Basics of steel (and chocolate)

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What is steel?

Steel: a strong metal that is a mixture of iron and carbon, used for making things that need a strong structure, especially vehicles and buildings. [and much more…]

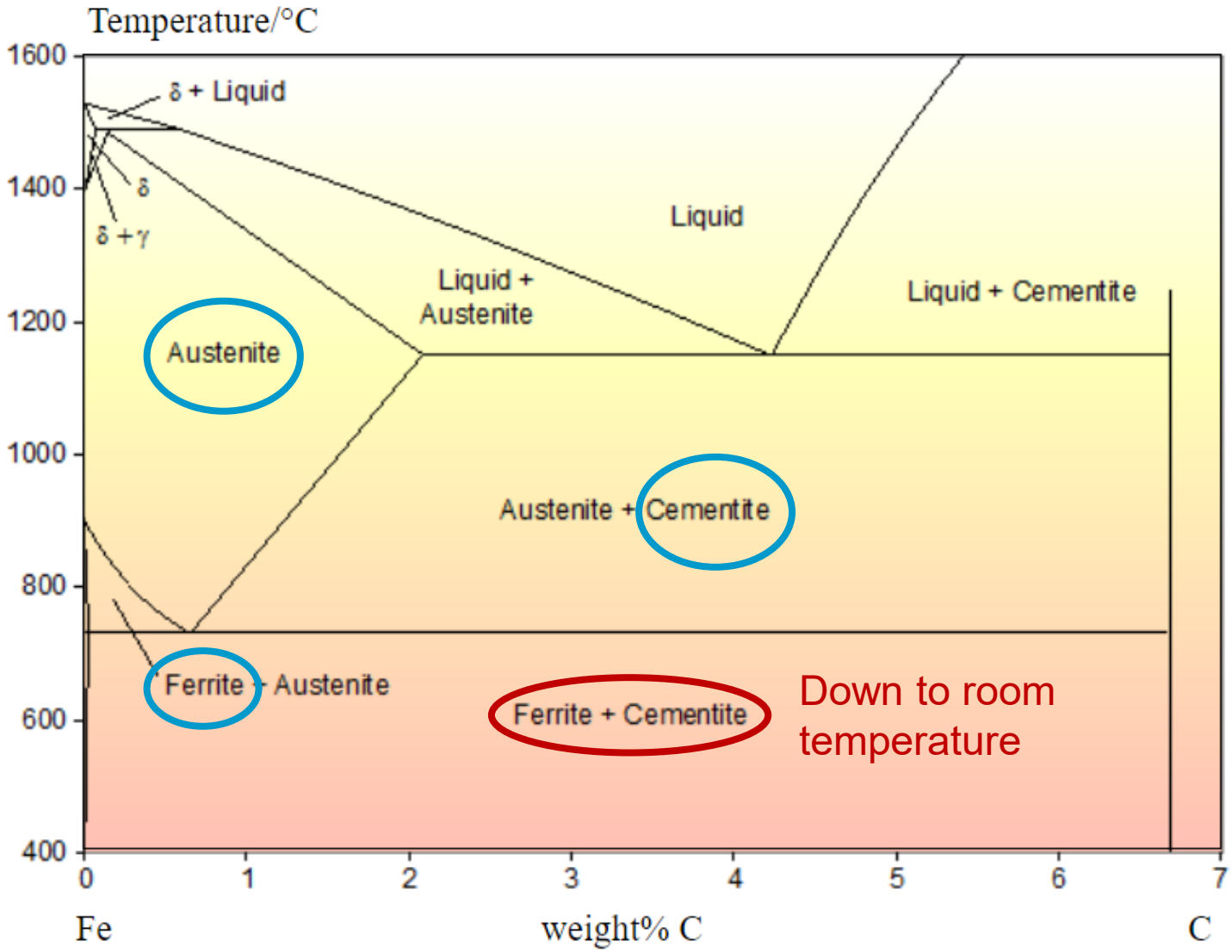
Cambridge Dictionary

Staal: smeedbaar, hardbaar ferrometaal met relatief laag koolstofgehalte, dat in vloeibare toestand is bereid.

