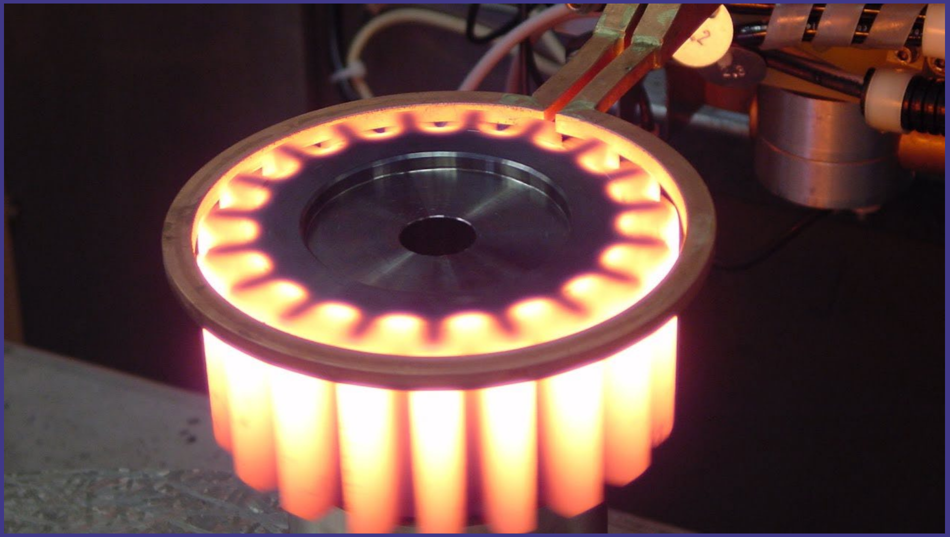
Imperial College London



https://www.youtube.com/watch?v=wOv3i0eoo0Q

Materials and Manufacturing

Altering material properties

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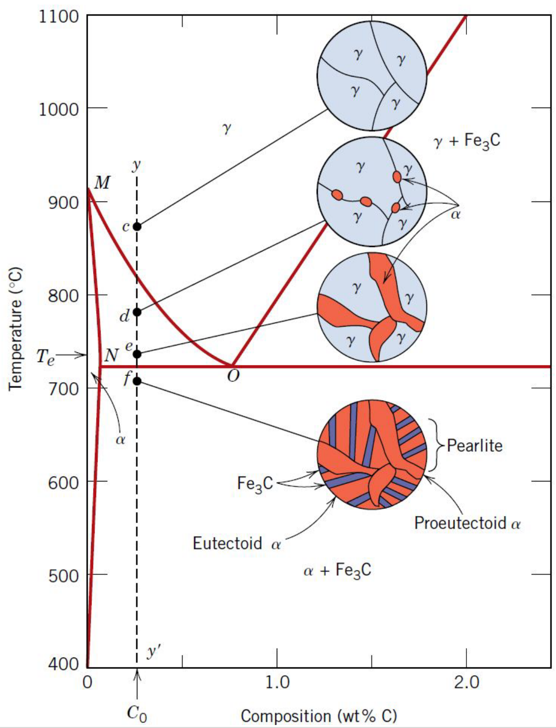
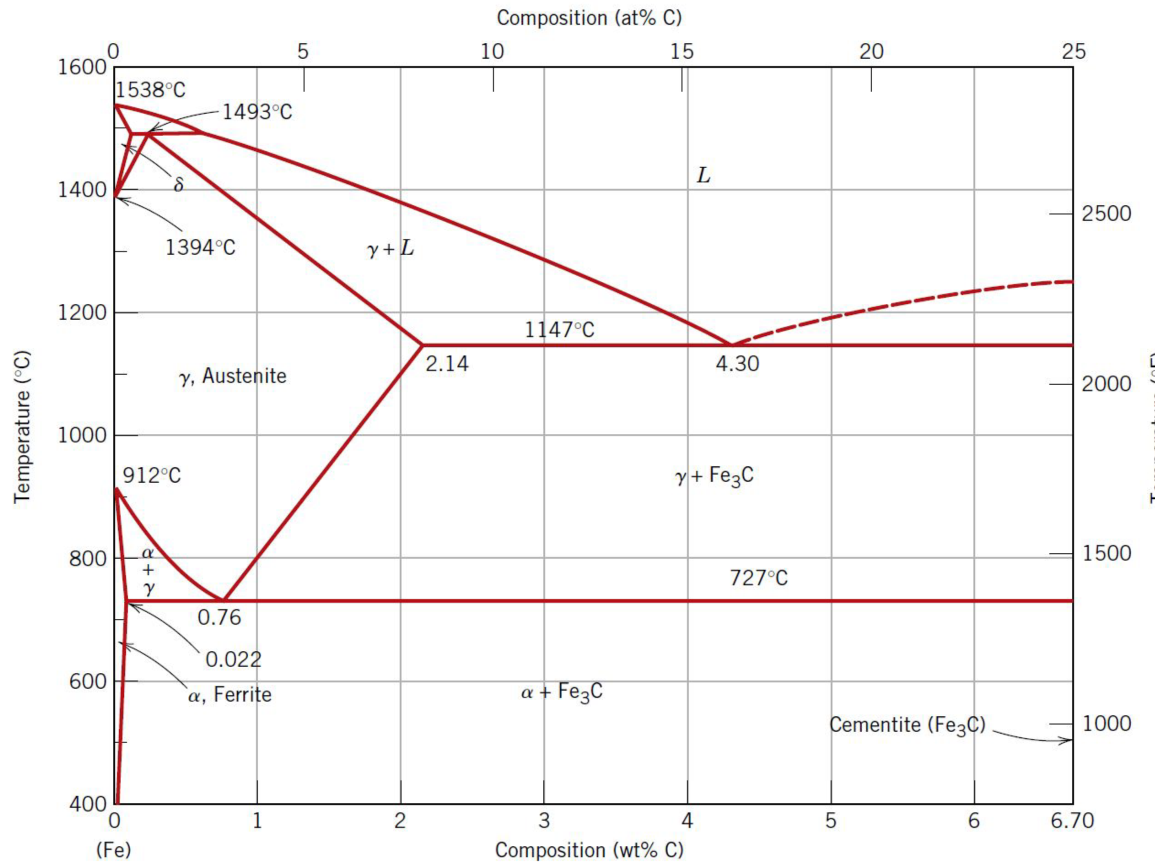
Dyson School of Design Engineering

Last time on M&M…

Iron-carbon alloys

- Iron-carbon phase diagrams. Hypo-, hyper- and eutectoid compositions
- Ferrite, Cementite, Pearlite
- Cast irons
  - Gray, nodular, white, malleable, compacted graphite



