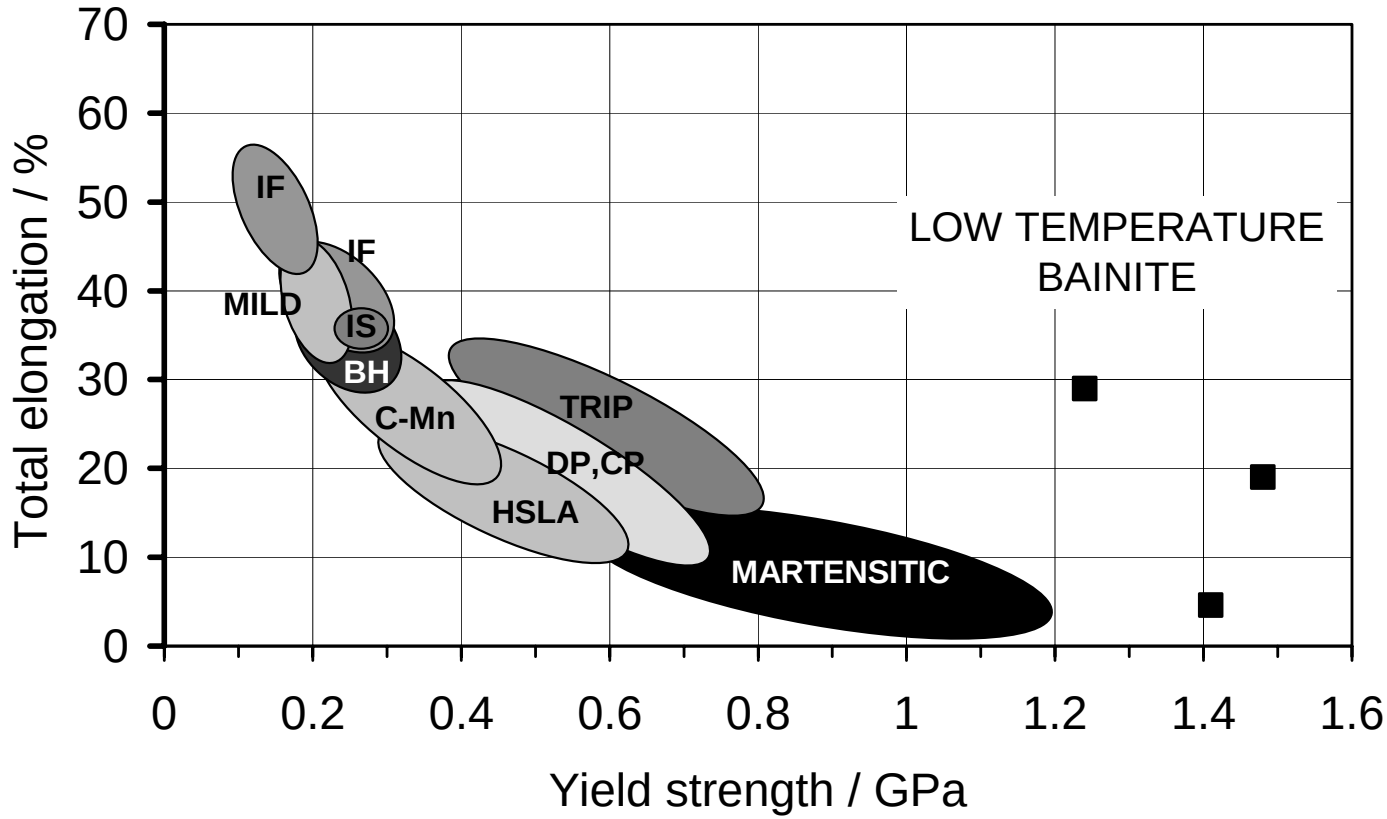
Mechanical Properties of Low-Temperature Bainite



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-Steel design, heat treatment

-Microstructure, characterization

-Mechanical properties

- Microstructure $\Leftrightarrow$ Mech. properties

Bainite Phase Transformation Theory (*)

Paraequilibrium Nucleation
(only C diffuses)

$$\Delta G_m < G_N$$

Diffusionless growth

$$\Delta G^{\gamma \rightarrow \alpha} < -G_{SB}$$

B_S

(*) H.K.D.H Bhadeshia. Bainite in Steels. 2nd edition
The Institute of Materials (2001)

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Some simple metallurgical considerations

- Low transformation temperature
- Reasonable transformation times
- Bainitic hardenability
- Elimination of cementite
- Avoidance of temper embrittlement

