

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...]

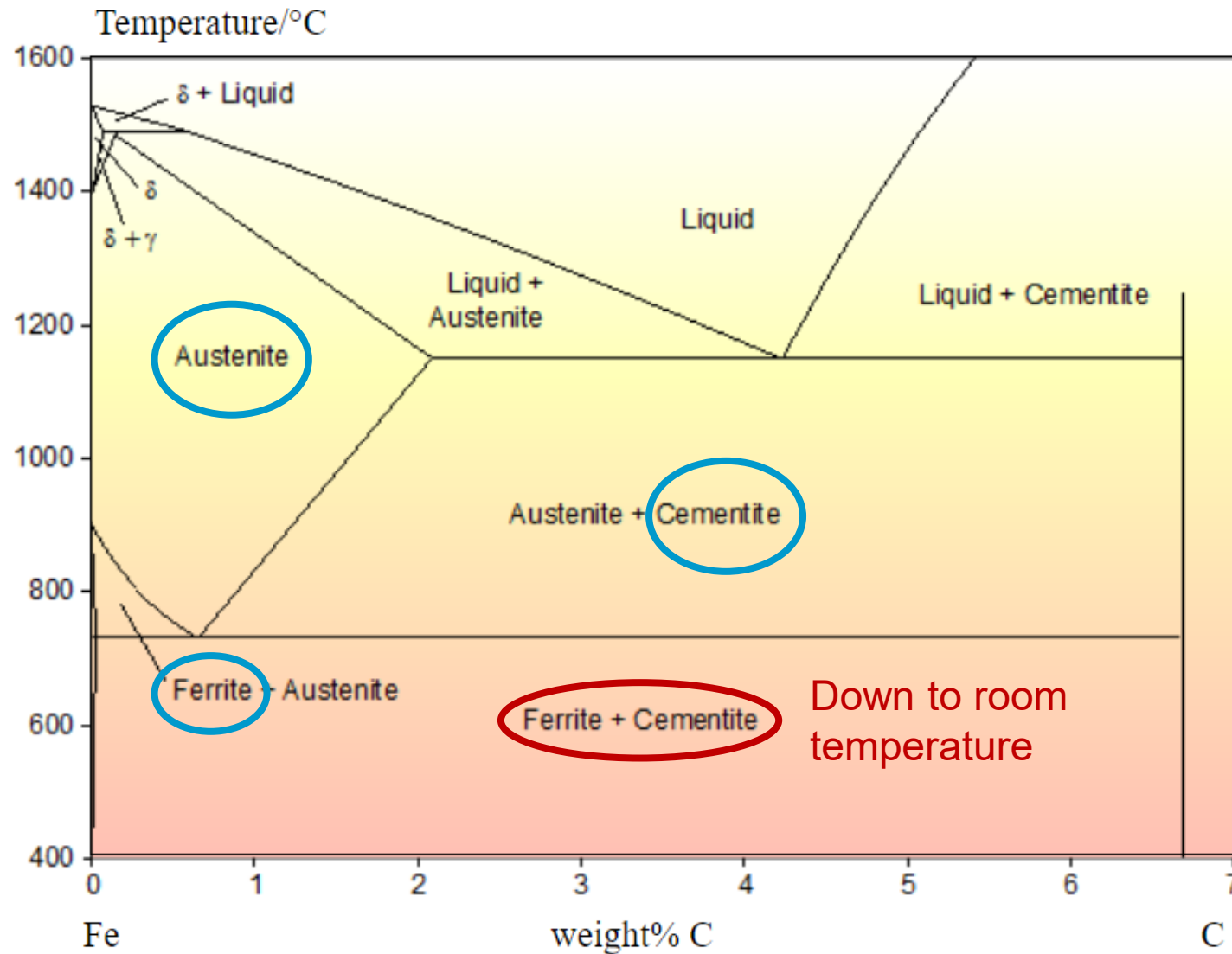


Staal: smeedbaar, hardbaar **ferrometaal** met relatief laag **koolstofgehalte**, dat in vloeibare toestand is bereid.

