7

Theory of Alloys

Contents

7.1 Pig Iron

- Pig iron is the raw material for all iron and steel products. Pig iron is of great importance in the foundry and steel making industry.
- Pig iron for foundry is roughly 20" X9" X4".
- The raw material for pig iron is ore. (Iron oxide or carbonate limestone and coke).
- Pig iron produced in a blast furnace, is the first product in the process of converting iron ore into useful metal.
- Iron ores are rocks and minerals from which metallic iron can be economically extracted.
- The iron ore becomes pig iron which the impurities are burned out in a blast furnace. Though still containing some impurities, pig iron has a high metal content.
- Pig iron the product of blast furnace has the following composition.

Carbon	: 3.0-4.0%	Phosphorous	: 0.3-1.7%
Silicon	: 1.0-3.0%	Manganese	: 0.1-1.0%
Sulpher	: Under 1.0%	Iron	: Remaining

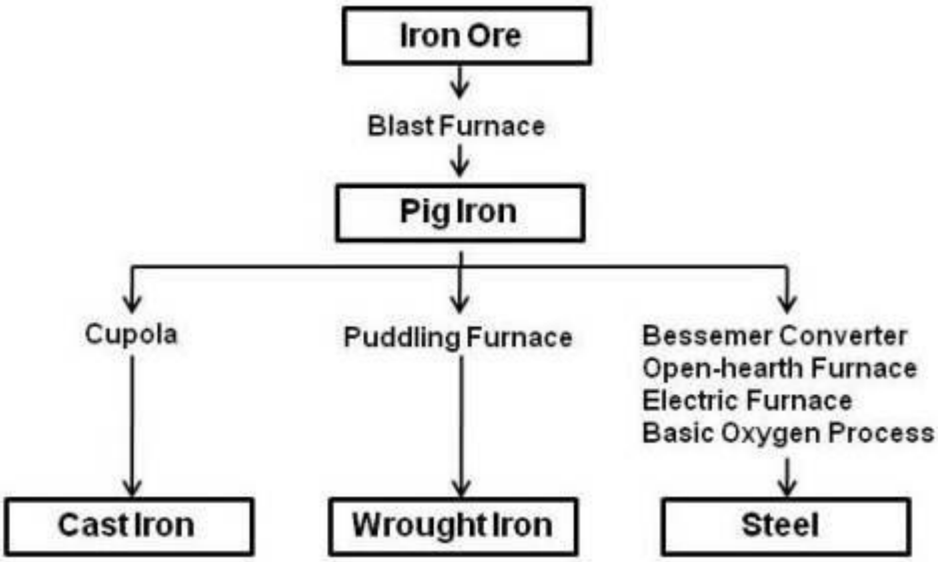

Fig.7.1 – Iron and Steel Production

7.2 Classification of Pig iron

1. **Basic pig iron**

- It is used for steel making and is low in silicon (1.5% maximum) to prevent an attack of the refractory lining of refining furnaces.
- Basic pig iron must be low in Sulpher (0.04% minimum). Since Sulpher is an active impurity in steel and is not eliminated in the refining furnaces.

Phosphorous: <1.0%   Carbon : 3.5-4.4%   Manganese: 1.0-2.0%

2. **Foundry pig iron**
   It is used for the production of casting.

- It contains

Carbon	: 3.0-4.5%	Phosphorous	: 0.035-0.9%
Silicon	: 0.5-3.5%	Manganese	: 0.4-1.25%
Sulpher	: Upto 0.05%	Iron	: Remaining

3. **Ferroalloys**

- Ferroalloys are of pig iron, each rich in one specific element.
- They are used as additives in iron and steel industries to control or alter the properties of iron and steel.
- Examples:

    Ferrosilicon(FeSi): Which is pig iron with 5 to 17 % silicon
    Ferromanganese(FeMn): Which is pig iron with 74 to 82 % manganese

7.3 Wrought Iron

- Wrought iron is a mixture of very pure iron and silicate slag.
- Wrought iron was originally produced by the hand pudding process later by mechanical pudding and since 1930 by Bayer or Aston process. There are 3 steps for the manufacturing of wrought iron.