Alloy

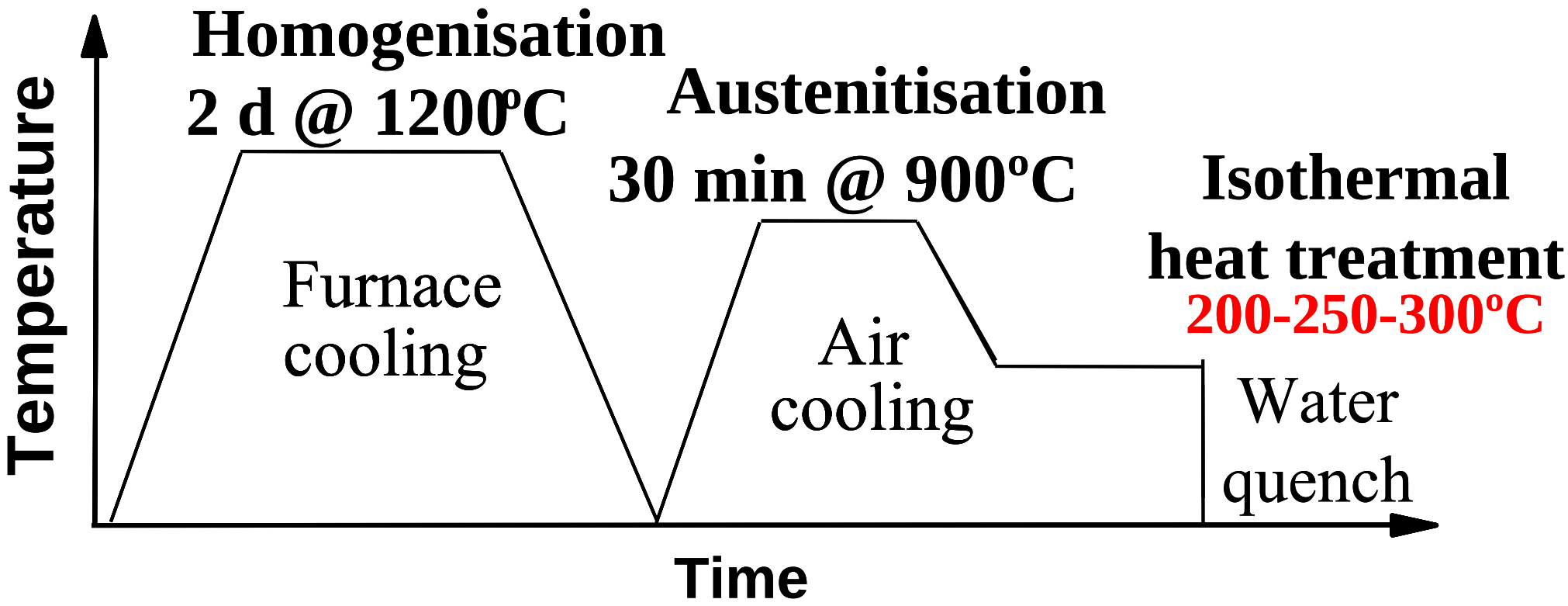
wt%

C	Si	Mn	Mo	Cr	Co	P/S
0.8	1.59	2.01	0.24	1	1.51	< 0.002

$B_S = 360°C$

$M_S = 120°C$

Very Simple Procedure



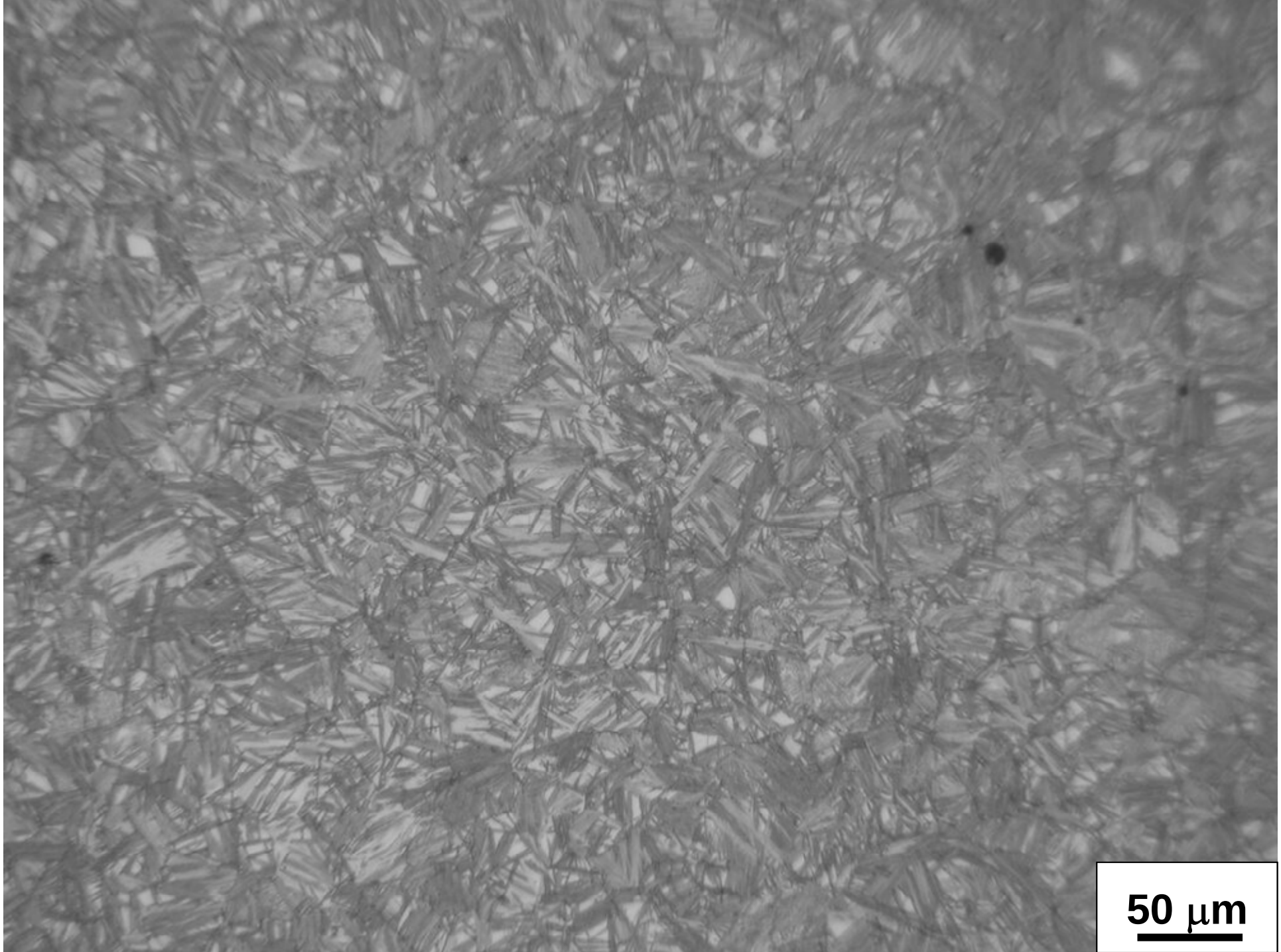