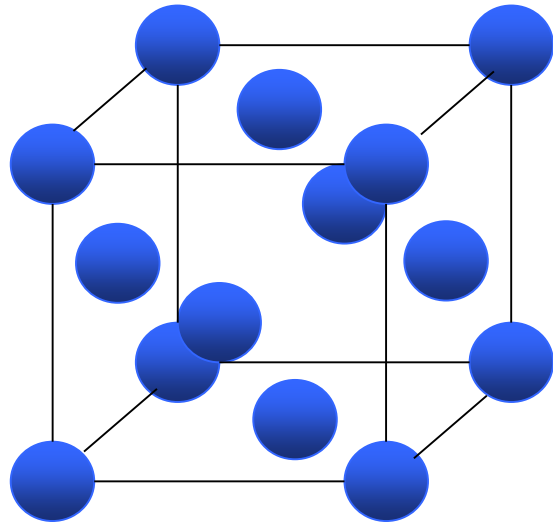
van Dale



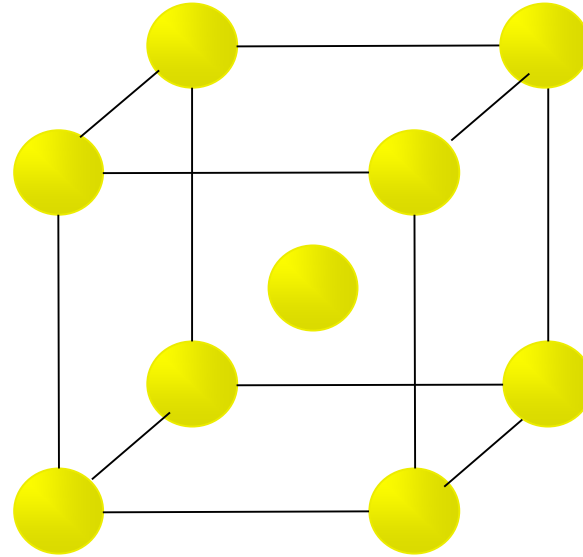
Equilibrium Fe-C phase diagram



Crystal structure equilibrium phases

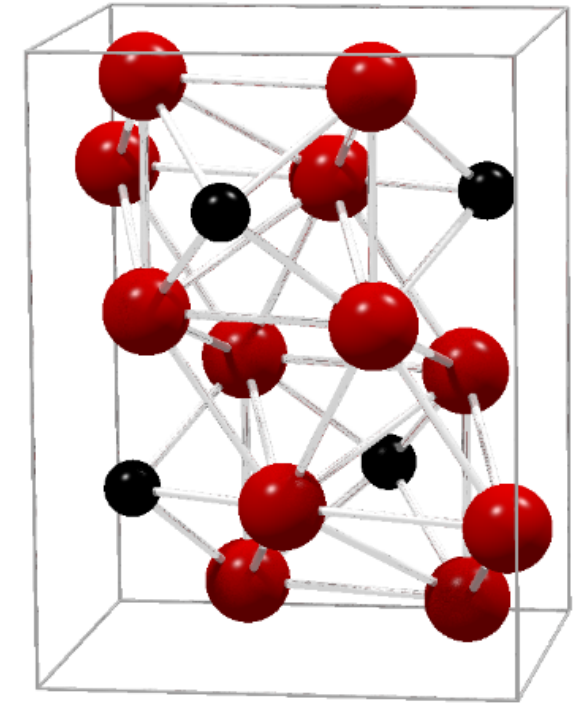


Austenite (γ)
0 – 2 wt.% Carbon



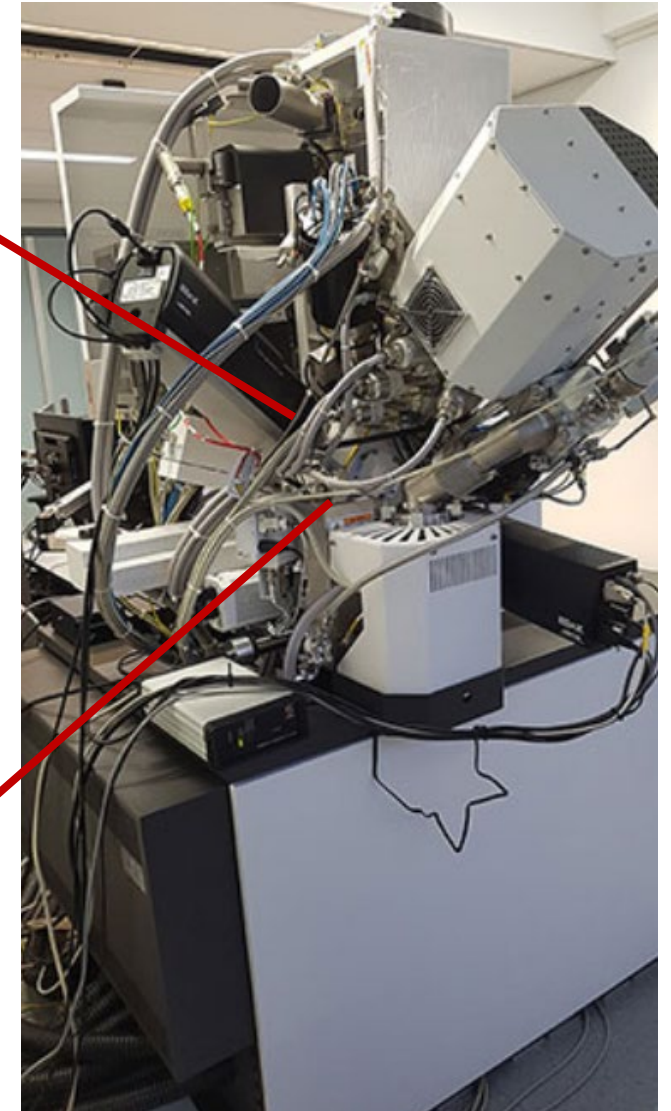
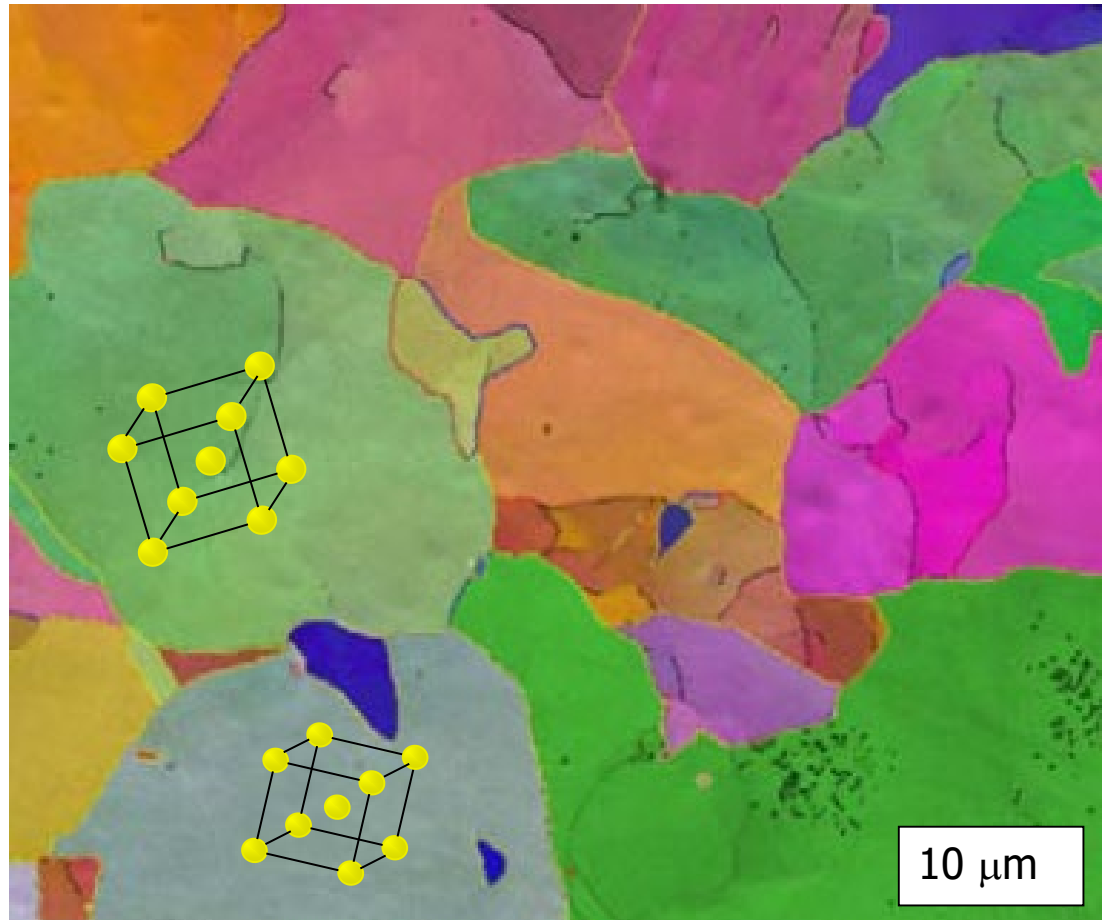
Ferrite (α)
0 – 0.022 wt.% Carbon

