CHAPTER TWO

CAST IRON

2.1 INTRODUCTION

What is cast iron? The term cast iron, like the term steel, identifies à large family of ferrous alloys. Cast irons are Multi component ferrous alloys. They contain major (iron, carbon, silicon), minor (<0.01%), and often alloying (>0.01%) elements. All cast irons contain more than 2% carbon and an appreciable amount of silicon (usually 1-3%).

Cast iron has higher carbon and silicon contents than steel. The high carbon and silicon content means that they are easily melted have good fluidity in the liquid state and have excellent pouring properties. Because of the higher carbon content, the structure of cast iron, as opposed to that of steel, exhibits a rich carbon phase.

2.2 PRODUCTION OF CAST IRON

2.2.1 IRON ORES

Iron occurs mainly as oxide ores, though it is also found in smaller quantities as its sulfide and carbonate. These other ores are usually first roasted to convert them into the oxide. On a world scale the most important ore is hematite (Fe_2O_3), but in New Zealand the starting materials are magnetite (Fe_3O_4) and titanomagnetite (Fe_2TiO_4).

Table 1 Common Iron Ores [1]

Mineralogical name	Chemical formula	Chemical composition	Class
Magnetite	Fe_3O_4	72.36% Fe, 27.64% O_2	Oxide
Hematite	Fe_2O_3	69.94% Fe, 30.06% O_2	Oxide
Ilmenite	$FeTiO_3$	36.80% Fe, 31.63% O_2, 31.57% Ti	Oxide
Limonite	$HFeO_2$ FeO(OH)	62.85% Fe, 27.01% O_2, 10.14% H_2O	Oxide
Pyrite	FeS_2	46.55% Fe, 53.45% S	Sulfide
Siderite	$FeCO_3$	48.20% Fe, 37.99% CO_2, 13.81% O_2	Carbonate

2.2.2 Raw materials: Concentrated iron ore, Coke, Blast of hot air and Flux.

2.2.3 METALLURGY OF IRON BY BLAST FURNACE

Blast furnace: is a furnace in which combustion is intensified by a blast of air, especially a furnace for smelting iron by blowing air through a hot mixture of ore, coke, and flux. The typical height of a blast furnace is 20 – 30 m with a diameter of 15 m. The wall-thickness ranges from 0.5 m to 1.2 m. The load capacity is 300 – 1000 m^3.Modern blast furnaces can produce up to 11.000 metric tons of iron per day. Due to the high temperatures and the reducing atmosphere carbon products are used for the coating of the inner walls of the blast furnaces. The life time of the inner walls is about 10 years. After this period the furnace has to be coated again completely.