3d @200°C
10h @300°C

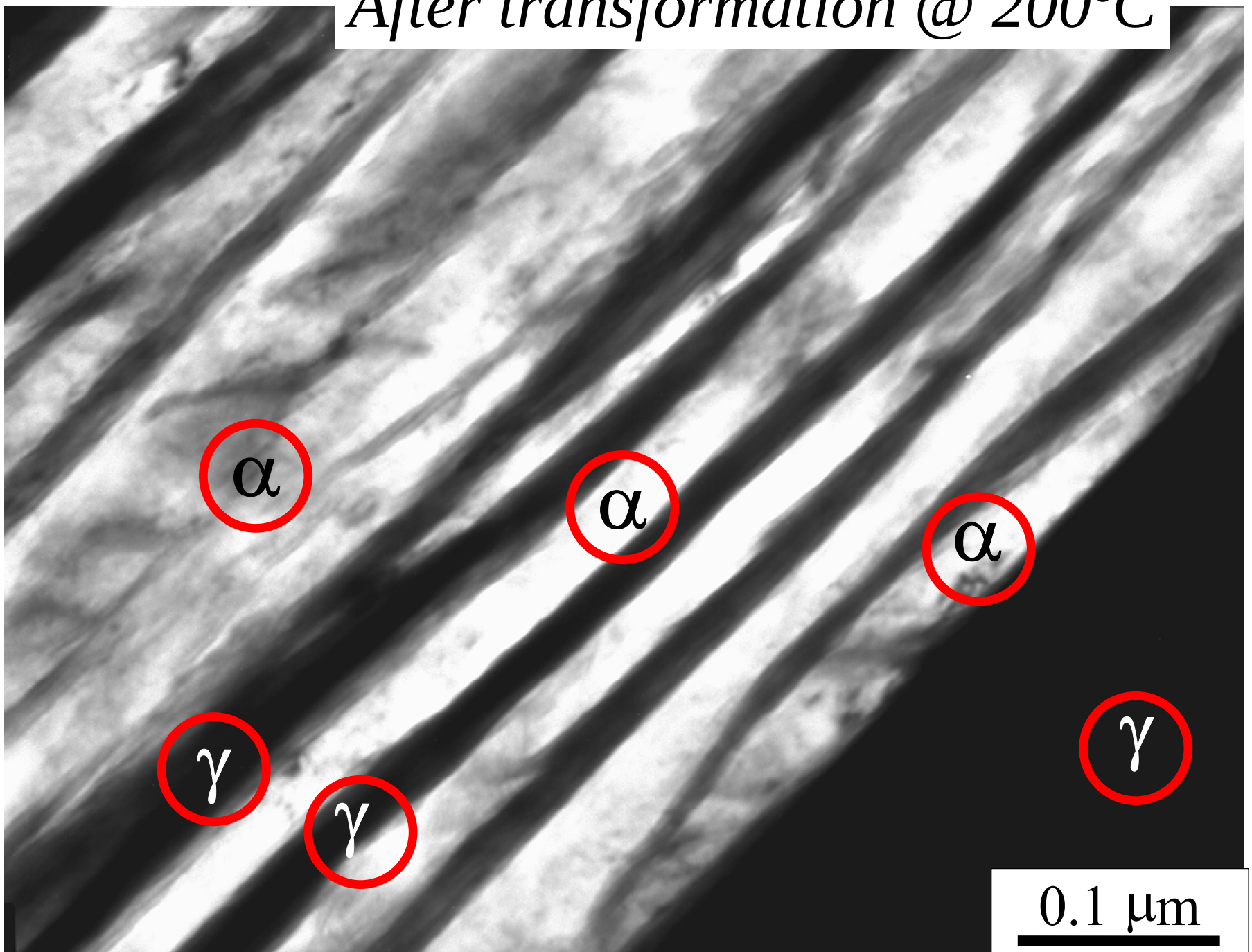
-Steel design, heat treatment

-**Microstructure, characterization**

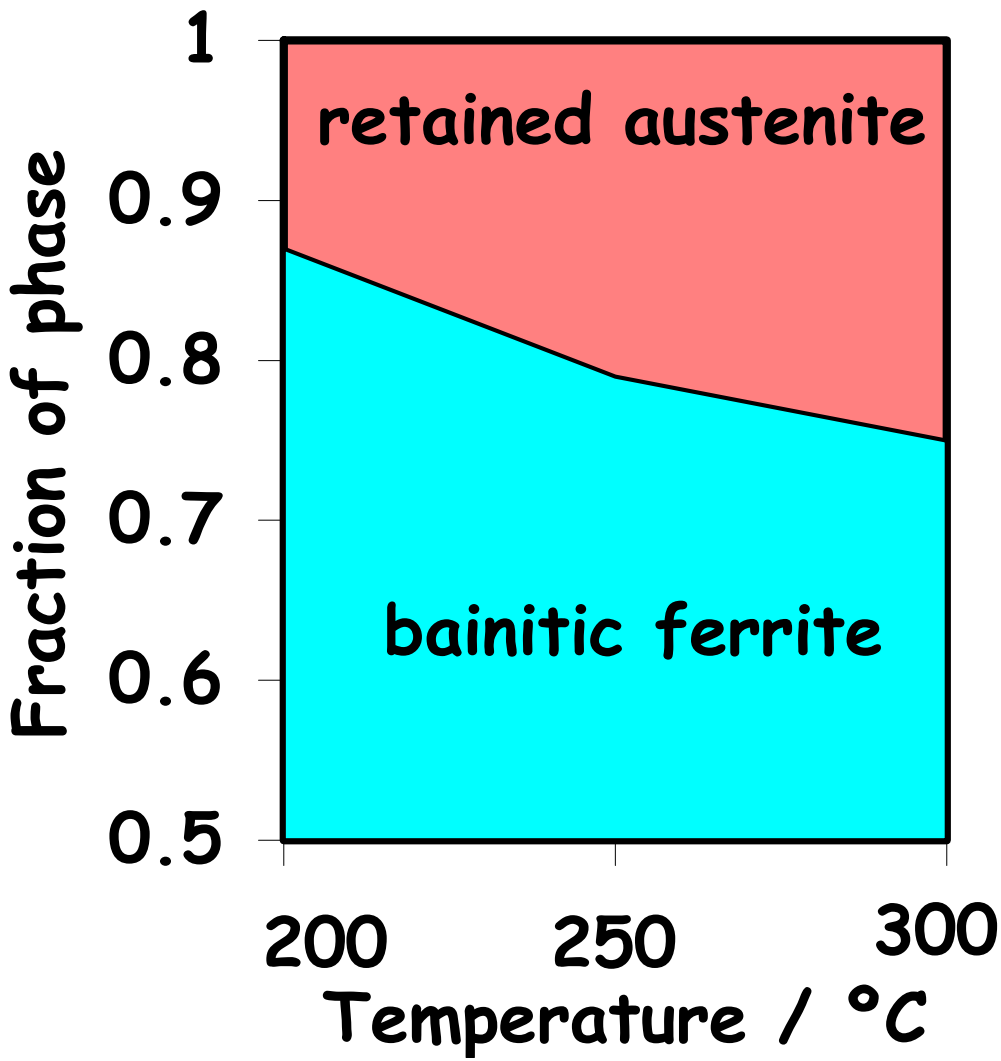
