Furnaces

High-Frequency Induction Furnace

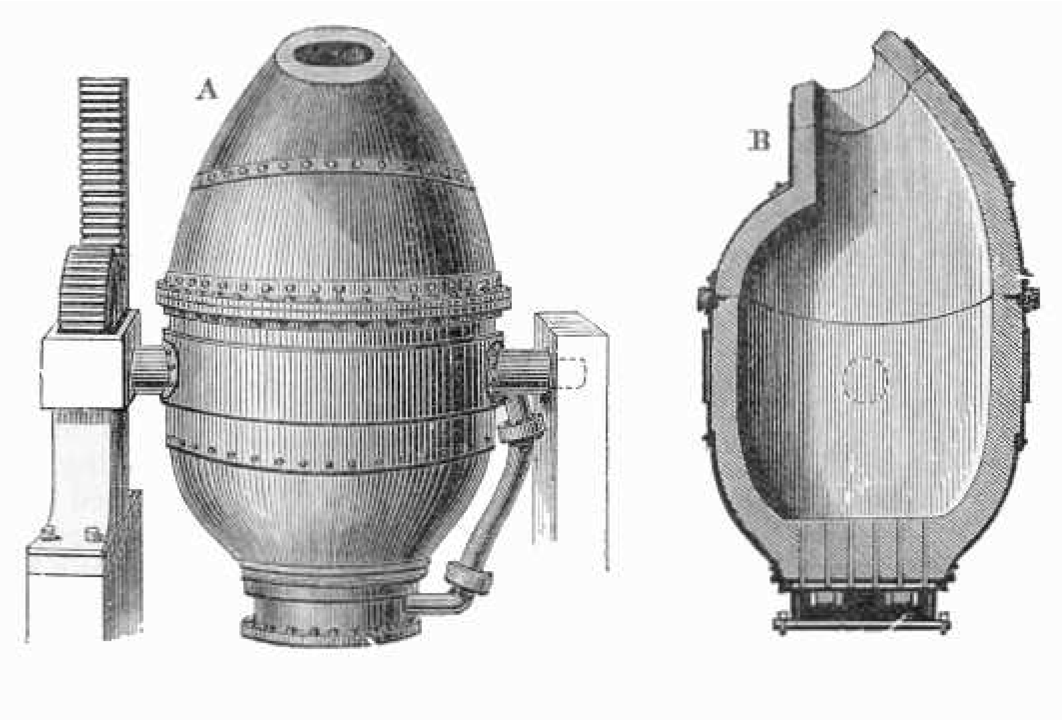
The High-Frequency induction furnace is widely used to produce tool steel (cast steel). The melt consists of selected scrap of known carbon content. This is placed in a crucible, which is surrounded by a water-cooled induction coil. A high frequency alternating current is passed through the coil and this set up an alternating magnetic field within the melt which generates intense heat and also has a stirring effect. Not only is it possible to obtain high temperatures, but the degree of heat may be accurately controlled. The furnace is tilted to pour out the molten metal. Most modern foundries use this type of furnace and now also more iron foundries are replacing cupolas with induction furnaces to melt cast iron, as the former emit lots of dust and other pollutants. Induction furnace capacities range from less than one kilogram to one hundred tonnes capacity, and are used to melt iron and steel, copper, aluminium, and precious metals. The one major drawback to induction furnace usage in a foundry is the lack of refining capacity; charge materials must be clean of oxidation products and of a known composition, and some alloying elements may be lost due to oxidation (and must be re-added to the melt).

The Electric Arc Furnace

The electric-arc furnace consists of a large shallow bath with either an acid or basic lining, carbon electrodes over the hearth which may be raised or lowered. Current is supplied to these electrodes from special transformers. The hearth is charged with lime, and either iron ore or mill scale to remove the impurities and form a slag. The metal which forms the melt is scrap steel of known composition. When the furnace is charged the electrodes are lowered and the current is switched on. The electrodes are then raised and an electric arc jumps across from the electrodes to the metal and melting begins. The temperature is about 3400ºC. The furnace is tilted and the slag is ladled off. Lime, fluorspar, carbon and Ferro-alloys are added to de-oxidize and de-sulphurize the metal. A sample is taken and tested and when the correct composition is achieved the furnace is tilted and the steel is poured into a ladle. The electric arc furnace is used to produce high grade alloy steels, HSS, High Tensile Steel and Silver Steel. This is possible because of the greater control over impurities and thus the steel making. It is increasingly used nowadays in the production of common steel. This process of making steel is very expensive due to the high cost of electricity. Arc furnaces range in size from small units of approximately one ton capacity used in foundries for producing cast iron products, up to about 400 ton units used for secondary steelmaking (arc furnaces used in research laboratories and by dentists may have a capacity of only a few dozen grams).