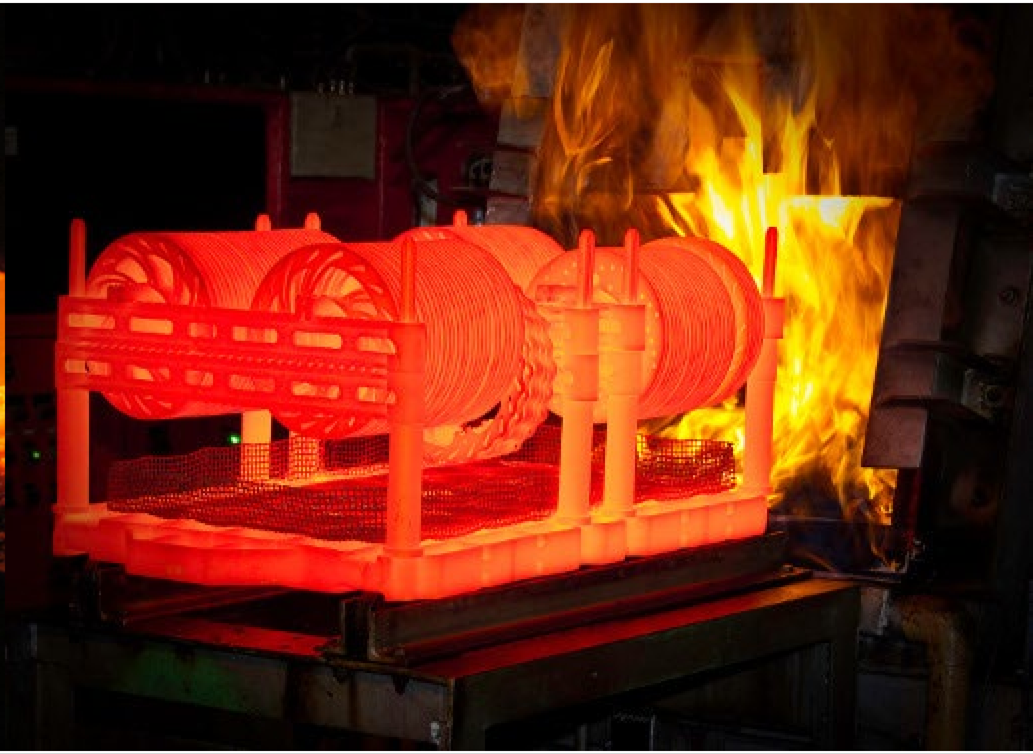


Learning objectives

- Define different heat treatment processes and explain why they are used
- Describe non-equilibrium forms of steel and their main microstructural features/mechanical properties
- Recognise the general mechanical characteristics for different microconstituents of steel
- Analyse a Time-Temperature Transformation diagram and use it to analyse the microstructure resulting from different heat treatments

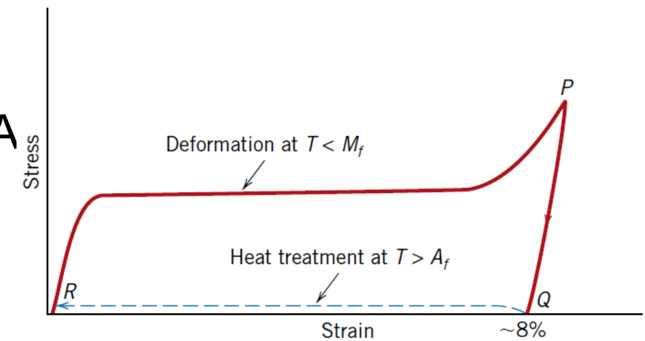
Why is it important

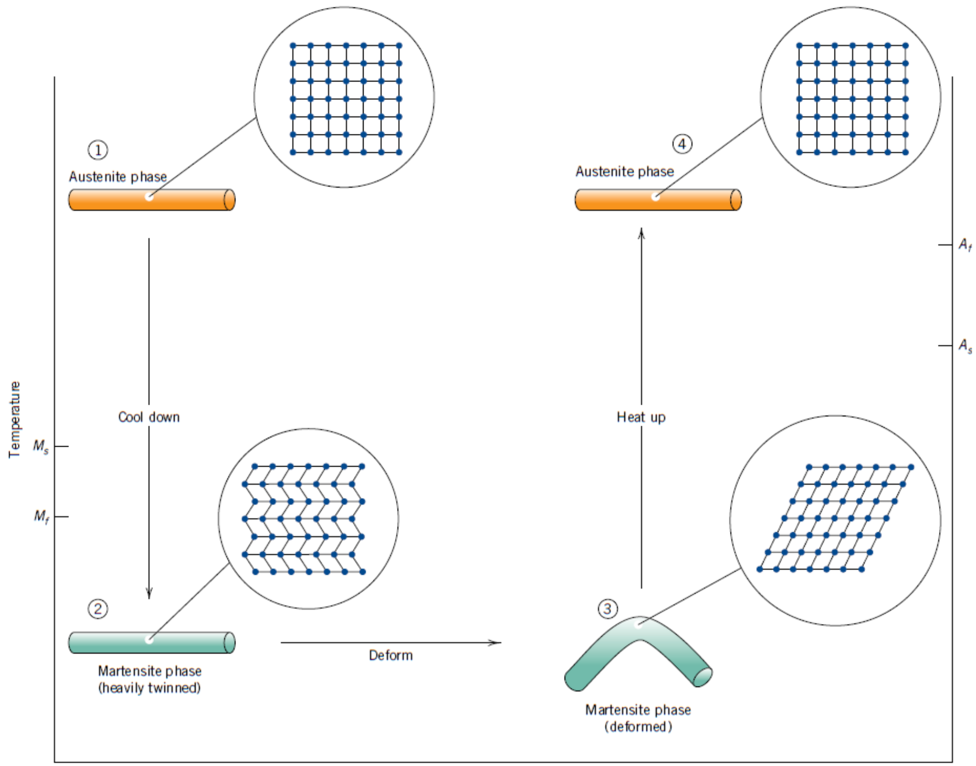
The properties of materials can vary significantly depending not only on the composition but also the synthesis conditions of that material in terms of the cooling rates and inclusions of additional alloying elements.

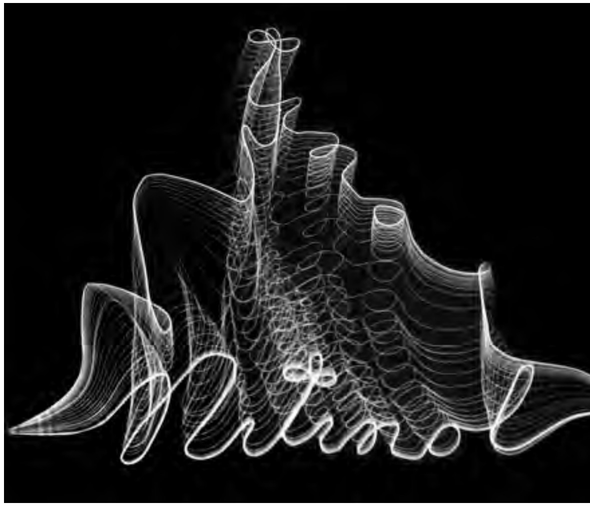


Shape memory alloys

- Shape memory alloys have the ability to remember its initial shape after deformation when heated
- Deformation normally is carried out at a relatively low temperature, whereas, shape memory occurs upon heating
- Nickel–titanium alloys (Nitinol, is their tradename), and some copper-base alloys (Cu–Zn–Al and Cu–A



