Chapter 4

Cast Irons

Generically, cast irons are a class of ferrous alloys with carbon contents above 2.14 wt%; in practice, however, most cast irons contain between 3.0 and 4.5 wt% C and, in addition, other alloying elements. In addition to carbon, cast iron contains other elements such as silicon, sulphur, phosphorus and manganese. The iron–iron carbide phase diagram below reveals that alloys within this composition range become completely liquid at temperatures between approximately 1150 and 1300^{0}C, which is considerably lower than for steels. Thus, they are easily melted and amenable to casting. Furthermore, some cast irons are very brittle, and casting is the most convenient fabrication technique. Cementite (Fe_3C) is a metastable compound, and under some circumstances it can be made to dissociate or decompose to form ferrite and graphite, according to the reaction;

$$Fe_3C \rightarrow 3Fe\ (\alpha) + C\ (\text{graphite})$$

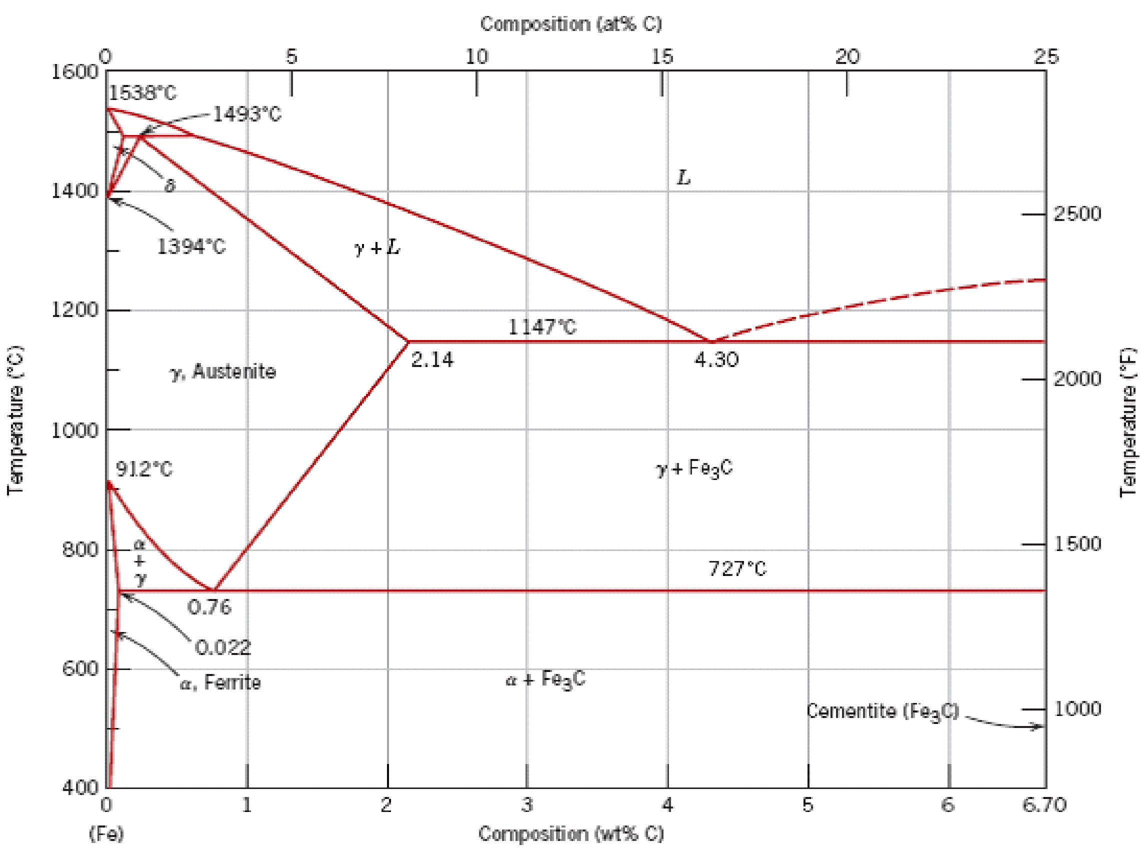
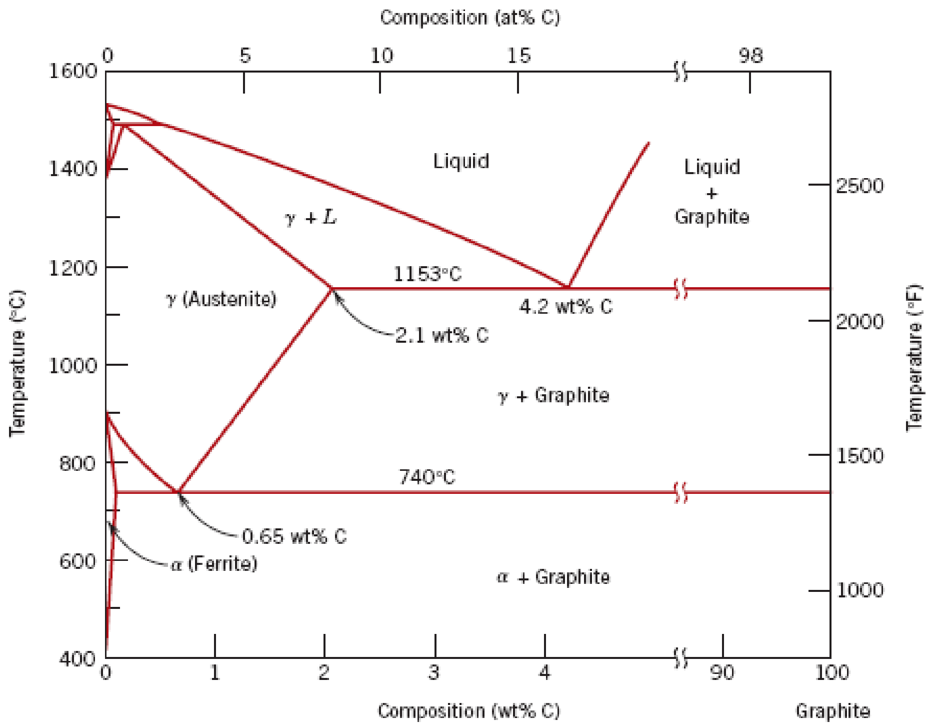