1. To melt and refine the base metal.
2. To produce and keep molten a proper slag.
3. Disintegrate the base metal and mechanically incorporate with it the desired amount of slag.

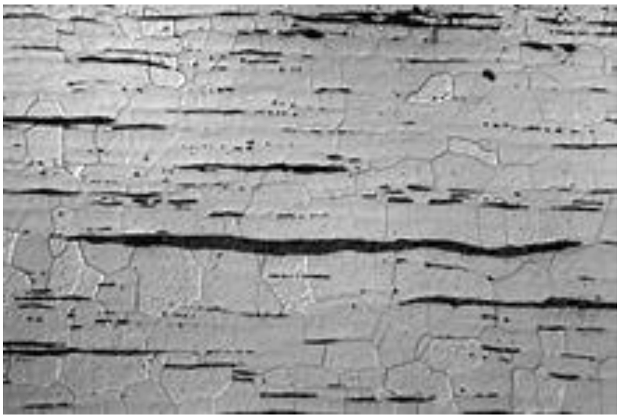

Fig.7.2 - Wrought Iron

Properties of Wrought Iron

- Quality wrought iron is distinguished by its low carbon and manganese content.
- Carbon is generally below 0.08% and manganese content below 0.06%.
- Phosphorous is higher than that of steel and ranges from 0.05 to 0.160%.
- Sulpher content is kept low and silicon content 0.10 to 0.20% is concentrated almost entirely in the slag.
- The slag content usually varies from about 1.0 to 3.0% by weight.

A typical chemical analysis of wrought iron is as under.

Carbon	: 0.6%	Sulpher	: 0.009%
Silicon	: 0.101%	Slag by weight	: 1.97%
Phosphorous	: 0.068%	Iron	: Balanced
Manganese	: 0.045%		

- Wrought iron is a composite metal. The figure shows the fracture of wrought iron.
- The mechanical properties of wrought iron are largely those of pure iron. Because of the nature of slag distribution, the tensile strength and ductility are greater in a longitudinal direction.
- It has the ability to resist corrosion. As corrosion continues the slag fibers begin to function as rest resistors.
- Wrought iron is never cast. All shaping is accomplished by hammering, pressing and forging.
- It is possible to improve the strength of wrought iron by alloying. The most popular alloy wrought irons is those containing 1.5 to 3.5% nickel.
- Tensile properties of wrought iron.

Property	**Longitudinal**	**Transverse**
Tensile strength in PSI	48000-50000	36000-38000
The yield strength in PSI	27000-30000	27000-30000
% Elongation in 8 inch	18-25	2-5
Reduction in area %	35-45	3-6

- Tensile properties of unalloyed and nickel wrought iron.

Property	**Unalloyed Wrought Iron**	**Nickel Wrought Iron**
Tensile strength in PSI	48000	60000
The yield strength in PSI	30000	45000
% Elongation in 8 inch	25	22
Reduction in area %	45	42

Application of Wrought Iron

- Wrought iron is available in the form of plates, sheets, bars, forging blooms and billets, rivets and a wide range of tubular products like pipe, tubing, and casing cold-drawn tubing and welding fittings.

1. Building construction: Service lines and electrical conduits, soil, waste.
2. Public work: Bridge, railing, blast plates, towers, etc.
3. Industrial process: Condenser tubes, heat exchangers, acid and alkali lines.
4. Railroad and marine: Diesel exhaust and air brake piping.
5. Others: Coal handling equipment, cooling towers, spray pond piping.

7.4 Cast Iron

- Cast iron is basically an alloy of iron and carbon. Cast iron contains 2.0-6.67% carbon. Since higher carbon content tends to make the cast iron very brittle.
- The most common commercial manufactured cast iron is in the range if 2.5 to 4.0% carbon.
- The ductility of cast iron is very low, and it cannot be rolled, drawn or worked at room temperature. Cast iron melts readily and can be cast into complicated shapes which are usually machined into final dimensions.
- The common cat iron is brittle and has lower strength property than most steel.

- In addition by proper alloying, good foundry control and appropriate heat treatment the property of cast iron may be varied over a wide range.