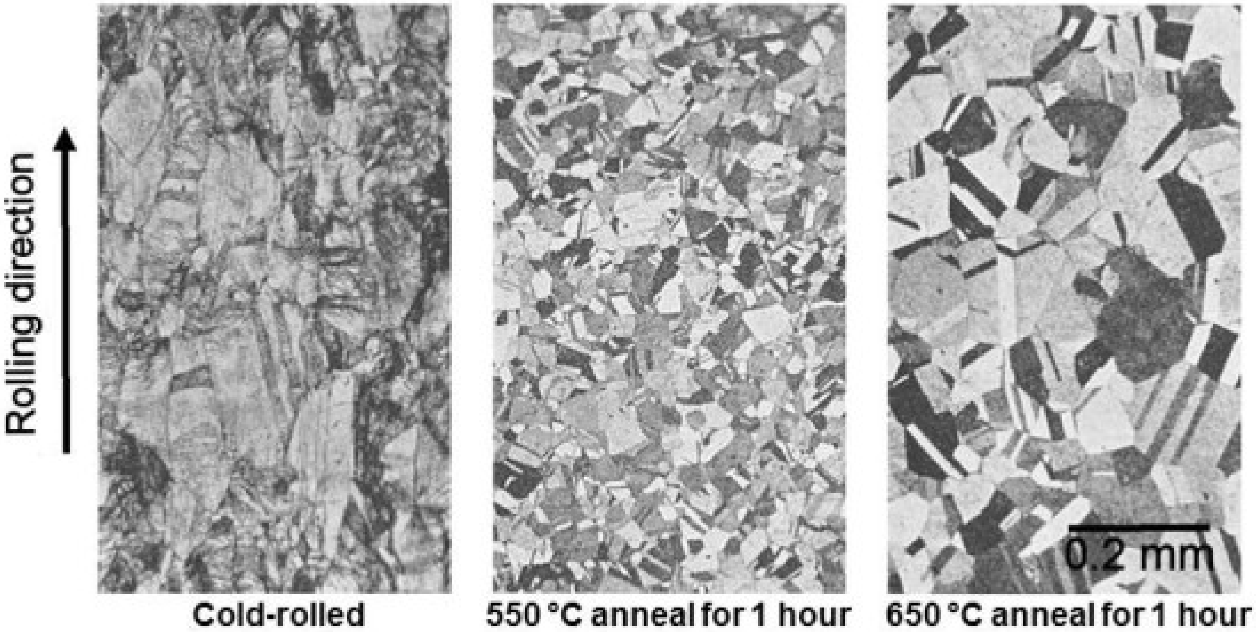




https://www.youtube.com/watch?v=-K57cbOhA5g

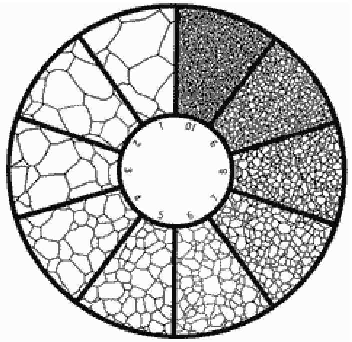
Grain size

- Grain size influences mechanical properties
- During plastic deformation slip or dislocations must happen over these boundaries
- Grain boundaries act as barriers to dislocation
- A fine grained material is harder and stronger as it has more grains to impede dislocations
- Yield strength (σ_y) will vary according to grain size. Described by the **Hall-Petch equation**

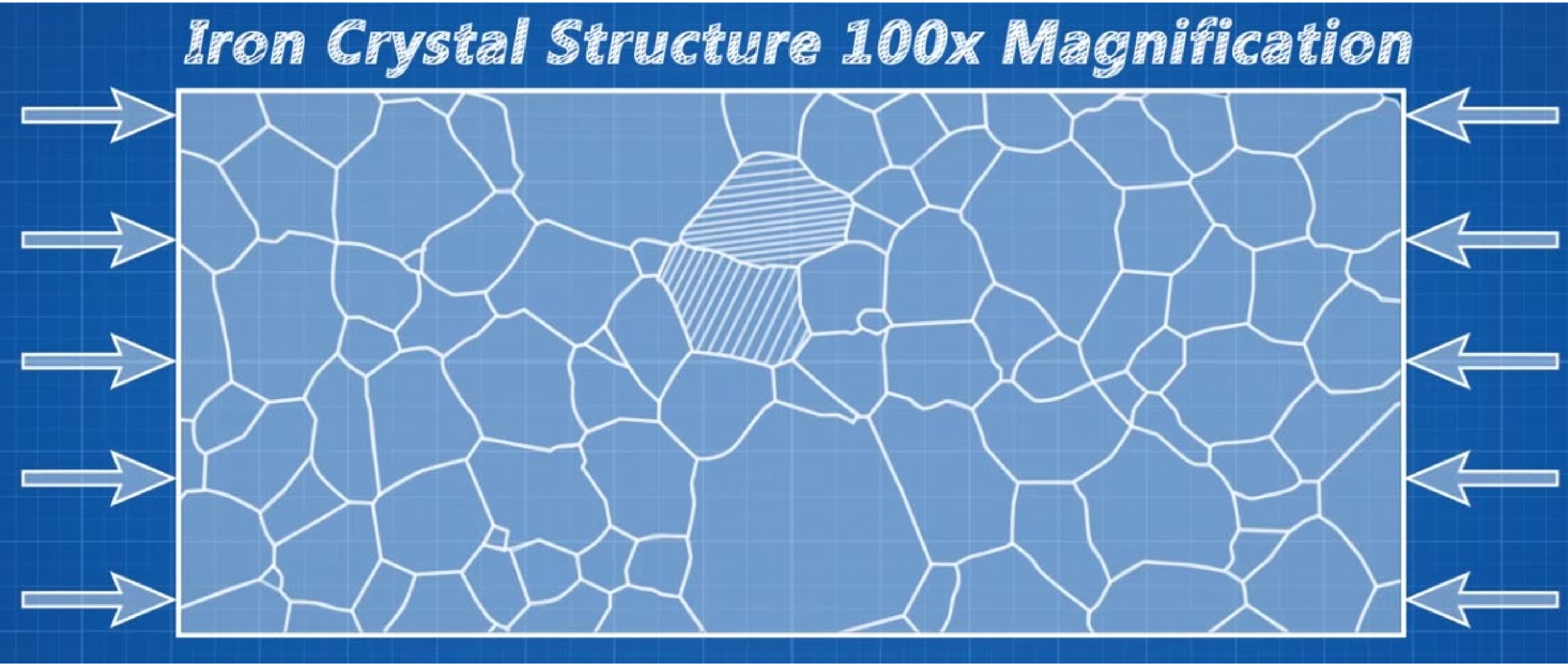


$$\sigma_y = \sigma_i + \frac{k}{\sqrt{d}}$$

d = Average grain size
σ_i = Constant
K = Constant



Grain size



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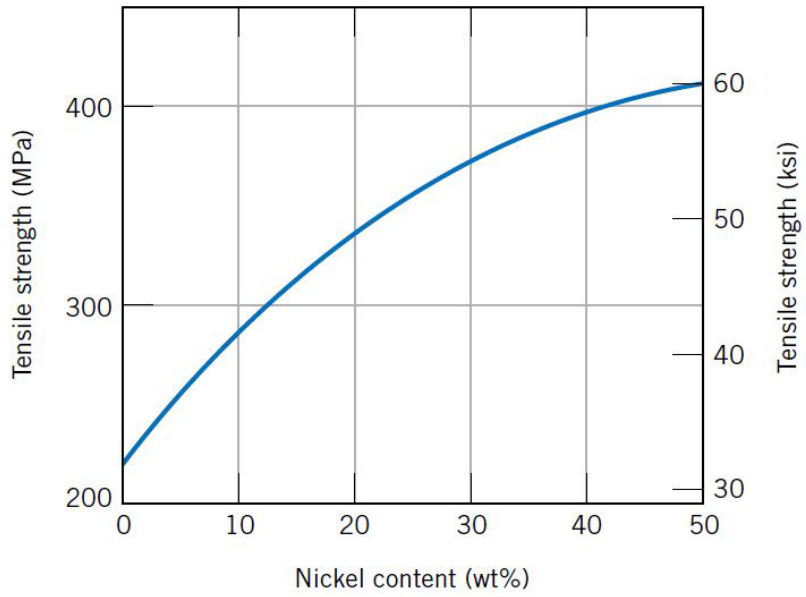
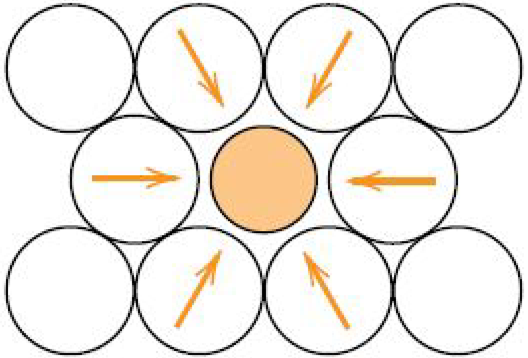
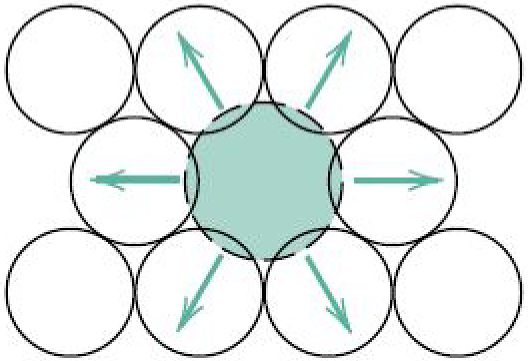
Solid solution hardening

