Ferrous Metals
Lecture 2

Introduction

Metals form about a quarter of the earth crust by weight

One of the earliest material used dated back to pre-historic time

Some of the earliest metals used include:
copper, bronze and iron

Stone age → Bronze age → … →'discovery' of steel →Industrial Revolution in the 18th century

All metals except gold are generally found chemically combined with other elements in the form of oxides and sulphates. Commonly known as **ores**.

Pure Metals and Alloys

Metal that are not mixed with any other materials are known as pure metals. Metals listed in the Periodic Table are pure metals

E.g. Iron (Fe), Copper (Cu) and Zinc (Zn)

Alloys are **mixtures** of two or more metals formed together with other elements/materials to create new metals with improved Mechanical Properties and other properties of the base metal.

E.g. Brass (Copper and Zinc),
Stainless steel (steel and chromium)

Alloy = metal A + metal B + … + other elements

Ferrous Metals & Non-Ferrous Metals

Ferrous metals are metals that contain iron
E.g. Steel (iron and carbon)

Non-ferrous metals are metals that do not contain iron
E.g. Zinc (pure metal), Bronze (Copper and tin)
(non-ferrous may contain slight traces of iron)

Ferrous Metal = alloy metals that contains iron
(Primary base metal is iron)

Non-ferrous Metal = alloy metals that do not contain iron
Primary base metal does not contain iron)

Classification

Metals can be divided into 2 groups

Metals

Ferrous Metals	**Non- Ferrous Metals**
Iron	Aluminum
Low Carbon Steel	Copper
Medium Carbon Steel	Brass
High Carbon Steel	Bronze
Cast Iron	Zinc
Stainless Steel	Lead
Tool Steels	Tin
Others	Others

Extraction of Iron

- Iron is found in iron oxide in the earth.
- Three primary iron ores: magnetite, hematite, taconite

- Iron is extracted using blast furnace

- Steps in extraction of iron
  - Ores is washed, crushed and mixed with limestone and coke
  - The mixture is fed into the furnace and is then melted
  - Coke(a product of coal, mainly carbon) is used to convert the iron oxides to iron

Extraction of Iron

- Limestone helps to separate the impurities from the metal

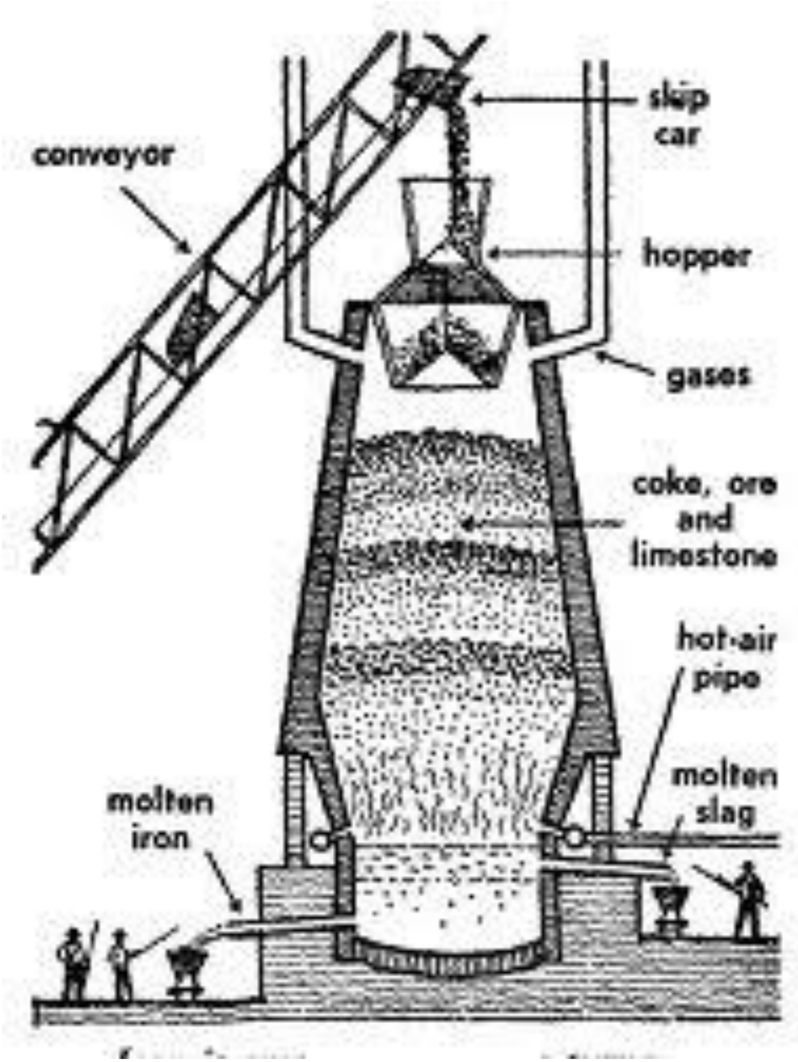
- The liquid waste is known as slag that floats on the molten iron