Figure: 4.1 (a) The Iron- Iron carbide phase diagram



(b)

Figure: 4.1 (b) The true equilibrium iron–carbon phase diagram with graphite instead of cementite as a stable phase.

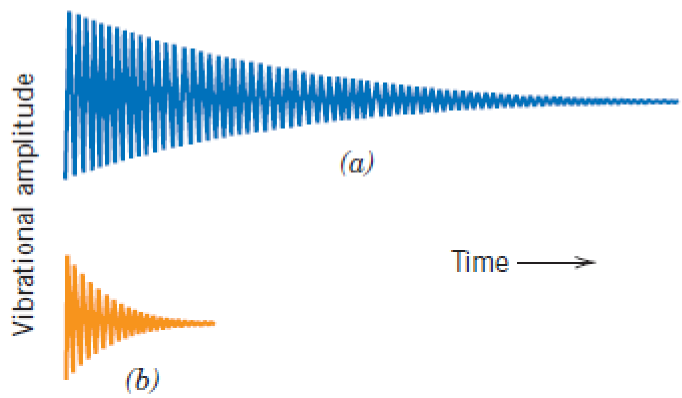
The two diagrams shown above (a and b) are virtually identical on the iron-rich side (e.g., eutectic and eutectoid temperatures for the $Fe–Fe_3C$ system are 1147 and 727^0C respectively, as compared to 1153 and 740^0C for Fe–C); however, Figure b above extends to 100 wt% carbon such that graphite is the carbon rich phase, instead of cementite at 6.7 wt% C (Figure b above).

This tendency to form graphite is regulated by the composition and rate of cooling. Graphite formation is promoted by the presence of silicon in concentrations greater than about 1 wt%. Also, slower cooling rates during solidification favor graphitization (the formation of graphite). For most cast irons, the carbon exists as graphite, and both microstructure and mechanical behavior depend on composition and heat treatment.

Advantages of Cast- Iron over steel

1. It is least expensive casting material. All the raw materials used are relatively cheap—pig iron, cast iron scrap, steel scrap, lime stone, coke , and Iron ore.
2. Cast iron has lower melting temperature (1140 to 1200^0C) than steel (1380- 1500^0C).