- Alloying metals with impurities
- High purity metals are almost always softer than their alloys
- Increasing impurities increases their tensile + yield strength
- Impurities cause lattice strains which impede dislocations
- Smaller impurity = tensile lattice strain
- Larger impurity = compressive lattice strain





Smaller substitutional



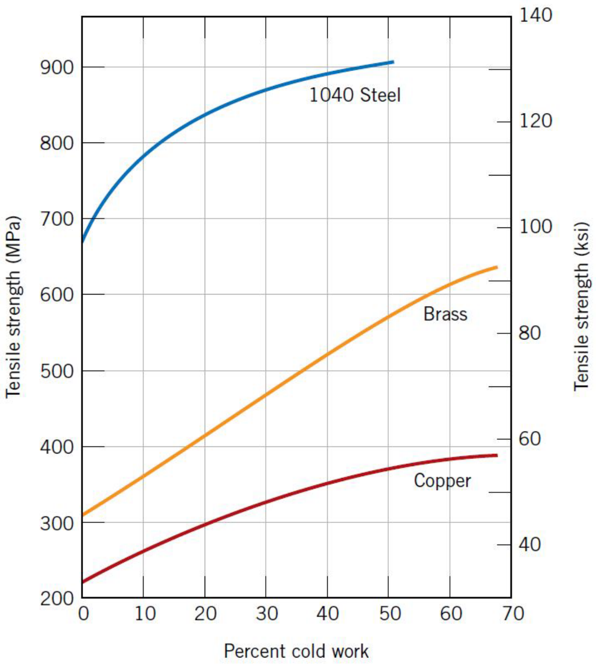
Larger substitutional

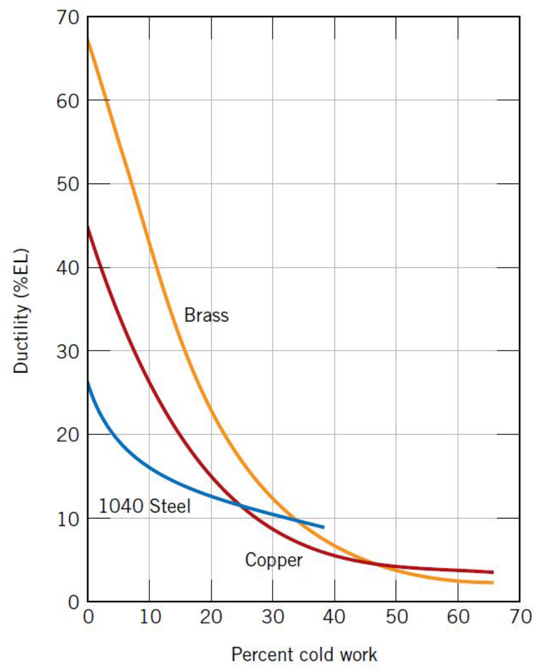
Strain hardening

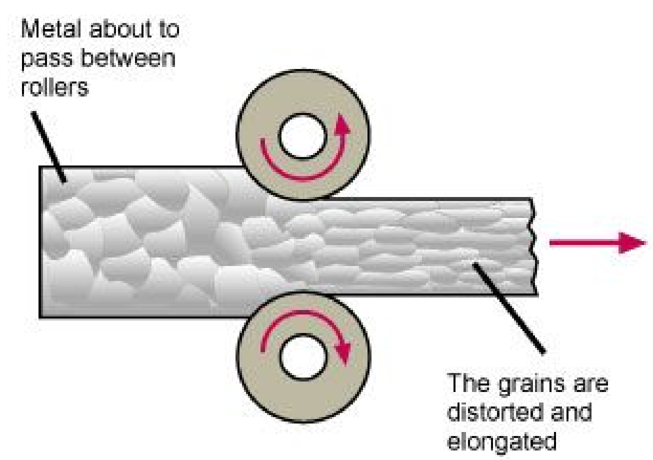
- Strain hardening (cold working) is the phenomenon whereby a ductile metal becomes harder and stronger as it is plastically deformed
- The degree of plastic deformation can be defined by the %CW
- The price for increased tensile strength is a reduction in ductility
- Strain hardening increases the dislocation density meaning it is harder to deform the material

$$\%CW = \left(\frac{A_0 - A_d}{A_0}\right) \times 100$$

%CW = percentage cold working
A_0 = Original area
A_d = Area after deformation

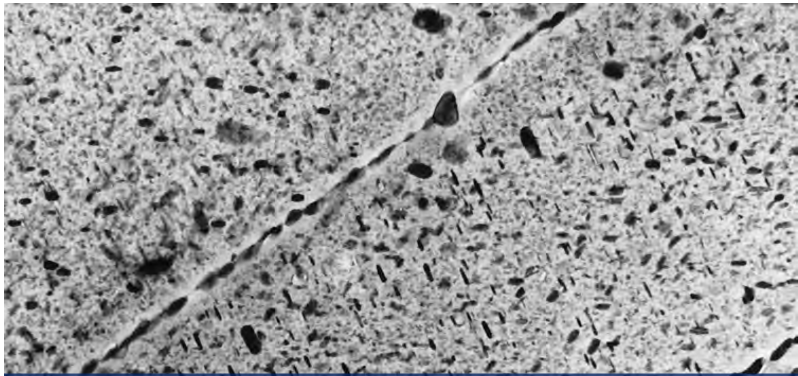




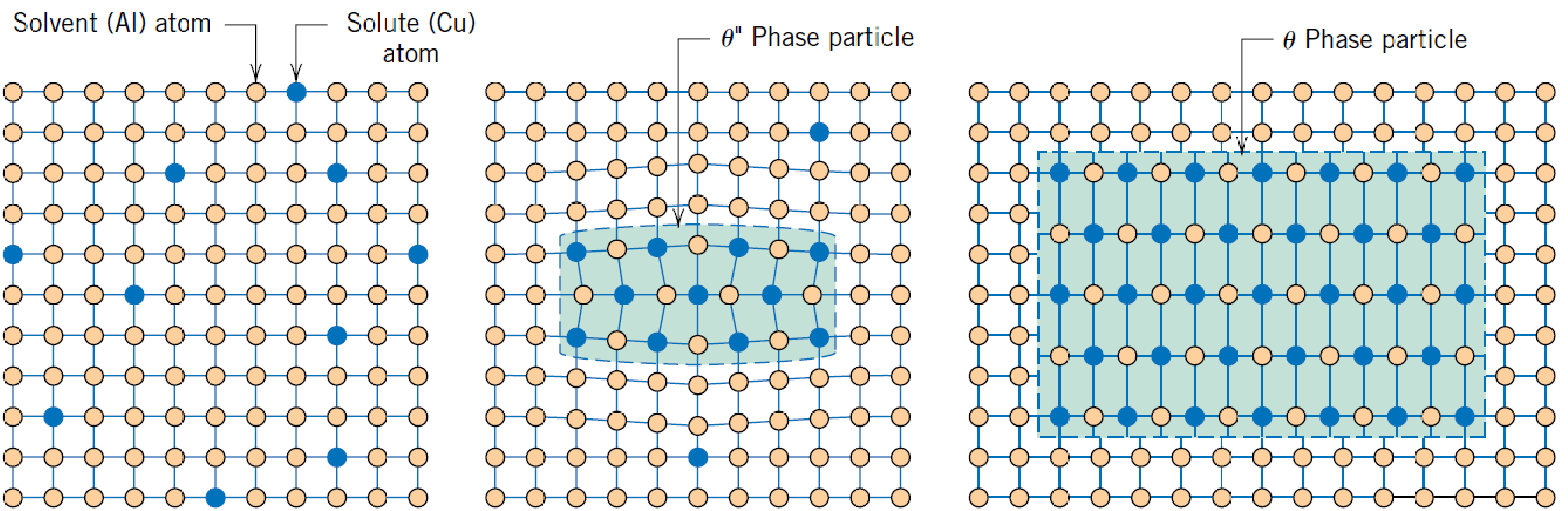


Precipitation hardening

- The strength and hardness of some metal alloys may be enhanced by the formation of extremely small uniformly dispersed particles of a second phase within the original phase matrix
- This is accomplished by phase transformations that are induced by appropriate heat treatments
- 2 Stages: Solution heat treating + precipitation heat treatment