-Mechanical properties

- Microstructure $\Leftrightarrow$ Mech. properties

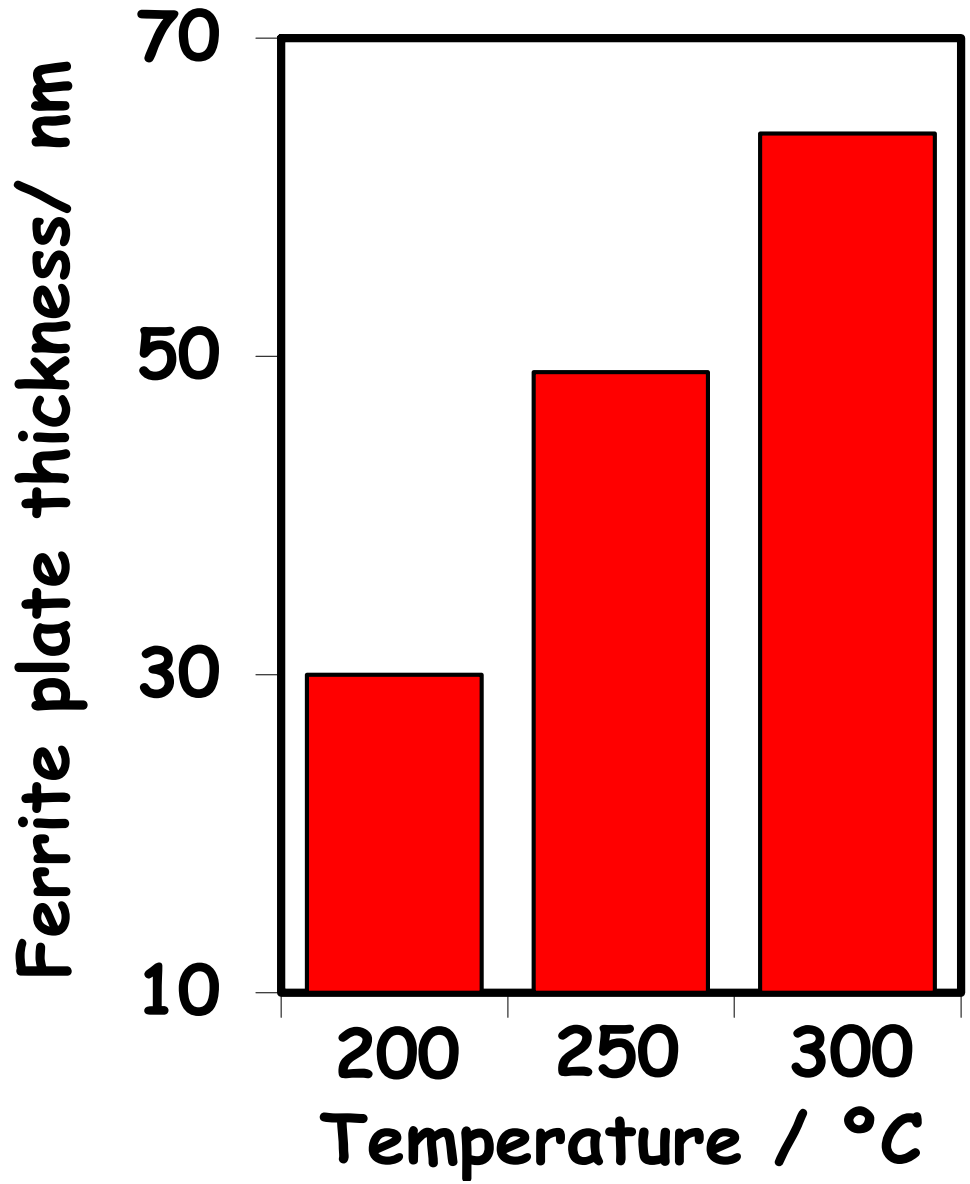

50 μm

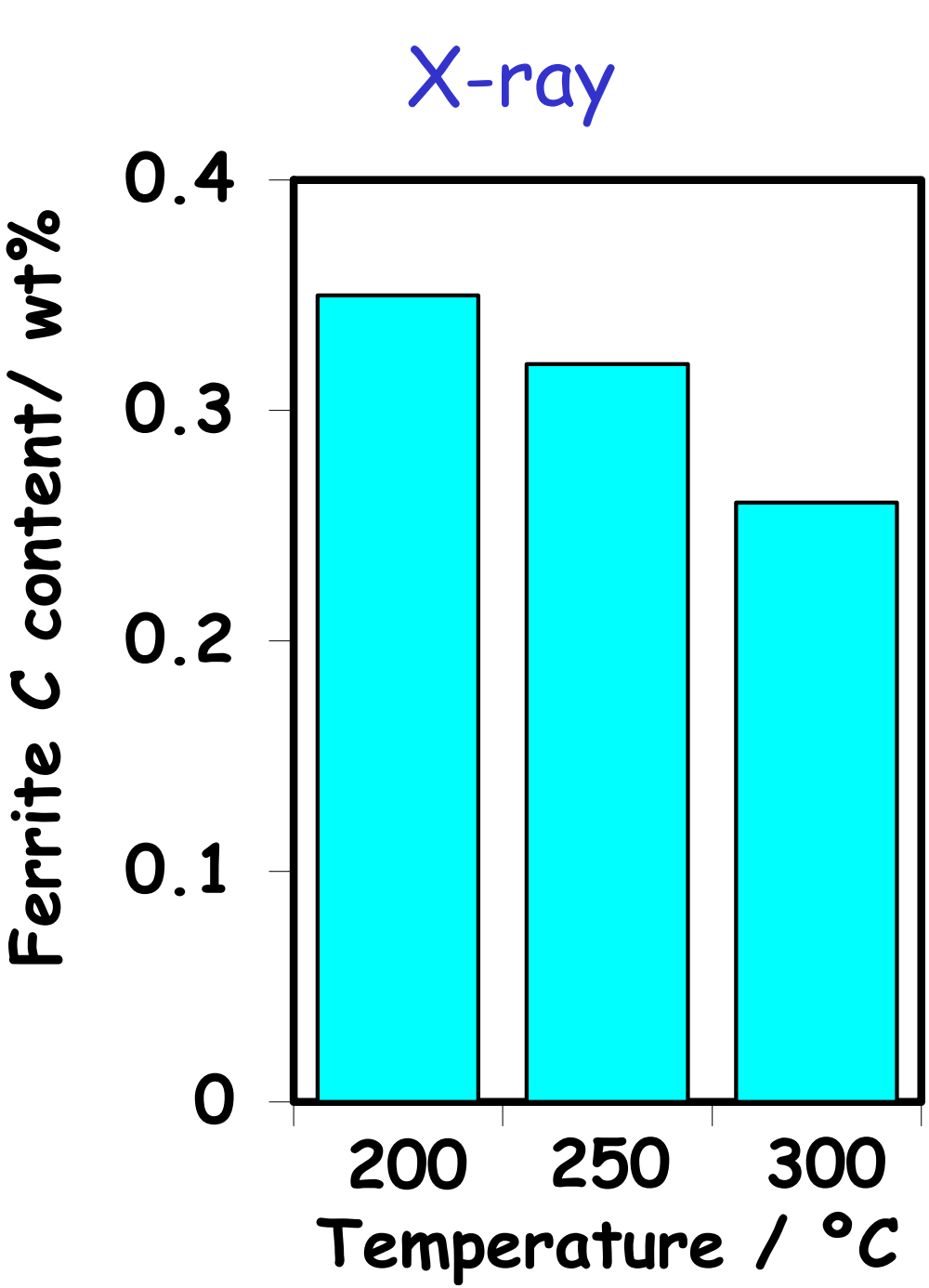

After transformation @ 200ºC
