CHAPTER FOUR

Ferrous Metals

Introduction

The ferrous metals are based on iron, one of the oldest metals known to humans.

The ferrous metals of engineering importance are alloys of iron and carbon. These alloys divide into two major groups: steel and cast iron. Together, they constitute approximately 85% of the metal tonnage in the United States.

The carbon is added into iron in varying amounts to produce a number of useful alloys such as mild steel, stainless steel, white cast iron, etc. In order to understand the microstructure of these alloys, we shall first discuss the phase transformation occurring at different temperatures in the iron-carbon system. This discussion of the ferrous metals begins with the iron–carbon phase diagram.

Contents:

- **Phase diagram of Iron-carbon system.**
- **Plain Carbon Steel**
- **Alloy Steel**
- **Stainless steel**
- **Cast Iron**
- **Super Alloys**

THE IRON–CARBON PHASE DIAGRAM

The iron–carbon phase diagram is shown in Figure .1. Pure iron melts at 1539°C.

During the rise in temperature from ambient, it undergoes several solid phase transformations, as indicated in the diagram. Starting at room temperature the phase is alpha (α), also called ferrite. At 912°C, ferrite transforms to gamma (γ), called austenite. This, in turn, transforms at 1394°C to delta (δ), which remains until melting occurs. The three phases are distinct; alpha and delta have BCC lattice structures, and between them, gamma is FCC.

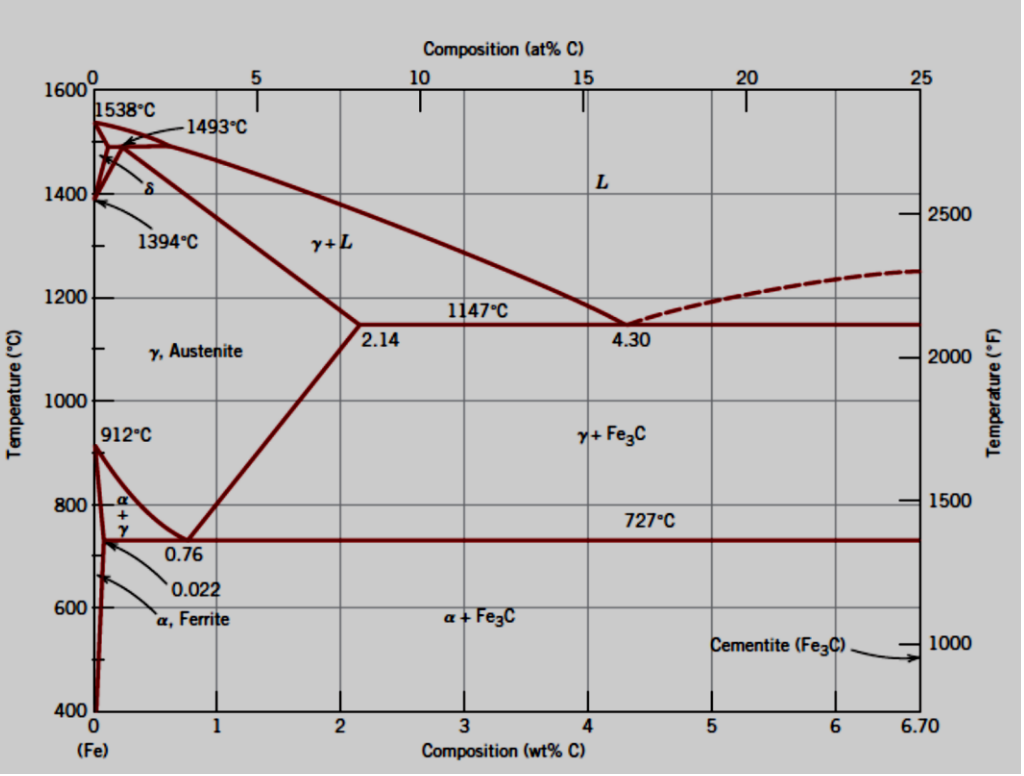


Figure.1: The iron-iron carbide ($Fe\text{-}Fe_3C$) phase diagram.

From the figure above, the low- carbon – region found 1400°C is not of any practical importance, however, the region lying in the 700-900 °C temperature range and (0-1%) carbon range is the most important region in the phase diagram.
In this region, an engineer can develop within steel, those microstructures which are required for desired properties.

Solid Phases in Iron- Iron Carbide Phase Diagram:

The iron-Iron carbide phase diagram shown in figure.1 contains four solid phases:

α – Ferrite, γ- Austenite, Cementite (Fe_3C), and δ- Ferrite.

1. **α – Ferrite:** Is a solid solution has a (BCC) structure. The maximum solid solubility of the carbon in α – Ferrite decreases with the decrease in temperature, until about (0.008%) at 0°C.
   The α – Ferrite is soft, ductile , and highly magnetic.

2. **γ- Austenite:** The solid solution of carbon in γ-Iron is called austenite, it has a (FCC) structure. The solubility of carbon in austenite reaches a maximum of 2.11% at 1148°C, and then decrease to 0.8% at 723°C.
   The austenite is soft and ductile, it is not ferromagnetic at any temperature.

3. **Cementite (Fe_3C):** Is an intermediate phase. It is a metallic compound of iron and carbon, is called Iron Carbide or Cementite, it contains 6.7% carbon. It extremely hard and brittle. It is magnetic below 210°C.