7.5 Types of Cast Iron

- The best method of classifying cast iron is according to a metallographic structure.
- There are four variables for types of cast iron.
  1. Carbon content.
  2. The alloy and impurity content.
  3. The cooling rate during and after freezing.
  4. Heat treatment after casting.
- These variables control the conclusion of carbon and its physical form. The carbon may be combined as iron carbide in cementite or free carbon in graphite. The shape and distribution of free carbon particles will influence the physical property of cast iron.

1. **Gray cast iron:** Most of or all the carbon is uncombined in the form of graphite flanks.
2. **White cast iron:** All the carbon is in the combined form as cementite.
3. **Malleable cast iron:** All the carbon is uncombined in the form of irregular round particle known as temper carbon. This is obtained by the heat treatment of white cast iron.
4. **Chilled cast iron:** In which white cast iron layer at the surface is combined with gray cast iron interior.
5. **Nodular cast iron:** In which by special alloy addition the carbon is largely uncombined in the form of compact spheroids.

- This structure offers from malleable iron is that it is obtained directly from solidification and round carbon particles are more regular in shape.

7.5.1 Gray Cast Iron

- A low-cost material that can be used for any purpose. Available to the foundry as virgin and selected scrap.

Mechanical properties

1. High compressive strength.
2. Low tensile strength.
3. High rigidity.
4. High stability after weathering.

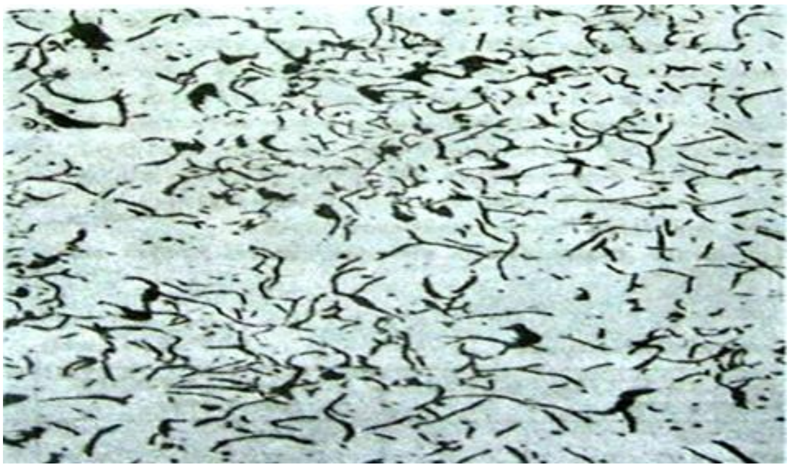

Fig.7.3 – Graphite flakes in gray cast iron

Casting Properties

1. High fluidity and ability to a male sound casting.
2. The relatively low melting temperature of 1130° - 1250° C.

Machinability

Easily machined to a good finish once the ‘skin’ has been removed forms a discontinuous chip.

Special Properties

1. Self-damping – does not vibrate.
2. Self-lubricating.
3. Good anti-friction properties.

Characteristics

1. Gray cast iron basically an alloy of carbon and silicon with iron.
2. It is readily cast into the desired shape in a sand mold.
3. It contains

Carbon	: 2.5-3.8%	Sulpher	: 0.009%
Silicon	: 0.101%	Manganese	: 0.4-1.0%
Silicon	: 1.1-2.8%	Sulpher	: 0.1%
Phosphorous	0.15%		

4. It is marked by the presence of graphite flakes in a matrix of ferrite or pearlite.
5. Graphite flakes occupy 10% of metal volume.
6. The length of flanks may vary from 0.05 to 0.1 mm.
7. When fractured a bar of gray cast iron gives a gray appearance.
8. It contains the lowest melting point of ferrous alloys.
9. It possesses high fluidity and hence it can be cast into complex shapes and thin sections.
10. It possesses better machinability then steel.
11. It has high resistance to wear.
12. It possesses high vibration damping capacity.
13. It has low ductility and low impact strength as compared to steel.
14. Gray cast iron has a solidification range of 2400º -2000º F
15. It has shrinkage of 1/8 inch/foot.(1mm/100mm)
16. It associated low cost combined with hardness and rigidity.
17. It possesses a high compressive strength.