Factor ~100

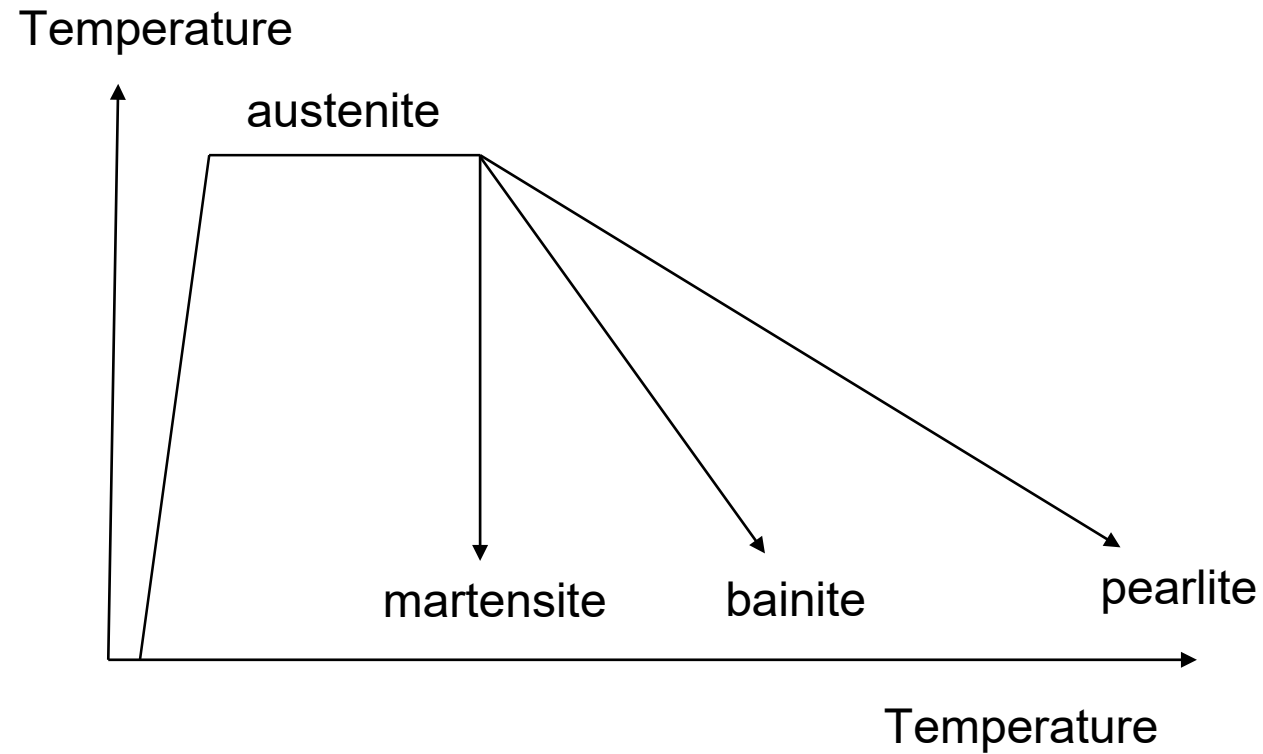


Cementite ($\theta = \text{Fe}_3\text{C}$)
6.7 wt.% Carbon

Microscopic structure of steel

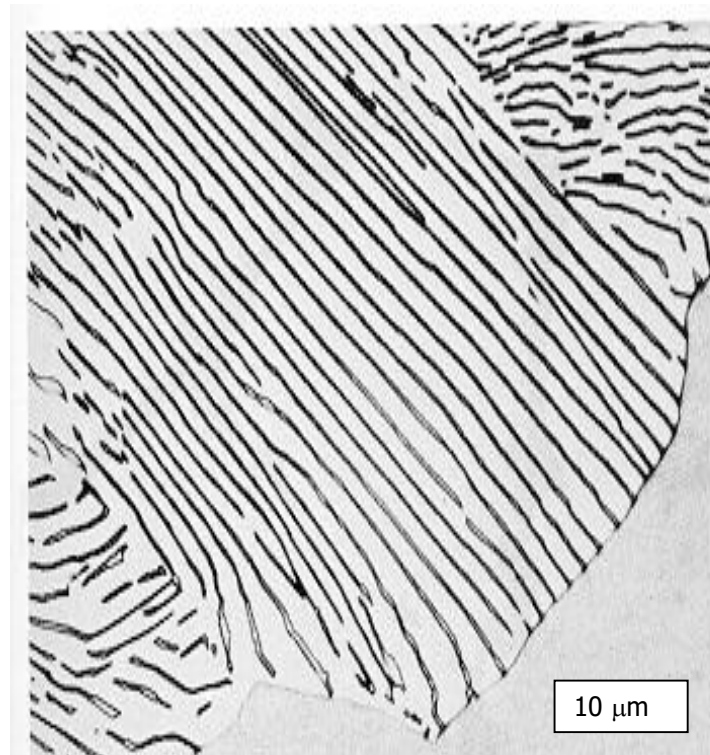


Effect of cooling rate on microstructure formation



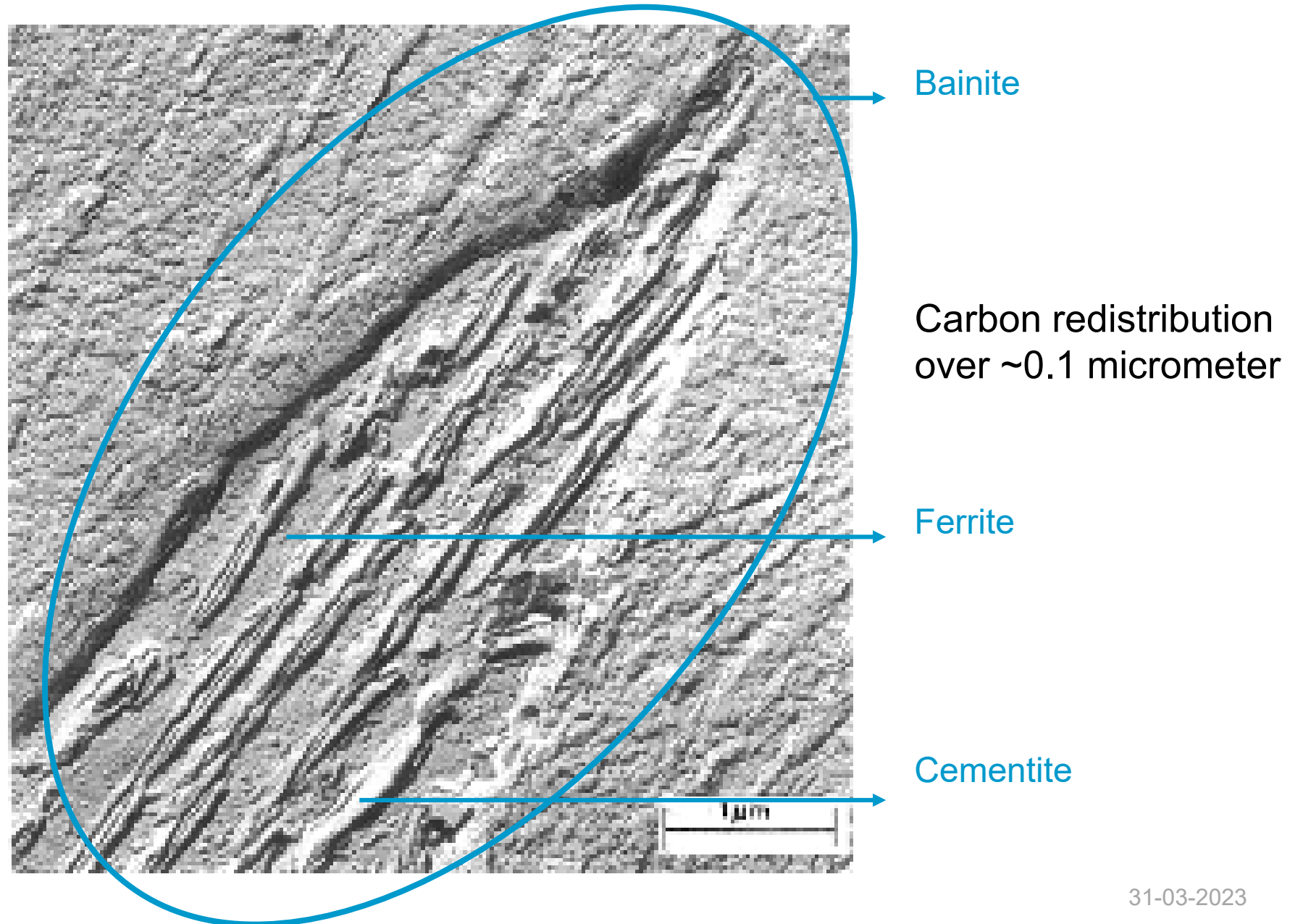
Pearlite

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



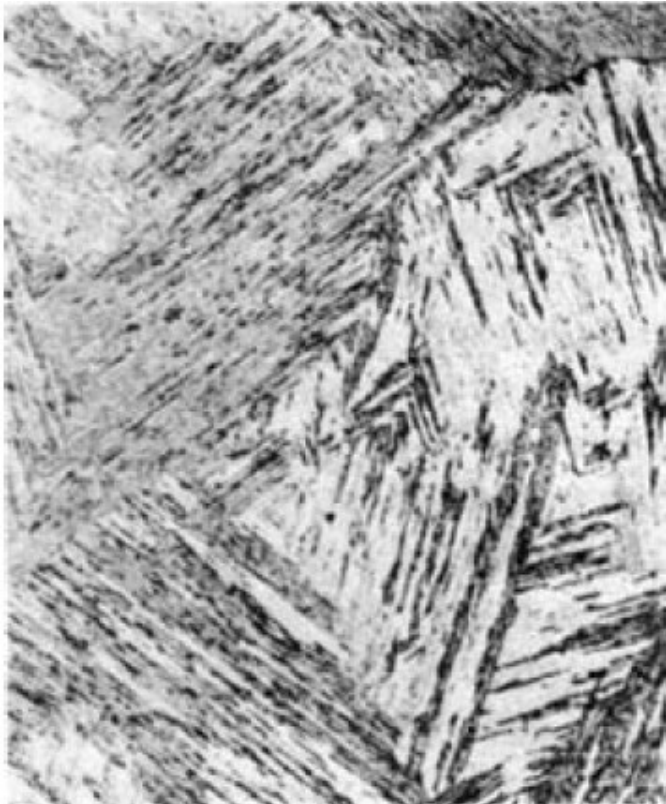
Carbon redistribution over ~1 micrometer

Bainite



Martensite

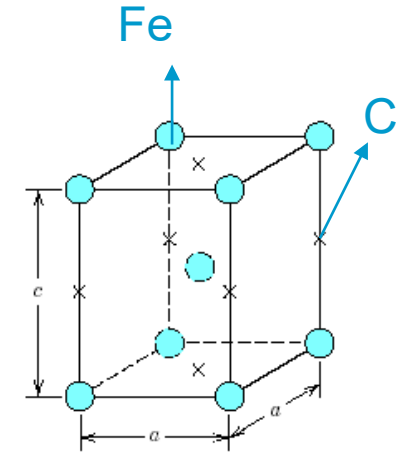
Martensite: Supersaturated ferrite; no carbon redistribution