- They are then tapped off (separated)

- The iron produced is only about 90% to 95% pure.

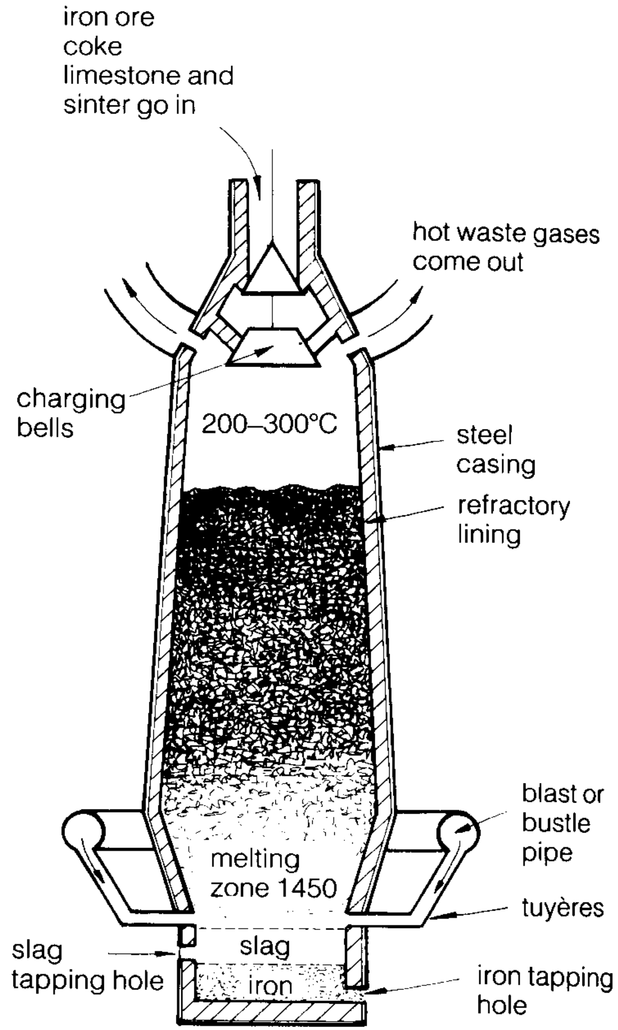
- The iron is then further refined using the basic oxygen furnace and the electric arc furnace to produce steel which is widely used now.