α
α
α
γ
γ
γ
0.1 μm

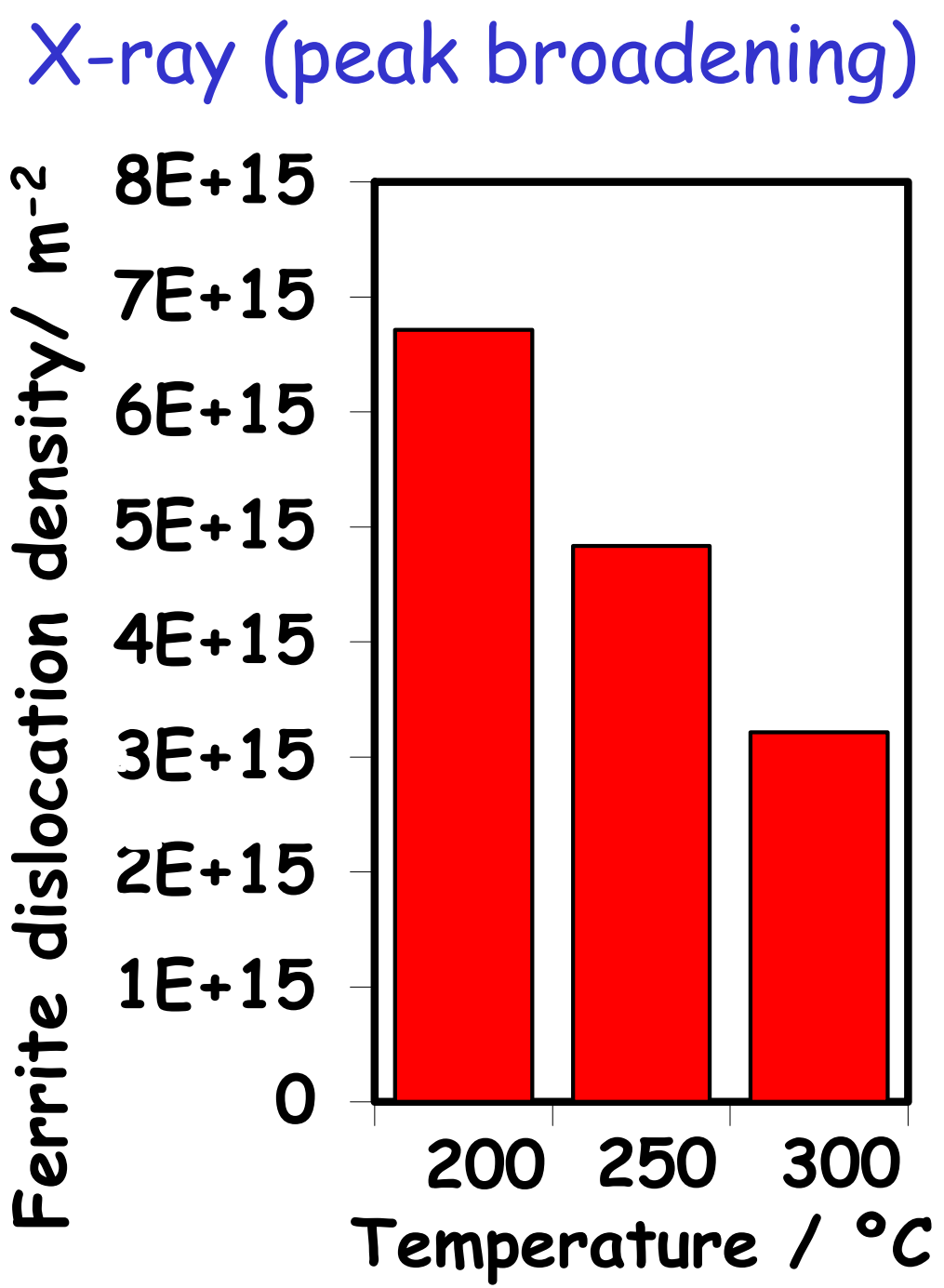
X-ray


retained austenite
bainitic ferrite
Fraction of phase
1
0.9
0.8
0.7
0.6
0.5
200
250
300
Temperature / °C