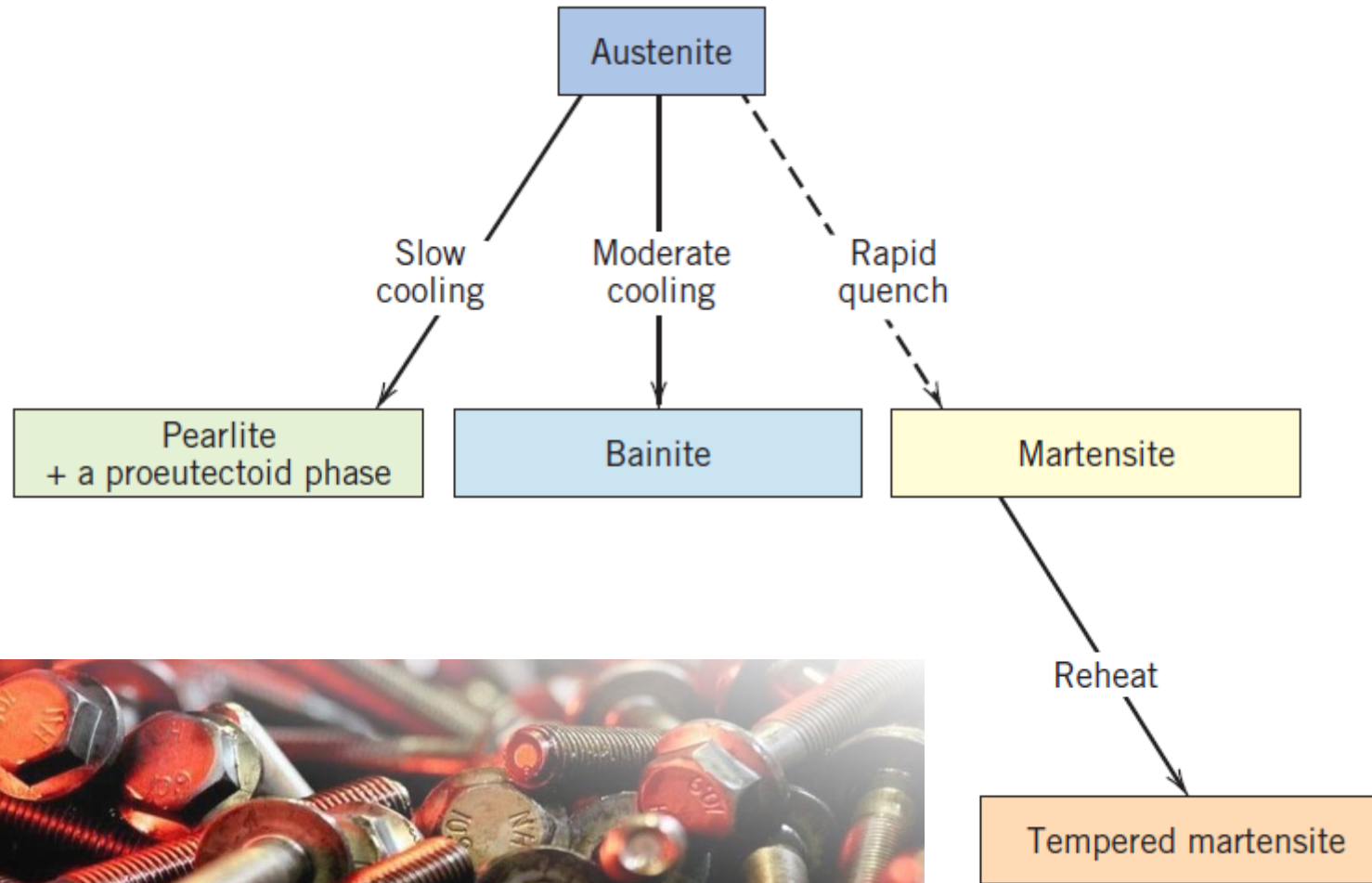
100 μm Lath (low carbon)



20 μm Plate (medium carbon)

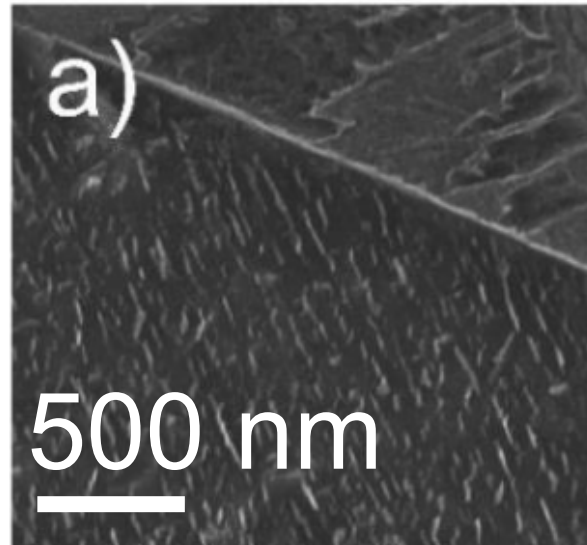


Effect of cooling rate on microstructure formation

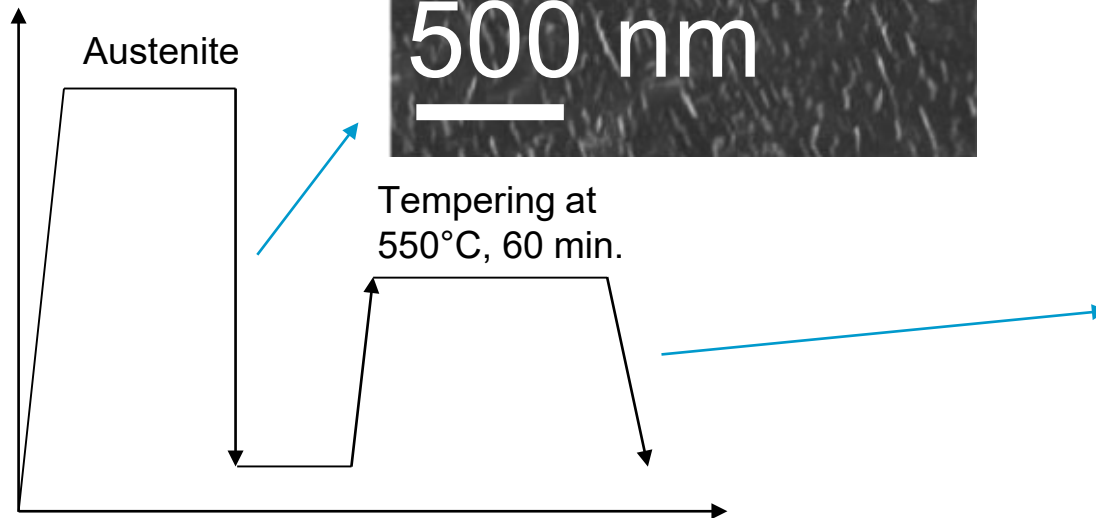
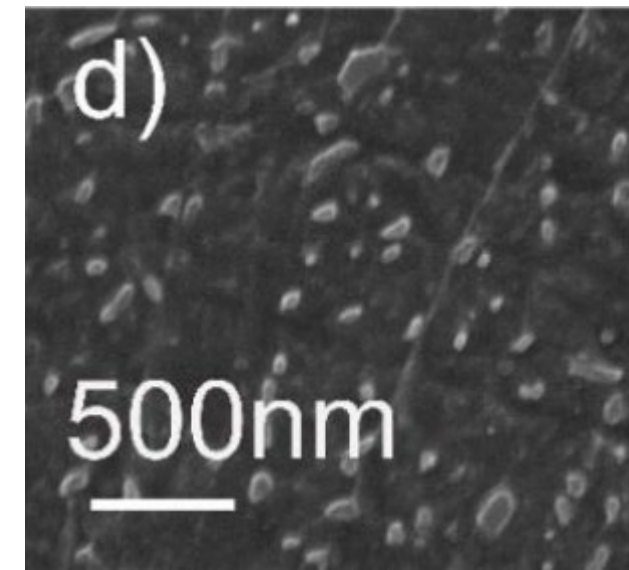


Tempering of martensite


As quenched

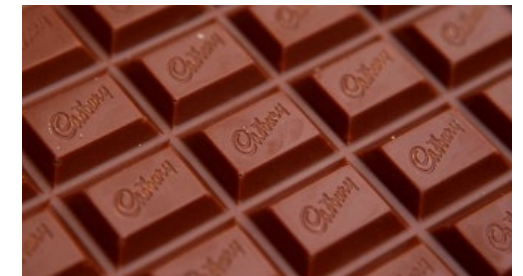


Tougher steel after tempering at 550°C, 60 min.