4. **δ- Ferrite:** It has (BCC) structure. The maximum solubility of carbon in δ- Ferrite is 0.09% at 1495°C.

**** Pearlite(P):** Pearlite is the product of the decomposition of austenite by a eutectoid reaction and comprises a lamellar arrangement of ferrite and cementite. Has good mechanical properties because it consider as composite material of ferrite and cementite. See figure. 2.

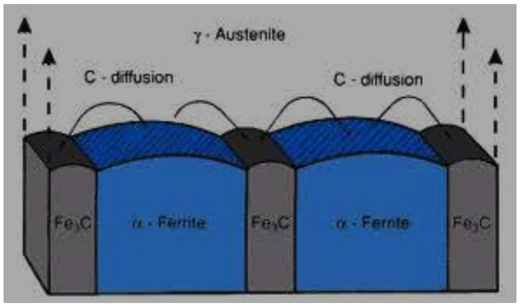


Figure.2: Microstructure of Pearlite steel

Eutectoid, Hypo-eutectoid, and Hyper- eutectoid steel:

Steel is an alloy of iron that contains carbon ranging by weight between 0.02% and 2.11% (most steels range between 0.05% and 1.1%C). These steels are referred as plain carbon steel when they do not contain any alloying element.

A plain carbon steel containing 0.8% carbon is known as **eutectoid steel,** if carbon content of the steel is less than 0.8% it is called **hypo-eutectoid steel.** Most of these steels produced, commercially are hypo-eutectoid steels.

The steel, which contain more than 0.8% of carbon are called **hyper-eutectoid steels.**

Hyper-eutectoid steels with carbon content up to (1.4%) are produced commercially, when the carbon content is more than 1.4% it becomes very brittle, thus very few steels are made with carbon content more than (1.4%).

In order to increase the strength of steel. Other alloying elements are added, these elements increase strength as well as maintain ductility and toughness.

Plain Carbon Steel

These steels contain carbon as the principal alloying element, with only small amounts of other elements. Most of steel produced now-a days is plain carbon steel.

A plain carbon steel is defined as a steel which has it properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese.

The plain carbon steel varying from o.o6% to 1.4% carbon are divided into the following types depending upon the carbon content:

1. **Low carbon steel (Mild steel)= 0.06%- 0.19% carbon.**
2. **Medium carbon steel = 0.20% - 0.55% carbon.**
3. **High carbon steel = 0.55% - 1.4% carbon.**

These steel are (strong , tough, ductile) and has poor atmospheric corrosion resistance.

The properties of plain carbon steel depends on the presence of carbon content.

The hardness and strength increase with an increase in carbon content. These properties increase due to presence of hard and brittle cementite. The ductility and toughness decrease with an increase in carbon content.

Figure.3 shows the effect of carbon content on steel properties.

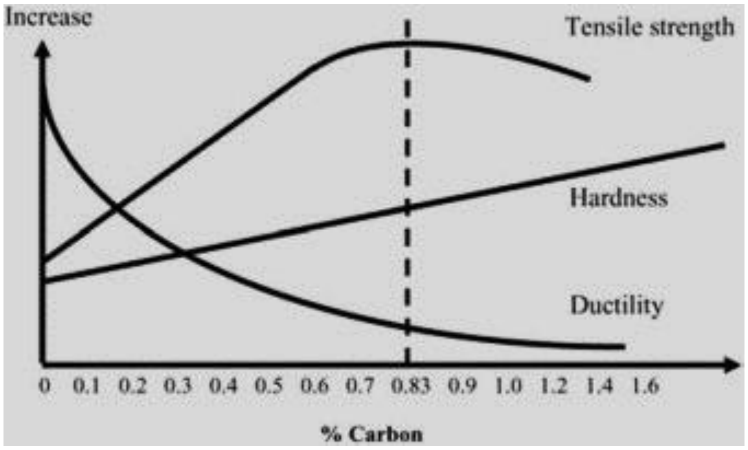


Figure.3: Effect of carbon content on mechanical properties of carbon steel

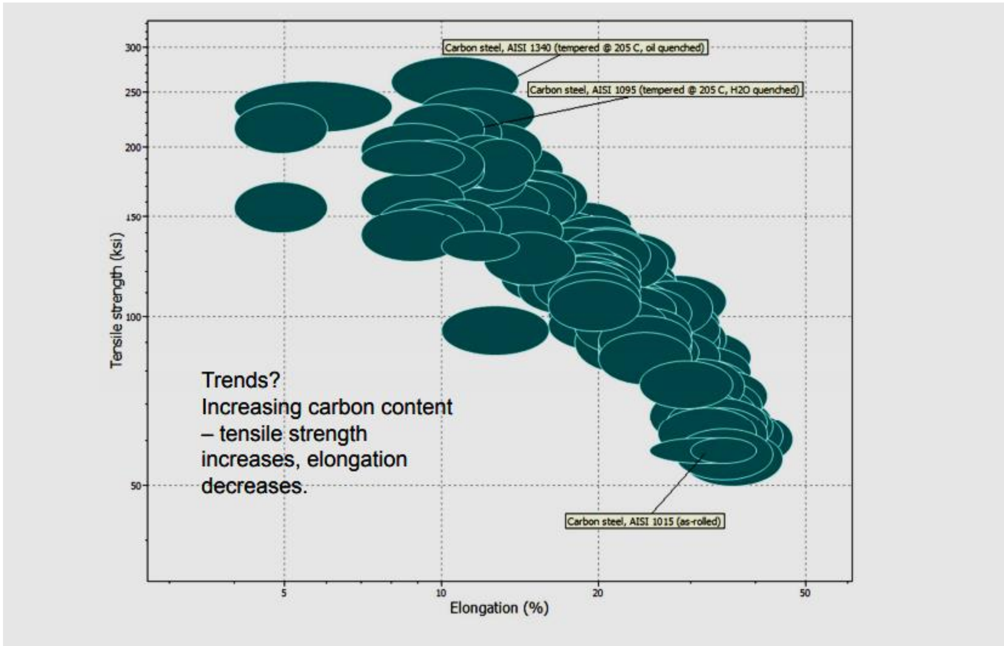
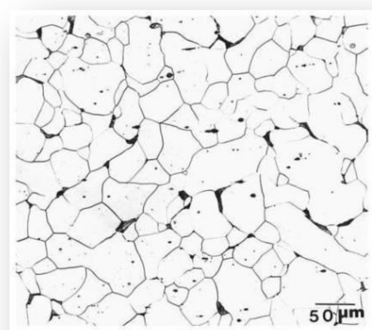