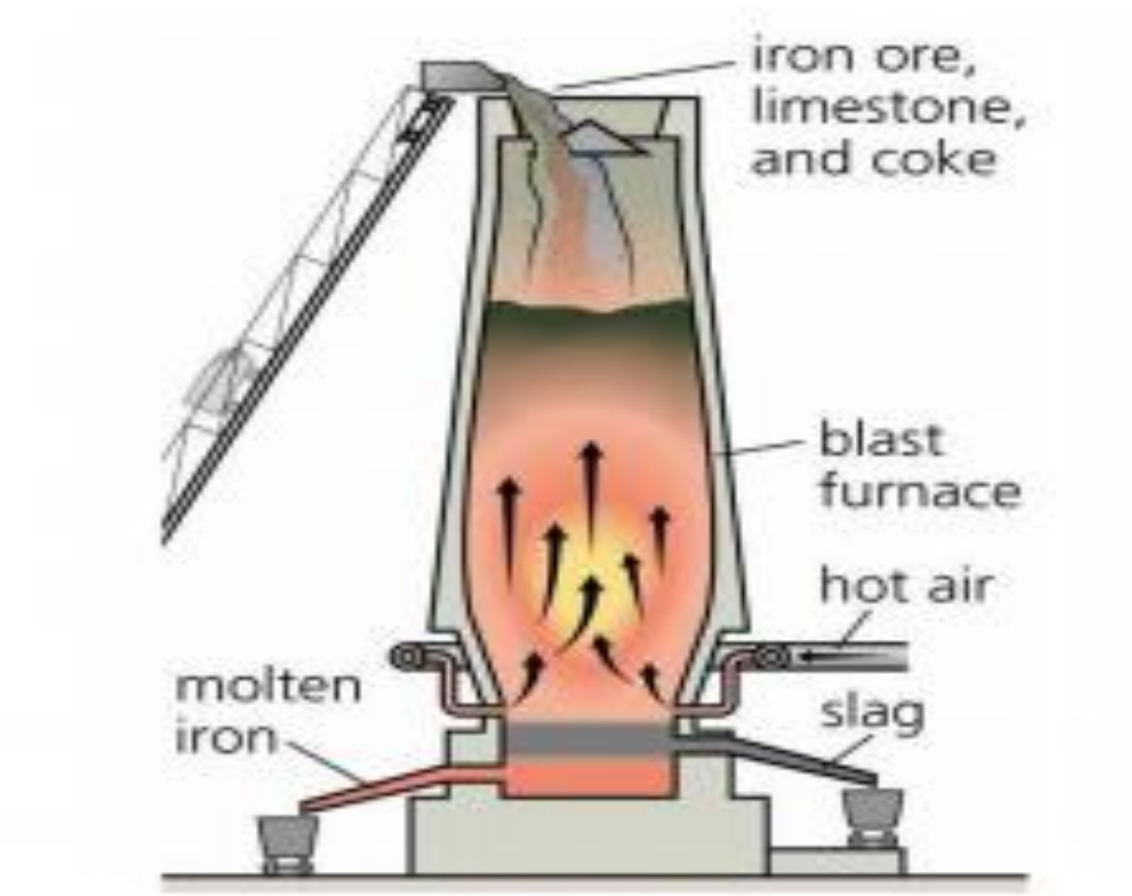


Figure 2.1: Blast furnace

Reactions taking place in the Blast furnace:-

- **Combustion of Coke:**

$$C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)} + \text{heat}$$

$$CO_{2\,(g)} + C_{(s)} \rightarrow 2CO_{(g)}$$

- **Reduction of Fe_2O_3:**

In a blast furnace iron is produced by the reduction of iron-ore by coke at high temperatures up to 1900°C:

$$2Fe_2O_{3(s)} + 3C_{(s)} \rightarrow 4Fe_{(l)} + 3CO_{2\,(g)}$$

$$Fe_2O_{3(s)} + 3CO_{(g)} \rightarrow 4Fe_{(l)} + 3CO_{2\,(g)}$$

- **Calcination:**

$$CaCO_{3(s)} + \text{heat} \rightarrow CaO_{(s)} + CO_{2\,(g)}$$

- **Slag formation:**

$$CaO_{(s)} + SiO_{2(s)} \rightarrow CaSiO_{3\,(l)} \text{ (slag)}$$

$$CaO_{(s)} + Al_2O_{3(s)} \rightarrow Ca(AlO_2)_{2(l)}$$

STAGES IN THE BLAST FURNACE:-

1. A blast furnace forces in extremely hot air through a mixture of ore, coke, and limestone, called the charge.

2. Carts called skips dump the charge into the top of the furnace, where it filters down through bell-shaped containers called hoppers.

3. Once in the furnace, the charge is subjected to air blasts that may be as hot as 870° C (1600° F).

4. The waste metal, called slag, floats on top of the molten pig iron. Both of these substances are drained, or tapped, periodically for further processing.