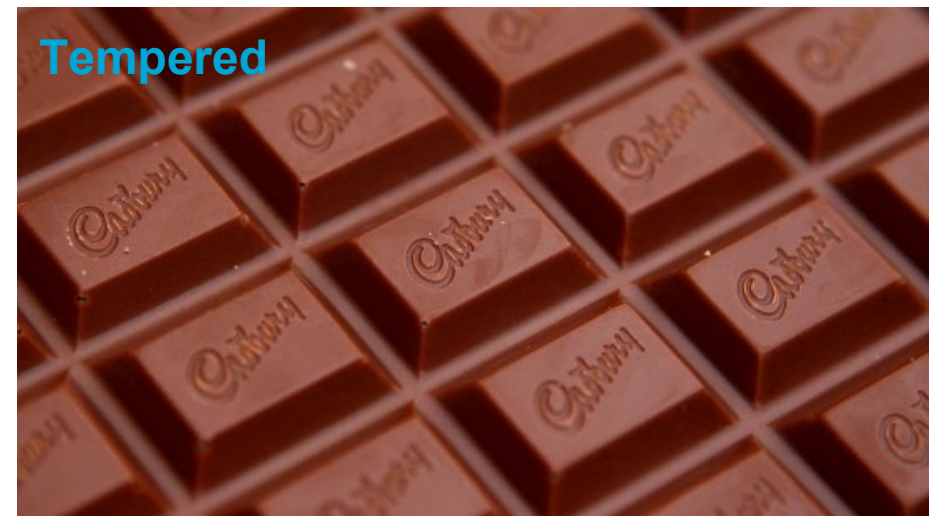
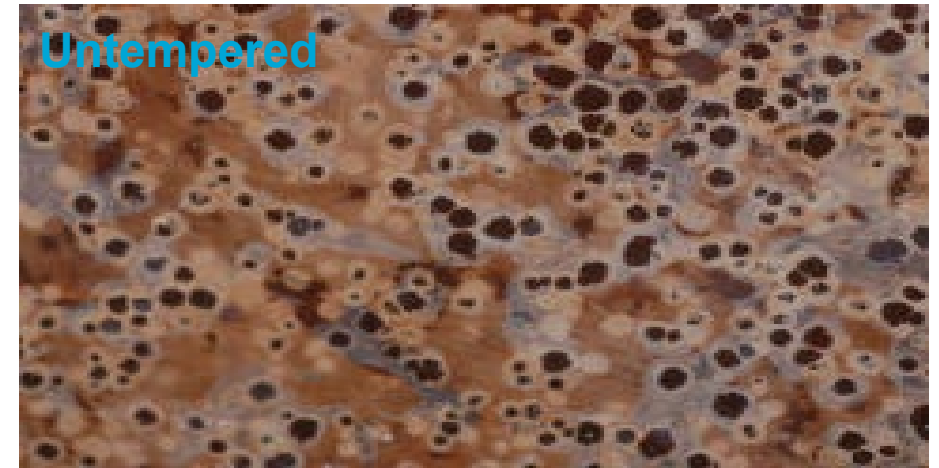
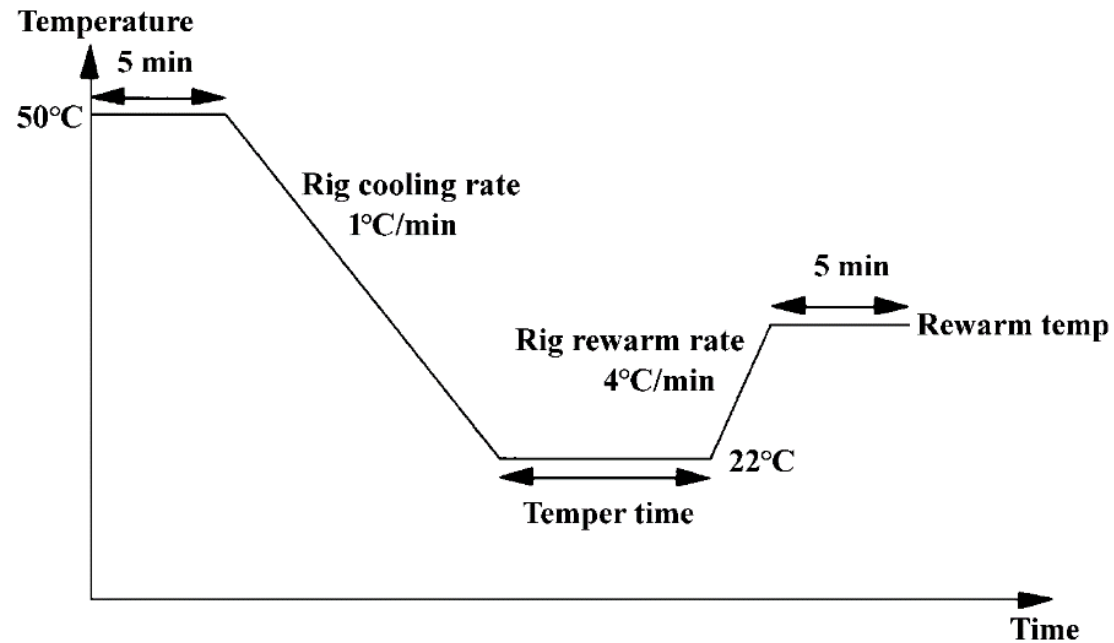
Cocoa butter: 6 polymorphs

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		Shiny, smooth texture, good snap, melts in mouth
Transformation of V after 4 months (equilibrium)	VI	36.3 °C		



Tempering of chocolate

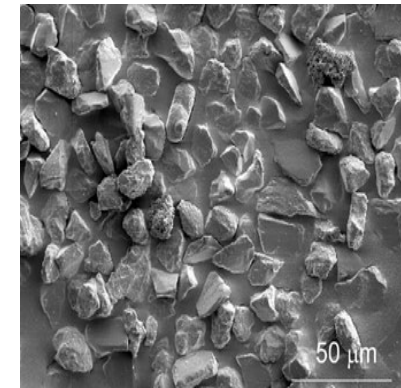
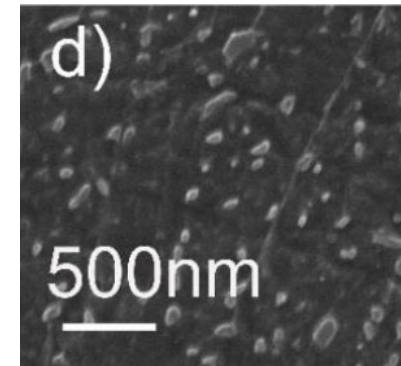
Hard, shiny chocolate forms via a temper treatment



Materials science of steel and chocolate

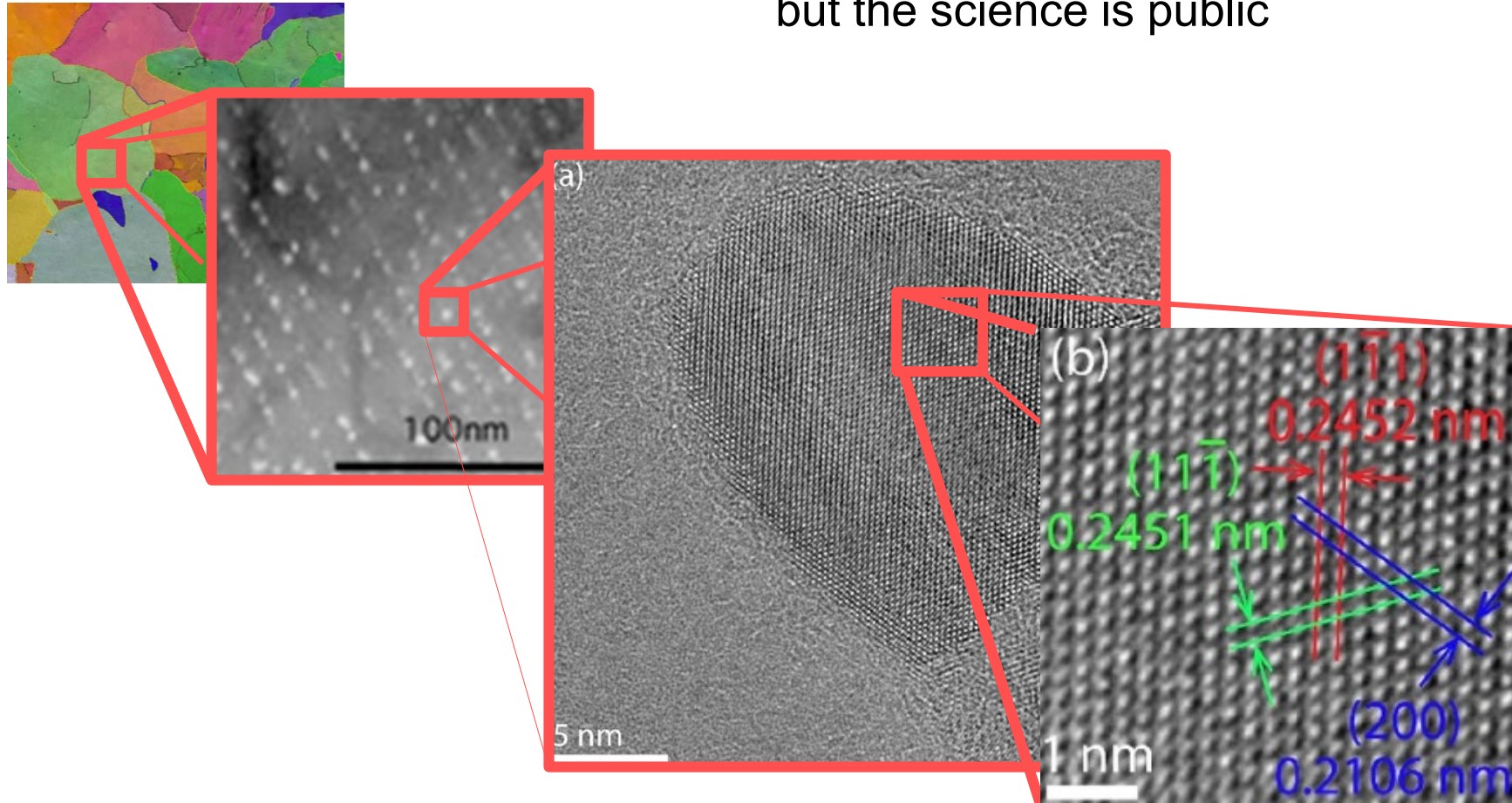
Composition → Processing → Microstructure → Properties