Bessemer converter

The outside consists of a steel casing lined with firebricks. The process starts by pouring molten pig iron into the converter while in the horizontal position. The converter is now turned to the upright position. And air from the blast box passes up through the tuyeres. The pressure of the air prevents the molten steel from entering the blast box. The oxygen in the air burns out the carbon and oxidizes the other impurities. This stage is indicated by a flame leaping form the converter. The final stage of the process is marked by the appearance of a large white flame, when this flame suddenly rescinds the process is complete. All steels contain carbon and this can be obtained by adding a small amount of ferro-manganese, the amount used depends on the type of steel required. The converter is then tilted forward and the slag raked off. The steel is poured into moulds to form ingots. Low carbon steel is produced by this process. Henery Bessemer was born in England 1856 August. The Bessemer process was the first inexpensive industrial process for the mass-production of steel from molten pig iron. The key principle is removal of impurities from the iron by oxidation through air being blown through the molten iron. The oxidation also raises the temperature of the iron mass and keeps it molten



Open Hearth Furnace

The Open hearth Furnace is used for the production of steel and produces most of the steel used today. This process is slow requiring 10-14 hours per batch. The open hearth furnace is a large shallow bath with either an acid or basic lining. The bath is frequently made to tilt in order that the molten metal may be poured. The hearth is enclosed by a steel casing lined with special fire brick and with charging doors in front, at both ends of the hearth are openings for air and gas. The mixture of air and gas burns over the hearth, and the flame is directed down to the metal. The very hot gases from the hearth go to special chambers of chequered brickwork before escaping through the chimney. The direction of flow of the gas and air is reversed every 15 mins. The incoming gas and air then pass through the hot brickwork and are pre-heated. The gas used is usually coal gas, but where natural oil is plentiful this may be used instead. Oil is not pre-heated. The charge that goes into the open hearth furnace is;

- Pig iron 50% (from the blast furnace)
- Lime 20% removes the impurities
- Steel Scrap 20% reduces cost and recycles
- Iron ore of Mill Scale 10% oxidize the unwanted elements

Once the steel making is completed the metal is tapped into ingot moulds and sent to the rolling mills or forging workshops.Open hearth furnaces are one of a number of kinds of furnace where excess carbon and other impurities are burnt out of pig iron to produce steel. Since steel is difficult to manufacture due to its high melting point, normal fuels and furnaces were insufficient and the open hearth furnace was developed to overcome this difficulty. Most open hearth furnaces were closed by the early 1990s, not least because of their fuel inefficiency, being replaced by basic oxygen furnace or electric arc furnace.