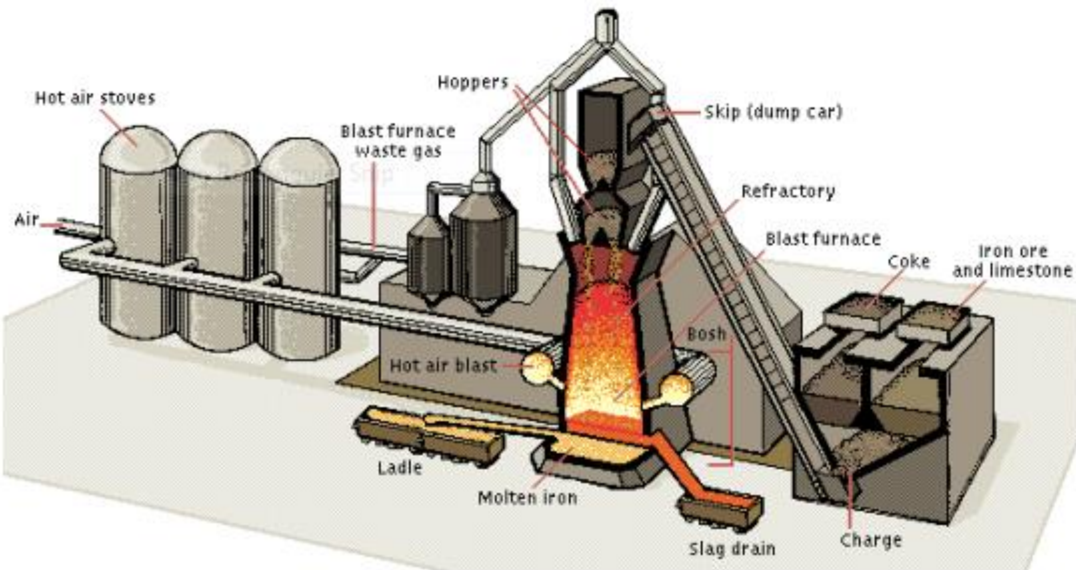


Figure 2.2: Iron blast furnance

Products of the Blast furnace:-

- **Pig iron** : 93-95% Fe, 3-5% C, 1% Si, 0.1- 0.3% P, <1% S
- **Waste gases** : CO_2 and CO
- **Slag** : $CaSiO_3$ and $Ca(AlO_2)_2$

The molten iron and slag **collect** in the hearth at the base of the furnace. The by-product gas is collected through off takes located at the top of the furnace and is recovered for use as fuel.

The molten iron and slag are **removed**, or cast, from the furnace periodically.

The blast furnace by-product gas, which is collected from the furnace top, contains **CO** and **particulate.** Because of its high CO content, this blast furnace gas has a low heating value and is used as a fuel within the steel plant.

2.3 CLASSIFICATION OF CAST IRON

The basic types of cast iron are best differentiated by their microstructure as opposed to their chemical analysis because the various types overlap.

1. GREY CAST IRON

Grey cast iron is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used cast iron and the most widely used cast material based on weight. Grey cast iron has less tensile strength and shock resistance than steel, but its compressive strength is comparable to low and medium carbon steel.

Generally the Properties of gray cast iron are:

- Carbon exceeds the amount that can dissolve in austenite and precipitate as graphite flakes.
- Fractured surface appears gray.
- Excellent machinability, hardness and wear resistance, and vibration damping capacity.
- 2.5 – 4% C and 1 – 3% Si (Promotes formation of graphite).
- Weak & brittle under tension and stronger under compression