Figure.4: Mechanical properties for different plain carbon steels

1. Low Carbon Steel:

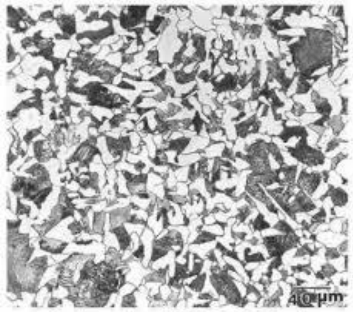
These generally contain less than about 0.20 wt% of carbon. Microstructure consist of ferrite and pearlite constitutes. These alloys are relatively soft and weak but have ductility and toughness, in addition, they are machinable and weldable.



Low-carbon AISI/SAE 1010 Steel

Typical applications include: automobile body components, structural shapes (I-beam, channel and angle iron), and sheets that are used in pipelines, buildings, bridges, and railroad rails. These steels are relatively easy to form, which accounts for their popularity where high strength is not required. Steel castings usually fall into this carbon range, also.

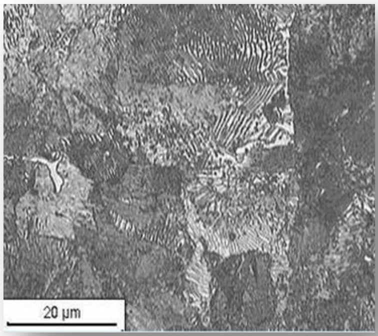
2. Medium Carbon Steel:



Medium-carbon AISI/SAE 1040 Steel

These have carbon concentrations between 0.25and 0.55% carbon. These alloys may heat – treated by austenitizing, quenching, and then tempering to improve their mechanical properties.
The plain medium carbon steel has low hardenability. Theses heat treated alloys are stronger than the low carbon steel, and are specified for applications requiring higher strength than the low-C steels.
Applications of medium carbon steel include railway wheels and tracks, machinery components and engine parts such as crankshafts, gears and connecting rods.

3. High Carbon Steel:



These normally have carbon contents between 0.55% and 1.4%. Are hardest, strongest, and yet least ductile of carbon steel.
These used in a hardened and tempered condition and as such are especially wear resistant.
Applications of high carbon steel include Springs, cutting tools and blades, punches, dies, and wear-resistant parts are examples.

Table.1: The important applications of plain carbon steel.

	Types of steels	*Uses*
1.	Low- carbon steel or mild steel	Chain links, nails, rivets, ship hulls, car bodies, bridges, cams, light duty gears ,etc.
2.	Medium carbon steel	Axles, connecting rods, gears ,wheels for trains and rails, etc.
3.	High carbon steel	Clutch plate, razor blades scissors, knives, punches, dies, etc.

Effect of Impurities on Steel:

The following are important effects of impurities like: silicon (Si), Sulphur (S), manganese (Mn), and phosphor (P) on steel.

1. **Silicon:** Range between 0.05% to 0.30% . Is added in low carbon steel to: -
   - Prevent them from becoming porous.
   - Remove the gasses and oxides.
   - Make the steel tougher and harder.

2. **Sulphur:** It occurs in steel either as iron sulphide or manganese sulphide. Iron sulphide because of its melting point produces red shortness, whereas manganese sulphide does not affect so much. Sulphur is added to improve machinability only.

3. **Manganese:** Is added in low carbon steel to:
   - It serves as a deoxidizing and purifying agent in steel.
   - Manganese combines with sulphur and thereby decreases the harmful effect of this element in the steel.
   - Improve yield strength, toughness, and hardenability.

4. **Phosphorus:** Is added to steel to:
- It make the steel brittle.
- Raises the yield point.
- Improve the resistance to atmospheric corrosion.

Classification of Metal Alloys

The metal alloys include steel alloys and other metal alloys are classified according to many designation codes:

The Society of Automotive Engineers (SAE),

The American Iron and Steel Institute (AISI), and

The American Society for Testing and Materials (ASTM) are responsible for the classification for these steels as well as other alloys.

- **Steel series.**

According to the AISI/ SAE designation for these steels can be divided into different series.

four-digit number + any prefix: the first two digits indicate the alloy content, the last two digit give the carbon content.