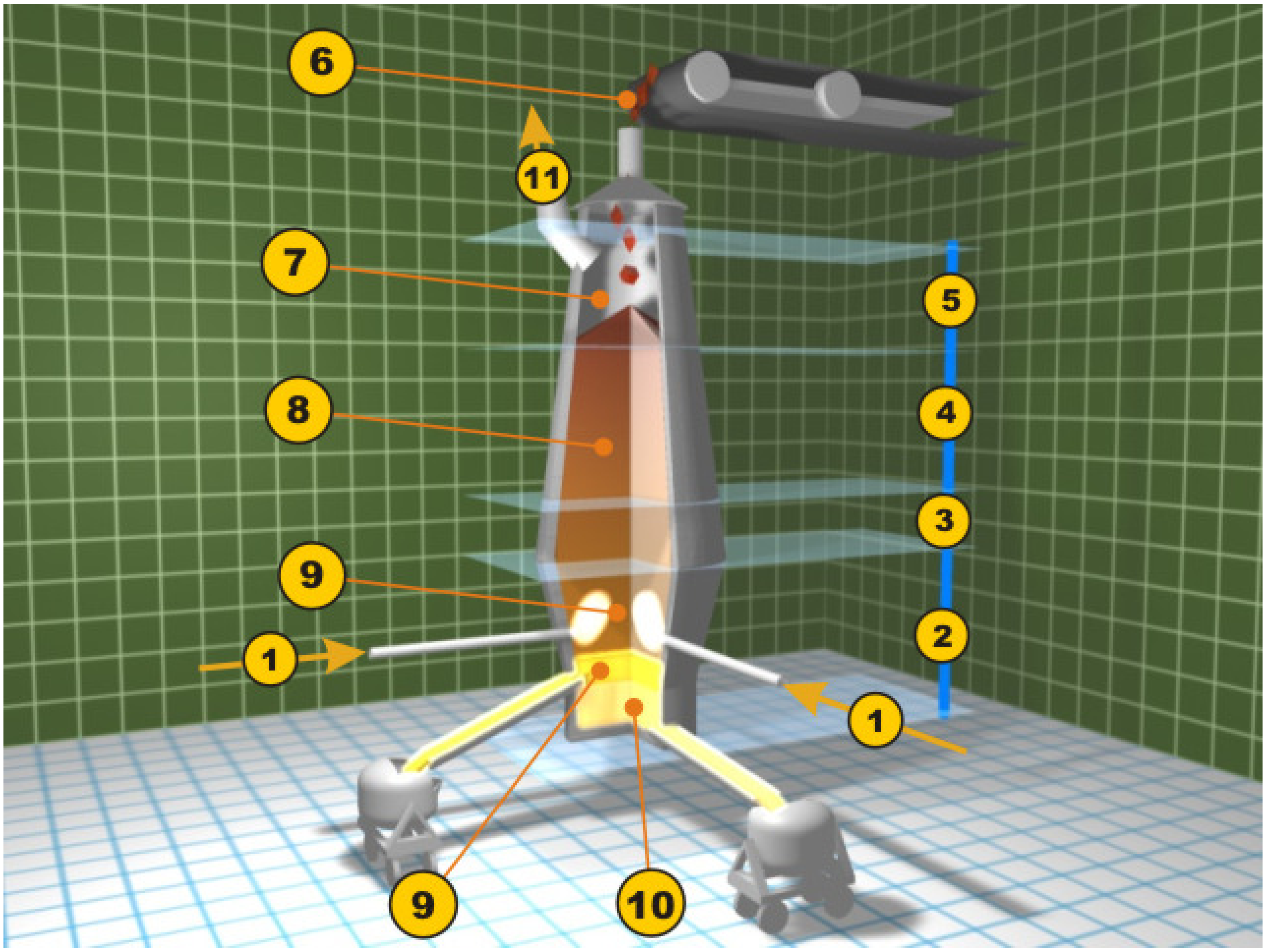
Cupola furnace

The cupola furnace is used in the production of cast iron. Cast iron is produced by melting pig iron with steel scrap or scrap iron. The amount of scrap varies on the grade of cast iron required. The preparation of the furnace is 1. A coke fire is lit at the base of the furnace, once hot enough layers of pig iron and steel scrap are added. Limestone is added to act as a flux in controlling the impurities in the melt. When sufficient iron is melted it is tapped off at the bottom into a ladle or directly into moulds.

The blast furnace

A blast furnace is a type of furnace for smelting iron ore. The combustion material and ore are supplied from the top while an air flow is supplied from the bottom of the chamber, so that the chemical reaction takes place throughout the ore, not only at the surface. This type of furnace is typically used for smelting iron ore to produce pig iron, the raw material for wrought and cast iron.

The blast furnace is to be distinguished from the bloomery in that the object of the blast furnace is to produce molten metal that can be tapped from the furnace, whereas the intention in the bloomery is to avoid it melting so that carbon does not become dissolved in the iron. Bloomeries were also artificially blown using bellows, but the term 'blast furnace' is normally reserved for furnaces where iron (or other metal) is refined from ore.