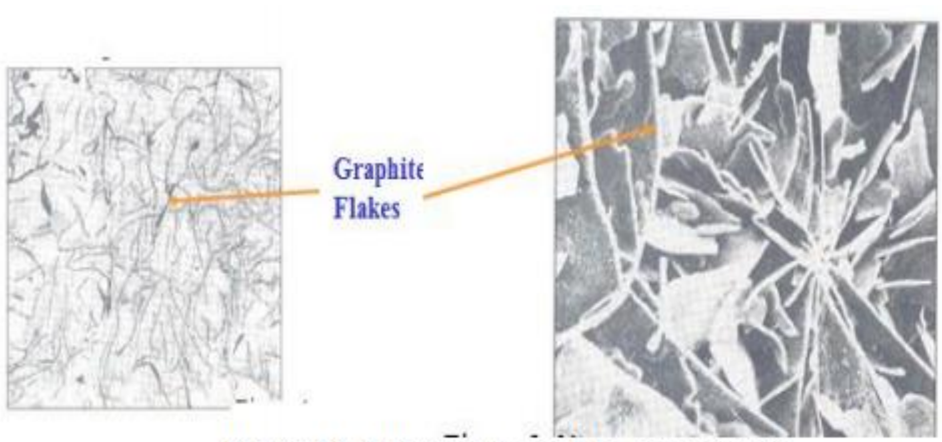


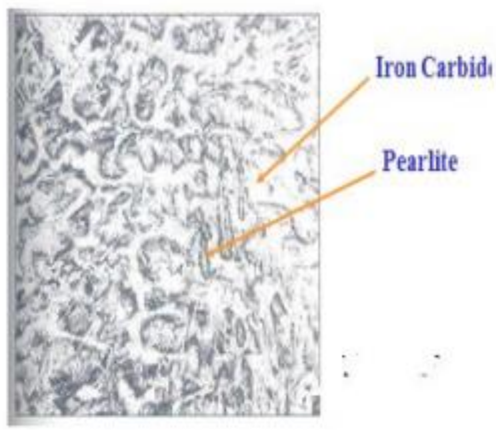
Figure 2.3: Microstructure of the gray cast iron

2. White cast iron

It is the cast iron that displays white fractured surface due to the presence of cementite. With a lower silicon content (graphitizing agent) and faster cooling rate, the carbon in white cast iron precipitates out of the melt as the metastable phase cementite, Fe3C, rather than graphite. The cementite which precipitates from the melt forms as relatively large particles, usually in a eutectic mixture, where the other phase is austenite (which on cooling might transform to marten site). White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenous grinding mills, balls and rings in coal pulverizes, and the teeth of a backhoe's digging bucket (although cast medium-carbon martensitic steel is more common for this application). The carbon is on the surface of ferrites with small fraction and is in the form of Fe3C, the section of white cast iron is in sliver white color, its features is hard and fragile, it is difficult to be processed with machine and little used to produce parts. The main usage: it is used as the raw materials to make steel, also can be deal to malleable irons.

Generally the properties of white cast iron are:

- Much of Carbon forms Iron Carbide instead of graphite up on solidification.
- Fractured surface appears white and crystalline.
- Low carbon (2.5 – 3%) and silicon (0.5 – 1.5%) content.
- Excellent wear resistance.



3. Malleable cast iron

Malleable iron starts as a white iron casting that is then heat treated at about 900 °C (1,650 °F). Graphite separates out much more slowly in this case, so that surface tension has time to form it into spheroidal particles rather than flakes. Due to their lower aspect ratio, spheroids are relatively short and far from one another, and have a lower cross section vis-a-vis a propagating crack or phonon. They also have blunt boundaries, as opposed to flakes, which alleviates the stress concentration problems faced by grey cast iron.

Properties of malleable cast iron:

- 2-2.6 % C and 1.1 – 1.6% Si.
- White cast iron is heated in malleablizing furnace to dislocate carbide into graphite.
- Irregular nodules of graphite are formed.
- Good castability, machinability, moderate strength, toughness and uniformity.

4. Ductile cast iron/ Nodular cast iron

A more recent development is nodular or ductile cast iron. Tiny amounts of magnesium or cerium added to these alloys slow down the growth of graphite precipitates by bonding to the edges of the graphite planes. Along with careful control of other elements and timing, this allows the carbon to separate as spheroidal particles as the material solidifies. The properties are similar to malleable iron, but parts can be cast with larger sections.