For Plain Carbon Steel (1000 series):

First digit: 1,

Second digit: 0 (carbon steel),

1 (resulphurized carbon steels,

2 (resulphurized and rephosphorized carbon steels)

Third and fourth digits: carbon content *100.

For Alloy Steel : The first two digit indicate the alloy content as in table below:

SAE designation	Type
1xxx	Carbon steels
2xxx	Nickel steels
3xxx	Nickel-chromium steels
4xxx	Molybdenum steels
5xxx	Chromium steels
6xxx	Chromium-vanadium steels
7xxx	Tungsten steels
8xxx	Nickel-chromium-vanadium steels
9xxx	Silicon-manganese steels

The first digit of AISI/SAE Steel Designation represents a general category grouping of steels. This means that 1xxx groups within the SAE-

AISI system represent carbon steels. Thus the plain carbon steels are represented within the 10xx series, resulfurized carbon steels are represented within the 11xx series, resulfurized and rephosphorized carbon steels are represented within the 12xx series. The second digit of the series indicates the presence of major elements, which may affect the properties of the steel. For example in 1018 steel, indicates non-modified carbon steel containing 0.18% of carbon.

SAE 5130 indicates a chromium alloy steel containing 1% of chromium and 0.30% of carbon.

Alloy Steel / الفولاذ السبائكي

Definition: A steel in which elements other than carbon are added in sufficient quantity in order to obtain special properties, is known as alloy steel.

- The alloying of steel is generally done to increase its strength, hardness, toughness, resistance to abrasion and wear, and to improve electrical and magnetic properties.
- The various alloying elements are: Nickel, Chromium, Molybdenum, Cobalt, Vanadium, Manganese, Silicon, and Tungsten.
- Low alloy: Added in small percent's (<5%) to increase strength and hardenability.
- High alloy: Added in large percent's (>20%) – i.e. > 10.5% Cr = stainless steel where Cr improves corrosion resistance and stability at high or low temps
- The effect of these alloying elements are discussed below:

1. Nickel: **It is one of the most important alloying elements:**

- Steel sheets contain (**2% to 5% nickel and 0.1% to 0.5% carbon**). In this range, nickel improves tensile strength, raises elastic limit, imparts hardness, toughness, and reduce rust formation. It is largely used for boiler plates automobile engine parts, crank shafts, connecting rods.

- When nickel is added to steel **(about 25%)** it results in higher strength steels with improved shock and fatigue resistance. It makes the steel resistant to corrosion and heat. It is used in the boiler tubes, valves for gas engine, sparking blogs for petrol engines.
- A nickel steel alloy containing about (**36% Ni and 0.5% Carbon**) is known as (Invar). It can be rolled, forged, turned, and drawn, it is widely used for making pendulums of clocks, precision measuring instruments.
- 2xxx is Nickel steel alloy.

2. ***Chromium:*** Addition of chromium to steel increases its strength, hardness, and corrosion resistance:

- A chrome steel containing (0.5% to 2% Cr) is used for balls, rollers, and races for bearings, die, permanent magnets, etc.
- 5xxx is chrome steel alloy
- A steel containing (3.25% Ni, 1.5% Cr, and 0.25% C) is known as (Nickel- chrome steel 3xxx). The combination of toughening effect of nickel and the hardening effect of chromium produces a steel of high tensile strength with great resistance to shock. It is used for motor car crank shafts, axles and gears requiring strength and hardness.

3. ***Vanadium:*** It is added in low and medium carbon steels in order to increase their yield and tensile strength properties. It is added to steel usually about 0.03% to 0.25 % to increase strength without loss of ductility

- In combination with chromium about (0.5% to 1.5% Cr, 0.15% to 0.25% V, and 0.13% to 1.1% C), it produces a marked effect on properties of steel and makes the steel tough and strong. These steel is used for spring steel, high speed tools, and other parts of automobiles. Code of this alloy is 6xxx.

4. ***Tungsten:*** the addition of tungsten raises the critical temperature of steel and hence it is used for increasing strength of alloyed steel at high temperatures. It helps to form stable carbides and increases hot hardness

- When added to the extent of 5% to 6%, it gives steel good magnetic properties, thus it is commonly used for magnets in electrical instruments.
- The tungsten is usually used with other elements, steel containing (18% tungsten, 4% Cr, 1% V, and 0.7% C) is called tool steel or high speed steel.

  Since the tool made with this steel the ability to maintain its sharp cutting edge even at elevated temperature, therefore it is used for making high speed cutting tools such as cutters, drills, dies…. etc.
- Code of this steel is 7xxx.

5. ***Manganese:*** It is added to steel to reduce the formation of iron sulphide by combining with sulphur. It make the steel hard, tough, and wear resisting.

- The manganese alloy steel containing over (1.5% Mn with carbon of 0.4% to 0.55%) are widely used for gears, axles, shafts, and other parts where high strength combined with fair ductility is required.

- A steel containing manganese from (10% to 14% and carbon 1% to 1.3%) form an alloy steel, which is extensively hard and tough and has high resistance to abrasion. It is Ideal for impact resisting tools. is largely used for mining, rock crushing and railways equipment.

6. *Cobalt:* It is added to high speed steel from (1% to 12%), to give red hardness by retention of hard carbides at high temperatures.

It increases hardness and strength. But too much of cobalt it decreases impact resistance of steel.