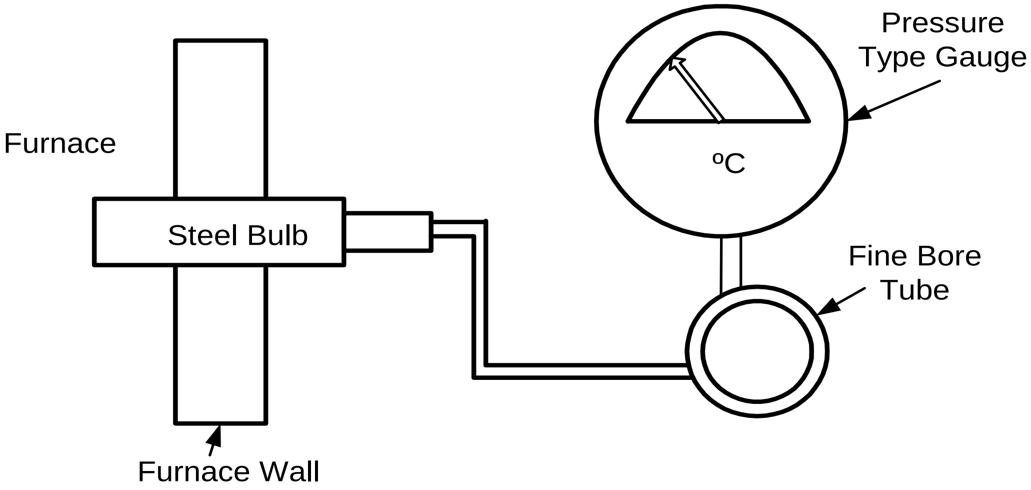


1. Hot blast from Cowper stoves
2. Melting zone
3. Reduction zone of ferrous oxide
4. Reduction zone of ferric oxide
5. Pre-heating zone
6. Feed of ore, limestone and coke
7. Exhaust gases
8. Column of ore, coke and limestone
9. Removal of slag
10. Tapping of molten pig iron
11. Collection of waste gases

Temperature Measurement

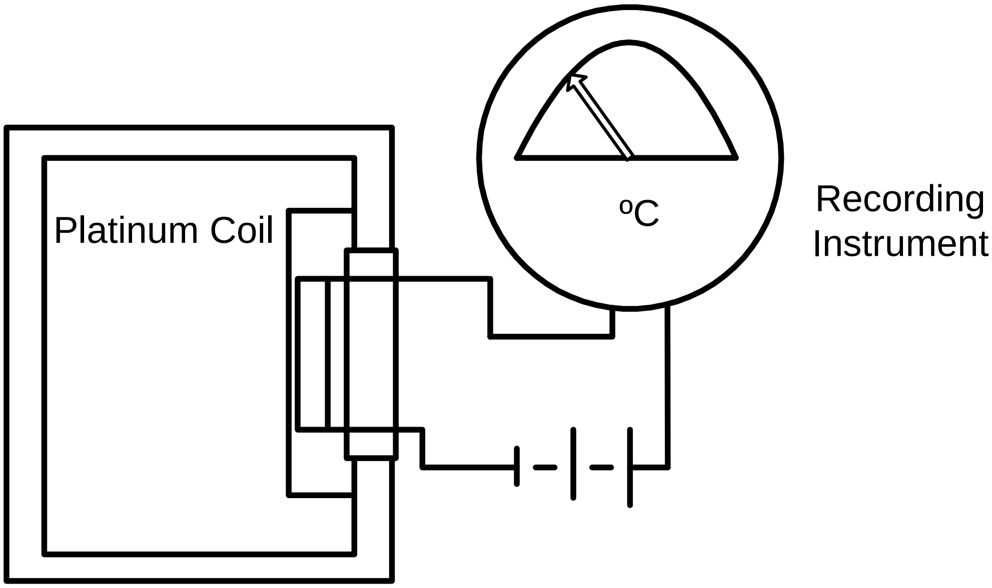
Mercury Thermometers

Mercury boils at 357ºC therefore temperatures above this mercury cannot be used. Mercury if handled incorrectly can be quite dangerous.