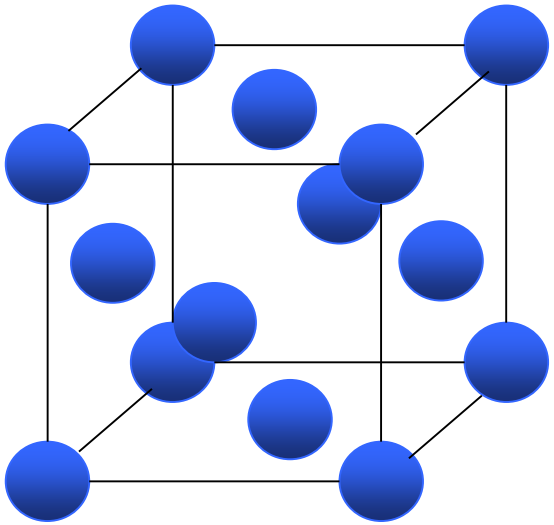
van Dale

TU Delft

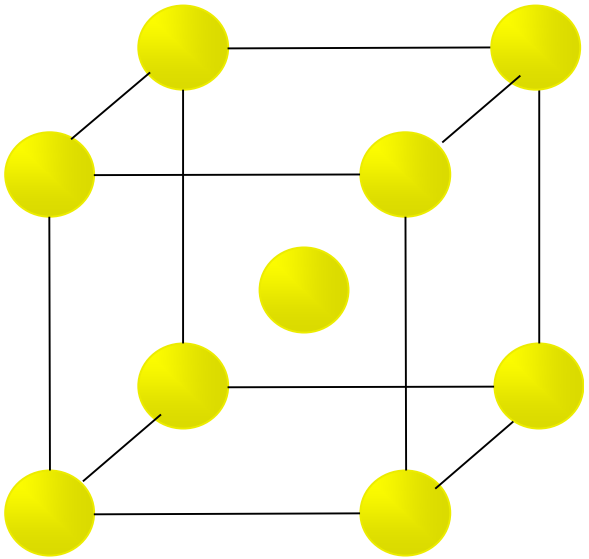
Equilibrium Fe-C phase diagram



Crystal structure equilibrium phases

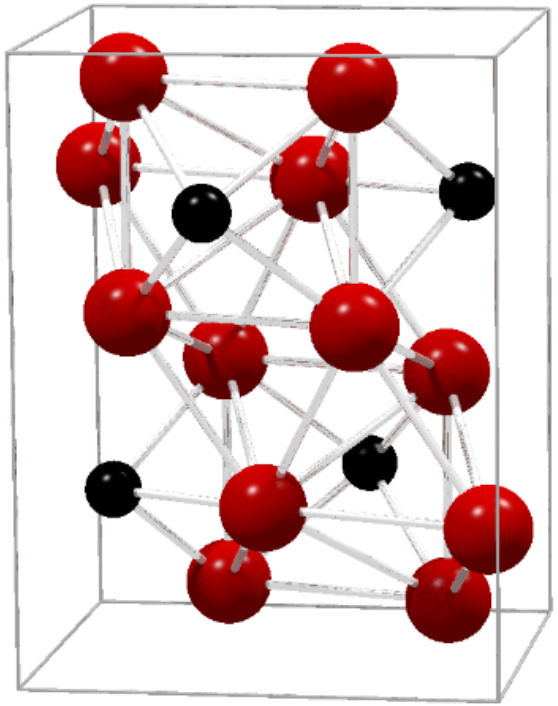


Austenite (γ)
0 – 2 wt.% Carbon



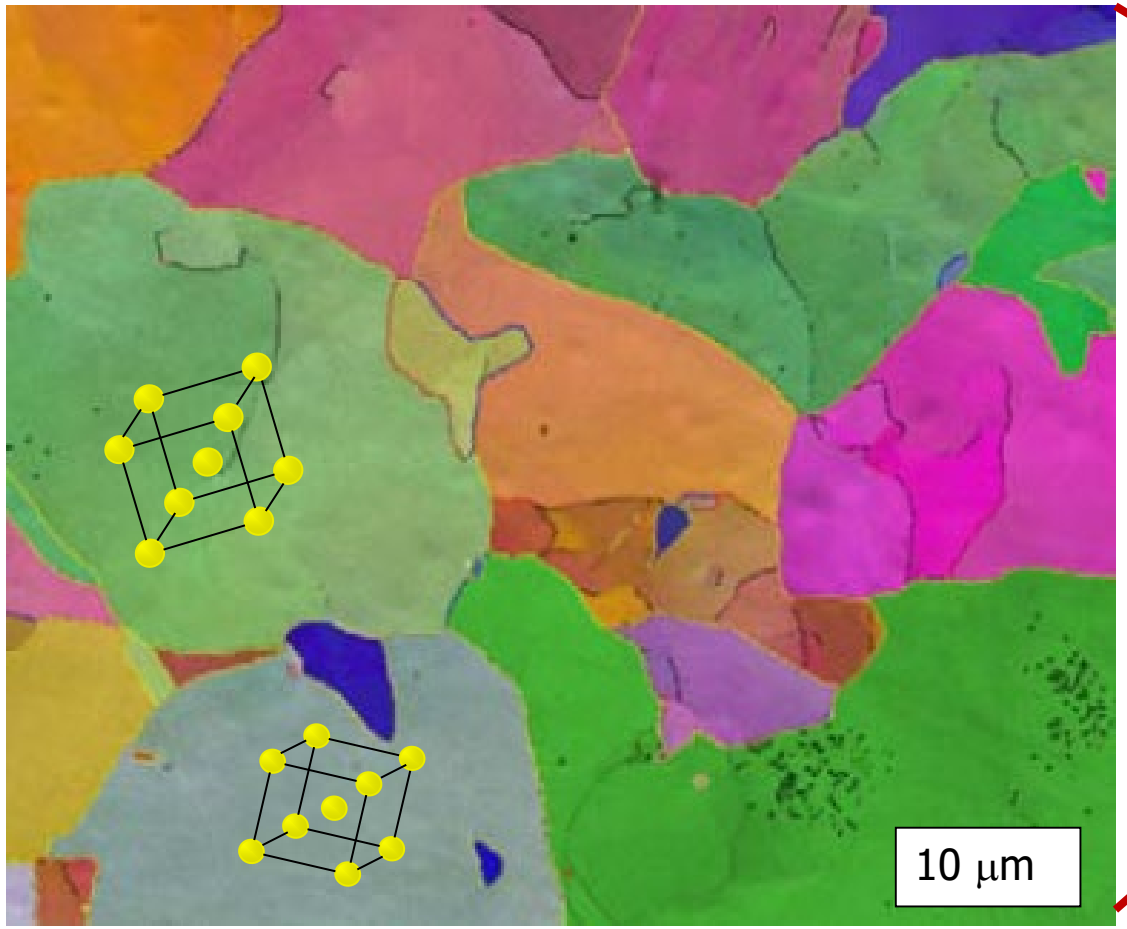
Ferrite (α)
0 – 0.022 wt.% Carbon

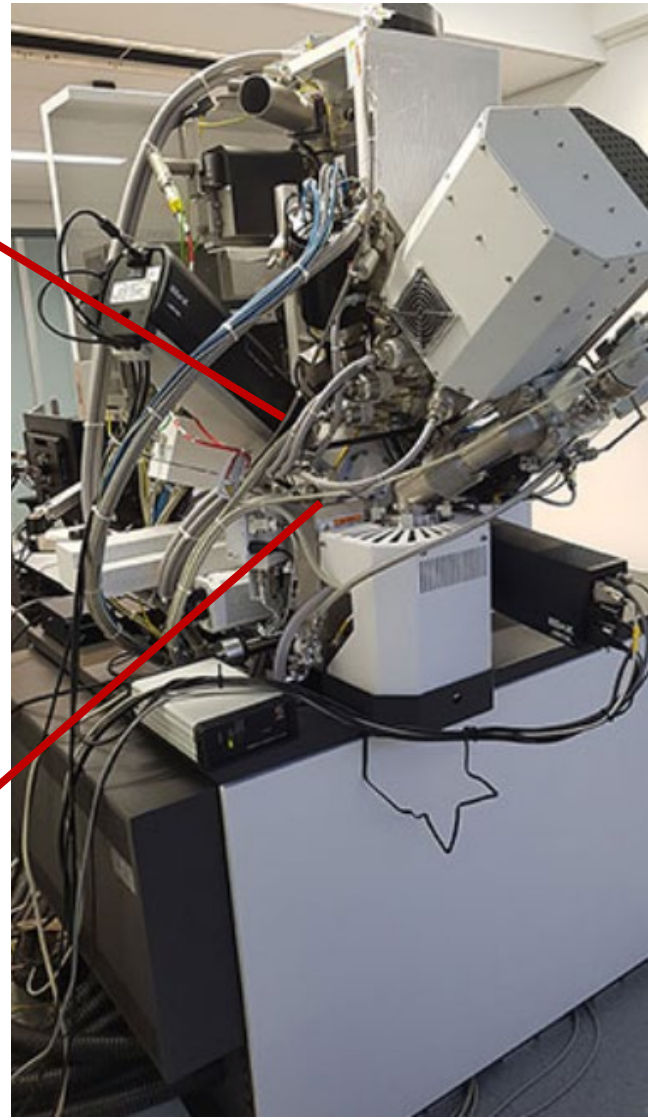
Factor ~100



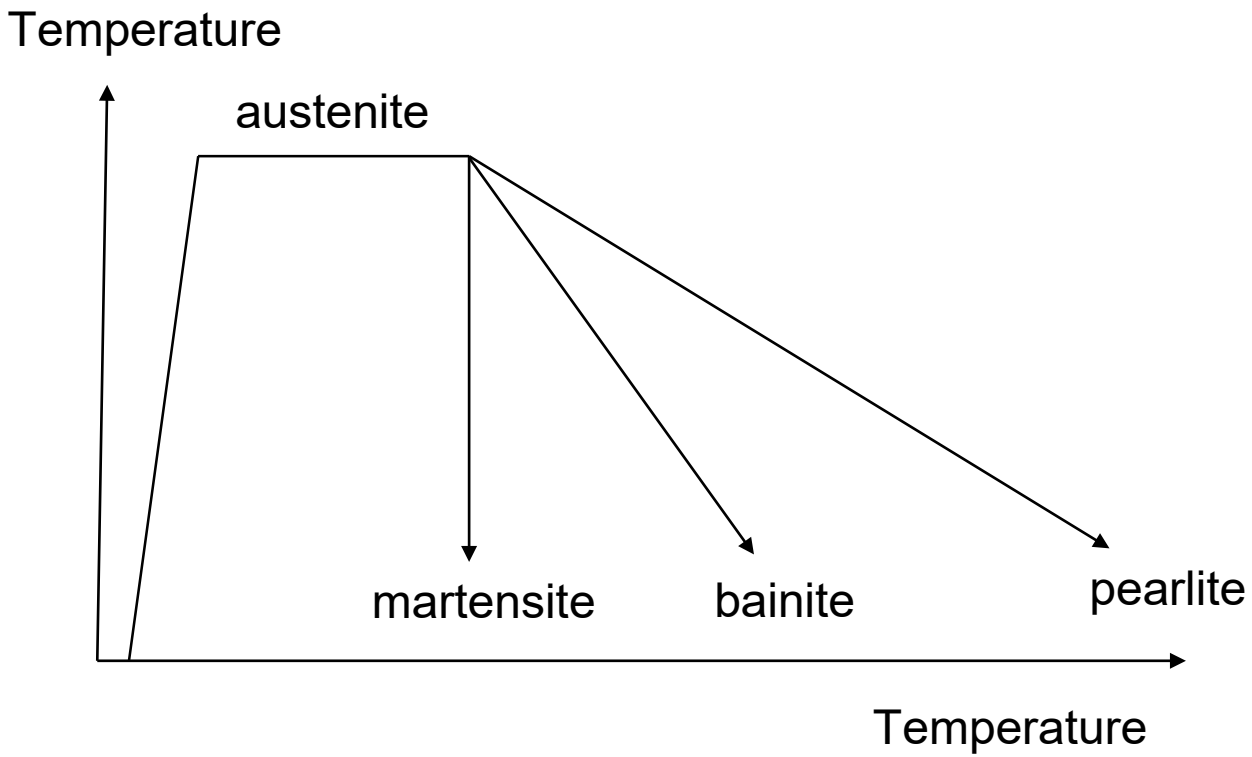
Cementite ($\theta = Fe_3C$)
6.7 wt.% Carbon