Blast Furnace

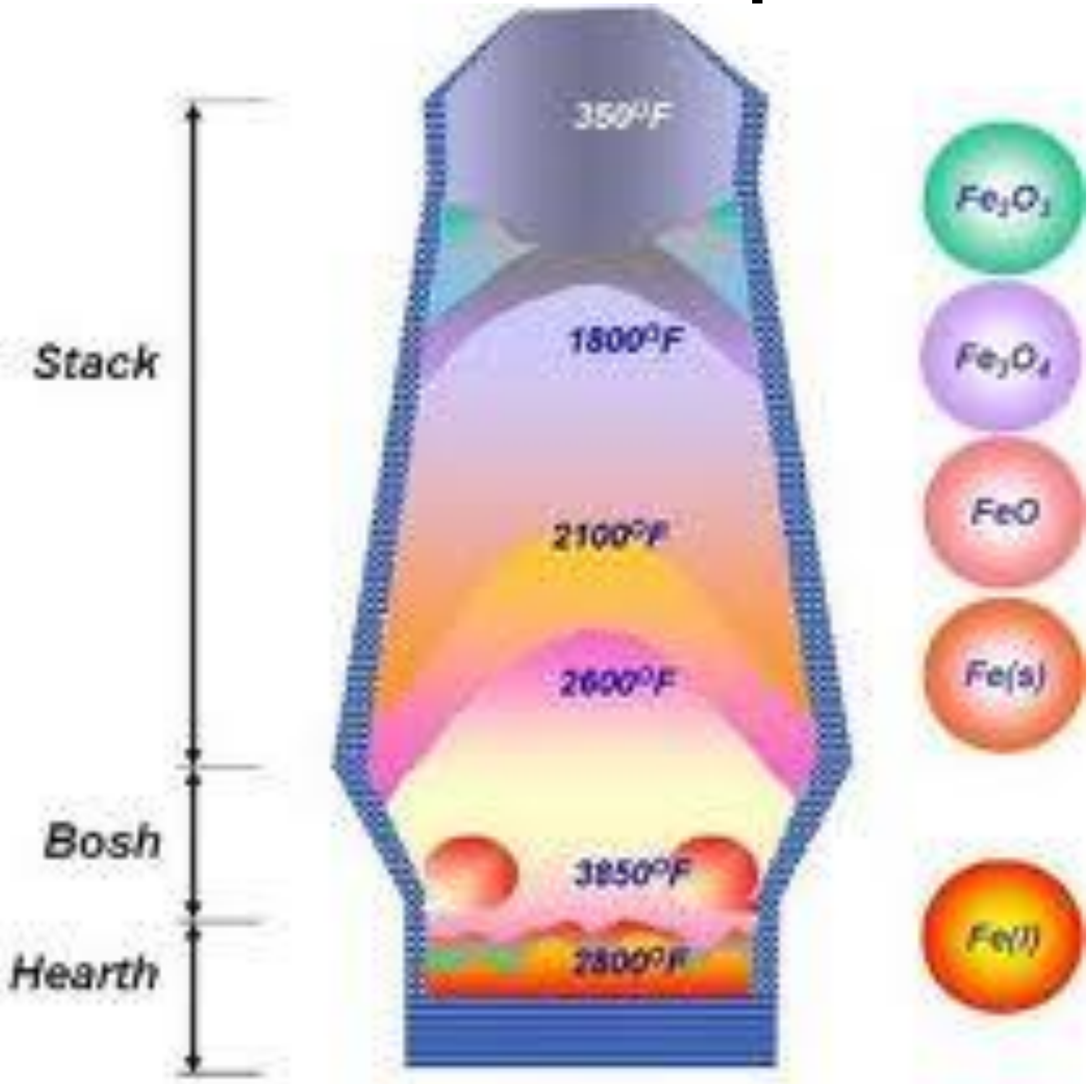


Extraction of Iron

A blast furnace



Blast Furnace Temperatures



Ferrous Metals - Iron and Steel

Pure iron is soft and ductile to be of much practical use.

BUT when carbon is added, useful set of alloys are produced. They are known as carbon steel.

The amount of carbon will determine the hardness of the steel.