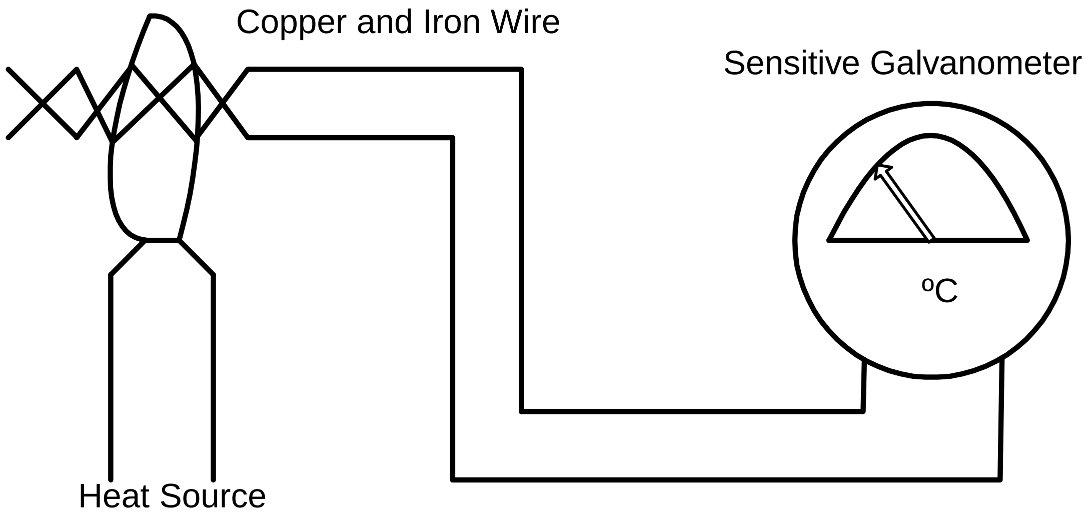
Electrical resistance thermometer

These thermometers operate on the principle that the resistance to the passage of an electrical current increases as the temperature of the conductor raises. A permanent record of the furnace is recorded.



Pyrometer

The pyrometer is an instrument which measures the temperature within the furnace. The junction between two dissimilar metal wires forming part of a closed circuit is heated, an electric current will be generated in the circuit.



Radiation Pyrometer:

The thermocouple is not in contact with the furnace atmosphere. The heat is reflected onto the thermocouple by a parabolic mirror. This is used to measure the temperature of a component, where a thermocouple might be damaged, inaccessible component, where a component in a furnace needs to be measured not the furnace temperature.

Optical Pyrometer:

The brightness of an electrical bulb is adjusted until it matches the brightness from the furnace. This is when the filament of the light bulb can no longer be seen. The brightness of the bulb is controlled by a variable resister. The temperature is read from an ammeter. It can only measure from 650ºC and up in a darkened room. It measures the temperature of a component and not the furnace.

Heat Treatment Processes

Hardening:

This is carried out in order that a component may be able to resist wear or to cut other metals such as in the case of a chisel. Hardening is usually carried out by heating the material to the correct temperature and then cooling rapidly. The correct temperature is carbon content dependant. The quenching medium is either oil or water. This sudden drop in temperature makes the material hard and brittle. The hardness depends on the speed of cooling. The material is usually plunges in vertically and then rotated. If using water it should be slighted heated it may cause cracking. When steel is heated it undergoes certain changes one of these is that it looses its magnetic property. This above method is used on steels between 0.3% and 1.3% carbon. Steels lower than 0.3% need to be hardened by a process called case hardening.

Case Hardening:

If steel with 0.2% of carbon is heated and quenched in a bath of water nothing will happen as the carbon content is missing. Therefore if carbon is added to the surface a hardened skin may be created (1.5mm thick).

The procedure is

1. Heat the steel to 850ºC place in a carbon rich compound (Kasenit). The surface can become 0.9% carbon in a few mins.
2. The skin is above 0.3% and can be quenched. A mottled appearance occurs if the component has “taken”.

Defects due to, overheating, cracking and distortion need to be planned against.

Gas Carburizing:

Gas carburizing uses the principle of carbon enrichment of the surface by immersing in a carbon rich atmosphere. The atmosphere is produced by either a gas or a liquid. The case depth depends on the temperature and time.

Nitriding:

Method of case hardening using ammonia (NH3), the steel must be hardened and tempered, and with the absorption of nitrogen and the formation of nitrides of molybdenum, aluminum and chromium in the case. The work temperature is 500ºC. the hardened skin builds 0.2mm per 20 hours, up to a depth of 0.8mm.