Microscopic structure of steel



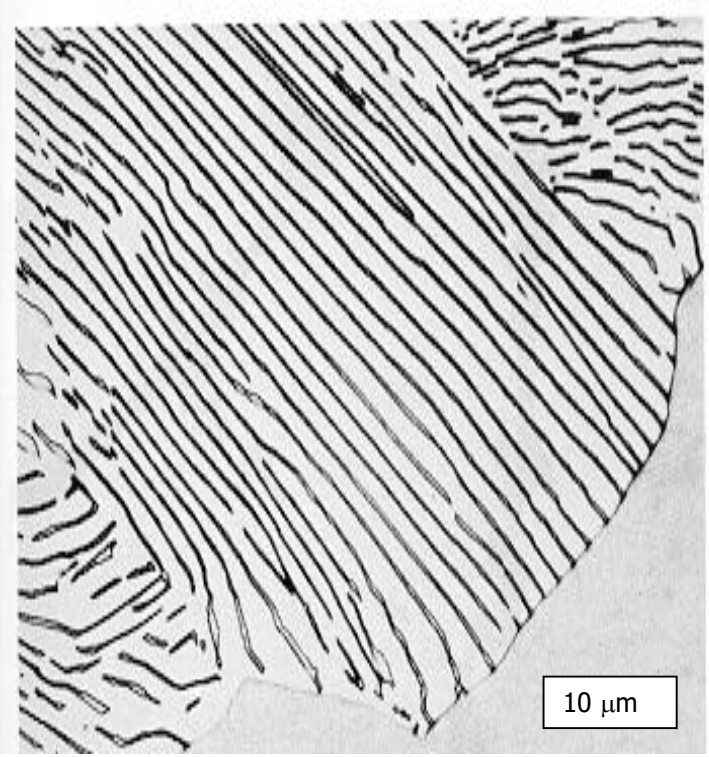


Effect of cooling rate on microstructure formation



Pearlite

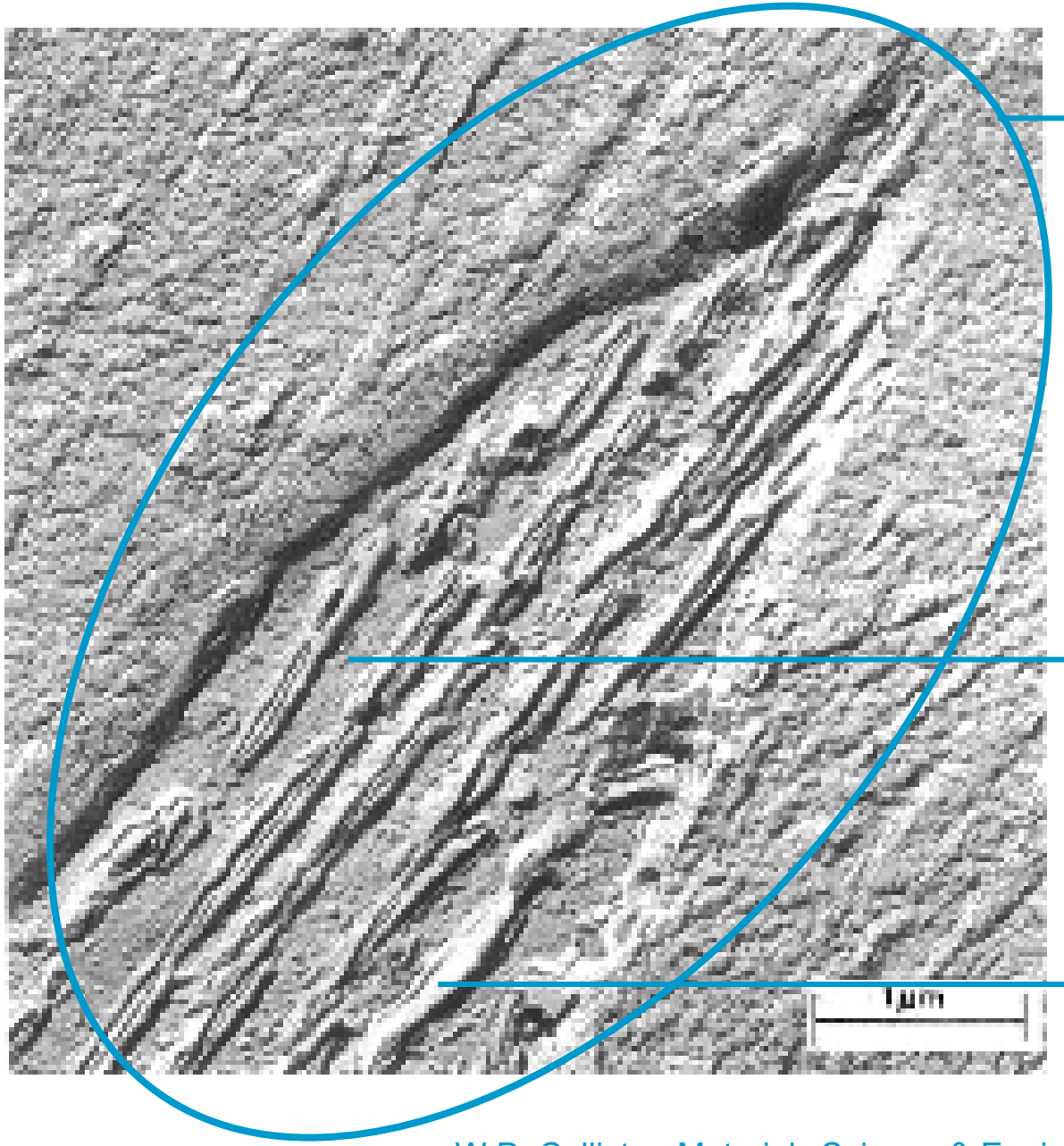
Pearlite: two interpenetrating crystals of ferrite and cementite that are locally ordered as alternating plates, but that are connected in the 3rd dimension.



Carbon redistribution over ~1 micrometer

M.V. Kral et al., Materials Characterization 45 (2000) 17.

Bainite



W.D. Callister, Materials Science & Engineering, Wiley (2015)

Martensite

Martensite: Supersaturated ferrite; no carbon redistribution

Lath (low carbon)

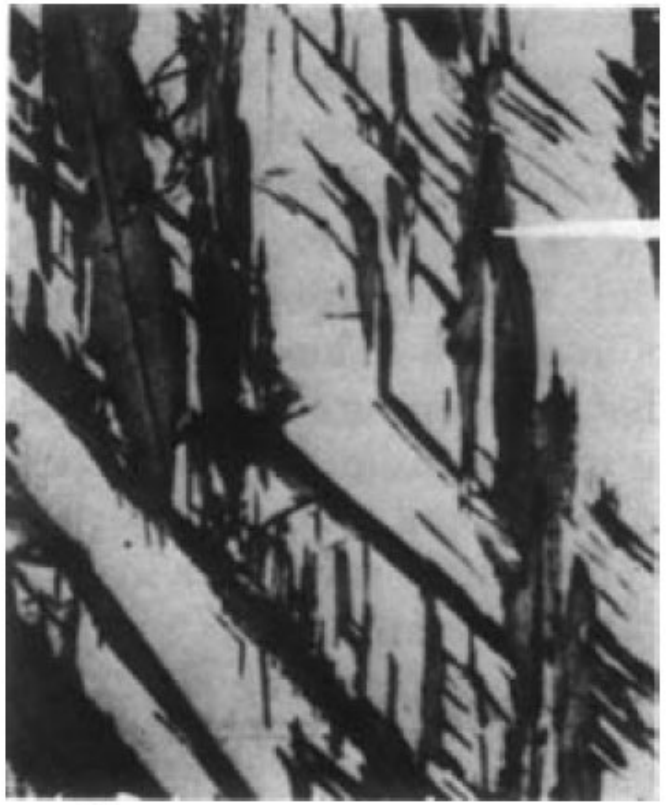
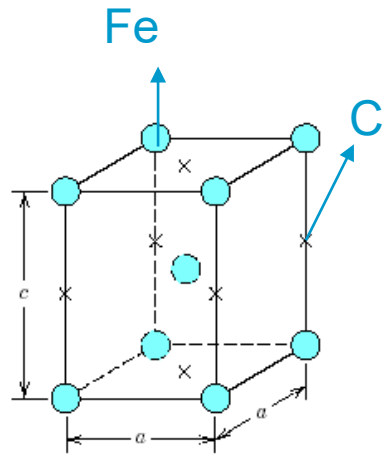
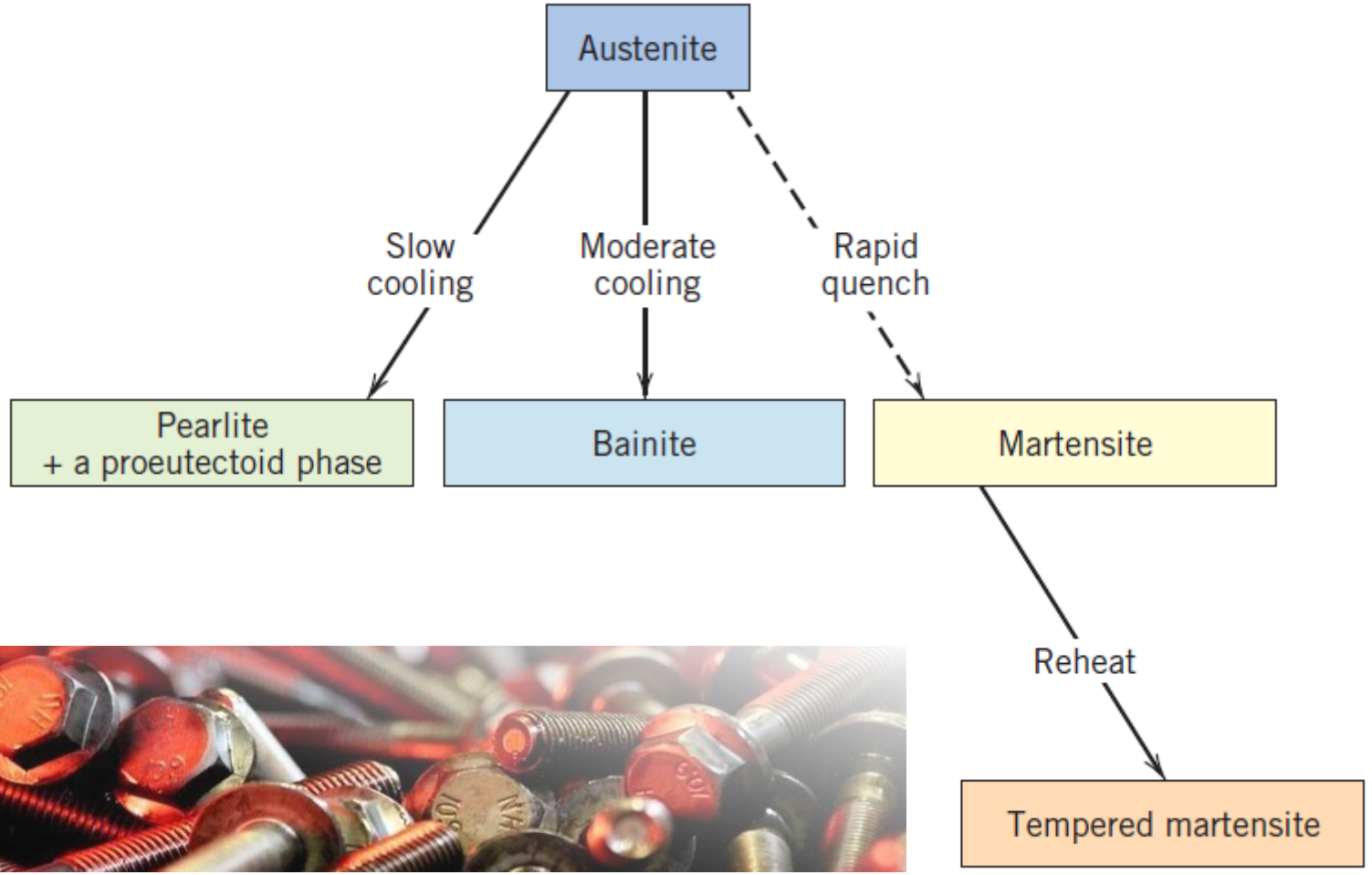