7. Molybdenum: A small quantity (0.15% to 0.3%) of molybdenum is generally used with chromium and manganese (0.5% to 0.8%) to make molybdenum steel.

- ***Mo*** increase hardenability and strength
- Mo-carbides help increase creep resistance at elevated temps
- typical application is hot working tools
- It can replace tungsten in high speed steel.

8. Silicon: It increases the strength and hardness of steel without lowering its ductility.

- Silicon steel containing from (1% to 2% silicon and 0.1% to 0.4% carbon) have good magnetic properties and high electrical resistance.
- It can withstand impact and fatigue even at elevated temperature.
- These steel are used for generator and transformers in the form of laminated cores.

Tool Steel فولاذ العدد

Introduction: These are the steel used in making tools and dies which are required for cutting, shaping, forming, and blanking of materials.

These steels should have high hardness, greater abrasion or wear resistance, greater toughness, high impact strength, high thermal conductivity, low coefficient of friction.

Types of tool steel: The tool and dies steels are of the following types:-

1. **Plain carbon steels:**

   These steels contain carbon from (0.60% to 1.4%) and are hardened either by oil or water quenching. The important advantage of these steel is that they low cost, good machinability, and high impact resistance.

   The main disadvantage of carbon tool steel is poor hardenability. It needs quenching with water, brine or caustic water. Distortion and cracking tend to be large, and wear resistance and thermal strength are very low.

   Therefore, carbon tool steel can only be used to make small handmade tools or woodworking tools, as well as small cold working dies with low precision, simple shape, small size and light load. These steels are used for: keys, stamping dies, twist drills, general wood and leather cutting tools.

Plain carbon tool steel

2. **Low alloy tool steel:**

These steels containing alloying elements like: vanadium, chromium, tungsten, and silicon. The presence of alloying elements refine the structure and increases the toughness and impact resistance. Compare with carbon tool steel, its hardness, toughness and wear-resistance are raise. And its hardenability and hot hardness are raised dramatically.

The low – alloy tool steel are used for heavy duty pneumatic tools, pavement breakers. it was used to make measuring tools, molds and blade tools with big size, complex shape and high requirement of performance.

Different levels for alloy steel because of the different total amount of alloy elements. And if the alloy elements amount is less than 5%, then it is low alloy tool steel. The medium alloy tool steel is at the range of 5%-10%. And the high alloy tool steels are higher than 10%. At the present time, most of the alloy tool steel is low alloy tool steel.

3. **High speed steels:**

   These steels are used for cutting metals at a much higher speed than ordinary carbon tool steel. The carbon steel cutting tools do not retain sharp cutting edges under heavier loads and higher speeds. This is due to the fact that at high speed, sufficient heat may be developed during the cutting operation and causes the temperature of the cutting edge of the tool to reach a red hot. This temperature would soften the carbon tool steel and thus the tool will not work efficiently for a longer period.

   The high speed steels have the valuable properly of retaining their hardness even when heated to red hot.

   Following are the different types of high speed steels:-

   a. **18-4-1 high speed steel (tungsten series HSS):**

      This steel contains (18% tungsten, 4% chromium, and 1% vanadium). It is considered to be one of the best of all purpose tool steel.

      It is widely used for drills, lathes, planer and shaper tool, milling cutters, etc..

   b. **Molybdenum series HSS:**

      This steel contains (6% tungsten, 6% molybdenum, 4% chromium, and 2% vanadium). It has excellent toughness and cutting ability. Molybdenum high speed steels are better and cheaper than other types of steels.

It is used for drilling and tapping operations.

c. **Super high speed steel:**

This steel is called cobalt high speed steel, because cobalt is added from (2% to 4%) in order to increase the cutting efficiency especially at high temperatures.

This steel contains (20% tungsten, 4% chromium, 2%vandium, and 12% cobalt). Since the cost of this steel is more, is used for heavy cutting operation, which impose high pressure and temperature on the tool.

4. **High carbon high chromium steels:**

These steels are much cheaper than high speed steel (HSS), but have greater importance than HSS.

These are widely used for various types of dies like those used for drawing, coining, blanking, forming, and thread rolling.

Stainless steel

Introduction

The word STAINLESS could mean a steel that STAINS LESS. They are highly resistant to corrosion (rusting) in a variety of environments, especially the ambient atmosphere. Their important alloying element is chromium , a concentration of at least 11 wt % is required. Corrosion resistance may also be enhanced by nickel and molybdenum addition. The family of stainless steel can be split into four main groups: Martensitic, Ferritic, Austenitic and Duplex. Nearly all end use applications use either ferritic or conventional austenitic steel.