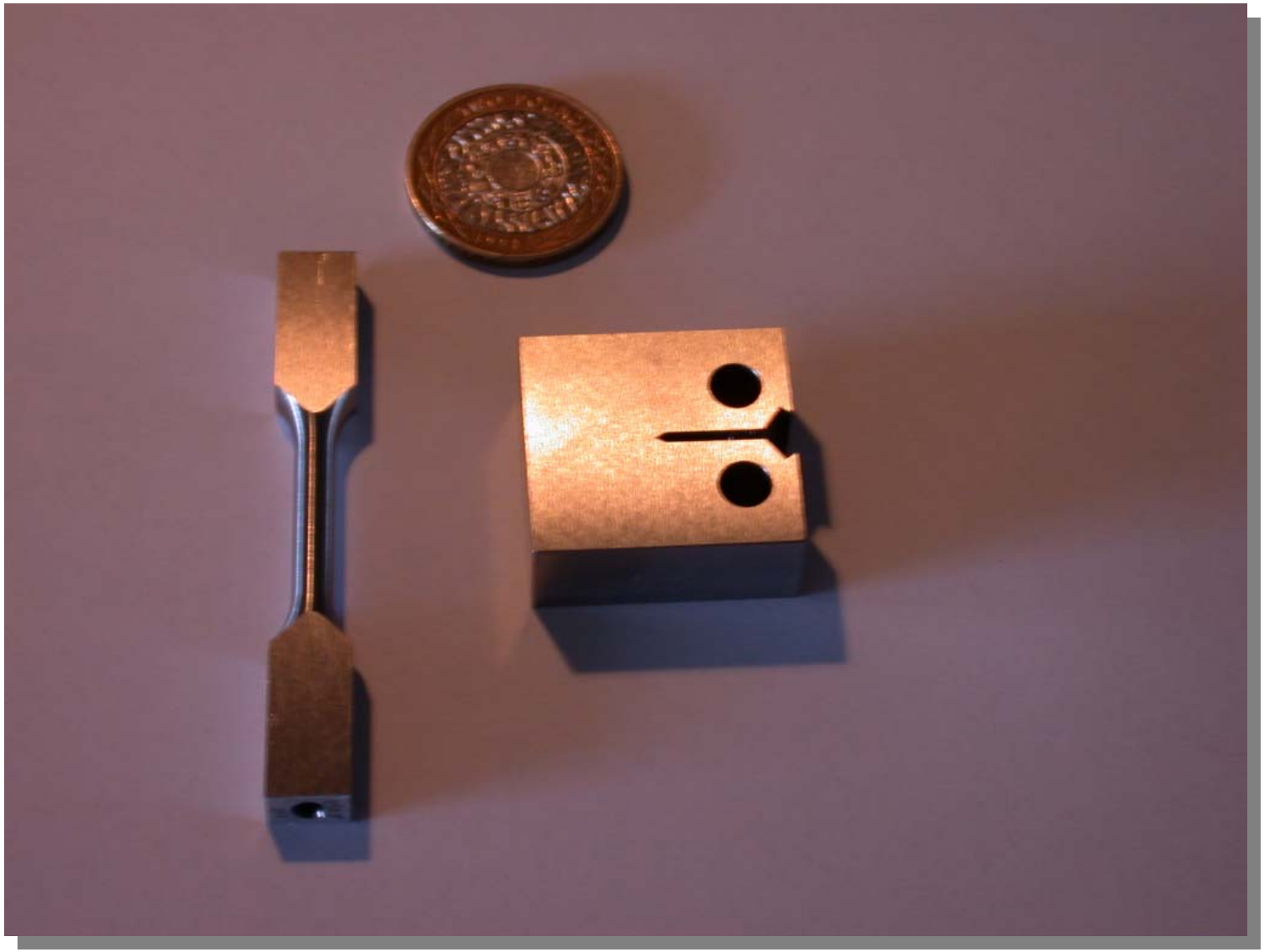
T.E.M


Ferrite plate thickness/ nm
70
50
30
10
200
250
300
Temperature / °C

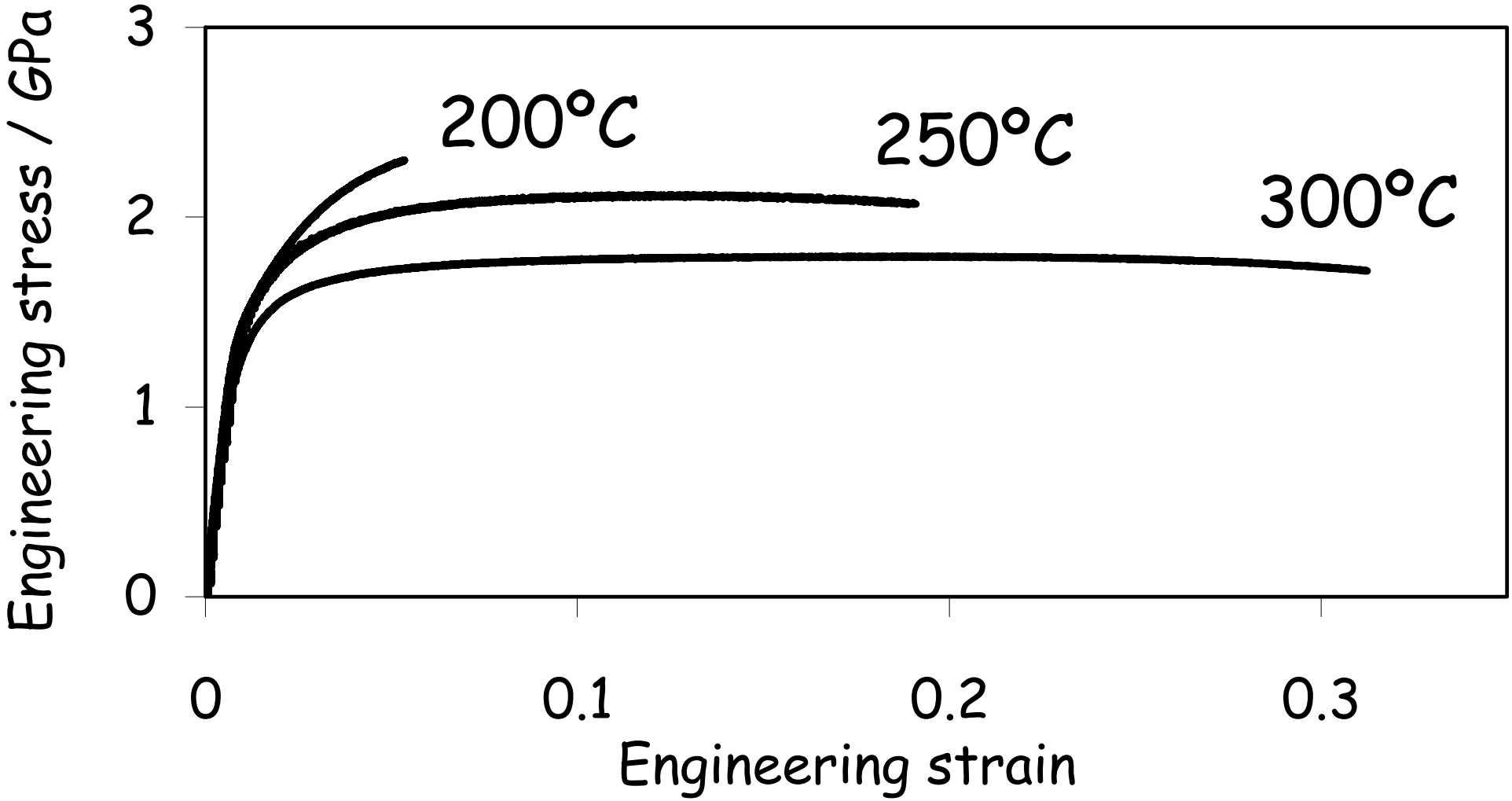

X-ray
Ferrite C content/ wt%
0.4
0.3
0.2
0.1
0