Plate (medium carbon)



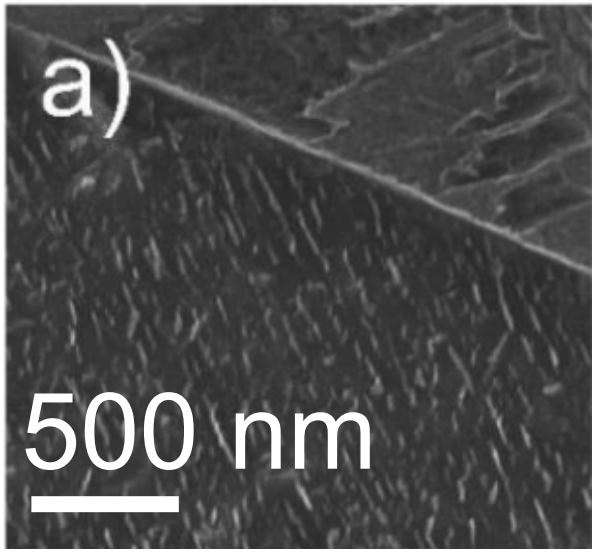
Effect of cooling rate on microstructure formation

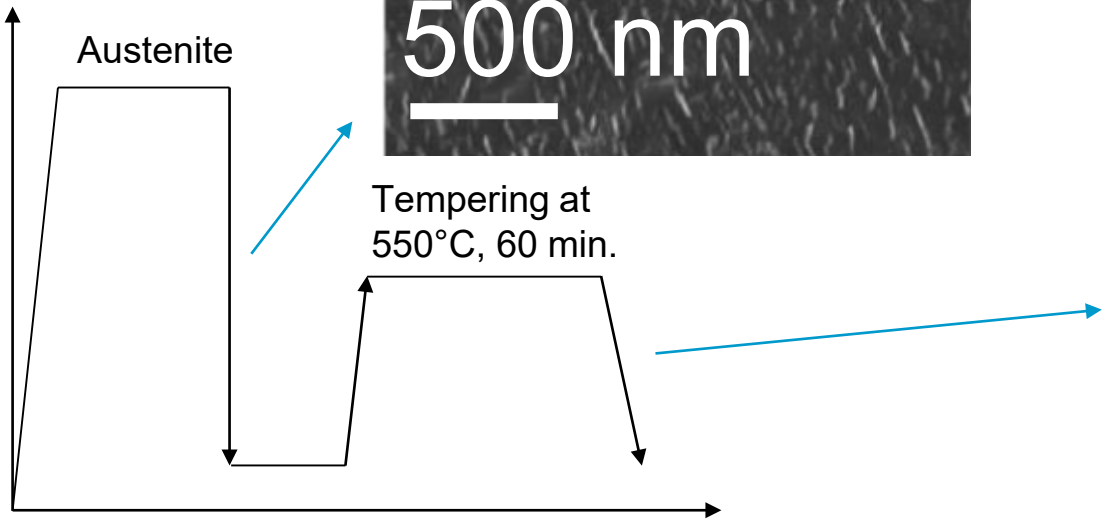


W.D. Callister, Materials Science & Engineering, Wiley (2015)

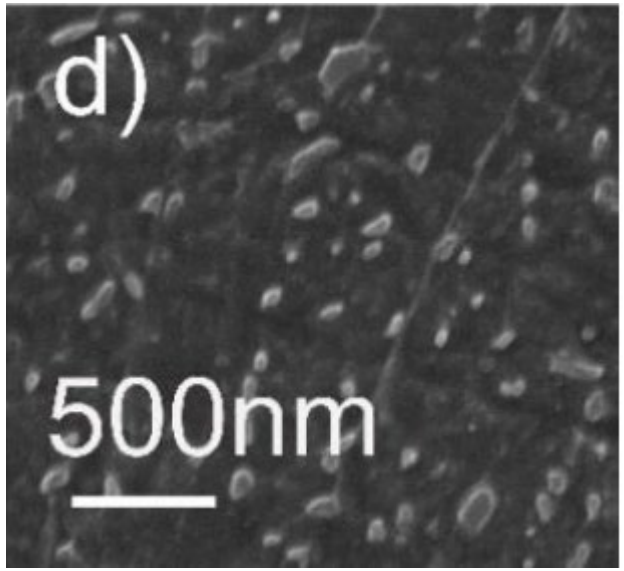
Tempering of martensite

As quenched





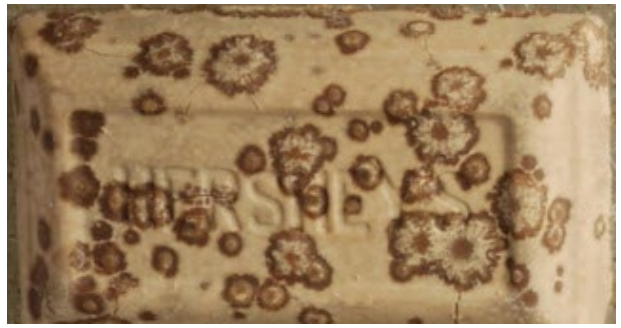
Tougher steel after
tempering at 550°C, 60 min.