Applications

- Machine tool structure (bed, frame, and details).
- Gear housing, pump housing, system turbine housing.
- Motor frame.
- Gas or water pipe for underground purposes.

- Manhole cover.
- Cylinder blocks and heads for IC engines, piston rings.
- Tunnel segments.
- Sanitary wares.
- Rolling mills and general machinery parts.
- Household applications.

7.5.2 Malleable Cast Iron

The purpose of malleabilisation is to convert all combine carbon (Fe3C) in white iron into irregular nodules of temper carbon (graphite) and ferrite. Commercially, this process is carried in two steps known as I and II steps of annealing.

Characteristics

1. Malleable cast iron is one that can be hammered and rolled to obtain different shapes.
2. Malleable cast iron is obtained from hard and brittle white iron through a controlled heat conversion process.
3. a) Ferritic malleable cast iron has a ferrite matrix.

   b) Pearlitic malleable cast iron has a pearlite matrix.

   c) An alloy malleable cast iron contains chromium and nickel and possesses high strength and corrosion resistance.
4. Malleable cast iron possesses high yield strength.
5. It has a high young's modulus and low coefficient of thermal expansion.
6. It possesses good wear resistance and vibration damping capacity.
7. It has shrinkage 1.5mm per 100mm.
8. It has a low moderate cost.
9. Chemical composition of malleable cast iron is

Carbon	: 2.0-3.0%	Manganese	: 0.25-0.55%
Silicon	: 0.6-1.4%	Sulpher	: 0.05%
Phosphorous	: less than 0.18%		

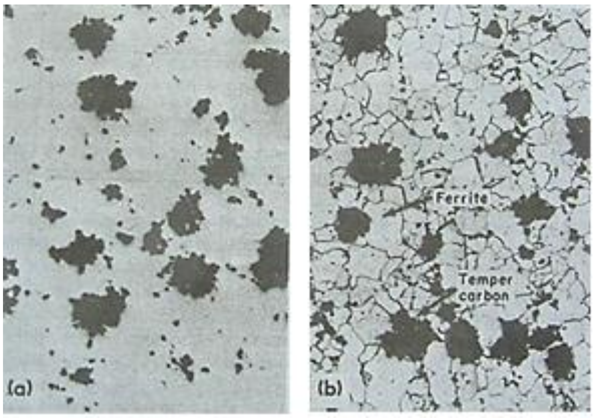

Fig.7.4 - a) Malleable iron unetched, irregular nodules of graphite called temper carbon

b) Ferritic malleable iron, temper carbon (black) in a ferritic matrix. Etched in 5% natal

*Table **7.1** - Tensile properties of malleable cast iron:*

Type	Tensile Strength 1000 PSI	Yield Strength 1000 PSI	Elongation % in 2 Inch	BHN
Ferritic	50-60	32-39	20-10	110-145
Pearlitic	65-120	45-100	16-20	163-269

Applications

- Axle and differential housing, camshaft and crankshaft in automobiles.
- Gears, chain link, sprockets, elevator brackets in conveyor equipment.
- Pumps, nozzles, cam, rocker arms as machine parts.
- Gun mounts, tank parts, pistol parts, etc and hammers wrenches, etc.

7.5.3 Nodular Cast Iron

- Nodular cast iron is known as ductile iron or spheroidal cast iron, which is cast iron in which graphite is present as spheroids or tiny balls.
- The compact spheroids interrupt the continuity of matrix much less than graphite flanks these results in higher strength and toughness compare with similar gray iron.
- Nodular cast iron differs from malleable iron in that it is usually obtained as a result of solidification and does not require heat treatment. The spheroids are more rounded than the irregular aggregates of temper carbon found in malleable iron.
- The total carbon content of nodular iron is the same as in gray cast iron.
- Spheroidal graphite particles form during solidification because of the presence of a small amount of alloying elements.
- The nodule forming addition, usually, magnesium or cerium is made to the ladle just before casting. Since these elements have a strong affinity for sulpher the base iron alloy sulpher content must be below 0.015% for the treatment to be effective and the alloy is described as 'desulphurized'.
- The amount of ferrite in the cast matrix depends on the composition and rate of cooling.
- Nodular iron with a matrix having a maximum 10% pearlite is known as 'ferritic iron'. This structure gives maximum ductility, toughness, and machinability.
- A matrix structure which is largely pearlite can be produced as cast or by normalizing.
- A martensite matrix may be obtained by quenching in oil or water from 1600°-1700° F. The quenched structure is usually tempered after hardening to the desired strength and hardness levels.
- Austenitic ductile irons are highly alloyed types that retain their austenitic structure down to at least -75° F. These irons are of interest because of their high corrosion resistance and good creep properties at elevated temperature.