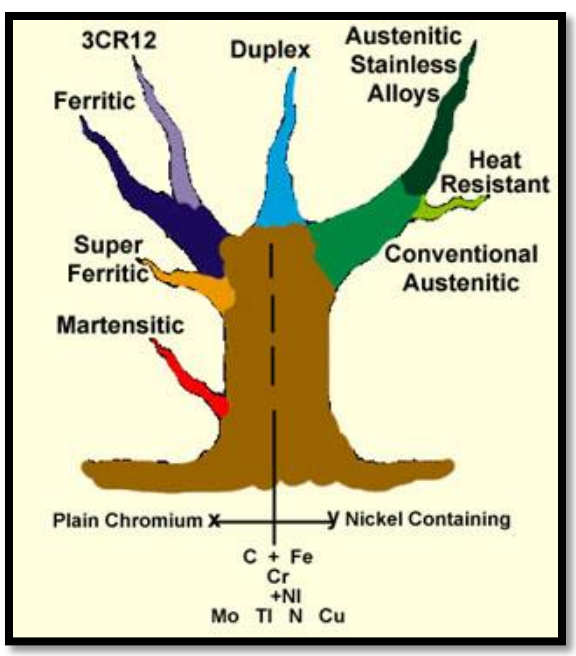


Fig. 1: The family tree of Stainless steel

Austenitic stainless steel :

Austenitic grades are those alloys which are commonly in use for stainless applications. The austenitic grades are not magnetic. The most common austenitic alloys are iron-chromium-nickel steels and are widely known as the 300 series which contain chromium normally in the range 17-25% and nickel in range 8-20% with various additional elements to achieve the desired properties.(commonly referred to as 18/8 steel).

The austenitic stainless steels, because of their high chromium and nickel content, are the most corrosion resistant of the stainless group providing unusually fine mechanical properties. They cannot be hardened by heat treatment, but can be hardened significantly by cold-working.

Table (1) shows some types of austenitic stainless steel(300 serirs).

Type 304	The most common of austenitic grades, containing approximately 18% chromium and 8% nickel. It is used for chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals.
Type 316	Contains 16% to 18% chromium and 11% to 14% nickel. It also molybdenum added to the nickel and chrome of the 304. The molybdenum is used to control pit type attack. Type 316 is used in chemical processing, the pulp and paper industry, for food and beverage processing and dispensing and in the more corrosive environments. The molybdenum must be a minimum of 2%
Type 317	Contains a higher percentage of molybdenum than 316 for highly corrosive environments. It must have a minimum of 3% “moly”. It is often used in stacks which contain scrubbers
Type 317L	Restricts maximum carbon content to 0.030% max. and silicon to 0.75% max. for extra corrosion resistance
Type 317LM	Requires molybdenum content of 4.00% min
Type 317LMN	Requires molybdenum content of 4.00% min. and nitrogen of .15% min.
Type 321 **Type 347**	These types have been developed for corrosive resistance for repeated intermittent exposure to temperature above 800 degrees F. Type 321 is made by the addition of titanium and Type 347 is made by the addition of tantalum/columbium. These grades are primarily used in the aircraft industry.

Martensitic Stainless steel

Martensitic grades were developed in order to provide a group of stainless alloys that would be corrosion resistant and hardenable by heat treating. The martensitic grades are straight chromium steels containing no nickel which contains a minimum of 12% chrome and usually a maximum of 14% with carbon in the range of 0.08%-2.00%. They are magnetic and can be hardened by heat treating. The martensitic grades are mainly used where hardness, strength,and wear resistance are required.

Table (2) shows some types of martensitic stainless steel (400 series)

Type 410	Basic martensitic grade, containing the lowest alloy content of the three basic stainless steels (304, 430, and 410). Low cost, general purpose, heat treatable stainless steel. Used widely where corrosion is not severe (air, water, some chemicals, and food acids. Typical applications include highly stressed parts needing the combination of strength and corrosion resistance such as fasteners.
Type 410S	Contains lower carbon than Type 410, offers improved weldability but lower hardenability. Type 410S is a general purpose corrosion and heat resisting chromium steel recommended for corrosion resisting applications.
Type 414	Has nickel added (2%) for improved corrosion resistance. Typical applications include springs and cuttlery.
Type 416	Contains added phosphorus and sulfer for improved machinability. Typical applications include screw machine parts.
Type 420	Contains increased carbon to improve mechanical properties. Typical applications include surgical instruments.
Type 431	Contains increased chromium for greater corrosion resistance and good mechanical properties.Typical applications include high strength parts such as valves and pumps.
Type 440	Further increases chromium and carbon to improve toughness and corrosion resistance. Typical applications include instruments.

Ferritic Stainless steel

Ferritic grades have been developed to provide a group of stainless steel to resist corrosion and oxidation, while being highly resistant to stress corrosion cracking. These steels are magnetic but cannot be hardened or strengthened by heat treatment. They can be cold worked and softened by annealing. This groub contains a minimum of 17% chrome and carbon in the range of 0.08%- 2.00%. As a group, they are more corrosive resistant than the martensitic grades, but generally inferior to the austenitic grades. Like martensitic grades, these are straight chromium steels with no nickel. They are used for decorative trim, sinks, and automotive applications, particularly exhaust systems.

Table (3) shows some types of ferritic stainless steel (400 series)

Type 430	The basic ferritic grade, with a little less corrosion resistance than Type 304. This type combines high resistance to such corrosives as nitric acid, sulfur gases, and many organic and food acids.
Type 405	Has lower chromium and added aluminum to prevent hardening when cooled from high temperatures. Typical applications include heat exchangers.
Type 409	Contains the lowest chromium content of all stainless steels and is also the least expensive. Originally designed for muffler stock and also used for exterior parts in non-critical corrosive enviornments.
Type 434	Has molybdenum added for improved corrosion resistance. Typical applications include automotive trim and fasteners.
Type 436	Type 436 has columbium added for corrosion and heat resistance. Typical applications include deepdrawn parts.
Type 442	Has increased chromium to improve scaling resistance. Typical applications include furnace and heater parts.
Type 446	Containes even more chromium added to further improve corrosion and scaling resistance at high temperatures. Especially good for oxidation resistance in sulfuric atmospheres.