Cocoa butter: 6 polymorphs

Processing	Form	melting point
Rapid cooling	I	17.3°C
Cooling: 2°C/min	II	23.3°C
Solidification at 5 - 10°C	III	25.5°C
Solidification at 16 - 21°C	IV	27.3°C
Temper treatment	V	33.8°C
Transformation of V after 4 months (equilibrium)	VI	36.3°C

blooming

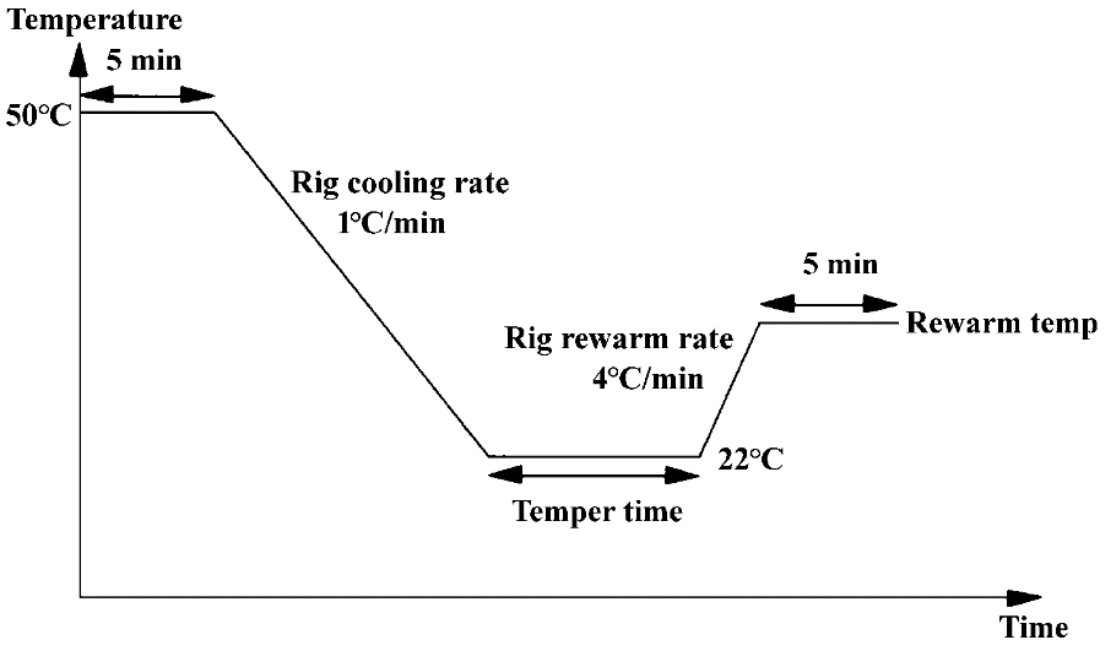


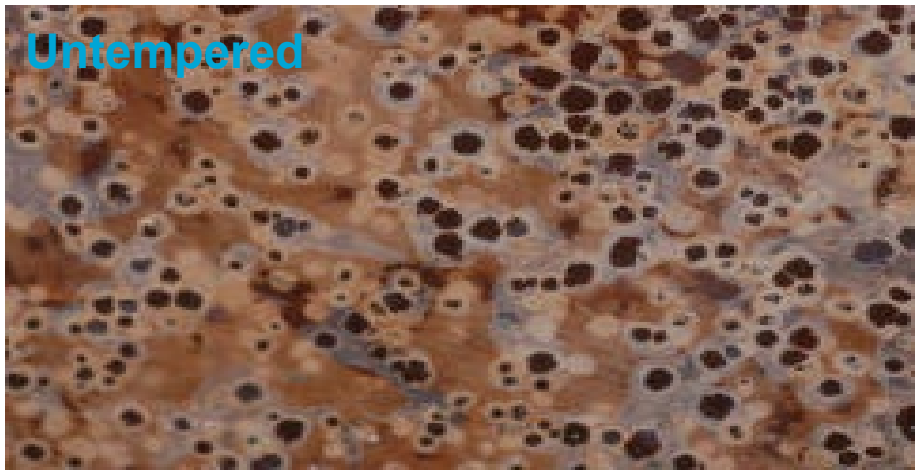
Shiny, smooth texture, good snap, melts in mouth

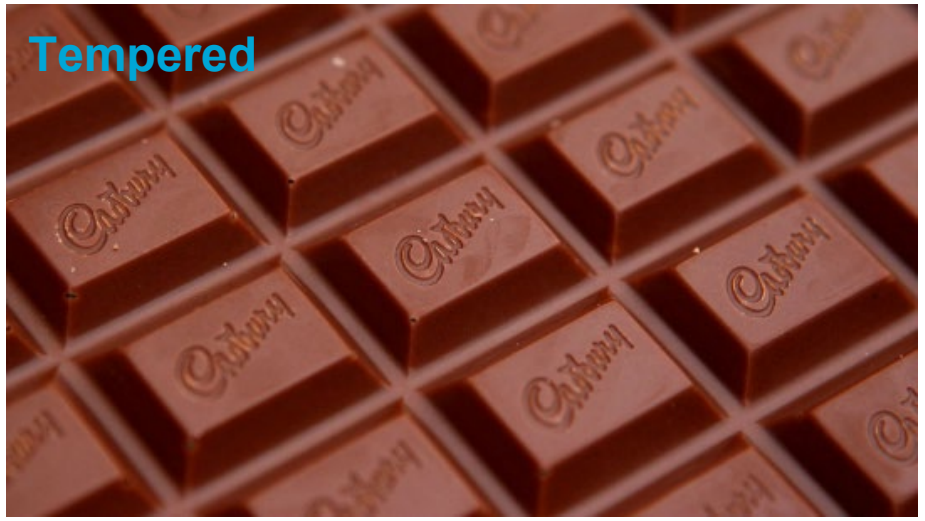
After Yrjö H. Roos, University College Cork, Ireland

Tempering of chocolate

Hard, shiny chocolate forms via a temper treatment



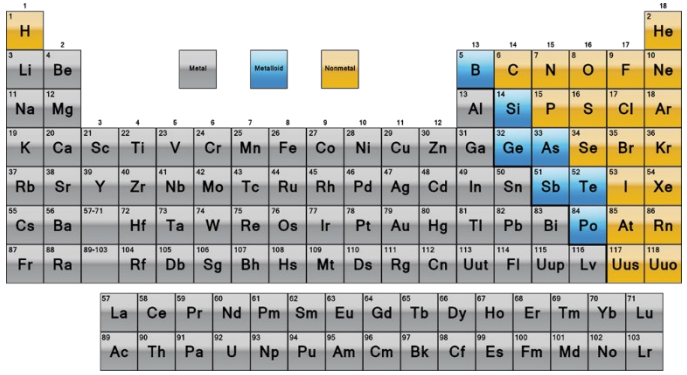


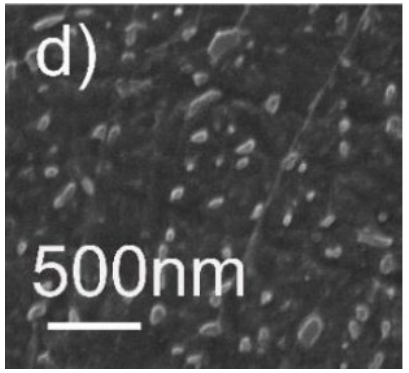


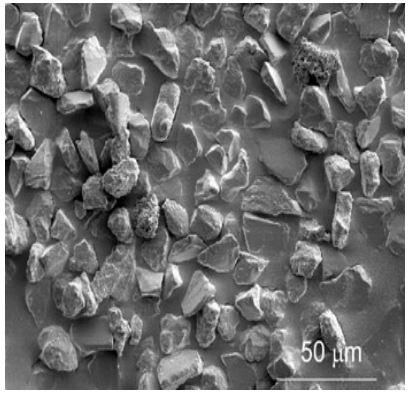
After Yrjö H. Roos, University College Cork, Ireland

