Ferrous Metals

Based on iron, one of the oldest metals known to man

- Ferrous metals of engineering importance are alloys of iron and carbon
- These alloys divide into two major groups:
  - Steel
  - Cast iron
- Together, they constitute approximately 85% of the metal tonnage in the United States

Steel and Cast Iron

What is the difference between steel and cast iron?!

Steel and Cast Iron Defined

Steel = an iron-carbon alloy containing from 0.02% to 2.1% carbon

Cast iron = an iron-carbon alloy containing from 2.1% to about 4% or 5% carbon

- Steels and cast irons can also contain other alloying elements besides carbon

Iron-Carbon Phase Diagram

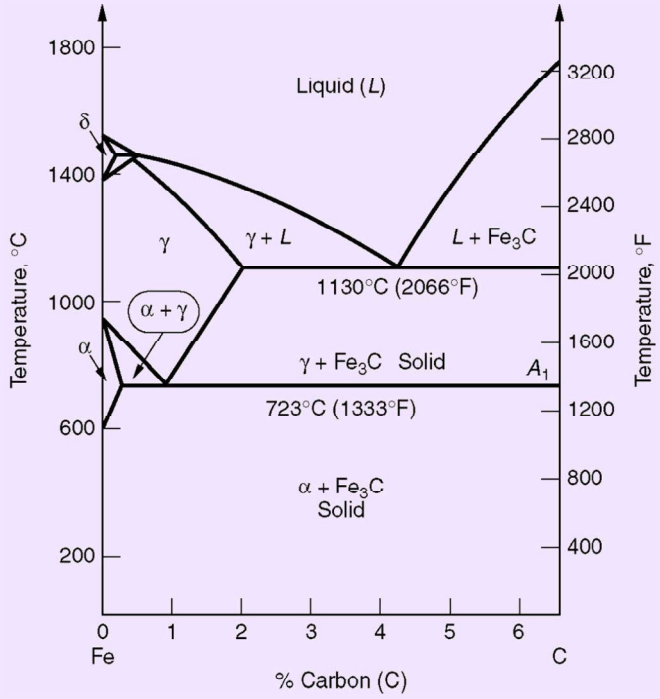

Figure 6.4 Phase diagram for iron-carbon system, up to about 6% carbon.

Steel

Steel

An alloy of iron containing from 0.02% and 2.11% carbon by weight

- Often includes other alloying elements: nickel, manganese, chromium, and molybdenum

- Steel alloys can be grouped into four categories:
  1. **Plain carbon steels**
  2. **Low alloy steels**
  3. **Stainless steels**
  4. **Tool steels**

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Plain Carbon Steels

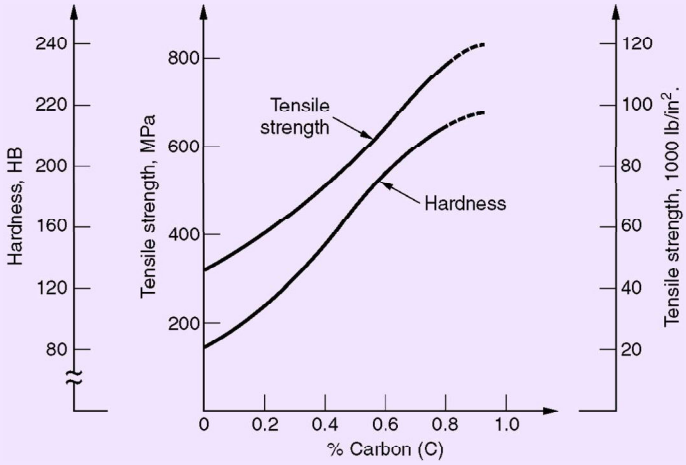
- Carbon is the principal alloying element, with only small amounts of other elements (about 0.5% manganese is normal)

- Strength of plain carbon steels increases with carbon content, but ductility is reduced

Carbon ↗ Strength ↗ Carbon ↗ Ductility ↘

- High carbon steels can be heat treated to form martensite, making the steel very hard and strong

Figure 6.12 Tensile strength and hardness as a function of carbon content in plain carbon steel (hot rolled).