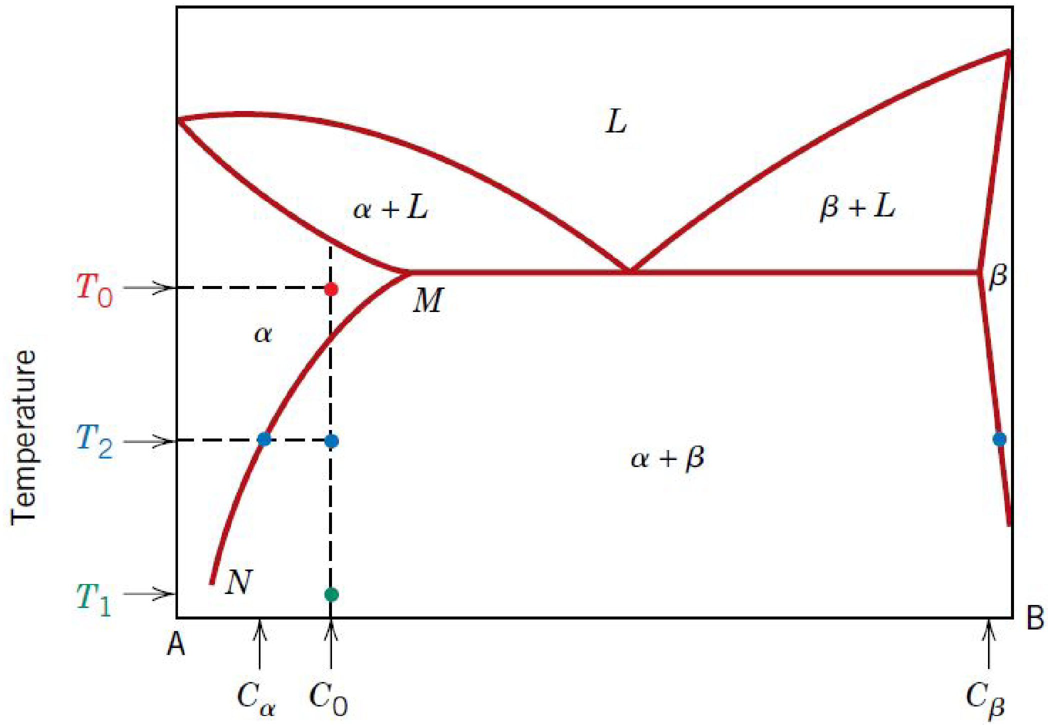


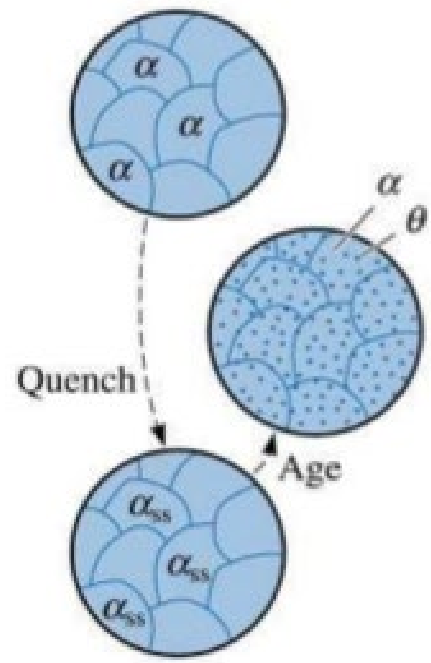
TEM micrograph of an Aluminium alloy
(6.2Zn, 2.3 Cu, 2.3Mg, 0.12Zr, Al balance)



Solution heat treating

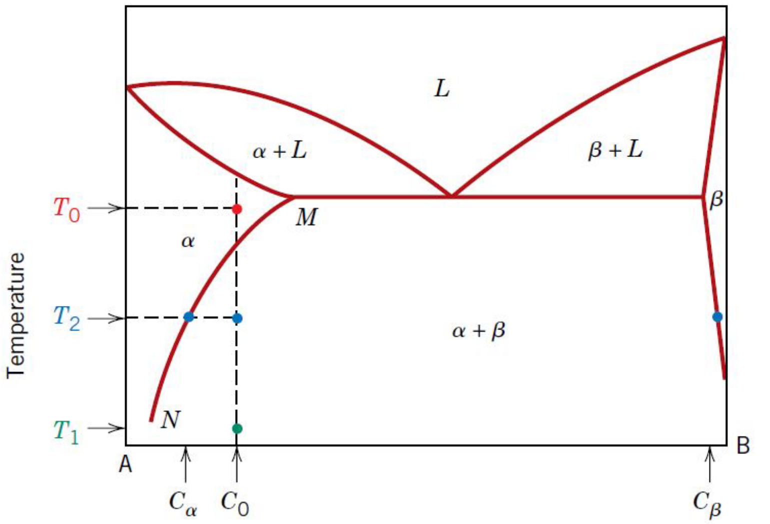
- Solute atoms are dissolved to form a single phase solid solution
- Heat to T_0 which is in the α phase (waiting till all the β phase is dissolved)
- Quench (rapidly cool) to T1 – So fast that diffusion of β is prevented and "locked in"
- Creates a non-equilibrium structure of α phase with supersaturated β phase
- At this stage the material is soft and weak

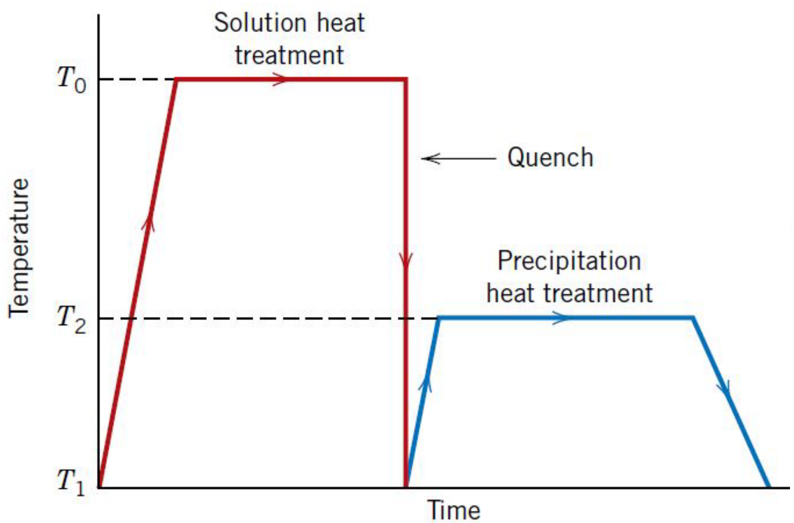


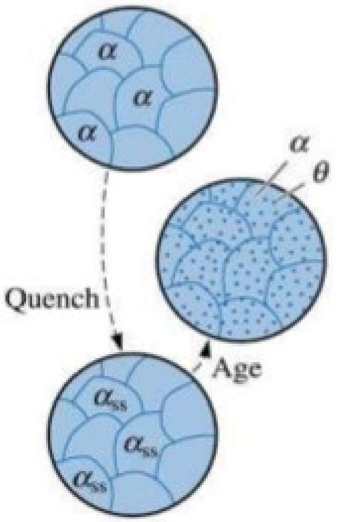


Precipitation heat treating

- Supersaturated α is heated to T2 within the α+β region where diffusion is faster
- Larger β particles start to form
- After holding for a set time it is cooled down
  - Normally cooling rates are less important here
- Strength and hardness increase which is a function of T_2 and time held at T_2
- Some alloys age at room temperature
- Strength and hardness increase and then decrease
- This is known as **overaging**