  Chemical composition:

Carbon	**3.2-4.2%**	**Manganese**	**: 0.3-0.8%**
Silicon	: 1.1-3.5%	Sulpher	: 0.2%
Phosphorous	: 0.08%		

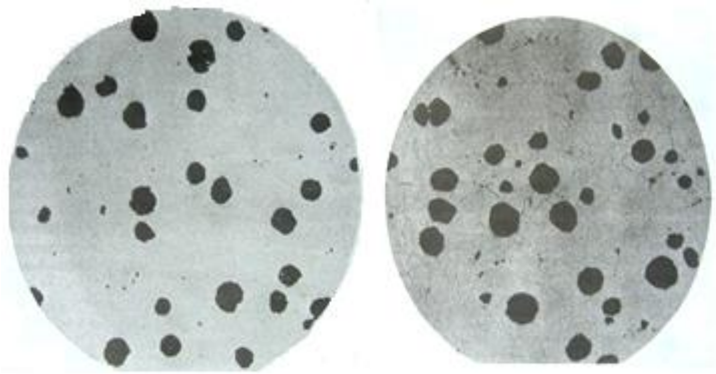

Fig.7.5 - a) Nodular iron unetched, showing spheroids.

b) Ferritic nodular iron showing graphite spheroids ferrite matrix, etched in 2% nital.

Applications

- Agricultural: Tractor and implement parts.
- Automotive and diesel: Crankshaft, piston, and cylindrical head.
- Electrical fittings: Switch box, motor frame, circuit breaker parts.
- Mining: Hoist drums, drive pulley, flywheel and elevator bracket.
- Steel mill rolls.
- Furnace doors.
- Bearings, tools and dies, wrenches.
- Miscellaneous dies for shaping steel, aluminum, bronze, and titanium.

7.5.4 White Cast Iron

- The typical microstructure of white cast iron consists of dendritic of transformed austenite (pearlite) in which interdendritic network of cementite. Higher magnification of some sample reveals that the dark areas are pearlite.
- Cementite is a hard, brittle interstitial compound. Since white cast iron contains a relatively large amount of cementite as a continuous interdendritic network, it makes the cast iron hard and wear resistance but extremely brittle and difficult to machine.
- White cast irons are limited in engineering applications because of brittleness and lack of machinability

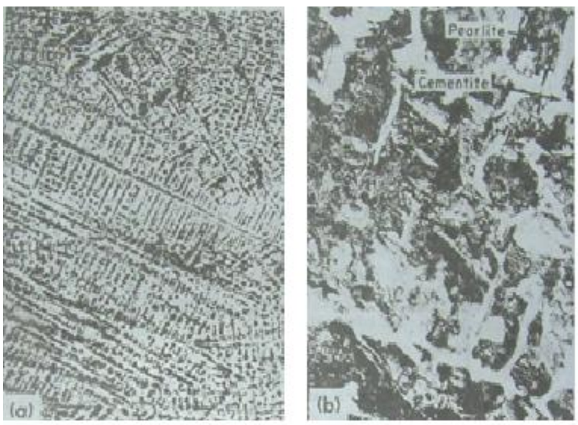

Fig.7.6 - white cast iron

- Examples: liners for cement mixers, ball mills, drawing dies, extrusion nozzles.
- It is used as a starting material for the manufacturing of malleable cast iron.
- Its freshly broken surface shows a bright white fracture.
- It contains

Carbon	:1.8-3.6%	Manganese	: 0.2-0.8%
Silicon	: 0.5-2.0%	Sulpher	: 0.1%
Phosphorous	: 0.18%		

- Shrinkage is 1mm per 100mm.
- Mechanical properties

BHN	: 375-600
Tensile strength	: 20000-70000 PSI
Compressive strength	: 200000-250000 PSI
Modulus of elasticity	: 24-28 million PSI

7.5.5 Chilled Cast Iron

- Chilled cast iron is obtained by casting the molten metal against a metal chiller, resulting in a surface of white cast iron.