Hardness is the characteristic of a solid material expressing its resistance to permanent deformation. It is expressed as Brinell hardness number or BHN or HB:
P = applied force (kgf)
D = diameter of indenter (mm)
d = diameter of indentation (mm)

$$\mathrm{BHN} = \frac{2P}{\pi D\left(D - \sqrt{(D^2 - d^2)}\right)}$$

AISI-SAE Designation Scheme

Specified by a 4-digit number system: 10XX, where 10 indicates plain carbon steel, and XX indicates carbon % in hundredths of percentage points

- For example, 1020 steel contains 0.20% C
- Developed by American Iron and Steel Institute (AISI) and Society of Automotive Engineers (SAE), so designation often expressed as AISI 1020 or SAE 1020

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Plain Carbon Steels

1. Low carbon steels - contain less than 0.20% C
   - Applications: automobile sheetmetal parts, plate steel for fabrication, railroad rails
2. Medium carbon steels - range between 0.20% and 0.50% C
   - Applications: machinery components and engine parts such as crankshafts and connecting rods
3. High carbon steels - contain carbon in amounts greater than 0.50%
   - Applications: springs, cutting tools and blades, wear-resistant parts

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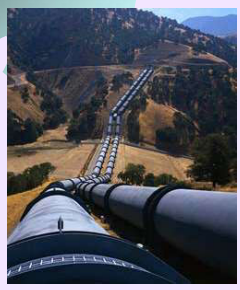
Low Alloy Steels

Iron-carbon alloys that contain additional alloying elements in amounts totaling less than ~ 5% by weight

- Mechanical properties superior to plain carbon steels for given applications
- Higher strength, hardness, wear resistance, toughness, and more desirable combinations of these properties
- Heat treatment is often required to achieve these improved properties



Large diameter pipeline

2 AISI-SAE Designation Scheme

AISI-SAE designation uses a 4-digit number system: YYXX, where YY indicates alloying elements, and XX indicates carbon % in hundredths of % points

- Examples:
  - 13XX - Manganese steel
  - 20XX - Nickel steel
  - 31XX - Nickel-chrome steel
  - 40XX - Molybdenum steel
  - 41XX - Chrome-molybdenum steel

3 Stainless Steel (SS)

Highly alloyed steels designed for corrosion resistance

- Principal alloying element is Chromium, usually greater than 15%
  - Cr forms a thin oxide film that protects surface from corrosion

- Nickel (Ni) is another alloying ingredient in certain SS to increase corrosion protection
- Carbon is used to strengthen and harden SS, but high C content reduces corrosion protection since chromium carbide forms to reduce available free Cr

Carbon ↗ Strength ↗

Carbon ↗ Corrosion protection ↘

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Properties of Stainless Steels

- In addition to corrosion resistance, stainless steels are noted for their combination of strength and ductility
  - While desirable in many applications, these properties generally make stainless steel difficult to work in manufacturing
- Significantly more expensive than plain C or low alloy steels

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Types of Stainless Steel

- Classified according to the predominant phase present at ambient temperature:
  1. Austenitic stainless - typical composition 18% Cr and 8% Ni
  2. Ferritic stainless - about 15% to 20% Cr, low C, and no Ni
  3. Martensitic stainless - as much as 18% Cr but no Ni, higher C content than ferritic stainless

3 Designation Scheme for Stainless Steels

- Three-digit AISI numbering scheme
- First digit indicates general type, and last two digits give specific grade within type
  - Examples:

    Type 302 – Austenitic SS

    18% Cr, 8% Ni, 2% Mn, 0.15% C

    Type 430 – Ferritic SS

    17% Cr, 0% Ni, 1% Mn, 0.12% C

    Type 440 – Martensitic SS

    17% Cr, 0% Ni, 1% Mn, 0.65% C

3 Additional Stainless Steels

- Stainless steels developed in early 1900s
- Several additional high alloy steels have been developed and are also classified as stainless steels:

4. Precipitation hardening stainless - typical composition = 17% Cr and 7%Ni, with additional small amounts of alloying elements such as Al, Cu, Ti, and Mo (Aerospace applications)
5. Duplex stainless - mixture of austenite and ferrite in roughly equal amounts (heat exchangers, pumps)

Tool Steels

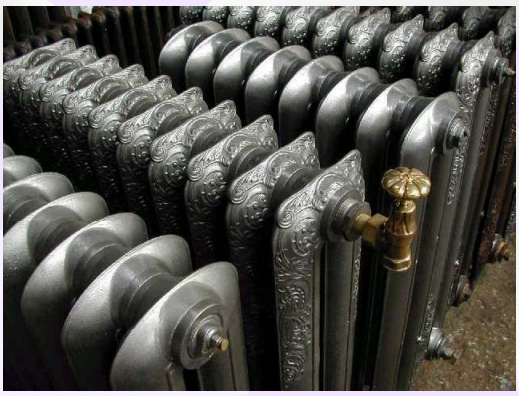
A class of (usually) highly alloyed steels designed for use as industrial cutting tools, dies, and molds

- To perform in these applications, they must possess high strength, hardness, wear resistance, and toughness under impact
- Tool steels are heat treated

AISI Classification of Tools Steels

T, M	*High-speed tool steels* - cutting tools in machining
H	*Hot-working tool steels* - hot-working dies for forging, extrusion, and die-casting
D	*Cold-work tool steels* - cold working dies for sheetmetal pressworking, cold extrusion, and forging
W	*Water-hardening tool steels* - high carbon but little else
S	*Shock-resistant tool steels* - tools needing high toughness, as in sheetmetal punching and bending
P	*Mold steels* - molds for molding plastics and rubber

Cast Iron



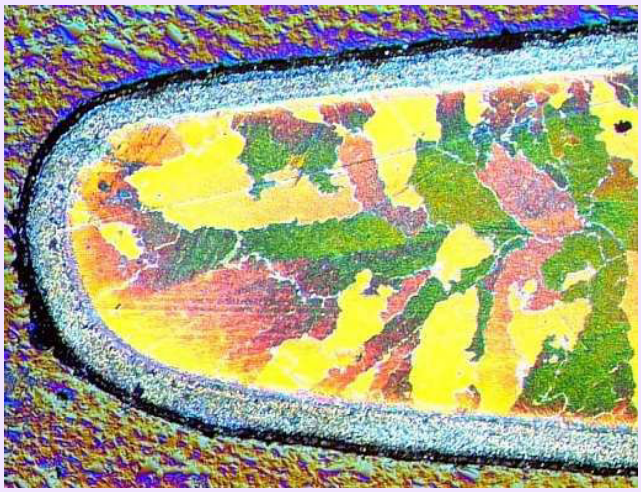
Cast Irons

Iron alloys containing from 2.1% to about 4% carbon and from 1% to 3% silicon

- This composition makes them highly suitable as <u>casting metals</u>
- Tonnage of cast iron castings is several times that of all other cast metal parts combined, excluding cast ingots in steel-making that are subsequently rolled into bars, plates, and similar stock
- Overall tonnage of cast iron is second only to steel among metals

Question

What do you think this is?



Cross-section of a gray cast iron using an optical microscopy (up to 1000 times magnification)

Types of Cast Irons

- Most important is *gray* cast iron
- Other types include *ductile* iron, *white* cast iron, *malleable* iron, and various alloy cast irons
- *Ductile* and *malleable* irons possess chemistries similar to the *gray* and *white* cast irons, respectively, but result from special processing treatments

Gray cast Iron →Special melting and pouring treatment (Chemical treatment) → **Ductile Iron**
White cast Iron →Heat treatment → **Malleable Iron**

Cast Iron Chemistries

Figure 6.13 Carbon and silicon % for cast irons, compared to steels (most steels have relatively low Si % - cast steels have higher Si %).

Ductile iron is formed by special melting and pouring treatment of gray cast iron.

Malleable iron is formed by heat treatment of white cast iron.