3. It possesses high casting properties such as, high fluidity, low shrinkage, casting soundness, ease of production, and a higher yield.
4. Cast irons can provide a very wide range of metallic properties ranging from a high yield strength to high ductility and toughness.
5. They possess a very high compressive strength, about 3 t0 4 times that of its tensile strength.
6. Cast irons can be machined easily.
7. They provide high wear and abrsion resistance.
8. An important characterstic of cast iron is its high damping capacity. It is that property which permits a material to absorb vibrational stresses. The relative damping capacity of



steel, nodular iron and gray iron.

Figure: Comparison of the relative vibrational damping capacities of (a) steel and (b) gray cast iron.

Production of Cast Iron

Cast iron is produced by remelting pig iron in any one of the following furnaces:

1. An electric or air furnace. It gives higher quality cast iron.
2. Duplex melting method using cupola furnace for melting and air or electric furnace for refining.
3. Melting in a cupola furnace.

In addition to carbon, cast iron contains other elements such as silicon, sulphur, phosphorus and manganese.

Silicon is one of the most important elements present in cast iron. It controls the form of carbon present in cast iron. Amount of silicon varies from 0.5 to 3.0 percent.

Sulphur content in cast iron generally varies between 0.06 to 0.12 percent. Sulphur tends to react with iron to form iron sulphide (FeS). This low melting compound increases the possibility of cracking at elevated temperatures, called hot shortness. Formation of iron sulphide can be avoided by the addition of manganese because of its greater affinity for sulphur.

Phosphorus content in cast irons varies between 0.1 to 0.3 percent. It comes from pig iron and iron ore. Most of the phosphorus combines with iron to form iron phosphide (Fe_3P). The formation of iron phosphide reduces toughness and makes the cast iron brittle. Phosphorus increases the fluidity of cast irons.

Manganese in cast iron varies from 0.1 to 1.0 percent. This amount of manganese has very little effect upon the properties of cast iron. The most important function of manganese is to take care of sulphur by forming manganese sulphide.

In addition to above elements, cast irons may contain alloying elements such as nickel, chromium, molybdenum, magnesium, copper, and vanadium to get the desired properties and structure.

On the basis of structure, cast irons have been classified into various groups such as:

i) gray cast iron
ii) Ductile cast iron
iii) White cast iron
iv) Malleable cast iron
v) Compacted graphite cast iron
vi) Alloy cast irons

Gray Iron

The carbon and silicon contents of gray cast irons vary between 2.5 and 4.0 wt%and 1.0 and 3.0 wt%, respectively. For most of these cast irons, the graphite exists in the form of flakes (similar to corn flakes), which are normally surrounded by a α-ferrite or pearlite matrix. Because of these graphite flakes, a fractured surface takes on a gray appearance, hence its name. Mechanically, gray iron is comparatively weak and brittle in tension as a consequence of its microstructure; the tips of the graphite flakes are sharp and pointed, and may serve as points of stress concentration when an external tensile stress is applied. Strength and ductility are much higher under compressive loads. Gray irons do have some desirable characteristics and, in fact, are utilized extensively.They are very effective in damping vibrational energy; which compares the relative damping capacities of steel and gray iron. Base structures for machines and heavy equipment that are exposed to vibrations are frequently constructed of this material. In addition, gray irons exhibit a high resistance to wear. Furthermore, in the molten state they have a high fluidity at casting temperature, which permits casting pieces having intricate shapes; also, casting shrinkage is low. Finally, and perhaps most important, gray cast irons are among the least expensive of all metallic materials.

Figure :4.2 Gray iron: the dark graphite flakes are embedded in an -ferrite matrix

Ductile (or Nodular) Iron

When the microstructure of cast iron consists of nodules or spheroids of graphite in pearlitic or ferritic matrix, the resulting material is called nodular cast iron. It consists of the product advantages of steel and process advantages of cast iron. Adding a small amount of magnesium and/or cerium to the gray iron before casting produces a distinctly different microstructure and set of mechanical properties. Graphite still forms, but as nodules or sphere-like particles instead of flakes. The resulting alloy is called nodular or ductile iron. The matrix phase surrounding these particles is either pearlite or ferrite, depending on heat treatment; it is normally pearlite for an as-cast piece. However, a heat treatment for several hours at about 700^0C will yield a ferrite matrix. Castings are stronger and much more ductile than gray iron, as a comparison of their mechanical properties. In fact, ductile iron has mechanical characteristics approaching those of steel. For example, ferritic ductile irons have tensile strengths ranging between 380 and 480 MPa (55,000 and 70,000 psi), and ductilities (as percent elongation) from 10% to 20%. Typical applications for this material inclwude valves, pump bodies, crankshafts, gears, and other automotive and machine components.