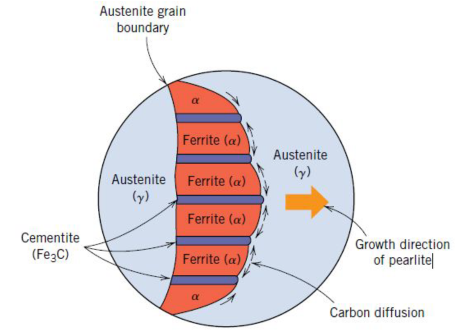




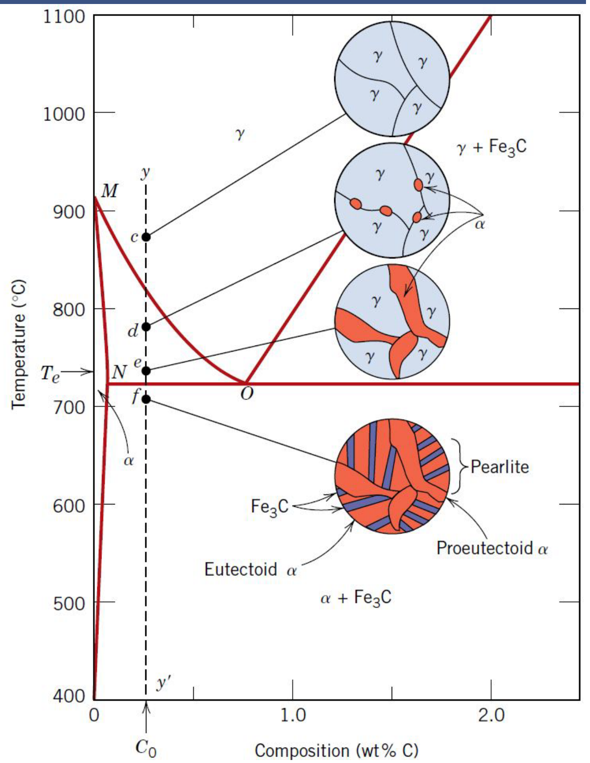
Non-equilibrium phases and structures

Going back to the iron-carbon system

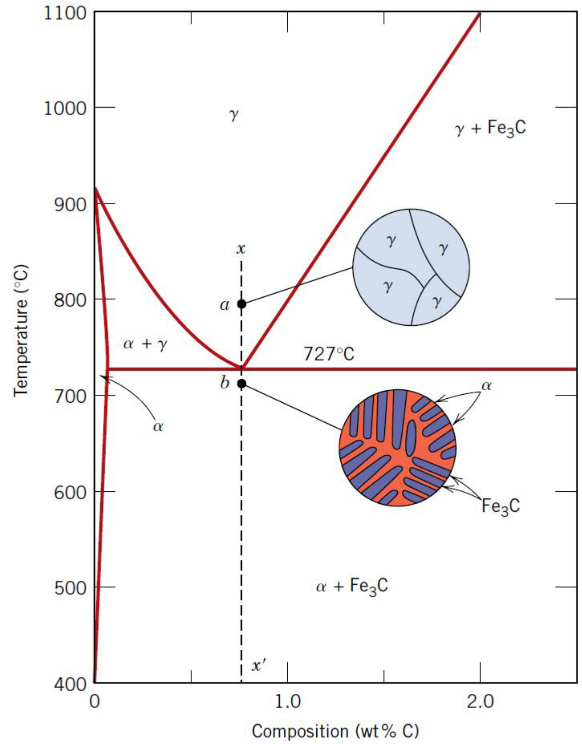
The equilibrium transformations are driven by the diffusion of atoms. However, if the rate of cooling is too fast for the normal diffusion of carbon atoms to occur, other structures or phases form.