Ductile iron is also called as spheroidal graphite cast iron or sg iron. Because of the nodular agent, the graphite form is shown as the spheroidal, so this iron will have larger elongation and higher tensile and yield strength.

Properties of ductile cast iron:

- ✓ Have processing advantages of cast iron and engineering advantages of steel.
- ✓ Good fluidity, castability, machinability, and wear resistance.
- ✓ High strength, toughness, ductility and hardenability
- ✓ 3-4% C and 1.8 – 2.8 % Si and low impurities.
- ✓ Bull's eye type microstructure.

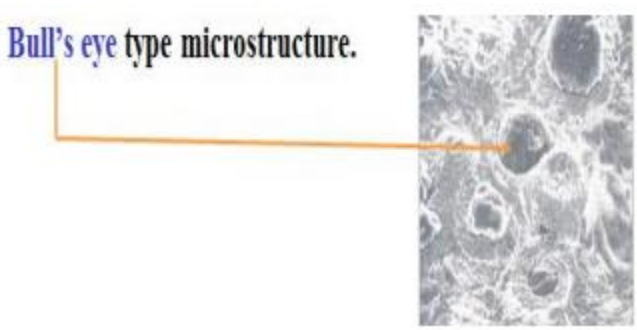


Table2.2: Comparative qualities of cast irons

Element	Gray iron, %	Malleable iron, %	White iron, %	Nodular iron, %
Carbon	2.5-4.0	2.00-2.60	1.8-3.6	3.0-4.0
Silicon	1.0-3.0	1.10-1.60	0.5-1.9	1.8-2.8
Manganese	0.25-1.0	0.20-1.00	0.25-0.80	0.10-1.00
Sulfur	0.02-0.25	0.04-0.18	0.06-0.20	0.03 max
Phosphorous	0.05-1.0	0.18 max	0.06-0.18	0.10 max

The factors which affect the micro-structure and property:-

1. The contents of carbon When C=0.8%, it is pearlitic grey iron, the graphite piece is small and intensity is high, so it used to produce important parts. When C<0.8% they are pearlites and ferrite gray pig iron they have high hardness and the property is good, so it suits to the common machine parts.

2. The degree of graphitization

The chemical component of cast irons, the cooling speed of cast irons crystallizes, the

Super heating of iron water and quiescence in high temperature all affect the graphitization.

5. ALLOY CAST IRON

Alloy cast iron - cast iron containing alloying elements (usually nickel or chromium or copper or molybdenum) to increase the strength or facilitate heat treatment alloy iron. Cast iron also can be alloyed with other metals to impart desirable characteristics impossible to achieve with cast iron alone, according to Machine Design. Cast iron typically is alloyed with chromium and/or nickel with anywhere from 3 percent to 30 percent or more of the alloying metal. For instance, high chromium iron (up to 16 percent) combines wear resistance and corrosion resistance. High-nickel iron (over 35 percent) is dimensionally stable under high heat, nonmagnetic and very rust resistant.

5.1 High-Alloy White Irons

High-alloy white cast irons are an important group of materials whose production must be considered separately from that of ordinary types of cast irons. In these cast iron alloys, the alloy content is well above 4%, and consequently they cannot be produced by ladle additions to irons of otherwise standard compositions. They are usually produced in foundries specially equipped to produce highly alloyed irons. The high-alloy white irons are primarily used for abrasion-resistant applications and are readily cast into the parts needed in machinery for crushing, grinding, and handling of abrasive materials. The chromium content of high-alloy white irons also enhances their corrosion-resistant properties. The large volume fraction of primary and/or eutectic carbides in their microstructures provides the high hardness needed for crushing and grinding other materials. The metallic matrix supporting the carbide phase in these irons can be adjusted by alloy content and heat treatment to develop the proper balance between the resistance to abrasion and the toughness needed to withstand repeated impact.