Fe-C alloy classification

- Fe-C alloys are classified according to wt.% C present in the alloys
  - Commercial pure irons % C < 0.008
  - Low-carbon steels 0.008 - %C - 0.3
  - Medium carbon steels 0.3 - %C - 0.8
  - High-carbon steels 0.8- %C - 2.14
  - Cast irons 2.14 < %C

Low Carbon Steel

Also known as mild steel
Contain 0.05% -0.3% carbon

Tough, ductile and malleable
Easily joined and welded
Poor resistance to corrosion
Often used a general purpose material

Nails, screws, car bodies,

Medium Carbon Steel

Contains 0.3% - 0.8% of carbon

Offer more strength and hardness BUT less ductile and malleable

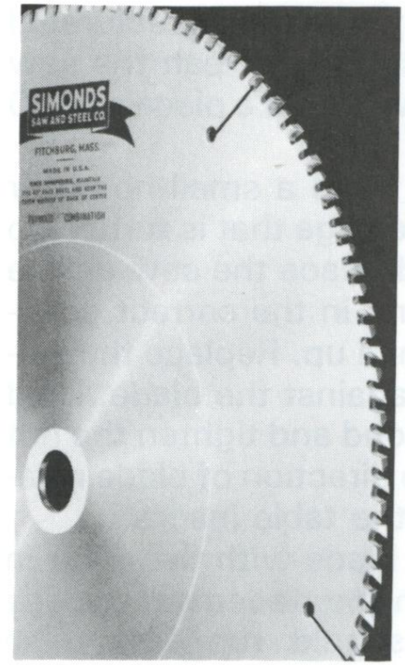
Structural steel, rails and garden tools

High Carbon Steel

Also known as ‘tool steel’
Contain 0.8%-2.14% carbon

Very hard but offers Higher Strength Less ductile and less malleable

Hand tools (punches)
Saw blades



Cast Iron

Contains 2.14%-4% of carbon

Very hard and brittle
Strong under compression
Suitable for casting [can be pour at a relatively low temperature]

Engine block, engineer vices, machine parts

Cast Iron

White:

Hard and brittle, good wear resistance

Uses: rolling & crunching

Equipment

Grey:

Good compressive & tensile strength, machinability, and vibration-damping ability

Uses: machine bases, crankshafts, furnace doors, Engine Blocks

Ductile:

High strength and ductility   Uses: engine and machine parts

Malleable:

Heat-treated version of white cast iron

Stainless Steel

Steel alloyed with
chromium (18%), nickel (8%), magnesium (8%)
Hard and tough
Corrosion resistance
Comes in different grades
Sinks, cooking utensils, surgical instruments

Stainless Steels

Main types:

Ferritic chromium:

very formable, relatively weak;
used in architectural trim, kitchen range hoods, jewelry, decorations, utensils Grades 409, 430, and other 400

Austentitic nickel-chromium:

non-magnetic, machinable, weldable, relatively weak;
used in architectural products, such as fascias, curtain walls, storefronts, doors & windows, railings; chemical processing, food utensils, kitchen applications.
series. Grades 301, 302, 303, 304, 316, and other 300 series.

Martensitic chromium:
High strength, hardness, resistance to abrasion; used in turbine parts, bearings, knives,. Grades 17-4, 410, 416, 420, 440 and other 400 series

Maraging (super alloys):
High strength, high Temperature alloy used in structural applications, aircraft components and are generally magnetic. Alloys containing around 18% Nickel.

High Speed Steel

Medium Carbon steel alloyed with
Tungsten, chromium, vanadium

Very hard
Resistant to frictional heat even at high temperature

Machine cutting tools (lathe and milling)
Drills

Heat Treatment

A process used to alter the properties and characteristics of metals by heating and cooling.