1																	2									
H																	He									
3	4											10														
Li	Be											B	C	N	O	F	Ne									
11	12											13	14	15	16	17	18									
Na	Mg											Al	Si	P	S	Cl	Ar									
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36									
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr									
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54									
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe									
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86									
Cs	Ba											Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118									
Fr	Ra											Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Ff	Uup	Lv	Uus	Uuo
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106									
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu												
107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123										
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr												

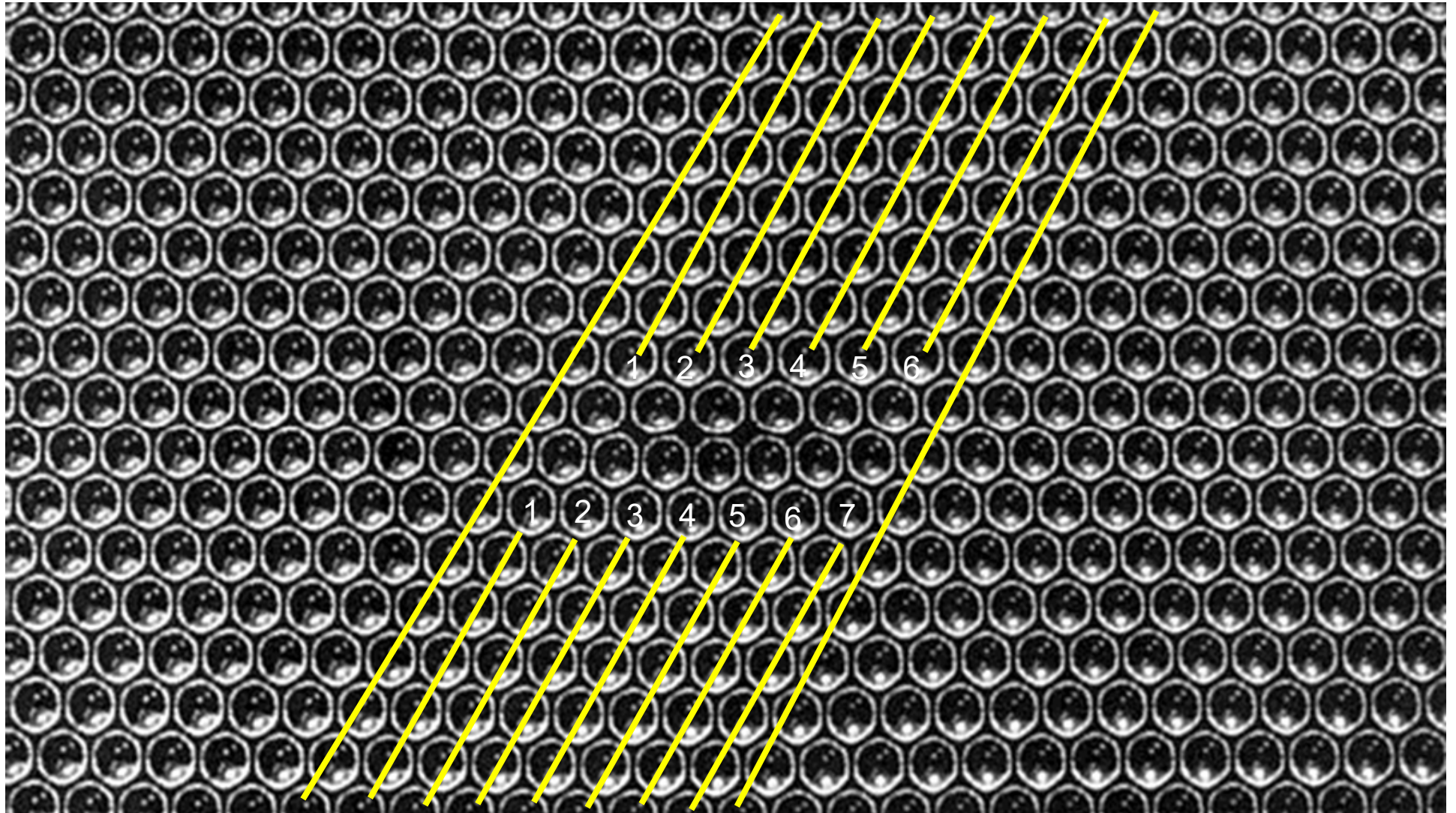


Hierarchical structure of steel: modern blacksmith's secret

but the science is public

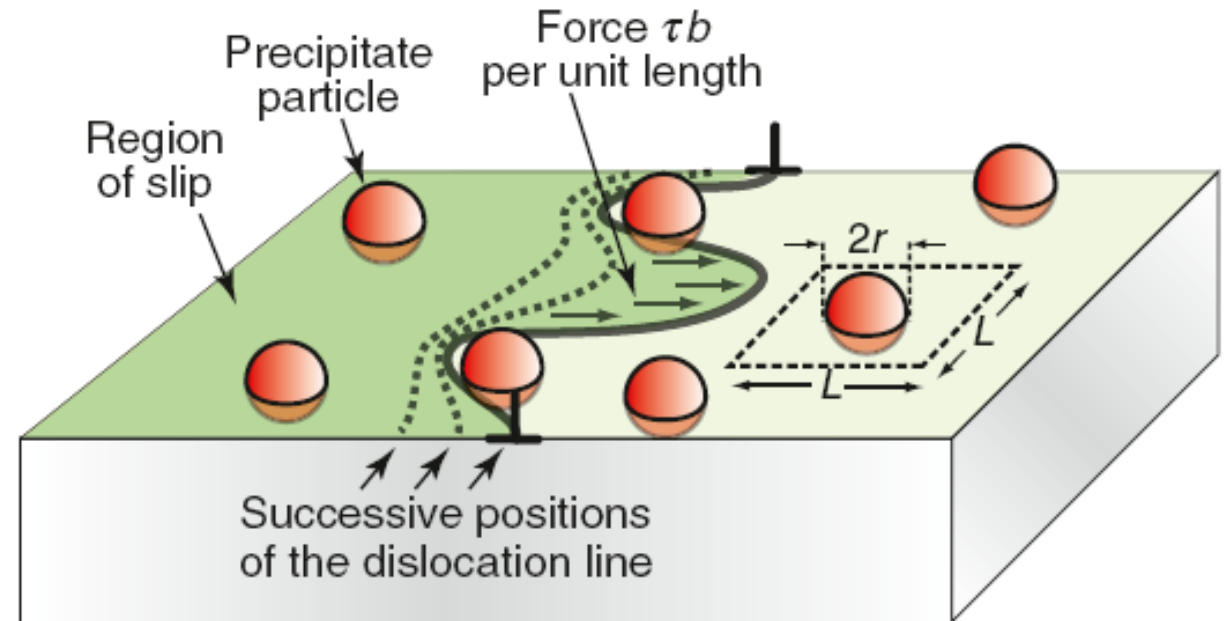
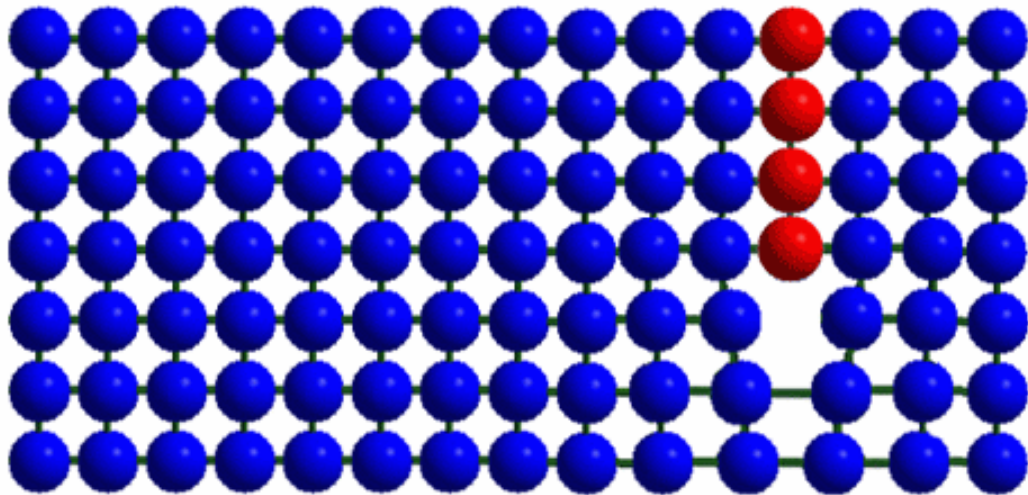