Advantages:

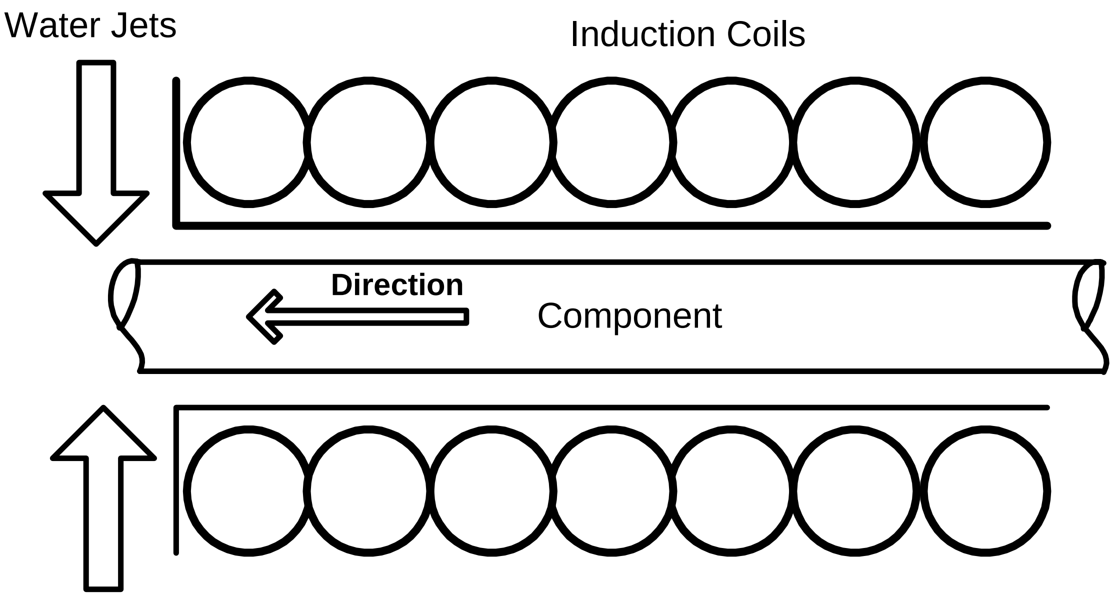
- Temperature below the critical range (no distortion)
- No quenching (no cracking)
- Case is extra hard

Carbo-Nitriding:

Both carbon and nitrogen are used to harden the steel. The temperature used is 800-900ºC. The hardened depth is twice as fast as normal Nitriding.

Induction Hardening

Method of heating hardenable steel to the hardening temperature and them quench it. This results in a hardened case and a soft core. By subjecting the metal to high frequency alternating currents in coils around the material and as steel has high thermal conductivity the raise in temperature can be instant. When quenched with jets of water the surface is hardened. Carbon content between 0.4% to 0.5% is best used.



Flame Hardening

Oxy-acetylene or some other high temperature flame is used to heat the work, the heat depth is more than the induction methods. Used for larger components hard to gauge but automation is possible, (i.e.) gear teeth.

Tempering:

This removes some of the brittleness caused by hardening and gives it a necessary toughness. Material that has been hardened should be polished to a bright finish. It is heated beyond the hardness line or below the lower critical temperature and the oxide colors are observed. Different temperatures produce different oxide colors. When the correct color is achieved the material is dipped in oil or water. The rate of cooling is not important. During tempering the highly strained distorted lattice of martensite breaks down.

Tempering chart

Straw	230ºC	Hammers, Scribers, Razor blades
Dark Straw	245ºC	Taps, dies, Drills
Brown	260ºC	Centre punch, centre drill
Purple	270ºC	Rivet snaps, wood chisels
Blue	295ºC	Springs, wood saws, rules

Annealing

This is the term given to the process of heating a metal or alloy to some pre-determined temperature below its melting point usually just below the upper critical limit and allowing it to cool slowly. Carbon shall absorb into the solid solution forming austenite. Annealing is controlling the conditions so that the metal becomes as close to equilibrium as possible. During cooling ferrite is produced with the remaining carbon diffusing into the remaining austenite. There is one exception to this rule copper may be heated to a dull red and cooled in water. Annealing is necessary because when metal is worked it becomes hard. Annealing removes work hardness and relives internal stresses.