Duplex Grades(Austenitic, Ferritic Stainless Steels)

Duplex grades are the newest of the stainless steels. This material is a combination of austenitic and ferritic material. This material has higher strength and superior resistance to stress corrosion cracking. An example of this material is type 2205. It is available on order from the mills.

This class of stainless steel has been available for about ten years. The very high proof strength is due to the smaller grain size owing to the two phase micro structure. The very small grain size prevents grain growth and increases strength and toughness. The duplex alloy contains more chromium, molybdenum, nickel and nitrogen than either 316 or 304. It has improved corrosion resistance to the chlorine ion (salt water). It's yield strength is 2 - 3 times greater than austentic alloys.

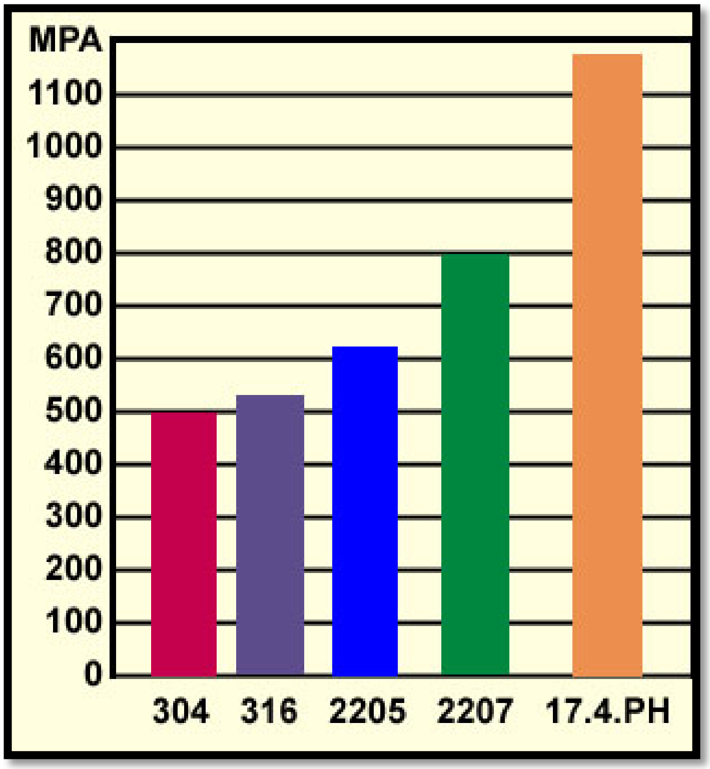
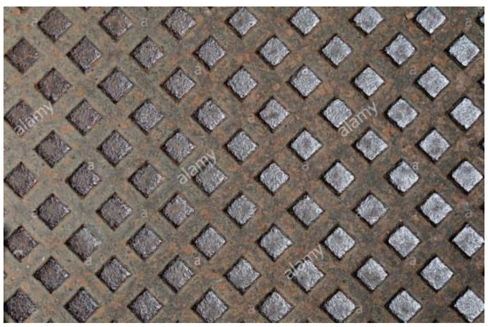


Fig. 2 : Comparison of Tensile Strength Duplex and Austenitic Grades

CAST IRON

Introduction

Cast iron is a cheap alloy. Ordinary cast iron is an alloy containing a total of up to 10% of the elements carbon, silicon, manganese, sulphur and phosphorus; the balance being iron. Alloy cast irons, contain also varying amounts of nickel, chromium, molybdenum, vanadium and copper.



Graphitization:

Cementite (Fe_3C) is a metastable compound, and under some circumstances it can be made to dissociate or decompose.

1-Composition: Graphite formation is promoted by the presence of silicon and to less degree phosphorus, nickel and copper. If silicon content is lower than 1 wt% graphitization may not takes place.

2-Cooling rate: Slower cooling rates during solidification favor graphitization. While higher rate of cooling during solidification tends to favor the formation of cementite. This effect is illustrated by casting a 'stepped bar' of cast iron of a suitable composition Here, the thin sections have cooled so quickly that solidification of cementite has occurred, as indicated by the white fracture and high Brinell values. The thicker sections, having cooled more slowly, are graphitic and consequently softer.

3-Heat treatment

Types of Cast Iron

1-White Cast Iron

If silicon content is lower and the cooling rates during solidification are higher, the resulting structure will contain cementite, and the fracture surface will appears bright .Since white cast iron is extremely hard and brittle is not used as such but they are made as the first step for conversion into the malleable iron. It is possible to form white cast iron structure on the surface layers of grey cat iron by chilling the surface. This is called chilled iron and is used for making wear resistance surfaces for iron rolls and ploughs

2-Grey Cast Iron

If silicon content is higher and the cooling rates during solidification are lower, complete graphitization takes place and the resulting structure will contain graphite flakes only. Then it is called grey cast iron, the fracture surface may be dull and grey.

The important engineering properties of grey cat iron are;

1. High compressive strength.

2. Moderate tensile strength

3. Good wear resistance

4. High damping capacity

The shortcoming of grey iron is the brittleness du to the flake form of graphite which introduces sharp notches at the edges. The most important applications of cast iron are machine beds, ingot moulds, lamp spots and others.