Dislocation



Precipitation strengthening (one of four mechanisms)

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

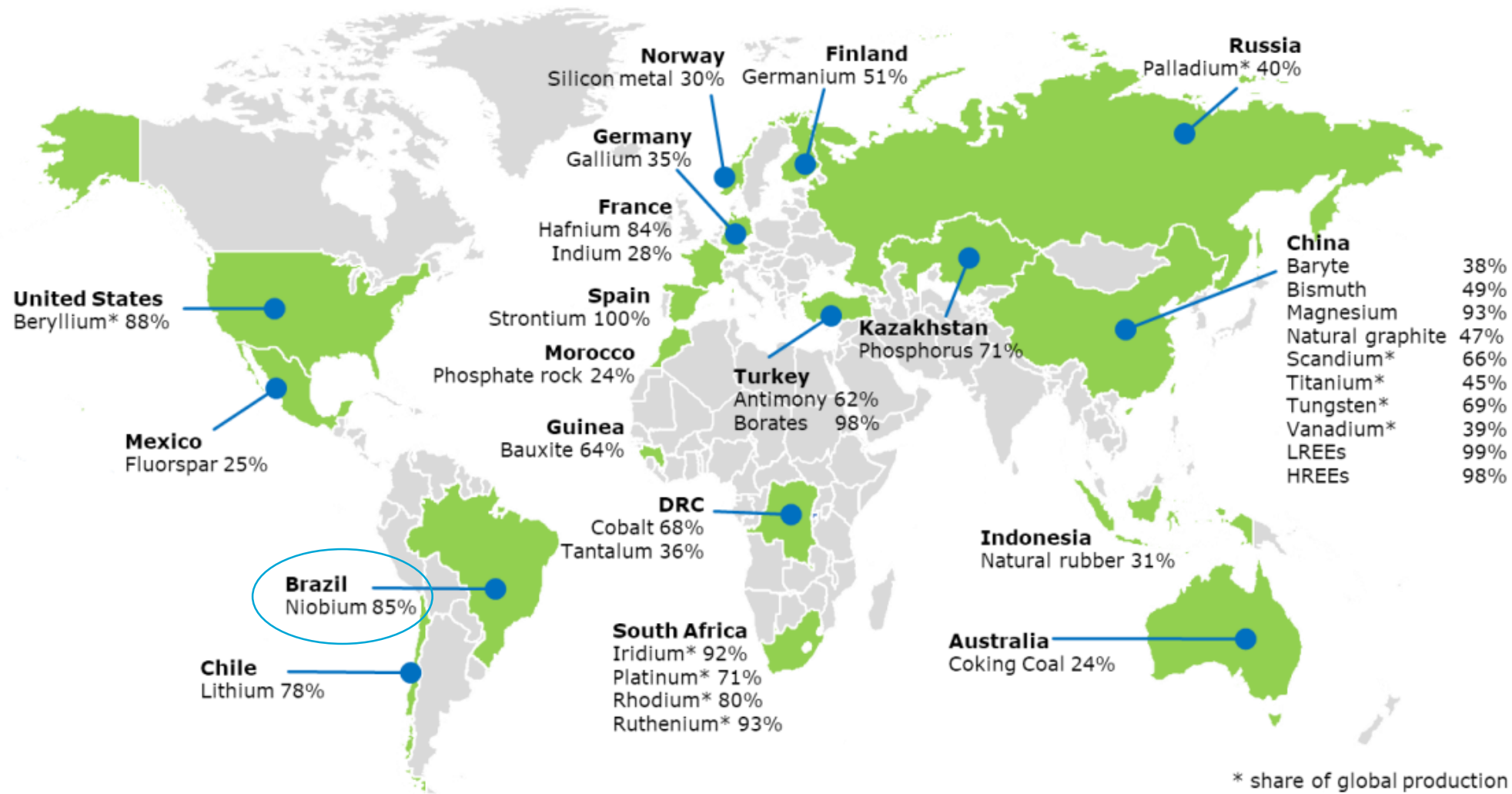


Niobium gives 'flavor' to steel: less than 0.1 wt.% does the trick

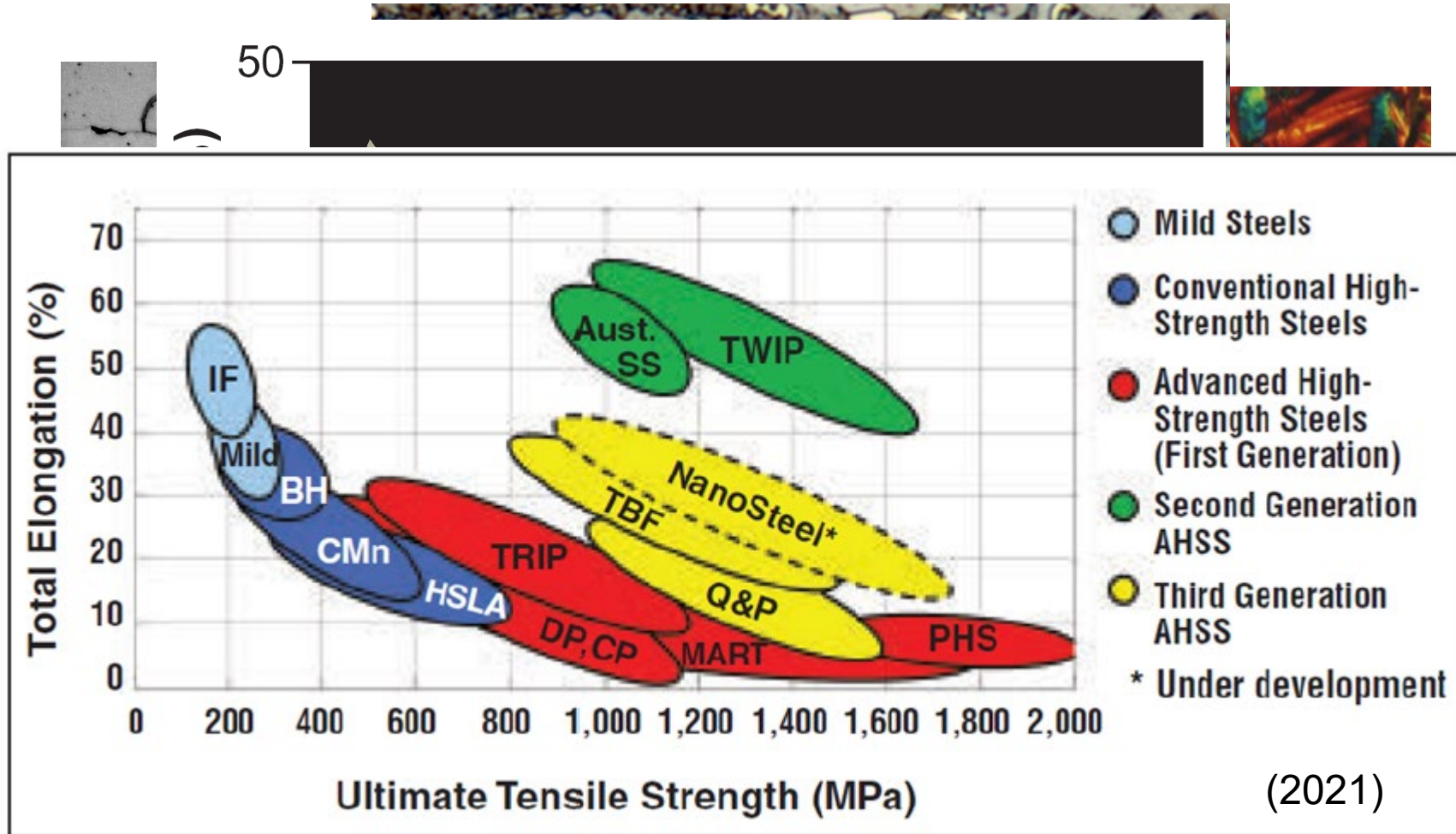
The image displays a periodic table of elements. The element Niobium (Nb) is highlighted with a red box. A red line connects this box to a larger, detailed view of Niobium. In this detailed view, the symbol 'Nb' and the atomic number '41' are shown at the top. Below them is the atomic weight '92.906'. The central part of the view shows a pile of grey, metallic, crystalline fragments of Niobium. At the bottom of this view, the word 'Niobium' is written in a large, grey font.