Annealing Table

Copper	650-750ºC	Cool in water
Aluminum	500-550ºC	Smear with soap
Brass	Dull Red	In air
Steel	Heat slowly till bright red	Sand

Normalizing

This is a similar operation to annealing, however the steel is heated up above the upper critical line, where carbon goes to solution and austenite is formed. Cooled in air does not allow complete carbon diffusion, therefore small crystals of ferrite appear, a finer crystal structure is produced. The hardness and toughness of the steel is increased.

Quenching

In quenching steel the cooling occurs so fast that the carbon is prevented from diffusing and allowing ferrite to form and the carbon atoms are held in solid solution. An unstable lattice structure known as Martensite is formed; this is intensely hard and brittle.

Age-Hardening

Dr. Wilm (German). An aluminum alloy containing 3.5% copper and 0.5% magnesium hardens after 5 days. The process or mechanism of age hardening was not understood till long after its use in aircraft and pistons, engine blocks. There is no visible difference in microstructure, when aluminum and copper are heated to 500ºC the copper becomes a solid solution alloy. If a temperature of 100ºC is maintained copper atoms move along to form together and create an area of higher concentration. This concentration takes place along slip planes therefore hardening the microstructure reducing the slip plane numbers.

Work-Hardening

When a material is deformed, plastic flow occurs. This changes the structure of the metal causing it to become stronger. If the material is worked in the cold under the lower critical point the structure will harden and become less ductile. The process is reversed by annealing this treatment creates re-crystallization and removes the undesirable qualities.

Metals

<u>Ferrous Metals:</u> Are metals containing Iron as the main constituent. They are magnetic and they rust.

Wrought Iron: is easily forged and welded, it is ductile and bend easily when cold, its uses vary from chains to crane hooks.

Cast Iron: Pig Iron is refined into cast iron in a furnace called a cupola. This is operated for short periods of about 3-6 hours. Cast Iron contains 2-4ºC Carbon.
Advantages: (i) cheap, (ii) easily machined, (iii) Cast into intricate shapes, (iv) absorbs vibrations, (v) graphite acts as a lubricant.
Uses: Machine beds, fire grates, manhole covers

Carbon Steels: Carbon content varying from 0.1% - 1.5%. Important to note that the carbon and iron exist in a chemical combination. In other words there is just enough carbon to form the compound. If more carbon above 1.5% was added carbon will exist in a free state as in cast iron.

Dead Mild Steel: this is very ductile and suitable for jobs that have to be pressed, motor car bodies, the carbon content is 0.1%-0.15%.

Mild Steel: this a general purpose steel, it is soft and ductile and can be forged or drawn in either hot or cold conditions. Easily machined it cannot be hardened by heating and quenching but it can be case hardened. Carbon content 0.15%-0.3%.

Medium Carbon Steel: it is harder and tougher than mild steel. It can be hardened by quenching. It carbon content is usually between 0.3%-0.8%, used for cold chisels and crankshaft forgings.

High Carbon Steel: It is much harder and less ductile and slightly less tough than medium carbon steel, can be forged between 700ºC-900ºC. Can be hardened by heating and quenching. Oil as the quenching medium to prevent distortion. Also known as Cast steel as its carbon content is 0.8%-1.4%. Used for wood chisels, drills taps, dies.

Alloys

An alloy is a mixture of two or more metals, or a metal with a non-metallic element (carbon).

Brass: is an alloy of copper and zinc.

Brazing brass: is 75% copper and 25% zinc and has a high melting point.

Spelter brass: is 50% copper and 50% zinc, low melting point and is used to join copper in brazing.

Bronze: is an alloy of copper and tin. It is used for coinage and for making statues.

Phosphor Bronze: is an alloy of copper, zinc and phosphorous, it used for sand casting, tubes and bearing bushes.

Solder: is an alloy of Lead and Tin used to unite metals.

Gilding metal: is an alloy of 90% copper and 10% Zinc. Similar to copper and is used for bowls, jugs and jewellery.