Cold working → induce stress in metal → lead to work hardening → prevent further work from taking place

Three stages of heat treatment

1. Heat the metal to the correct temperature
2. Keep it at that temperature for a the required length of time (soaking)
3. Cool it in the correct way to give the desired properties

Heat Treatment

Types of heat treatment:

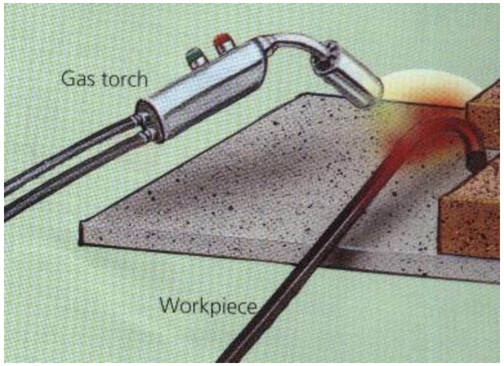
Annealing
Normalizing
Hardening
Tempering
Case hardening

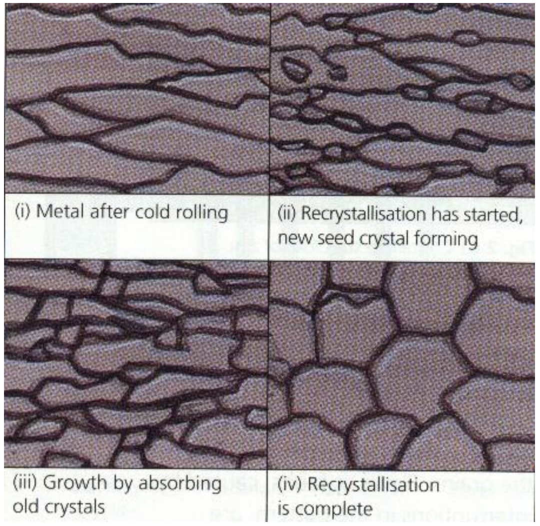
Annealing

Annealing is the process whereby heat is introduced to mobilise the atoms and relieve internal stress

After annealing, it allows the metal to be further shaped

It involves the re-crystallization of the distorted structure





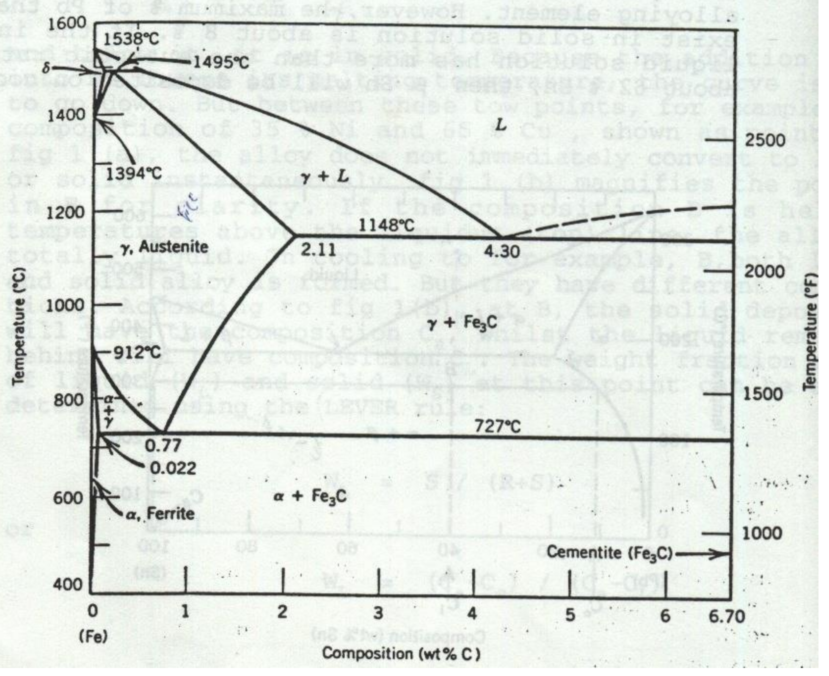
Normalizing

This process is only confined to steel.

It is used to refine the grain due to work hardening

It involves the heating of the steel to just above
Its upper critical point.

Phase diagram of
Iron-Carbon



Hardening

Hardening is the process of increasing the hardness of steel by adding a high amount of carbon

The degree of hardness depends on the amount of carbon present in steel and the form in which it is trapped during quenching.