1																	18	
1																	2	
3	4															16	17	18
11	12															9	10	
19	20	21	22	23	24											17	18	
37	38	39	40	41	42											35	36	
55	56	57-71	72	73	74											53	54	
87	88	89-103	104	105	106											85	86	
																117	118	
57	58	59	60													70	71	
89	90	91	92													102	103	

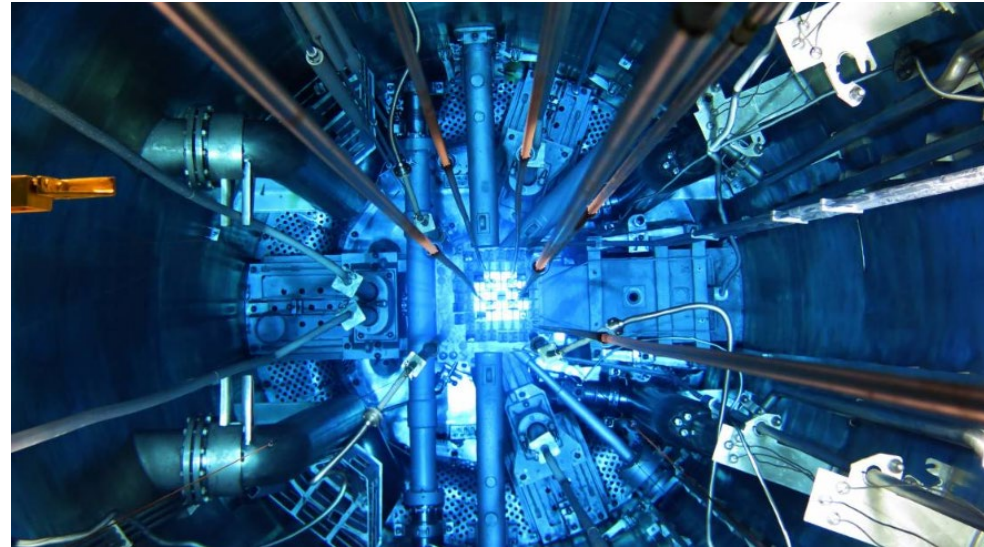
Critical raw materials EU



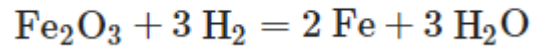
Microstructure gives properties to steel



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



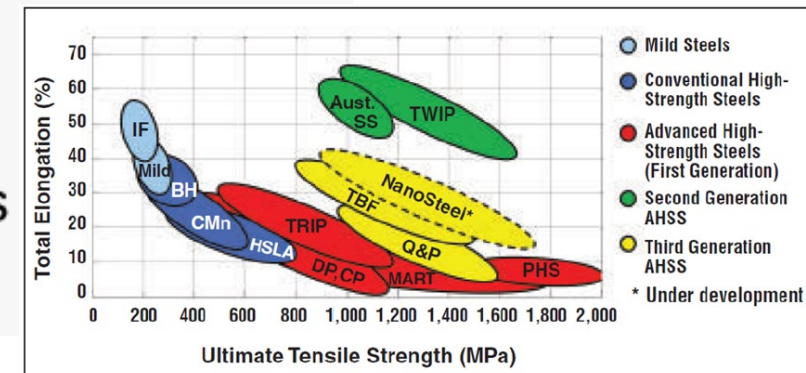
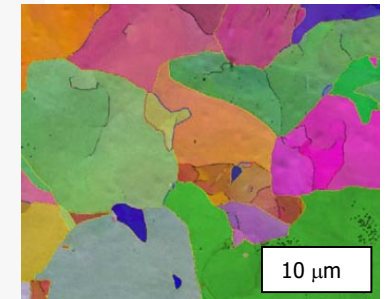
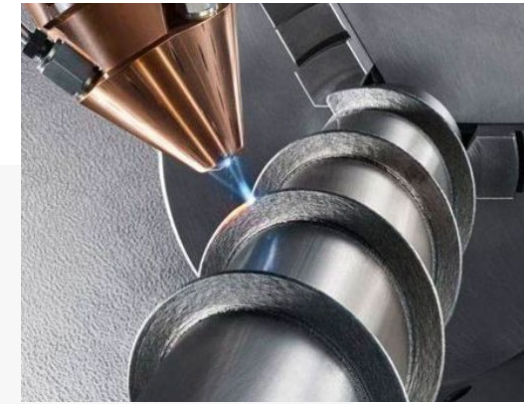
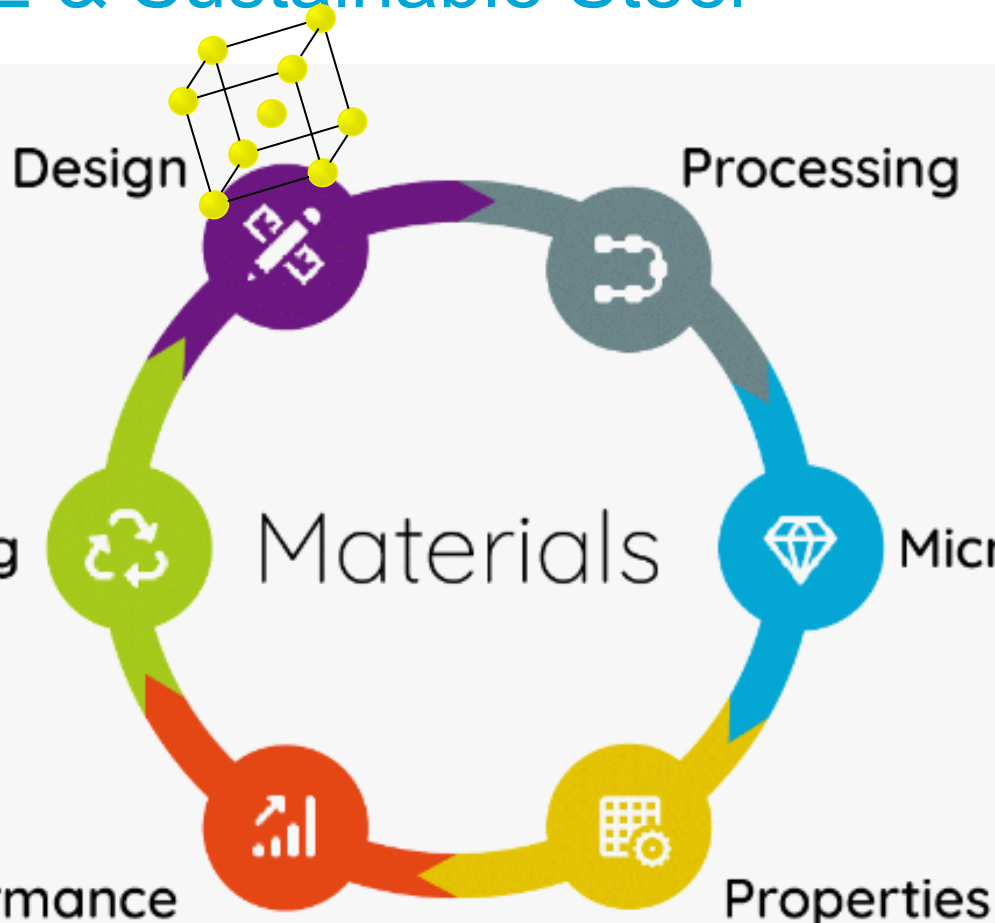
Department MSE & Sustainable Steel



Production & Recycling



Performance



Bedankt voor uw aandacht

S. Erik Offerman