200
250
300
Temperature / °C

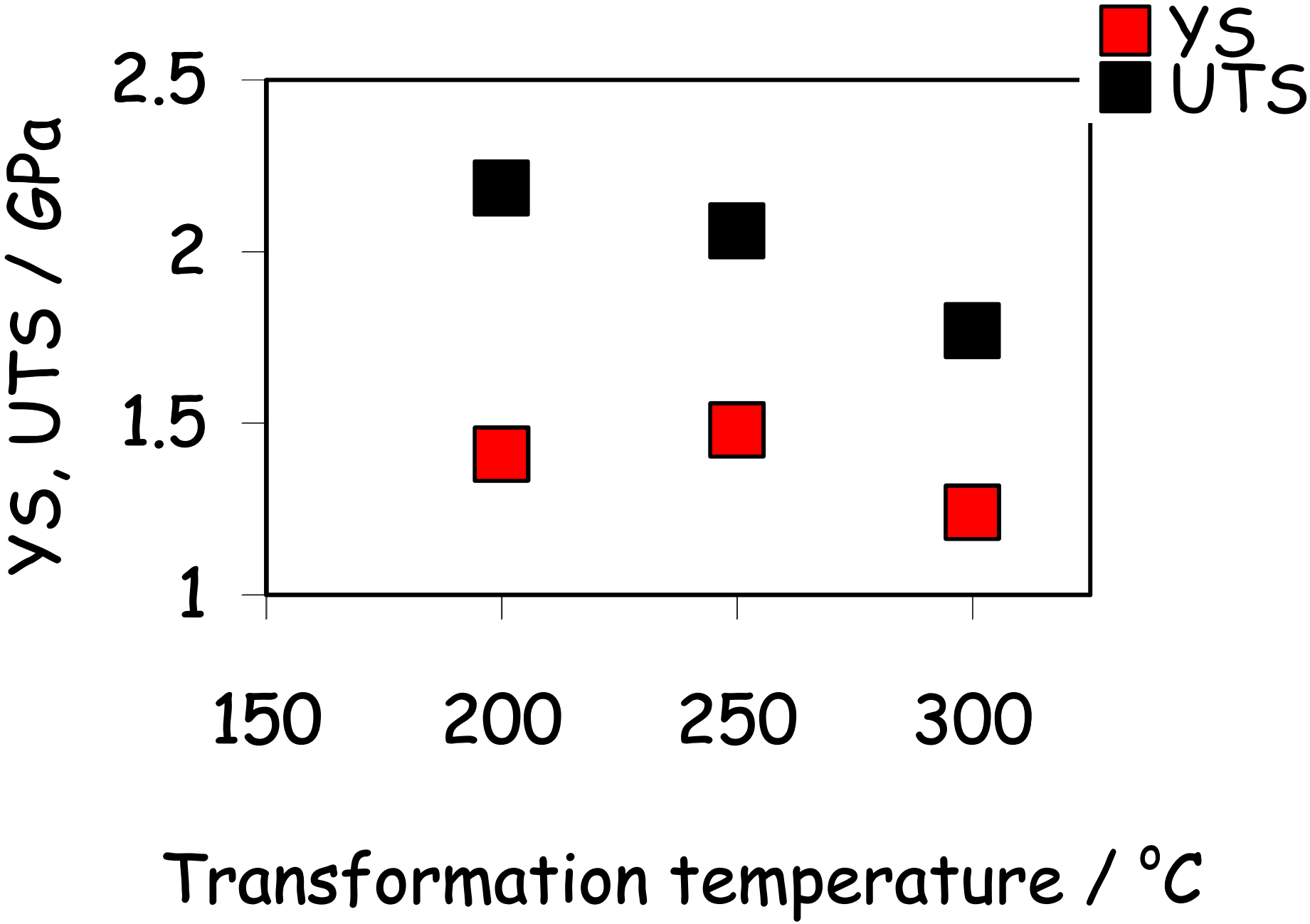

X-ray (peak broadening)
Ferrite dislocation density/ m-2
8E+15
7E+15
6E+15
5E+15
4E+15
3E+15
2E+15
1E+15
0
200
250
300
Temperature / °C