Figure: 4.3 Nodular (ductile) iron: the dark graphite nodules are surrounded by a ferrite matrix.

White Iron and Malleable Iron

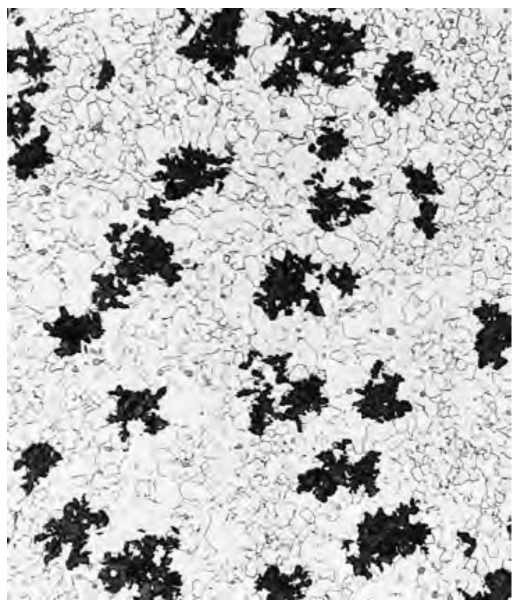
When carbon in the cast iron is present in the form of cementite, it is called white cast iron because it shows a white fractured surface. Microstructure of such a cast iron consists of pearlite, cementite and ledeburite.

White cast iron is obtained by controlling the chemical composition and the cooling rate. Lower silicon content and rapid cooling of the liquid alloy produce white cast iron because cementite is prevented from decomposing to graphite.

Due to the presence of cementite, white cast iron has high hardness and wear resistance. Depending the up on the carbon content the hardness can vary from 350 to 500 BHN. It possesses high compressive strength of the order of 140 to 180 kg/mm^2.

Thick sections may have only a surface layer of white iron that was “chilled” during the casting process; gray iron forms at interior regions, which cool more slowly. As a consequence of large amounts of the cementite phase, white iron is extremely hard but also very brittle, to the point of being virtually unmachinable. Its use is limited to applications that necessitate a very hard and wear-resistant surface, without a high degree of ductility—for example, as rollers in rolling mills. Generally, white iron is used as an intermediary in the production of yet another cast iron, malleable iron. Heating white iron at temperatures between 800 and900^0C for a prolonged time period and in a neutral atmosphere (to prevent oxidation) causes a decomposition of the cementite, forming graphite, which exists in the form of clusters surrounded by a ferrite or pearlite matrix, depending on cooling rate. The microstructure is similar to that for nodular iron, which accounts for relatively high strength and appreciable ductility or malleability. Representative applications include connecting rods, transmission gears, and differential cases for the automotive industry, and also flanges, pipe fittings, and valve parts for railroad, marine, and other heavy-duty services. Gray and ductile cast irons are produced in approximately the same amounts; however, white and malleable cast irons are produced in smaller quantities.

(a)



(b)

Figure: (a) White iron: the light cementite regions are surrounded by pearlite, which has the ferrite–cementite layered structure. (b) Malleable iron: dark graphite rosettes (temper carbon) in an –ferrite matrix.