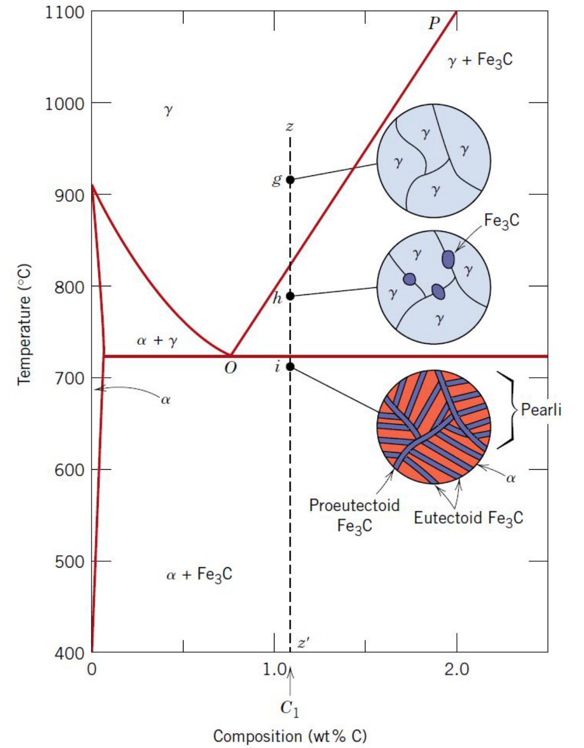
Hypo-eutectoid



Eutectoid

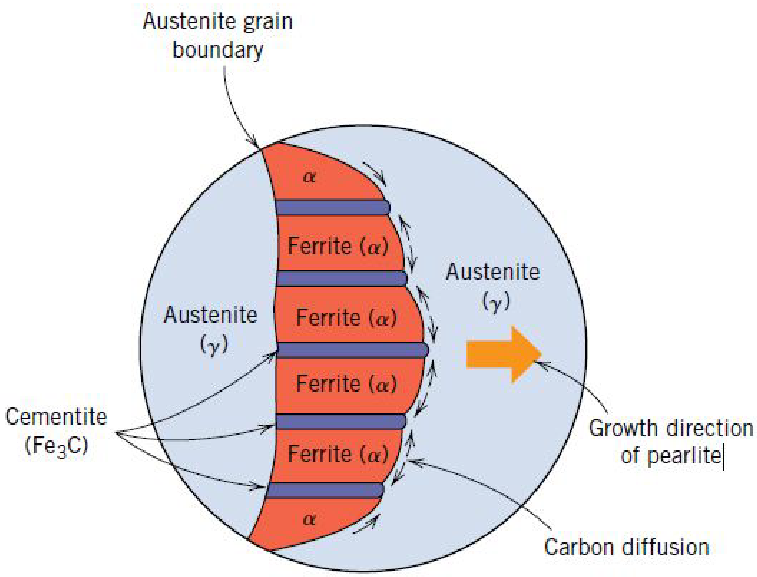


Hyper-eutectoid



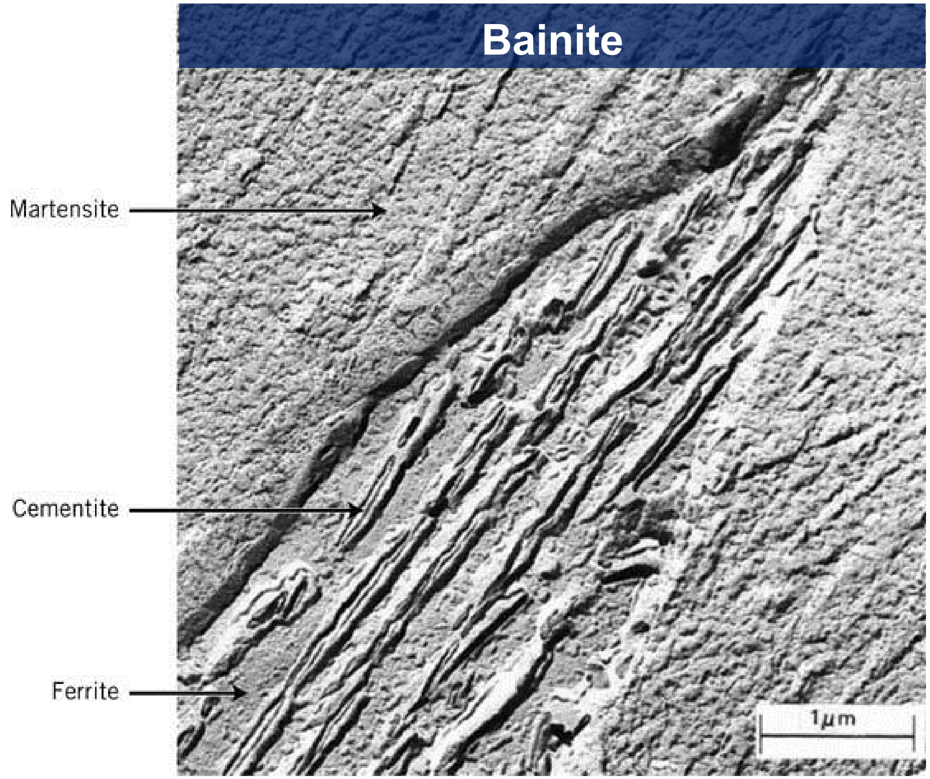
Fine and coarse pearlite

- **Full annealing**, i.e. very slow furnace cooling, leads to the formation of coarse pearlite, i.e. the equilibrium structure.
- **Normalising**, i.e. faster air cooling, leads to a finer pearlite structure. This is because there is less time for the atoms to diffuse, so they diffuse a shorter distance, leading to the finer structure. Fine pearlite imparts greater strength to the steel but is less ductile than coarse pearlite.



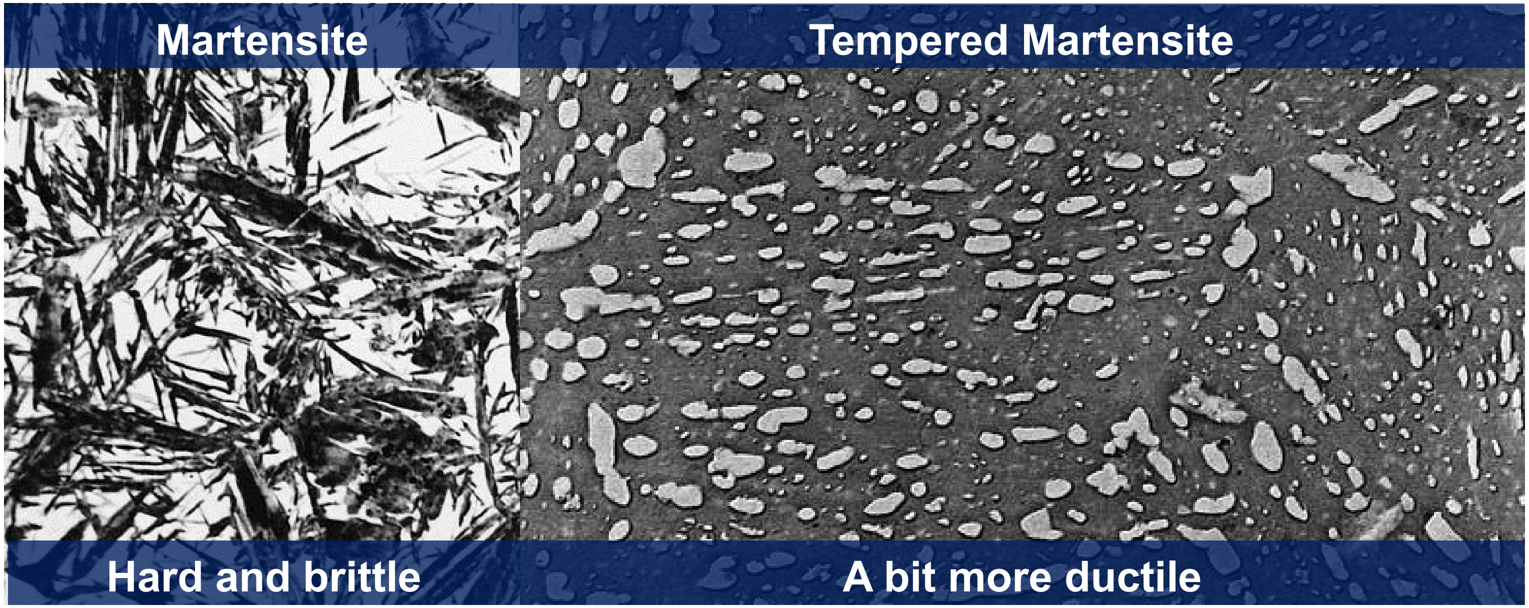
Bainite

- Bainite forms via the transformation from austenite
- Like pearlite, it consists of the two phases, ferrite and cementite. However, the structure of Bainite is very fine, being resolved only by an electron microscope
- Bainite forms as needles or plates, depending on the transformation temperature. It forms at lower temperatures than pearlite and typically under faster cooling rates



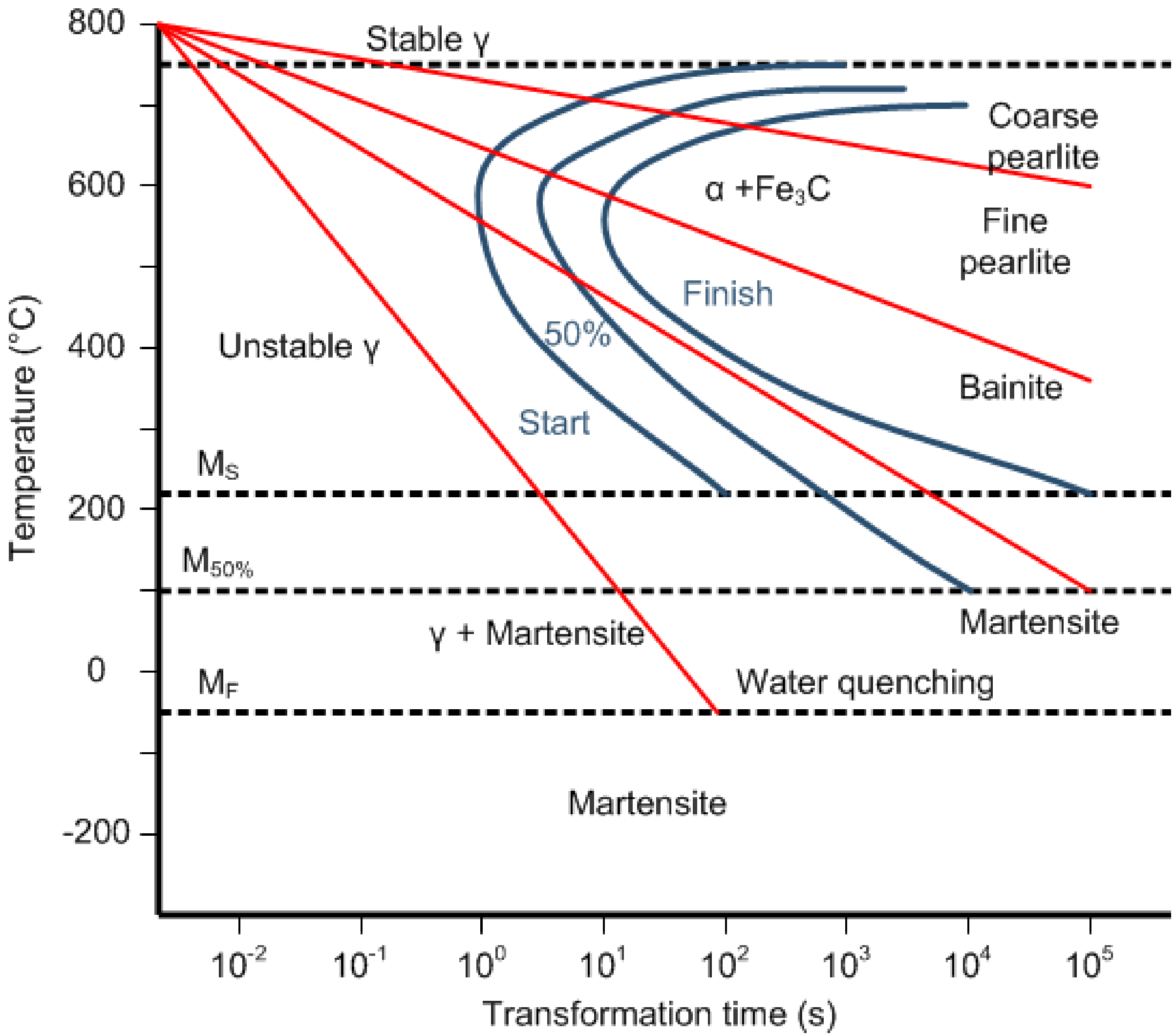
Martensite

- If **quenched**, e.g. cooled very fast in water, then there will be no time for atoms to diffuse through the structure
- If pure iron is cooled from within the γ field (> 910°C) very fast (which is possible only with very thin sections), there is no time for the Fe atoms to diffuse to change from γ-Fe (FCC) to α-Fe (BCC), so γ-Fe (FCC) persists to 550°C
- Below 550°C, γ-Fe is so unstable that small regions within crystals change by displacement, not diffusion
- To restore some ductility, martensite can be **tempered** (reheated)