Materials science of steel and chocolate

Composition → Processing → Microstructure → Properties

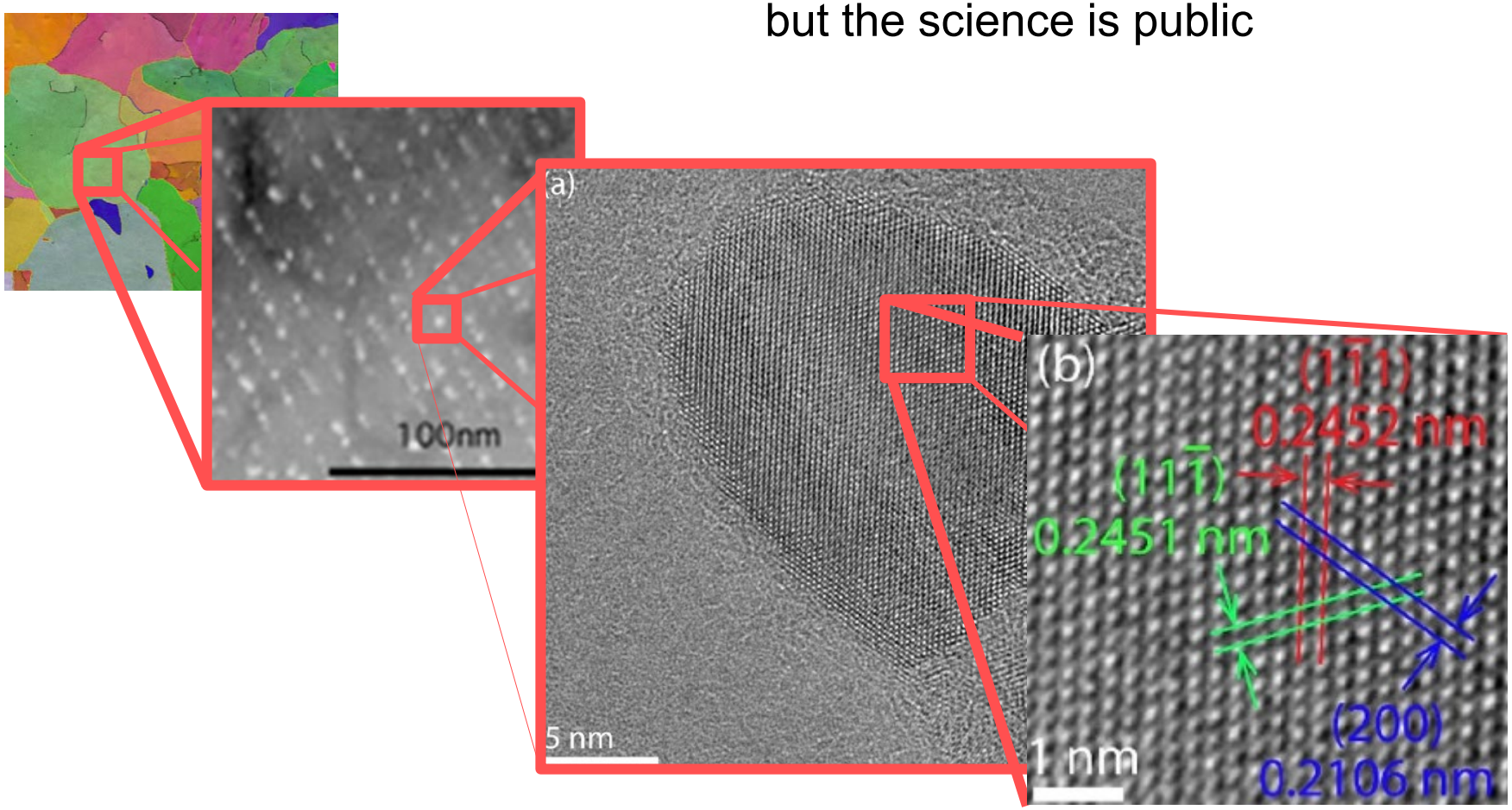






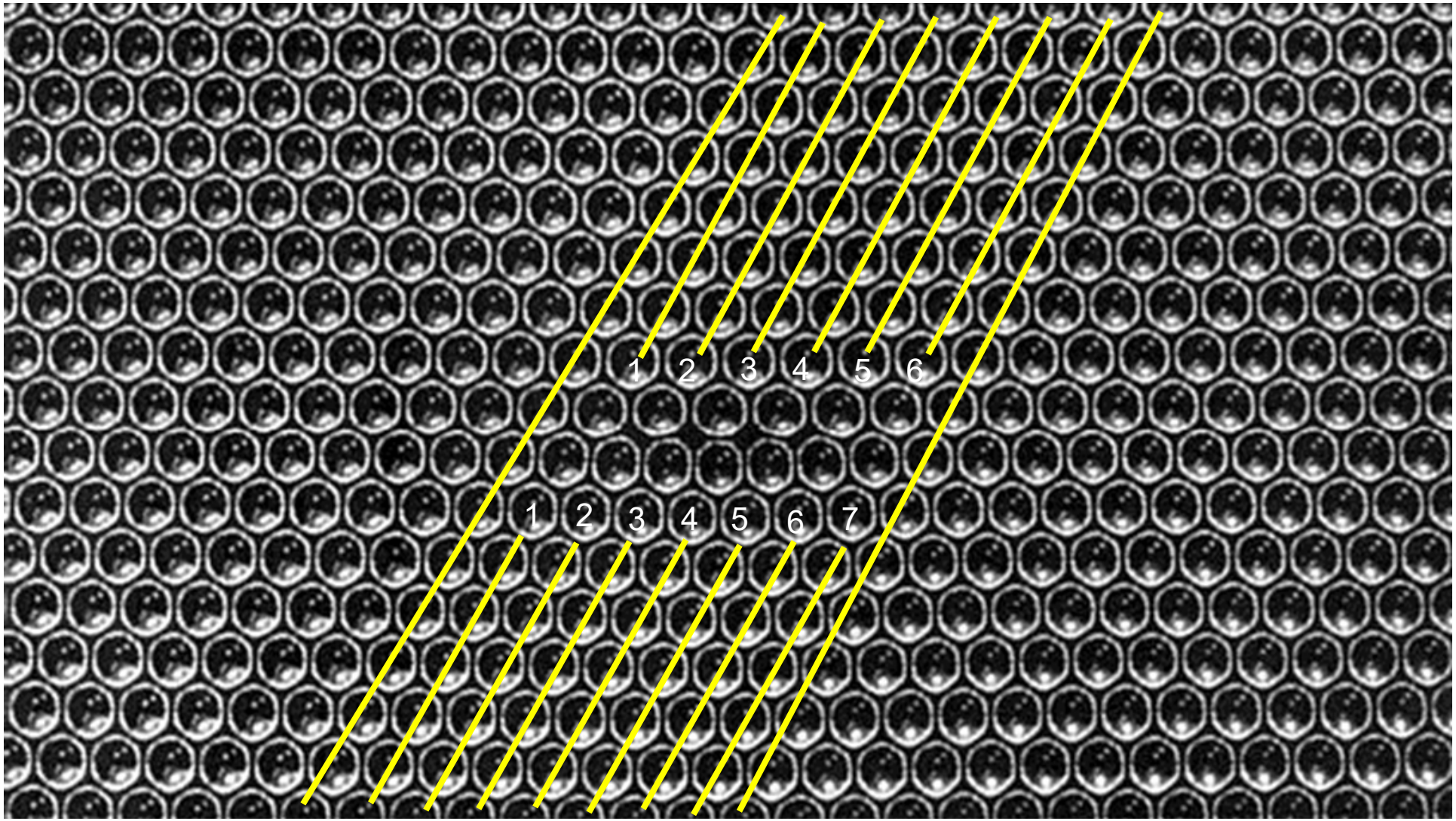
Hierarchical structure of steel: modern blacksmith's secret

but the science is public



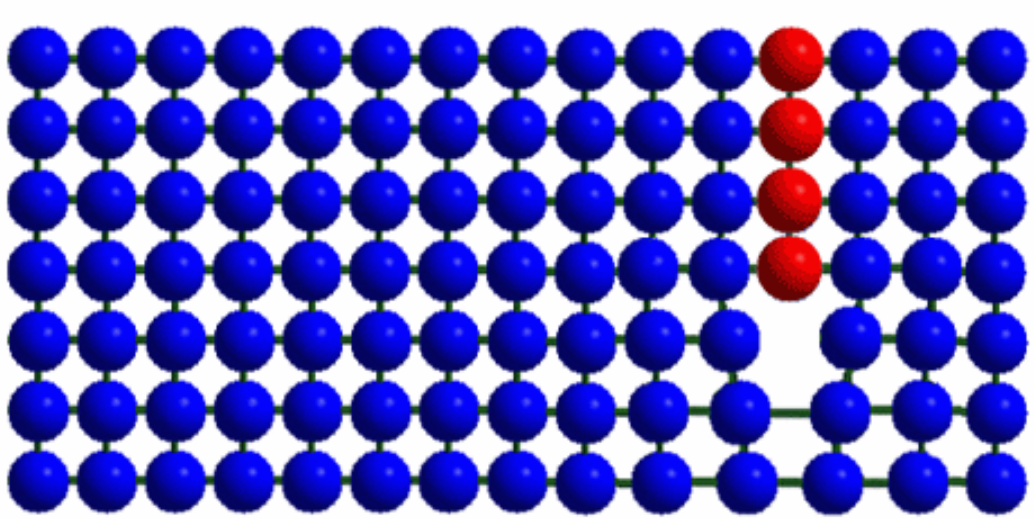
X. Zhang et al., Materials & Design (2020).

