Lecture 11: Metallic Alloys

TRIP Steels

A phase change can do work; a good example of this is how viruses infect bacteria. Similarly, in steel, when austenite is cooled rapidly to a sufficiently low temperature, *i.e.* when the chemical driving force is sufficiently large, martensite forms and causes a change in shape. It is the free energy of transformation which drives the deformation. This is called "transformation induced plasticity" or TRIP.

The converse situation is when there is insufficient chemical driving force but the application of stress assists the formation of martensite at a temperature above M_S.

This is very useful because there are stresses at an advancing crack, which stimulate the formation of martensite. Since the crack does work, its propagation becomes more difficult and hence the material is toughened.

Dual Phase Steels

Cars today are much safer to drive, have a higher performance and are lighter. The major reduction in weight, by some 375 kg has been achieved by the invention of better steels. Steels have a unique combination of low cost and versatility and corrosion is no longer an issue

Material	1978	Modern
Cast Iron	323	149
Aluminium	57	109
Plastics	95	136
Glass	38	27
Steel	1178	802
Others	209	137
Total wt / kg	1900	1360

(*e.g.* Mercedes offer a life–time guarantee). The major focus of research into new materials for automobiles is therefore steel.

Many of the steels used in automobiles have to be formed into particular shapes using presses. It is a major disadvantage if the steel exhibits a sharp yield point (Fig. 56) because this causes stretcher strains. The yield point is caused by the pinning of dislocations by segregated carbon or nitrogen atoms. Conventional steels for deep drawing are usually very low carbon/nitrogen steels to avoid sharp yield points. The microstructure is virtually fully ferritic and hence rather weak.

Dual phase steels were developed to provide high strength formable alloys for the automobile industry. They consist of a mixture of martensite and ferrite.The strains associated with the formation of martensite introduce free dislocations in the adjacent ferrite, thereby eliminating the sharp yield points. The mixture of hard martensite and soft ferrite also gives a higher average strength without sacrificing formability (uniform ductility).

Steels of this kind are used in the manufacture of wheels, side–impact

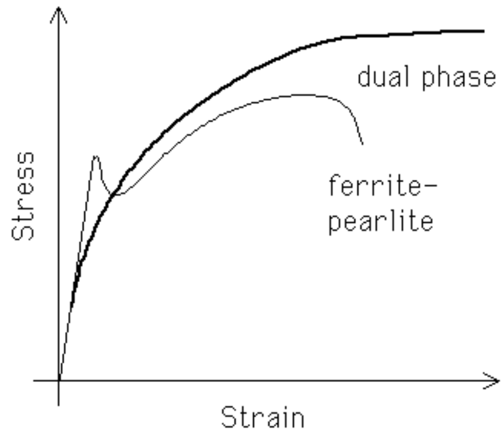

Fig. 56: Dual phase steel

bars *etc.*

Cast Irons

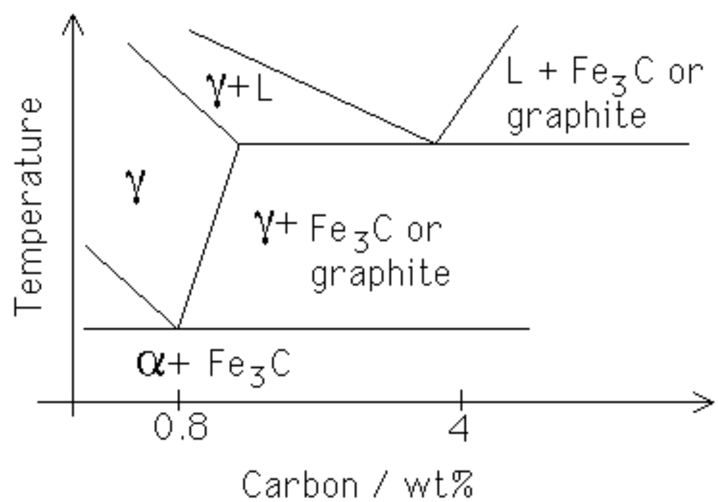

Fig. 57: Cast irons are high carbon iron alloys centered around the eutectic reaction at about 4 wt% C.