Once hardened, the steel is resistant to wear but is brittle and easily broken under load.

Tempering

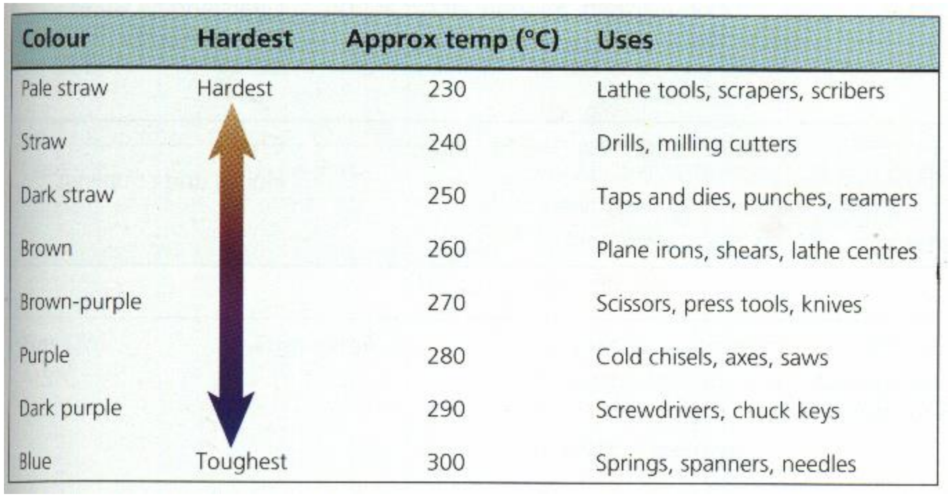
Tempering is the process to reduce hardness and brittleness slightly of a hardened steel workpiece.

It helps to produce a more elastic and tough steel capable of retaining the cutting edge after tempering

Prior to tempering, the steel must be cleaned to brightness with emery cloth so that oxide colour is visible when reheated

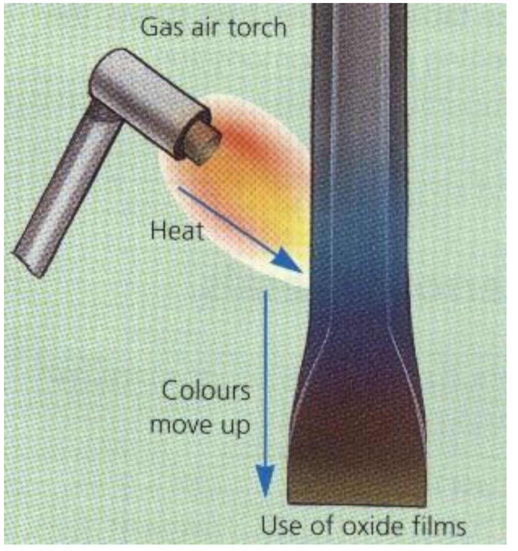
Tempering temperature 1/α hardness
Tempering temperature α toughness

Tempering



Colour	Hardest	Approx temp (°C)	Uses
Pale straw	Hardest	230	Lathe tools, scrapers, scribers
Straw		240	Drills, milling cutters
Dark straw		250	Taps and dies, punches, reamers
Brown		260	Plane irons, shears, lathe centres
Brown-purple		270	Scissors, press tools, knives
Purple		280	Cold chisels, axes, saws
Dark purple		290	Screwdrivers, chuck keys
Blue	Toughest	300	Springs, spanners, needles