Fig.7.7 –Fracture of chilled iron casting showing the white, mottled and gray portions

- This hard abrasion-resistant white cast iron surface of the core is backed up by a soft gray iron core. This core structure is obtained by careful control of overall alloy composition and adjustment of cooling rate.
- Freezing starts first, and the cooling rate is most rapid where the molten metal is in contact with mold walls. The cooling rate decreases as the center of casting is approached. Chilled cast iron may be produced by adjusting the composition of the iron so that the normal cooling rate at the surface is just enough to produce white iron while the slower cooling rate below the surface will produce gray iron.
- Chromium 1-4% is used in a small amount to control chill depth. It increases hardness and abrasion resistance.

Applications

- Railway car wheels.

- Crushing rolls.
- Stamp shoe and die.
- Sprockets.
- Heavy-duty machine parts.

7.5.6 Alloy Cast Iron

- An alloy cast iron is one in which contain specially added element to produce a measurable modification in the physical or mechanical properties.
- Alloying elements may be silicon, manganese, sulpher, phosphorous, chromium, copper, nickel and vanadium.
- Alloying elements are added to cast iron for special properties such as; Resistance to corrosion, heat and wear resistance, improve mechanical properties, etc.
- Chromium increases combined carbon by forming complex iron-chromium carbides that are stable than iron carbides. A small amount of chromium increases strength, hardness, depth of chill and resistance to wear and heat but decreased machinability.
- Copper is graphitized. Copper content is 0.25-2.5%. Copper tends to break up massive cementite and strength than the matrix.
- Molybdenum improves mechanical properties and ranges from 0.25- 1.25%. It increases fatigue strength, tensile strength, heat resistance, and hardness and hardenability.
- Vanadium is a powerful carbide former and ranges from 0.1-0.25%. It increases tensile strength, transverse strength, and hardness.
- Nickel is a graphitize. The purpose of nickel (0.5-0.6%) in engineering gray iron is to control the structure by retarding austenite transformation, stabilizing pearlite and maintaining combined carbon at the eutectoid quality.
- For excellence abrasion resistance about 4% nickel in combination with 1.5% chromium is added to white cast iron. Hardness 600-750 BHN along with good strength and toughness.
- Addition of 14-38% nickel to gray cast iron results in high heat resistance, high corrosion resistance, and low expansivity.

7.6 Plain Carbon Steel

- Plain carbon steel is an alloy of iron and carbon and it is malleable.
- Carbon steel is different from cast iron regarding % of carbon
- Carbon steel : 0.10 to 1.50 % carbon
- Cast iron: 1.80 to 4.20% carbon

Types of Steel

1. Low carbon steel (Mild steel).
2. Medium carbon steel.
3. High carbon steel.

7.6.1 Low Carbon Steel

a. Dead Mild Steel

- Carbon: 0.05 – 0.15 %.
- Application: steel wire, sheets, rivets, screw, pipe, chain.
- Tensile strength 390 N/mm2 and hardness 115 BHN.

b. Mild Steel:

- Carbon: 0.15 – 0.20 %.
- Application: camshaft, fan, blades, welded tubing, draglines.
- Tensile strength 420 N/mm2 and hardness 125 BHN.

c. Mild Steel

- Carbon: 0.20 - 0.30%.
- Application: gears, crankshaft, connecting rod, railway axle, forging components, etc.
- Tensile strength 555 N/mm2 and hardness 140 BHN.

