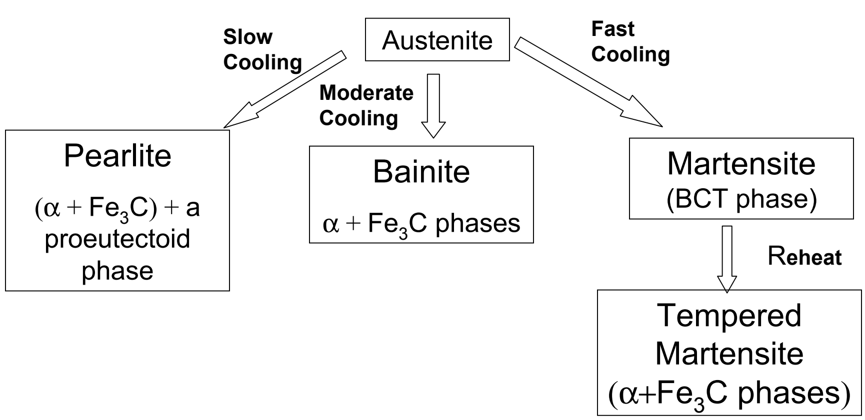
Lecture 4: Phase Transformations in Steel (non-equilibrium)

MMat 380

Summary



Non-equilibrium transformation of austenite (γ) - martensite

- Various microstructures occur depending on carbon content of steel:

~0.2%C	well defined laths of martensite
~0.6%C	plates of martensite form mixed with laths
~1.2%C	well defined plates of martensite

Non-equilibrium transformation of austenite (γ) - martensite

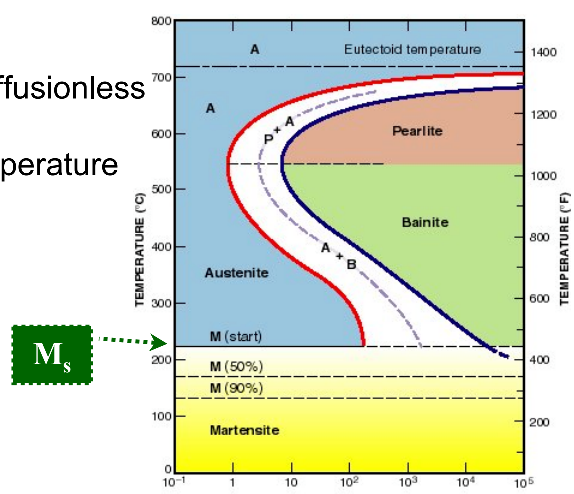
- Cool **rapidly** – no time for C diffusion so α - Fe_3C can form
- γ can be hundreds of degrees below 723°C therefore very **metastable**
- Transforms to structure by a diffusionless shear process – no time for atoms to intermix (martensite)
- No compositional change to parent phase

Transformation of austenite to martensite

- **Metastable** structure: supersaturated solid solution of carbon in α ferrite
- **Diffusionless** transformation – transformation too fast for atoms to diffuse
- Martensite transformation in steel starts at a definite temperature called the M_s

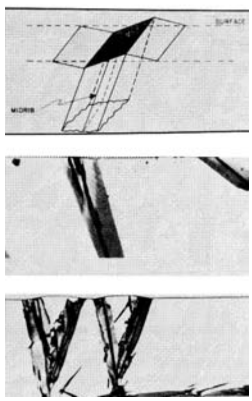
TTT Diagram

- Martensite reaction diffusionless
- Independent of time
- Only a function of temperature

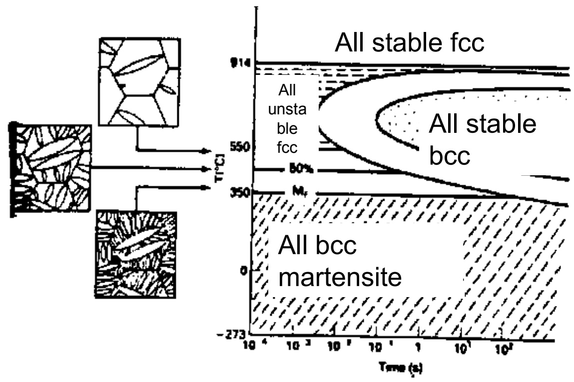


Diffusionless shear reaction

- Shape deformation of plate martensite



- Lens formation



Carbon dependent characteristics

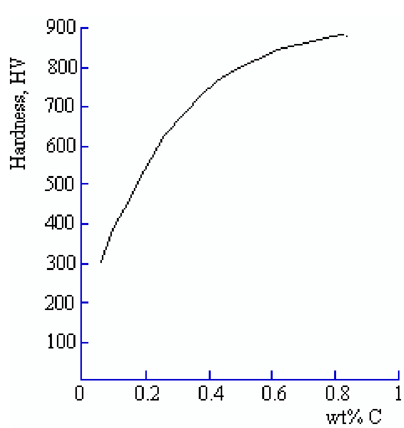
- Type of martensitic structure lath to plate
- Crystal structure BCC to BCT as %C ↑
- Hardening produced in Fe-C martensites directly related to their C content
- % retained austenite ↑ as % C ↑
- M_s martensite **start** and M_f martensite **finish** temperatures ↓ as %C ↑