Guidelines for tempering



Tempering of cold chisel

230 C = 446 F

300 C = 572 F

Case Hardening

Case hardening is a process used with mild steel to give a hard skin

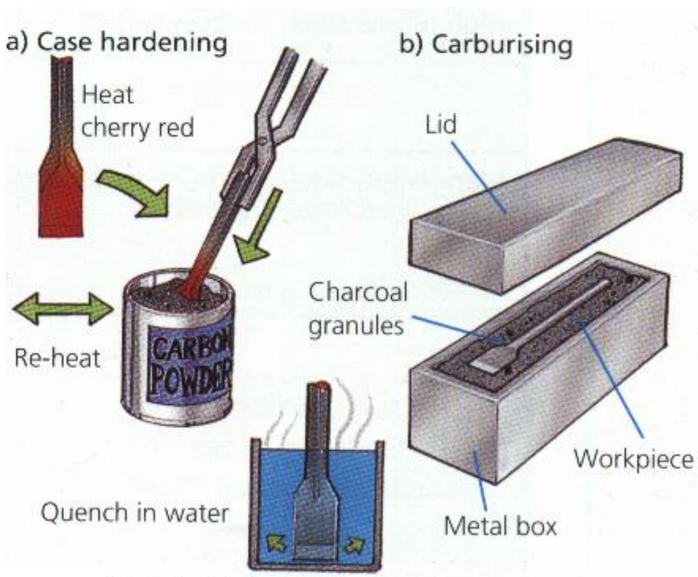
The metal is heated to cherry red and is dipped in Carbon powder. It is then repeated 2-3 more times before Quenching the metal in water to harden the skin.

This allows the surface of mild steel to be able to subject to wear but the soft core is able to subject to Sudden shock e.g. the tool holders

Case Hardening - Carburizing

Carburizing involves placing the mild steel in box packed with charcoal granules, heated to 950 ^{o} C (1742 ^{o}F) and allowing the mild steel to soak for several hours.

It achieves the same purpose of case hardening



Case hardening and carburising

<u>Carbon Steels Used for Construciton</u>

- Those steels in which the residual elements (carbon, manganese, sulphur, silicon, etc.) are <u>controlled</u>, but in which <u>no alloying elements are added</u> to achieve special properties.

A36 Carbon Structural Steel

- For years, the workhorse all-purpose steel for nearly all structural “shapes” (beams, channels, angles, etc.), as well as plates and bars, has been:

Wide Flanged Beams “W” shapes

- Recently (last few years), A36 has been displaced as the steel of choice for the major “shape” subcategory called <u>wide-flange beams</u>, or “W” shapes. The replacement steel is a high-strength, low-alloy steel, known as <u>**A992**</u> (see below). For the other <u>non</u>-wide-flange beam structural shapes, A36 remains the predominant steel.

Structural pipe and square tubing

- Pipe: **A53** Pipe, Steel, Black and Hot-Dipped, Zinc- Coated Welded and Seamless.
- Tubing: **A500** Cold-Formed Welded and Seamless Structural Tubing in Rounds and Shapes.
- **A501** Hot-Formed Welded and Seamless Carbon Steel Structural Tubing.

High-Strength, Low-Alloy Steels

- **<u>High-Strength, Low-Alloy Steels:</u>**
- A group of steels with chemical compositions specially developed to impart better mechanical properties and greater resistance to atmospheric corrosion than are obtainable from conventional carbon structural steels. Several particular steels used often in construction, and their ASTM specifications, are:

- **A572:** High-Strength, Low-Alloy Columbium-Vanadium Steels of Structural Quality.

- **A618:** Hot-Formed Welded and Seamless High-Strength, Low-Alloy Structural Tubing

- **A913:** High-Strength, Low-Alloy Steel Shapes of Structural Quality,
- Produced by Quenching and Self-Tempering Process

- **<u>A992</u>:** **Steel for Structural Shapes for Use in Building Framing**
  <u>This is the steel which has substantially replaced A36 steel for Wide-flange structural shapes.</u>

Corrosion – Resistant Steels

- **A242:** High-Strength, Low-Alloy Structural Steel.
- **A588:** High-Strength, Low-Alloy Structural Steel with 50 ksi Minimum Yield Point.
- **A847:** Cold-Formed Welded and Seamless High-Strength, Low-Alloy Structural Tubing with Improved Atmospheric Corrosion Resistance.