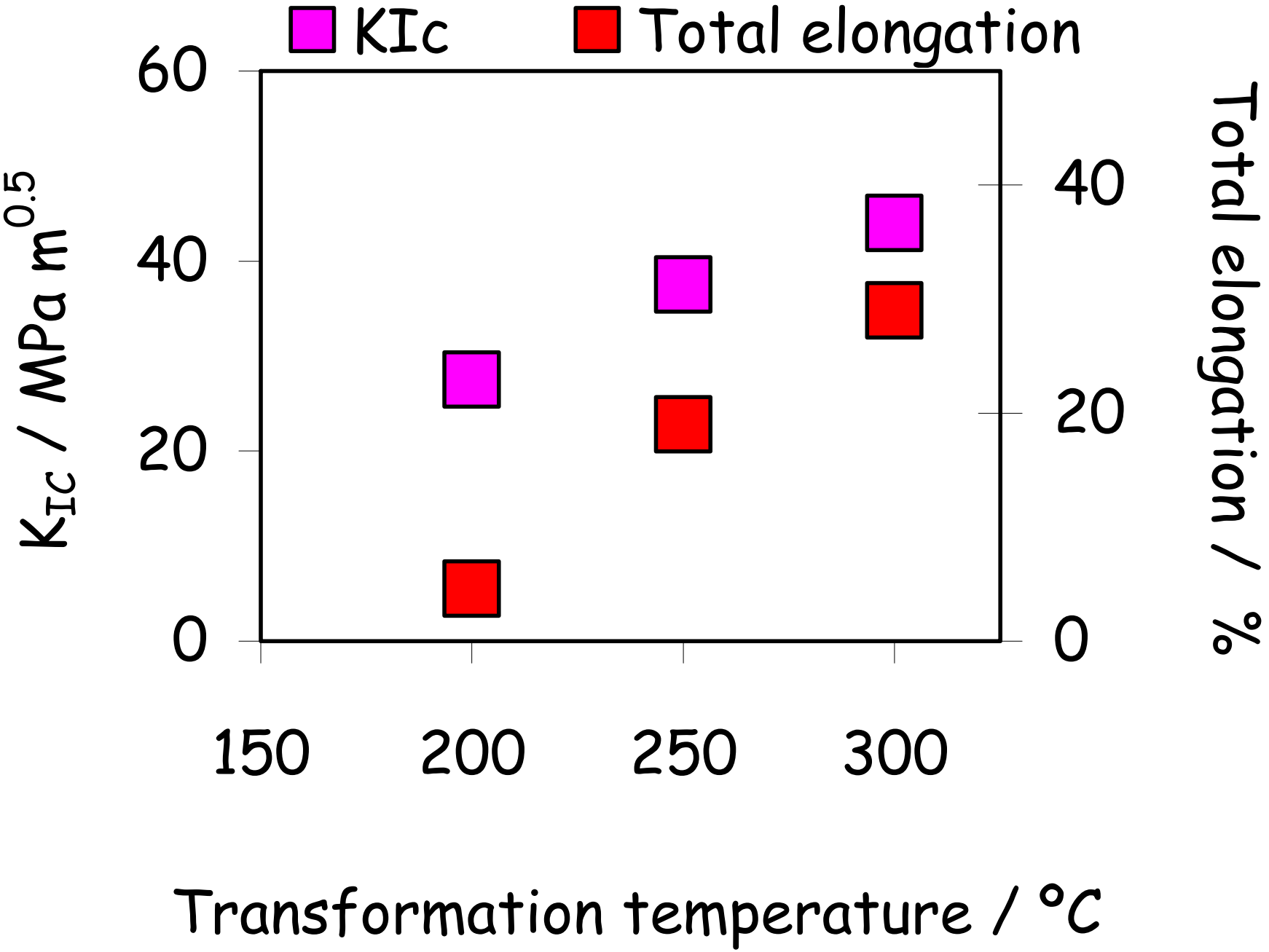
-Mechanical properties



Test at room temperature crosshead speed 0.1 mm/min.

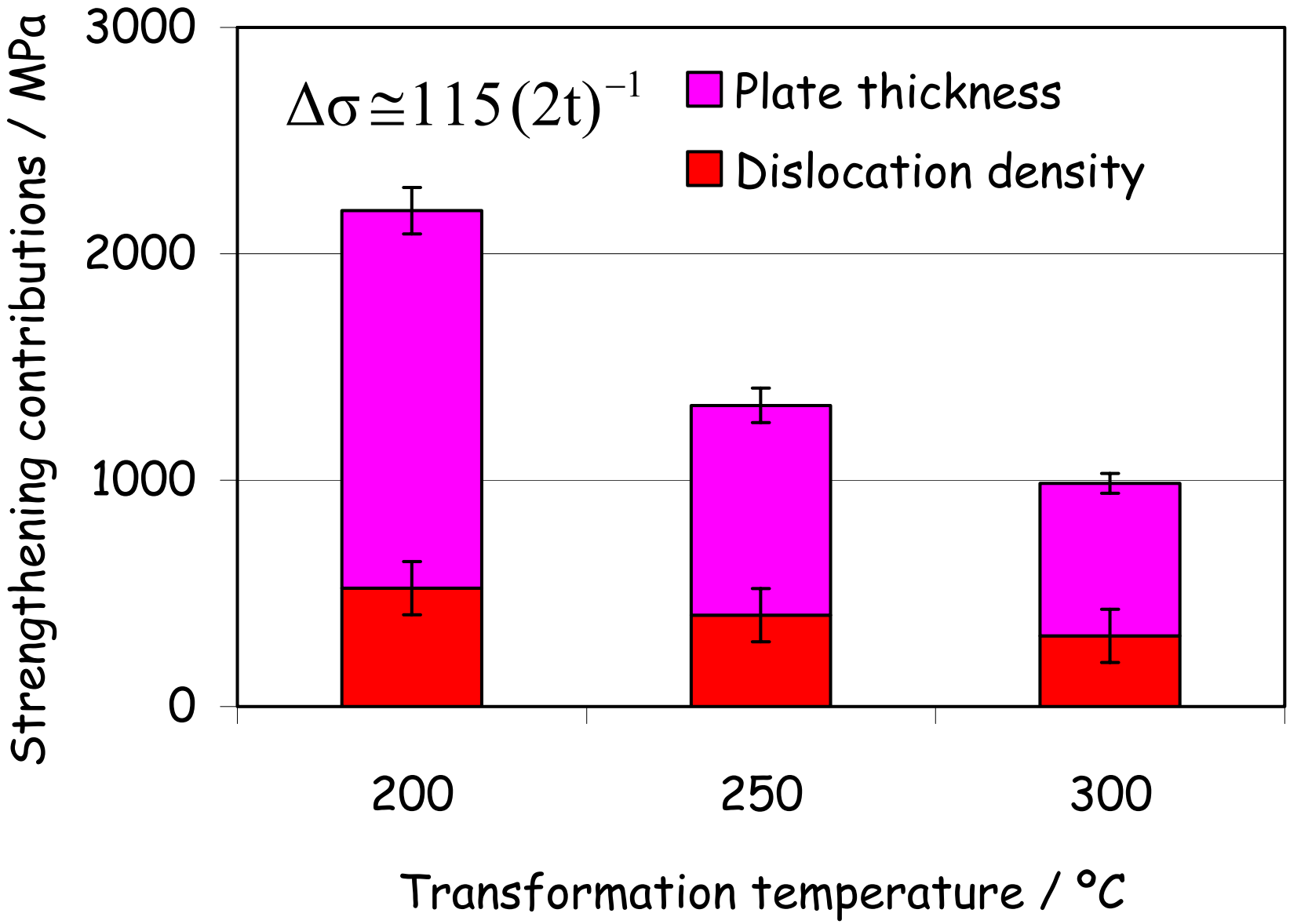



YS
UTS
2.5
2
1.5
1
YS, UTS / GPa
150
200
250
300
Transformation temperature / °C


KIc
Total elongation
60
40
20
0
40
20
0
150
200
250
300
K_{Ic} / MPa $m^{0.5}$
Total elongation / %
Transformation temperature / °C

- Microstructure $\Leftrightarrow$ Mech. properties

- Microstructure ⇔ Mech. properties



Conclusions

- Bainitic phase transformation theory + simple metallurgy
- Low transformation temperatures
- Mainly ferritic. Extremely fine and highly dislocated
- Main strengthening mechanism—slender ferrite plates
- Strength/ductility combinations never reported before