Time-Temperature-Transformation

- Heat treatments involve **non-equilibrium** processes and are used to alter the microstructure such that the desired mechanical properties are attained
- Time temperature transformation diagrams are used because they tell us what phases or structures form after different thermal histories
- Progression of the transformation of γ to $\alpha+Fe_3C$ in their various structures
- M_S, $M_{50\%}$, M_F lines shows the progression of equilibrium martensite formation



Summary

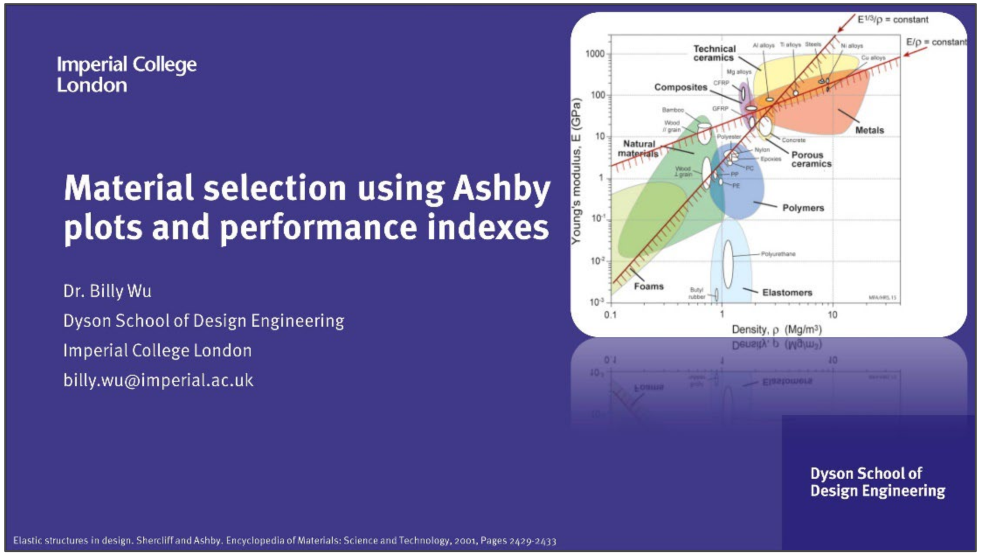
- Define different heat treatment processes and explain why they are used
- Describe non-equilibrium forms of steel and their main microstructural features/mechanical properties
- Recognise the general mechanical characteristics for different microconstituents of steel
- Analyse a Time-Temperature Transformation diagram and use it to analyse the microstructure resulting from different heat treatments

Keep flipping

Please watch this video on

"How to select materials using Ashby plots and performance indexes"

https://youtu.be/9RQkvcsRzbo



Materialise - DRAW week

- Materialise
- **Monday 6th of November 9.00-12.00**
- **Level 3 Dyson**
- Please access CES EduPack from Imperial softwarehub (It's free for you)
  - Works on a Window's operating system
  - If you have a Mac install Bootcamp or have a virtual machine

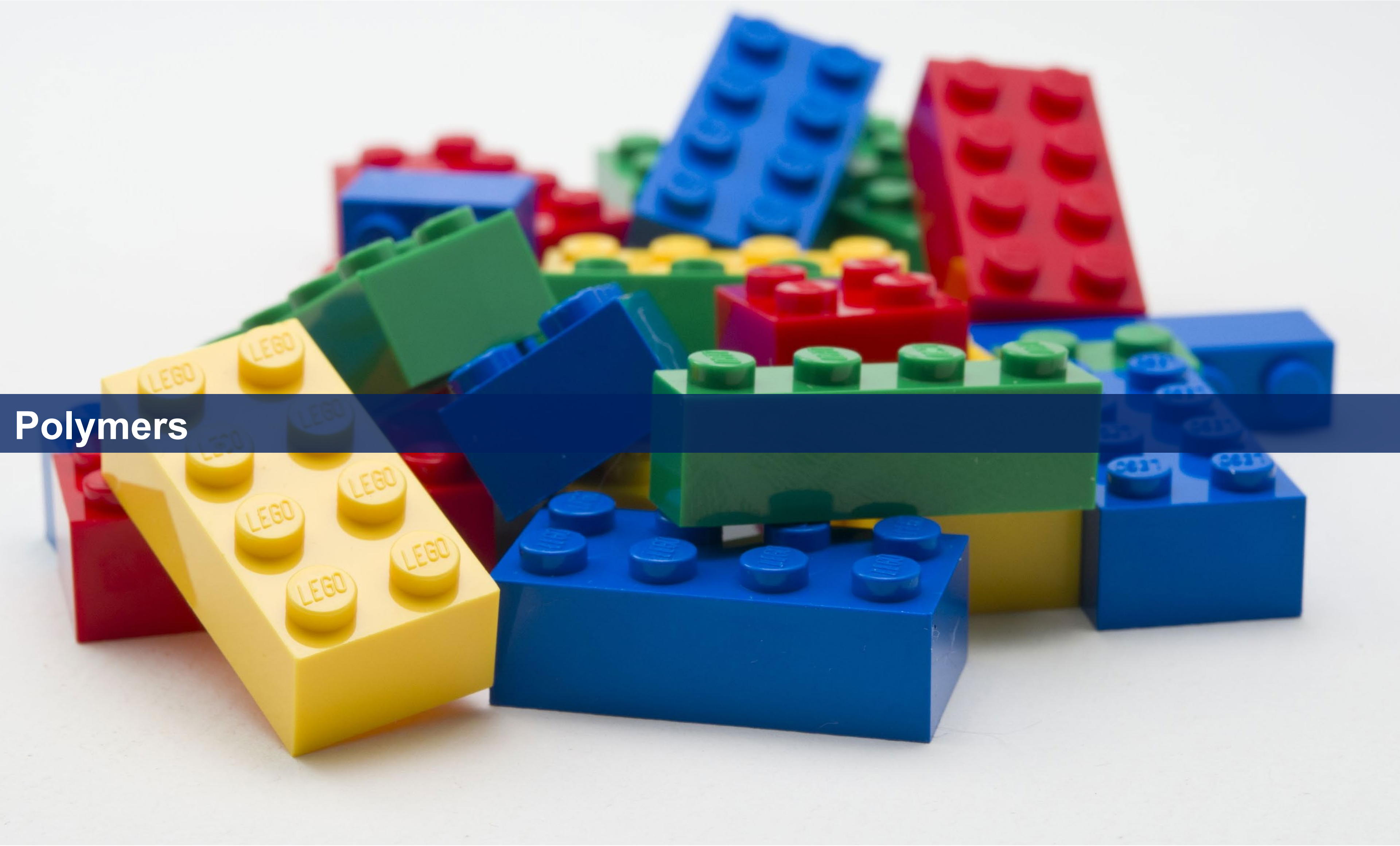
DE1-M&M - MATERIALS AND MANUFACTURING

MATERALISE

DYSON SCHOOL OF DESIGN ENGINEERING

GRANTA EduPack

Next time on M&M…



Polymers