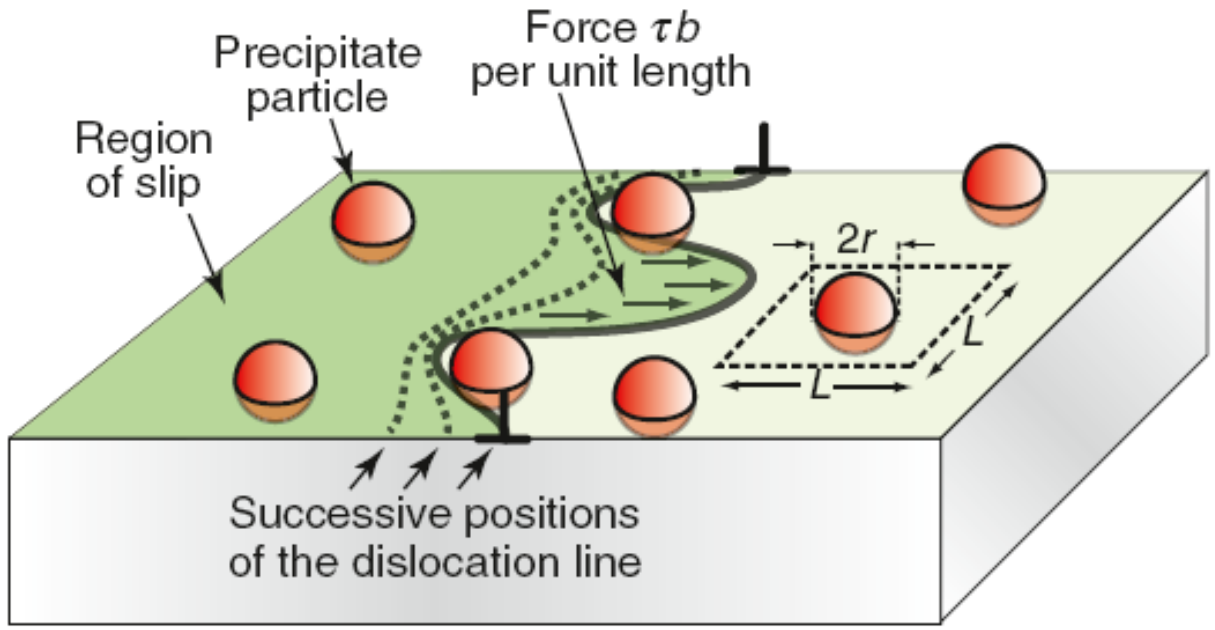
Dislocation



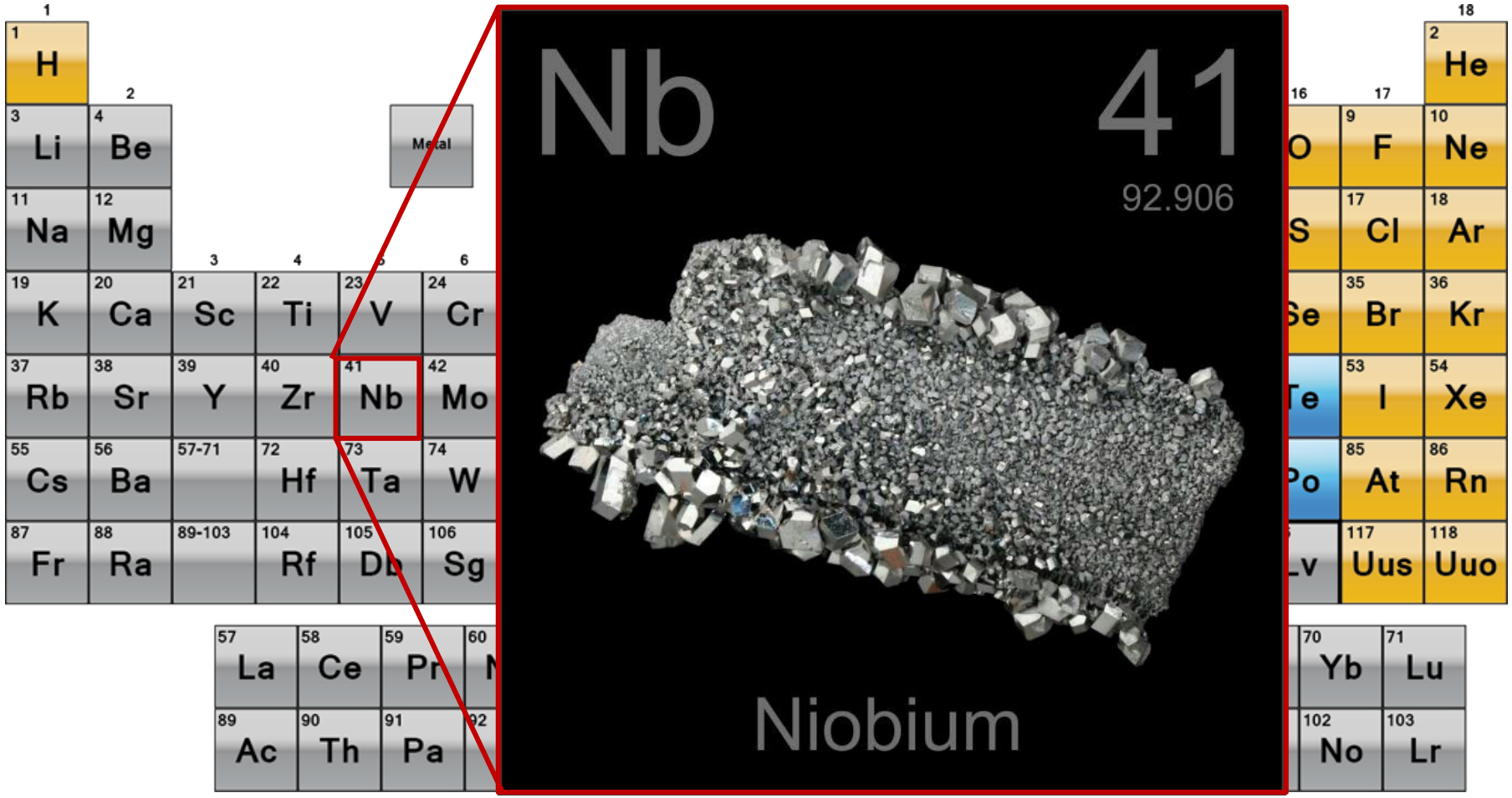
Precipitation strengthening (one of four mechanisms)

More precipitates means more pinning points that hinder the motion of dislocations, which means higher strength steel.