Grey (graphite)	White (cementite)
High C, Si	Low C, Si
Slow cooling	Fast cooling

White cast irons are hard and brittle and are used for grinding. They cannot be machined. When they are hypoeutectic

$$
\begin{array}{llll}
\text{Liquid} \rightarrow & \underbrace{\gamma - \text{dendrites}} + & \underbrace{\text{Liquid}} & \\
 & \qquad\downarrow & \quad\downarrow & \\
 & \underbrace{\gamma - \text{dendrites}} + & \overbrace{\underbrace{\gamma} \qquad + \mathrm{Fe_3C} \quad (\text{ledeburite eutectic})} & \\
 & \qquad\downarrow & \quad\downarrow & \\
 & \qquad \text{pearlite} & \qquad + \mathrm{Fe_3C} &
\end{array}
$$

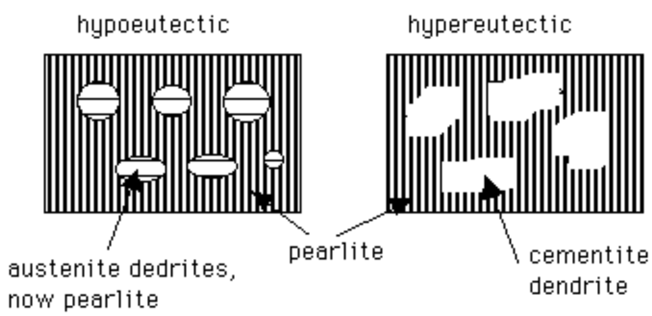

Fig. 57: Microstructures of white cast iron

Grey cast irons are softer with a microstructure of graphite in transformed austenite and cementite matrix. Graphite flakes (rosettes in three dimensions) have a low density and hence compensate for the freezing contraction, thus giving good castings free from porosity.

The flakes of graphite have good damping characteristics, good machinability but are stress concentrators, leading to poor toughness.

Minute additions of magnesium or cerium poison preferred growth directions and leads to isotropic growth resulting in spheroids of graphite. This spheroidal graphite cast iron has excellent toughness and is used widely, for example in crankshafts.

The latest breakthrough in cast irons is where the matrix of spheroidal graphite cast iron is not pearlite, but bainite. This results in a major improvement in toughness and strength. The bainite is obtained by isothermal transformation of the austenite at temperatures below that at which pearlite forms.

Aluminium Casting Alloys

Aluminium casting alloys closely resemble cast irons. Aluminium–12 wt% silicon eutectic compositions are frequently used because this gives the minimum melting temperature. The silicon which has a density of just $2.34\,\mathrm{g\,cm^{-3}}$, precipitates virtually as pure silicon. The resulting expansion compensates for freezing contractions to give castings with minimal porosity.

The silicon is coarse and brittle. The addition of a minute quantity of sodium (0.02 wt%) greatly refines the Si particles giving a higher toughness. It does so by removing P; AlP is a good nucleant for Si so its removal allows solidification to occur at a higher undercooling, where the nucleation rate can be larger.

Other Aluminium Alloys

Al–Si is designed specifically for casting. Other aluminium alloys are used in the wrought condition, *i.e.* after mechanical processing and heat treatment.

There are only a few common elements which have significant solubility in aluminium. Alloys where precipitation does not occur are Al–Mg, Al–Mg–Mn and Al–Zn. They all achieve strength by solid solution hardening or they may be used in a deformed, work–hardened condition. The first two alloys are used in the manufacture of cans, cooking utensils, roofing *etc.* Al–Zn is used primarily as cladding because it has good corrosion resistance.

Al–Cu, Al–Zn–Mg, and Al-Li are all alloys which can be heat treated to give precipitation hardening. Al–Li is particularly interesting because the addition of not only precipitation hardens but also reduces the density and increases the modulus. Al–Li alloys approach the density of fibre–reinforced polymer composites. These properties are advantageous in aerospace applications although there are difficulties with corrosion and joining.

Additional Resources

1. TRIP steels:
   www.msm.cam.ac.uk/phase-trans/2005/TRIP.steels.html
2. Aluminium–silicon casting alloys:
   www.msm.cam.ac.uk/phase-trans/abstracts/M7-8.html
3. Nickel–based superalloys:
   www.msm.cam.ac.uk/phase-trans/2003/Superalloys/superalloys.html
4. Cast irons:
   www.msm.cam.ac.uk/phase-trans/2001/adi/cast.iron.html