3-Spheroidal-graphite (SG) Cast Iron

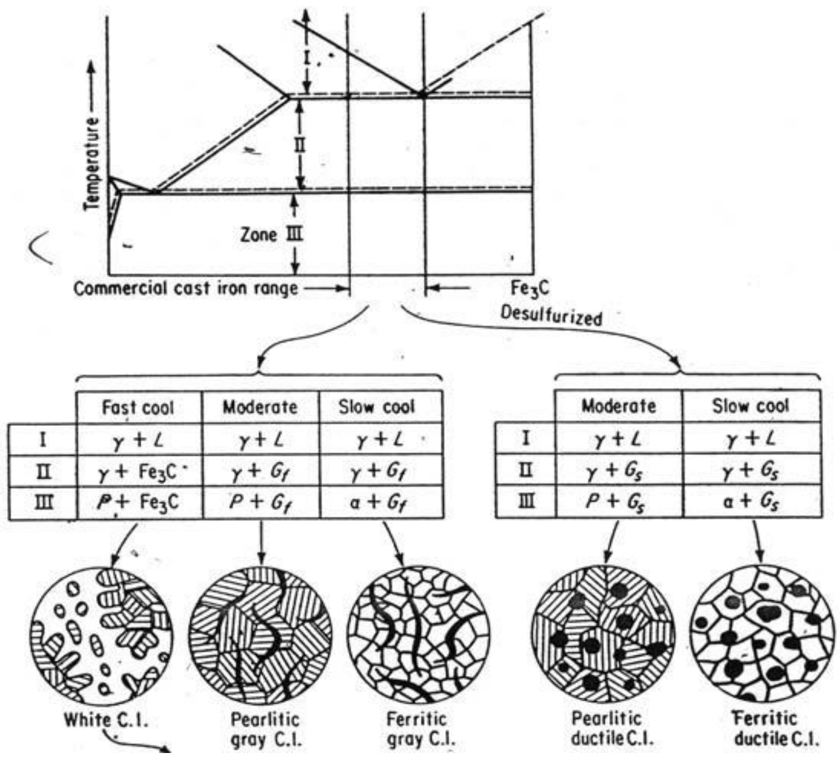
Also known as nodular cast iron or ductile cast iron. In SG cast iron the graphite flakes are replaced by spherical particles of graphite so that the sharp stress raisers are eliminated. The formation of this spheroidal graphite is effected by adding small amounts of cerium or magnesium to the molten iron just before casting.

4-Compacted-graphite (CG) Iron

The mechanical properties of this type is intermediate between those of ordinary grey flake-graphite irons and those of SG iron. The graphite flakes produced are short and stubby and have rounded edges. CG iron is produced when molten iron of near-eutectic composition is treated with a single alloy containing appropriate amounts of magnesium, titanium and cerium. CG has good resistance to scaling and 'growth' at high temperatures, so CG iron attractive as a heat-resisting material and it was developed originally for the manufacture of ingot moulds and vehicle brake components.

5-Malleable Cast Irons

The names of the two original malleabilising processes, the Blackheart and the White heart, refer to the color of a fractured section after heat treatment has been completed. Another process used for manufacturing pearlitic malleable iron. In all three processes the original casting is of white iron, which will be very brittle before heat-treatment.



G_f = flake graphite

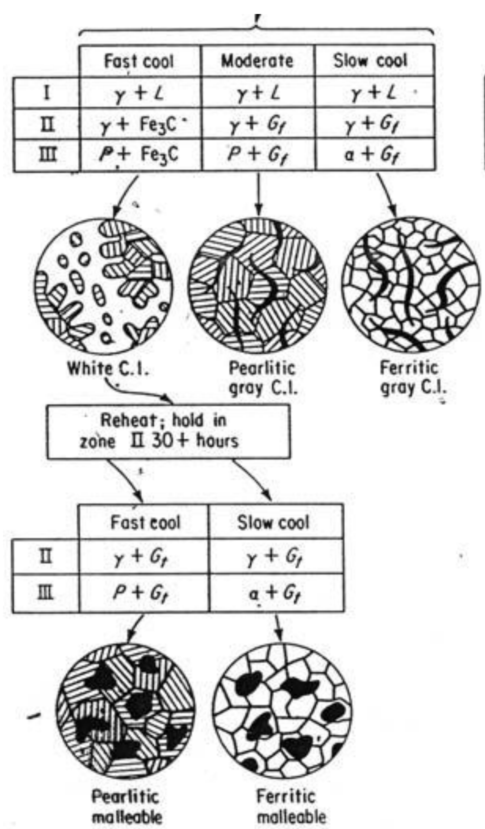
G_t = graphite-temper carbon

G_s = graphite spheroids

P = pearlite

α = ferrite

γ = austenite



Alloy Cast Irons

The microstructural effects which alloying elements have on a cast iron are, in most cases, similar to the effects these elements have on the structure of a steel.

1-Martensitic irons

Martesitic irons, which are very useful for resisting abrasion, usually contain 4-6% nickel and about 1% chromium. Such an alloy is Ni-hard, is martensitic in the cast state, whereas alloys containing rather less nickel and chromium would need to be oil-quenched in order to obtain a martensitic structure .

2-Austenitic irons

Austenitic irons usually contain between 10 and 30% nickel and up to 5% chromium. These are corrosion-resistant, heat-resistant, non-magnetic alloys. Some of them are treated to produce structures containing spheroidal instead of flake graphite .