Duralumin: is an aluminum alloy containing 4.5% copper and 0.5% manganese, and 95% aluminum. It age hardens and must be annealed; its uses vary from aircraft to tubing.

Copper: is a pure metal, reddish brown, malleable, ductile with a high metallic lustre. Copper may work harden and may be softened by annealing, great conductor of heat and electricity. Copper is the base alloy for many metals. Melting point of 1080ºC, SP 8.95 and chemical symbol Cu.

Lead: is a pure metal, blue grey in colour; lead is 4 times heavier than aluminum. It is malleable and corrosion resistant. Used in acid storage tanks and water piping, and flashing. It has a melting point of 327ºC, SG 11.36 and its chemical symbol is Pb.

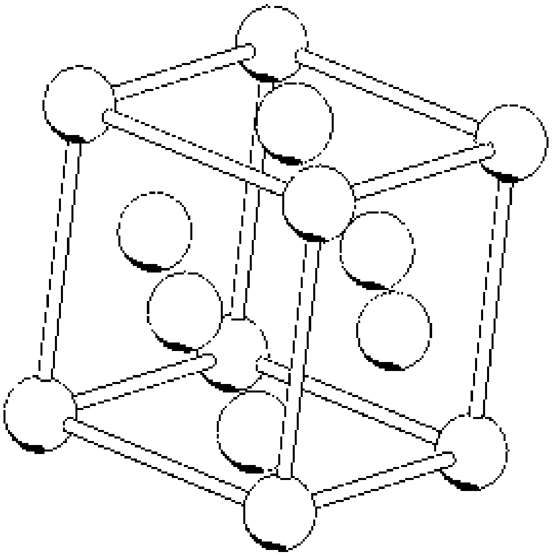
Tin: is a pure metal, bright, silvery with a yellow tingle. It is non-toxic and is used as a coating on various different metals. Melting point of 232ºC, SG of 7.29 and chemical symbol Sn.

Zinc: is a pure metal, bluish white in colour, hard and brittle at low temperature. Zinc is used as a coating on mild steel to form galvanized iron. Used as an alloy in the making of brass. Zinc alloys are used in die castings, the chemical industry make zinc chloride which is a soft solder flux. Melting point 419ºC and SG 7.14 and chemical symbol Zn.

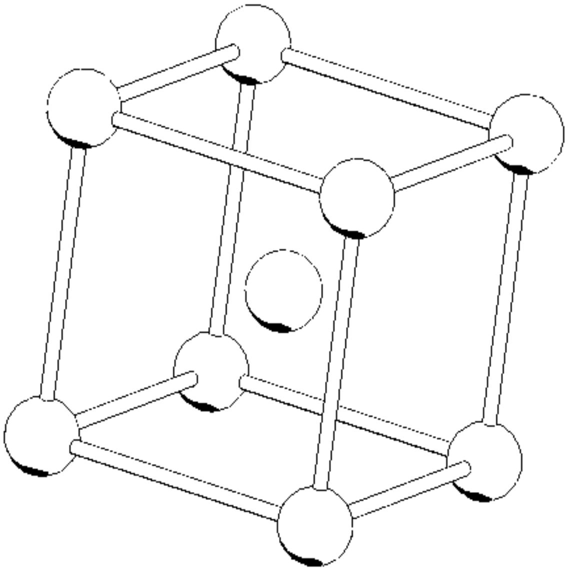
Aluminum: found on the earths crust in ore form called Bauxite. Aluminum is produced by electrical means from Alumina. Aluminum is a pure metal, bluish white in colour and is malleable and ductile. It is a good conductor of electricity and is used for electric cables. Recognized by its lightness in weight! Aluminum cannot be soldered but it can be brazed or welded. Its melting point is 660ºC and SG 2.7 and chemical symbol of Al.

Crystals in metals

Metals are crystalline in structure similar to common salt. Atoms are arranged in a certain order known as a space lattice. The unit cells that exist are the Face Centered Cubic and Body Centered Cubic. These cells can be seen below. Iron can exist in either of these microstructures depending on the conditions, this is known as allotropy. The body centered is known as alpha iron (ferrite) at room temperatures. The Face Centered Cubic structure is stable at high temperatures and is known as gamma iron or austenite.



Face Centered Cubic



Body Centered Cubic