Martensite structure

Photos from Cashen Blades website

- Low **C** < 0.6% lath structure
- High **C** >1.0% plate or needle (acicular) martensite

Hardness of martensite



http://www.matter.org.uk/steelmatter/manufacturing/surface_hardness/7_2_2.html

Alloy additions affect M_s & M_f

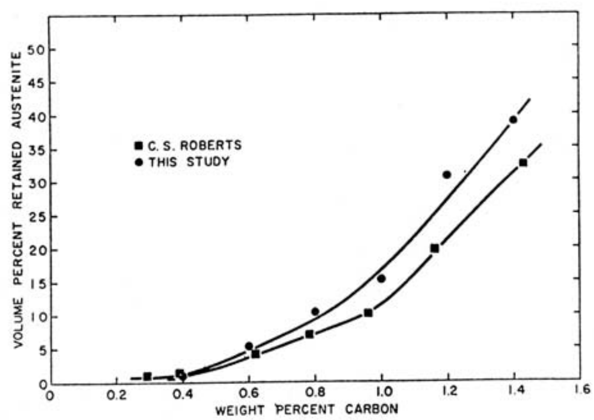
hardness of martensite **only** a function of %C

0.2%C – 50 Rc

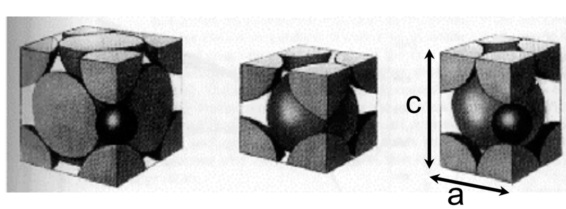
0.4%C – 58Rc

0.8%C – 65 Rc (2000 Mpa)

% Retained austenite



Crystal structure

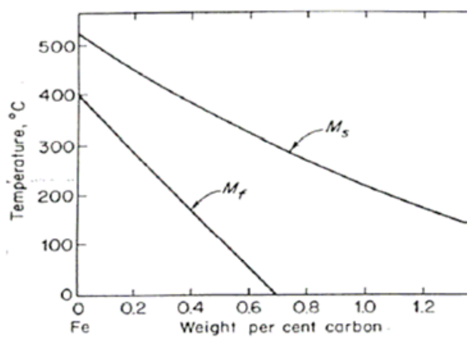


FCC (γ) BCC (α) BCT (martensite)

As %C ↑

- c/a up to 1.05
- Hardness of martensite ↑
- Distorted α (α^1)

M_s and M_f

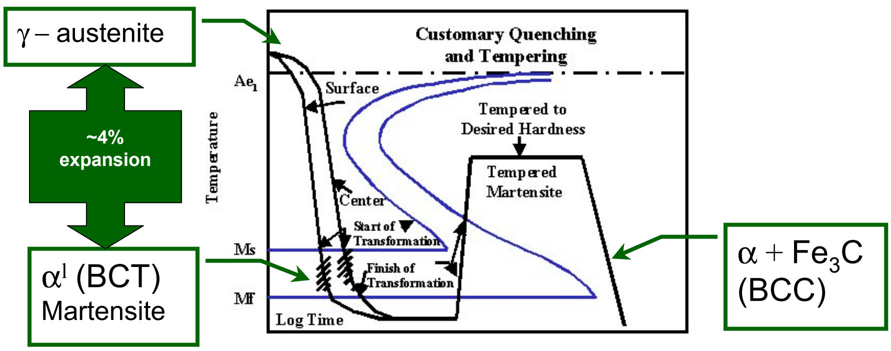


- If both well below room Temperature:
  - get γ stainless steel (i.e. 316)
- When C >0.4% start to get some **retained austenite**
- Must know how **alloy additions** affect M_s and M_f
- Generally alloy additions decrease M_s and M_f