The high-alloy white cast irons fall into two major groups:

I. Nickel-chromium white irons, which are low-chromium alloys containing 3 to 5% Ni and 1 to 4% Cr, with one alloy modification that contains 7 to 11% Cr,

II. Chromium-molybdenum irons containing 11 to 23% Cr, up to 3% Mo and often additionally alloyed with nickel or copper.

a. High-Chromium White Irons

The high-chromium white irons have excellent abrasion resistance and are used effectively in slurry pumps, brick molds, coal-grinding mills, shot-blasting equipment, and components for quarrying, hard-rock mining, and milling. In some applications they must also be able to withstand heavy impact loading. These alloyed white irons are recognized as providing the best combination of toughness and abrasion resistance attainable among the white cast irons.

b. Nickel-Chromium White Irons

The oldest groups of high-alloy irons of industrial importance, the nickel-chromium white irons, or Ni-Hard irons, have been produced for more than 50 years and are very cost-effective materials for crushing and grinding. Chromium is included in these alloys, at levels from 1.4 to 4%, to ensure that the irons solidify carbidic, that is, to counteract the graphitizing effect of nickel. The optimum composition of a nickel-chromium white iron alloy depends on the properties required for the service conditions and the dimensions and weight of the casting.

2.6 HEAT TREATMENT OF CAST IRON

The most common heat treatments applied to gray cast irons are stress relief because of non-uniform cooling of castings and annealing to improve machinability. Stress relief is done at temperatures between 1020 and 1200˚F (550 and 650˚C) without significantly lowering strength and hardness. Heating at temperatures between 1290 and 1400˚F (700 and 760˚C) lowers the hardness for improved machinability. Heat treatment of ductile cast iron includes stress relief and annealing, as well as heat treatments used for steels including normalize and temper (for higher strength and wear-resistance), quench and temper (for the highest strength), and austempering. Ferritizing (for the most ductile microstructure) is done by austenitizing at 1650˚F (900˚C), followed by holding at 1290˚F (700˚C) to completely transform austenite to ferrite and graphite. Malleable iron is obtained by the heat treatment of white iron so the hard iron carbide structure of ledeburite is converted to a matrix of ferrite or pearlite and graphite is precipitated within the iron.

2.7 APPLICATION OF CAST IRON

Cast iron is an important engineering material with a number of advantages, mainly good castability and machinability and moderate mechanical properties. Because of its economical advantages cast iron is used for many applications in the automotive and engineering industry. In addition, specific cast irons are the material of choice for sea water Pump housings, rolling mill rolls and parts for earth moving equipment. Cast iron is a material used to manufacture various items found in the home and in the construction of buildings and other structures. Cast iron is an alloy, a blend of the elements iron, carbon and silicon. It is used for producing items because of its durability and strength.

Gray cast iron is used in industry for engine blocks, light-duty gears, flywheels, brake discs or drums, and machine bases. Its ability to dampen vibration makes it valuable for precision machinery. It's also found in the home in items such as cookware, ornamental objects and toys. Ductile cast iron is used for engine crankshafts, heavy-duty gears and auto door hinges. White iron is used for applications requiring abrasion resistance, such as railroad brake shoes, mill liners and sandblasting or shot-blasting equipment. Malleable iron castings are used for bearing surfaces in trucks, construction equipment, railroad rolling stock and other extreme-wear service. Malleable cast iron parts are commonly used in machine construction, typically in the paper, printing and agricultural industries, where the material is used to make oil, cooling and lubrication pipes. In the automotive industry malleable cast iron parts are used for cylinder blocks and heads as well as gearbox cases. The material is particularly effective for producing large scale parts in commercial vehicles. Malleable cast iron parts are also used in the railway industry, particularly for railroad track construction and carriage joining mechanisms. Here, the material's ability to resist rust (oxidization) makes it well suited for heavy-duty use and exposure to extreme weather conditions. However, malleable cast iron's use in the transport industry is in decline as more cost-effective, durable materials are being developed.