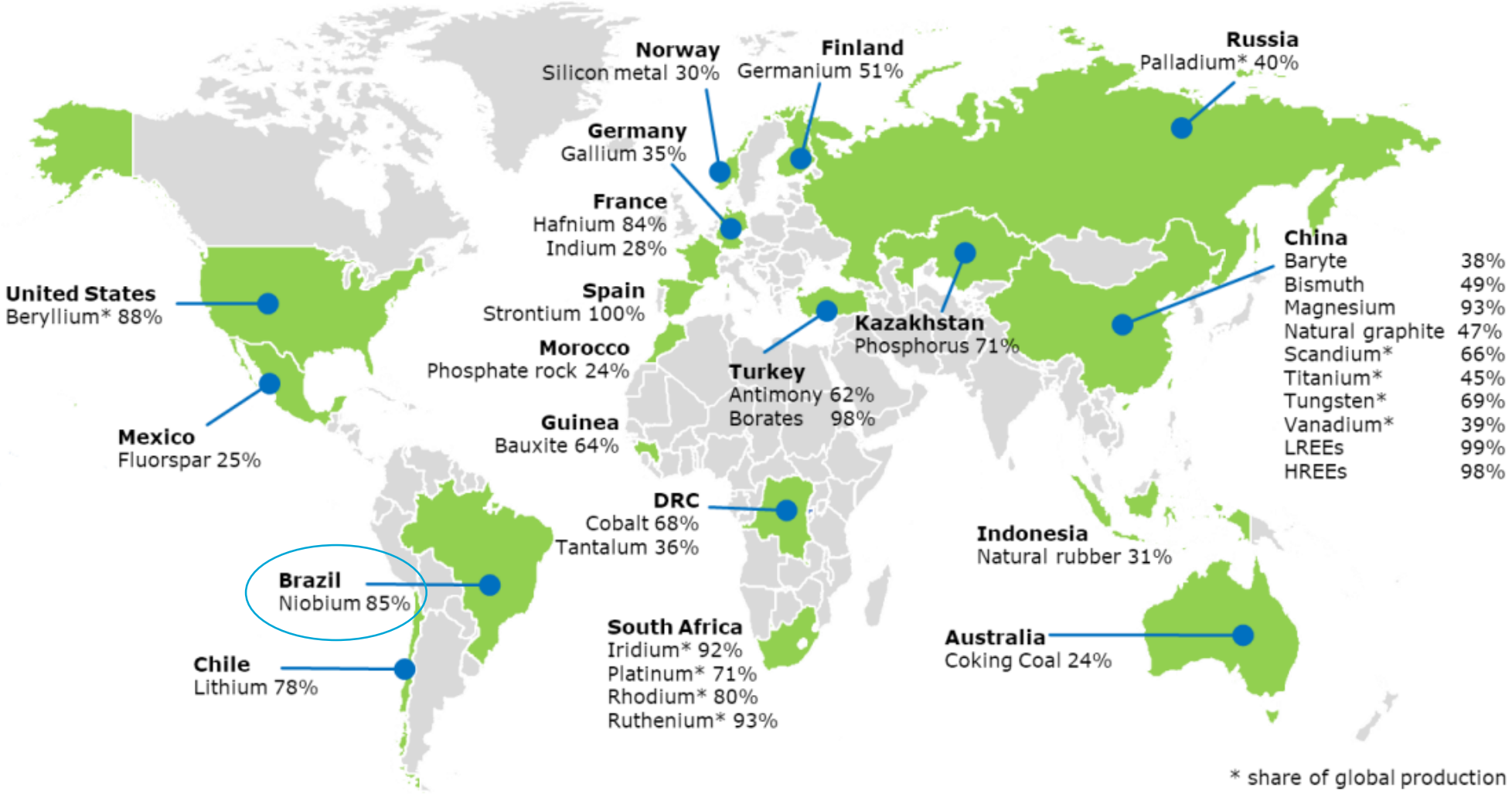




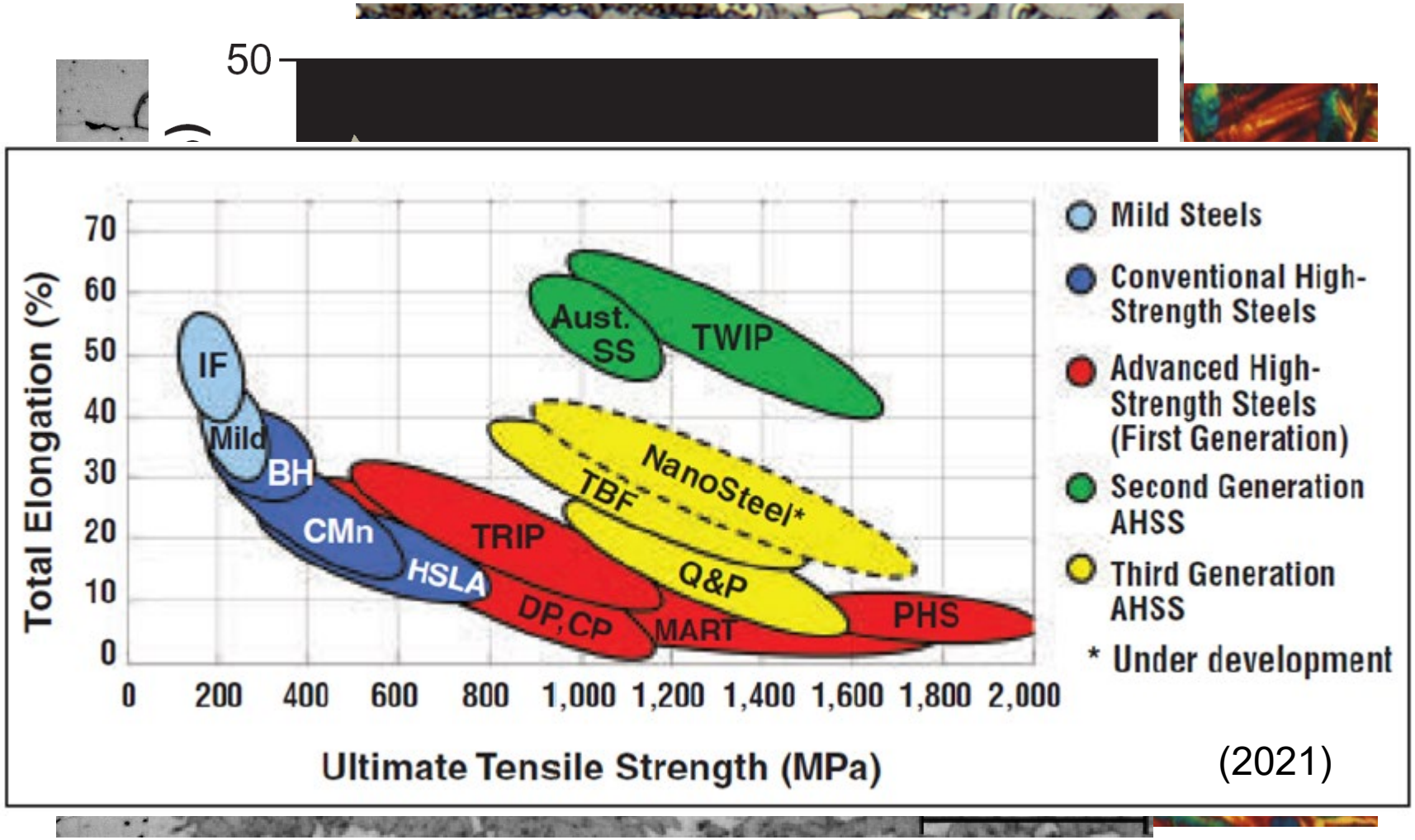
Niobium gives ‘flavor’ to steel: less than 0.1 wt.% does the trick



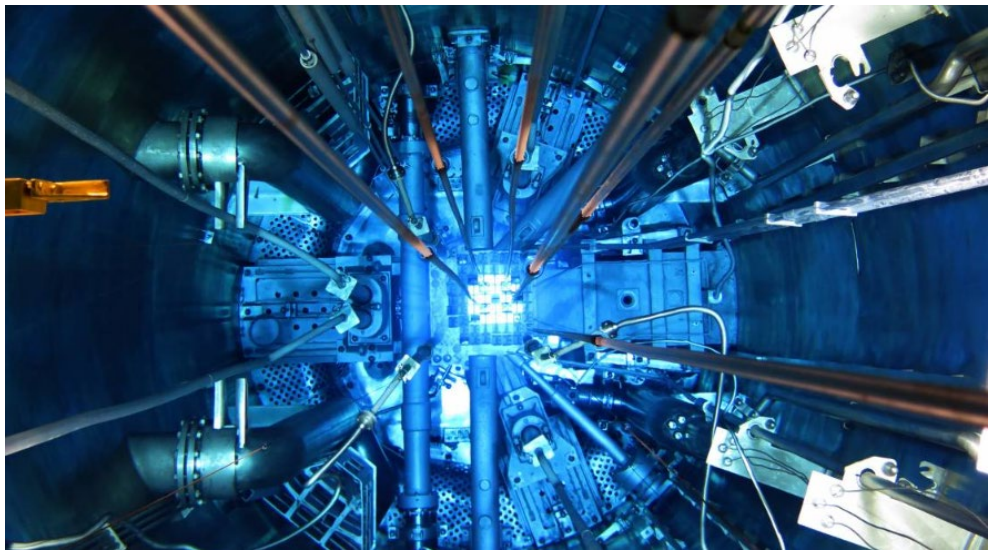
Critical raw materials EU



Microstructure gives properties to steel

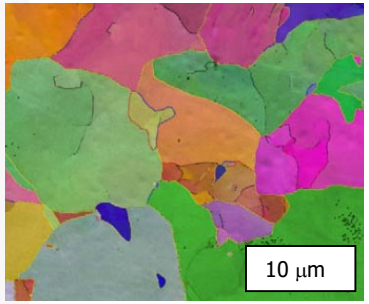


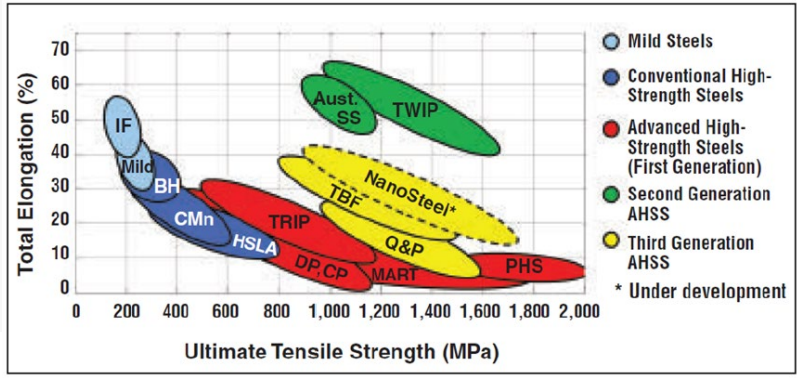
Stronger steel contributes to energy & materials transitions: less material, less weight



Department MSE & Sustainable Steel

$$Fe_2O_3 + 3\,H_2 = 2\,Fe + 3\,H_2O$$





Design

Processing

Microstructure

Properties

Performance

Production & Recycling

Materials

Bedankt voor uw aandacht

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