Review of carbon martensite

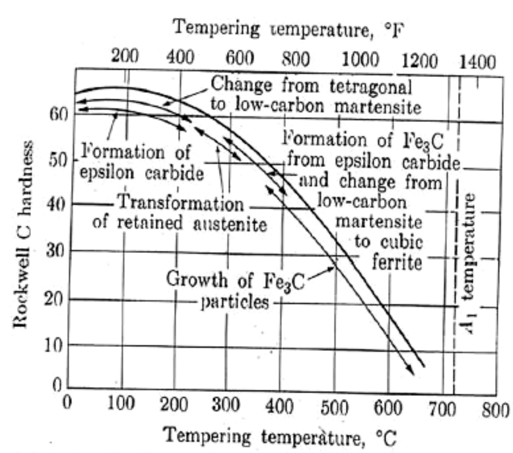
- Diffusionless shear reaction to lath or plate
- Body centred tetragonal crystal structure
- Lattice expansion – high stresses – crack risk
- High hardness depends on %C
- Transformation is athermal
  - – occurs @ decreasing T not constant T
- M_s and M_f are function of C content
- Above ~0.4%C can have retained γ

Tempering process



- Provides thermal energy for carbide precipitation
- Thermal energy = temperature + time
- c/a shrinks back to 1 – BCC

Microstructure changes during tempering



Microstructure changes during tempering

1. Precipitation of transition carbides $Fe_{2.4}C$ – epsilon carbide
2. Reduction in c/a as unit cell shrinks BCT to BCC
3. Retained g to bainite – intermediate Temp (200-300°C)
4. $Fe_{2.4}C$ to Fe_3C (shrinkage of structure) – Hi Temp
5. Growth of Fe_3C particles
6. Volume shrinkage

Tempering

1. Can't temper for short times on large parts
2. Outside lower hardness
3. Outside shrinks (therefore in tension – prone to fatigue failure)
4. High hardness – sharp edge; excellent wear resistance
   won't dull easily
   Low toughness – brittle – tends ot break and chip off

Examples: wood chisel; high quality cutting blades;
Razor blades, knives

Hardness vs toughness in tempered structures

Hi C martensite and low tempering T give:

- high strength, hardness
- Increase in sharpness edge of cutting tool
- Decreased ductility and toughness

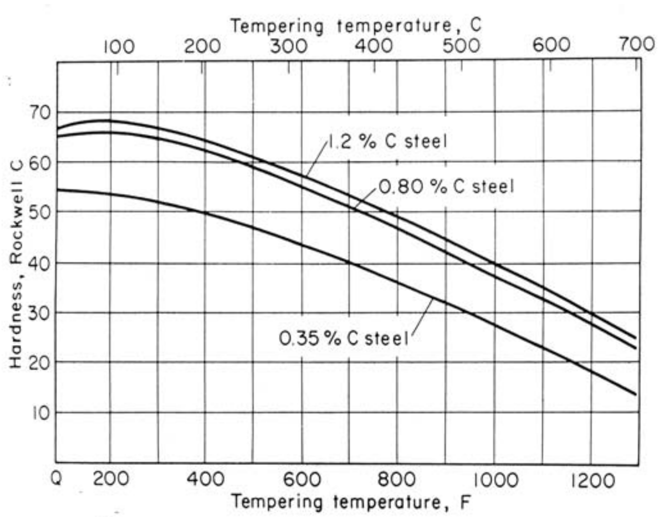
Low C martensite and high tempering T give:

- lower strength and wear resistance
- Decrease in sharpness
- Increased ductility and toughness

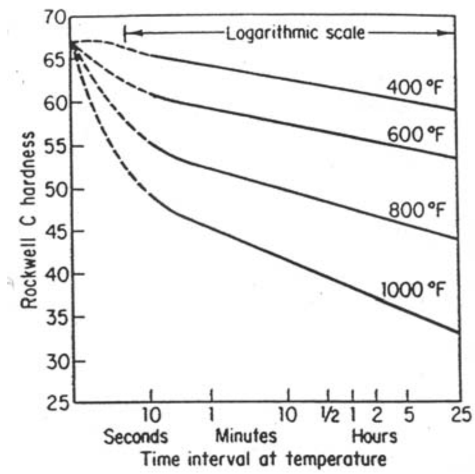
Always:

HARDNESS	Vs	TOUGHNESS
Increase C		Decrease C
Low tempering T		High tempering T

Effect of C-content



Effect of time and temperature



Tempering

- Rule of thumb for tempering:
  Need 1 hr/inch X-section
- Careful of surface over-tempering
  - Abrasive grinding on surface (localized friction)
    can cause surface over-temper
  - 3 examples:

Landing gear

- Original temper may have been R_c 50
  - abrasive grinding lowers surface to R_c 40
  - contraction at surface – residual tension
  - potential fatigue failure from the surface

Wood chisel (~0.6%C)

- Quenched R_c ~ 63
- Original temper 1 hour @ 200°C R_c ~ 60
  - During sharpening surface goes to 500°C (932°F) for ten seconds hardness decreases to ~R_c 45
  - Interior <200°C no change
  - Surface contracts and put into residual tension
  - Edge will dull rapidly – loses temper

Drill bit

- prolonged heating
- surface destroyed

Summary