Compacted Graphite Iron

A relatively recent addition to the family of cast irons is compacted graphite iron (abbreviated *CGI*). As with gray, ductile, and malleable irons, carbon exists as graphite, which formation is promoted by the presence of silicon. Silicon content ranges between 1.7 and 3.0 wt%, whereas carbon concentration is normally between 3.1 and 4.0 wt%. Microstructurally, the graphite in CGI alloys has a worm-like (or vermicular) shape; In a sense, this microstructure is intermediate between that of gray iron and ductile (nodular) iron, and, in fact, some of the graphite (less than 20%) may be as nodules. However, sharp edges (characteristic of graphite flakes) should be avoided; the presence of this feature leads to a reduction in fracture and fatigue resistance of the material. Magnesium and/or cerium is also added, but concentrations are lower than for ductile iron.The chemistries of CGIs are more complex than for the other cast iron types; compositions of magnesium, cerium, and other additives must be controlled so as to produce a microstructure that consists of the worm-like graphite particles, while at the same time limiting the degree of graphite nodularity, and preventing the formation of graphite flakes. Furthermore, depending on heat treatment, the matrix phase will be pearlite and/or ferrite. As with the other types of cast irons, the mechanical properties of CGIs are related to microstructure: graphite particle shape as well as the matrix phase/microconstituent. An increase in degree of nodularity of the graphite particles leads to enhancements of both strength and ductility. Furthermore, CGIs with ferritic matrices have lower strengths and higher ductilies than those with pearlitic matrices. Tensile and yield strengths for compacted graphite irons are comparable to values for ductile and malleable irons, yet are greater than those observed for the higherstrength gray irons. In addition, ductilities for CGIs are intermediate between values for gray and ductile irons; also, moduli of elasticity range between 140 and 165 GPa.

Compared to the other cast iron types, desirable characteristics of CGIs include the following:

• Higher thermal conductivity

• Better resistance to thermal shock (i.e., fracture resulting from rapid temperature changes)

• Lower oxidation at elevated temperatures Compacted graphite irons are now being used in a number of important applications—these include: diesel engine blocks, exhaust manifolds, gearbox housings, brake discs for high-speed trains, and flywheels.

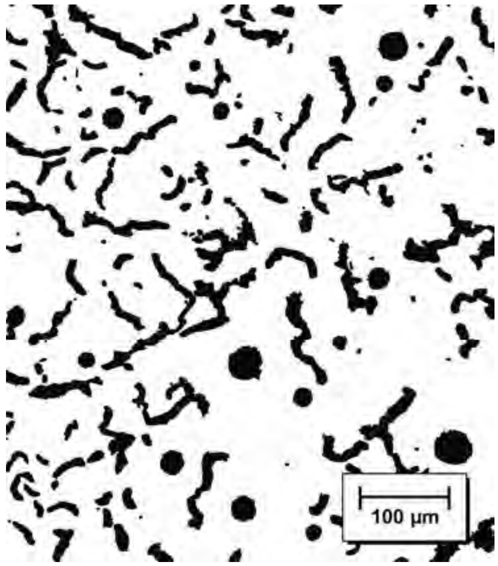


Figure: Compacted graphite iron: dark graphite worm-like particles are embedded within an -ferrite matrix.

Alloy Cast Iron

We have seen the properties of the different cast irons but many of the irons lack:

- Shock and impact resistance
- Corrosion and heat resistance at high temperatures

So alloying elements such as Ni, Cr, Mo, V, etc. can give additional properties for cast irons. The most common alloying elements are Nickel and Chromium. Thus depending on the composition of Nickel and Chromium, alloy cast irons can be classified in to two:

1. Ni- Hard and
2. Ni- resist

Effect of alloying Elements on Cast Irons:

Alloying elements in cast irons have similar effect like that of steels. They can be used to improve mechanical properties, refine grain, increase the hardness by stabilizing cementite and forming other hard carbides, stabilizing marten site and austenite structures, and improve corrosion resistance.

Nickel

- Nickel improve graphitization.
- It has grain refining effect.
  - -Prevent chilling in thin sections
  - - prevent coarse grain in thick section
- Reduce crack in thin section.

Chromium

- Chromium is a strong carbide stabilize which inhibits graphitization
- It will give the cast iron less grain growth
- Using both Ni and Cr can overcome the disadvantage of using them in separate.

Molybdenum

- If molybdenum is added in cast iron small amount of it will dissolve in ferrite
- Where as large amount of molybdenum forms double carbides

- Increase hardness of thick sections
- Promotes uniformity of microstructures

Vanadium

- It promotes heat resistance due to stable carbide formation
- Strength and hardness can also be increased by vanadium

Copper

- It has very slight graphitization effect.
- It has little influence on the mechanical properties.
- The main effect of copper on cast irons is that it improves resistance to corrosion.

Additionally, the properties of cast iron can be improved by applying heat treatment. The method of heat treatment of cast iron is the same as that of steel. The most common types of heat treatment works are:

- Stress relieving
- Annealing
- Quenching and tempering
- Surface hardening