7.6.2 Medium Carbon Steel

- Carbon : 0.3-0.70 %
- Steel with carbon 0.35-0.35% having tensile strength 750 N/mm2
- Application: connecting rods, gear shaft, spring clips, axles, small and medium forging, etc.
- Steel with carbon 0.45- 0.55% having tensile strength 1000 N/mm2
- Application: axles, spline shaft, railway coach, crankshaft
- Steel with carbon 0.60-0.70% having tensile strength 1230 N/mm2 and hardness 400-450 BHN.
- Application: die blocks, punch plate, drop forging dies, valve springs, set screws, self-tapping screw, etc.

7.6.3 High Carbon Steel

- Carbon: 0.7 – 1.5%
- Steel with carbon 0.70 - 0.80 % having tensile strength 1400 N/mm2 and hardness 450-500 BHN.
- Application: cold chisels, pneumatic drill, wrenches, a jaw of vices, wire for structural work, shear blades, etc.
- Steel with carbon 0.80 - 0.90 % having tensile strength 660 N/mm2 and hardness 500-600 BHN.
- Application: rock drill, railway rails, machine chisels, punch and dies, leaf spring, music wire, etc.
- Steel with carbon 0.90 - 1.0 % (high carbon tool steel) having tensile strength 580 N/mm2 and hardness 500-600 BHN.
- Application: punch and dies, springs, shear blades, keys, etc.
- Steel with carbon 1.0 - 1.1 %
- Application: machine tool, tap, mandrels, railway spring, etc.
- Steel with carbon 1.1 - 1.2 %
- Application: tap, thread metal die, twist drill, etc.
- Steel with carbon 1.2 - 1.3 %

- Application: file, reamer, metal cutting tool, etc.
- Steel with carbon 1.3 - 1.5 %
- Application: wire drawing dies, tools for turning chilled iron, metal cutting saws, etc.

7.7 Alloy Steel

Plain carbon steels are very satisfactory when strength and other requirements are not too serve.

They are also used successfully at ordinary temperatures and in an atmosphere that is not highly corrosive but their relatively low hardenability limits the strength that can be obtained except in firmly thin sections.

Most of the limitations of plain carbon steels may be overcome by the use of the alloying elements

Definition

Steel is considered to be an alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits:

Manganese	: 1.65% (In plain carbon steel up to 0.90%)
Silicon	: 0.60% (In plain carbon steel up to 0.30%)
Copper	: 0.60%

Alloying elements alter the properties of steel and put it into a slightly different class from ordinary carbon steel.

Purpose of alloying

1 Increase hardenability.

2 Improve the strength of ordinary temperature.

3 Improve mechanical properties at high or low temperatures.

4 Improve toughness at any minimum hardness or strength.

5 Increase wear resistance.

6 Increase corrosion resistance.

7 Improve magnetic properties.

Effect of Alloying Elements

1. Carbon

- Carbon content in steel effects in hardness, tensile strength, machinability, and melting point.

2. Nickel

- Nickel increase toughness and resistance to impact.
- Lessens distortion in quenching.
- It lowers the critical temperature of steel and widens the range of successful heat treatment.
- Strengthens steels.
- It does not unite with carbon.

3. Chromium

- Joins with carbon to form chromium carbide, thus adds to depth hardenability with improved resistance to abrasion and wear.

4. Silicon

- Improve oxidation resistance.
- Strengthens low alloy steels.
- Act as a deoxidizer.

5. Titanium

- Prevents localized depletion of chromium in stainless steel during long heating.
- Prevents the formation of austenite in high chromium steels.
- Reduce martensite hardness and hardenability in medium chromium steels.

6. Molybdenum

- Promotes the hardenability of steel.
- Make steel fine-grained.
- It makes steel unusually tough at various hardness levels.
- Counteracts tendency towards temper brittleness.
- Raise tensile and creep strength at high temperatures.
- Enhance corrosion resistance in stainless steel.
- Forms abrasion resisting particles.

7. Vanadium

- Vanadium (0.15-0.5%) added to steel.
- It is a powerful carbide former.
- Stabilizers cementite and improves the structure of the chill.
- Promotes fine grains in steel.
- Increase hardenability.
- Imparts strength and toughness to heat-treated steel.
- Causes marked secondary hardening.

8. Tungsten

- Increase hardness.
- Promotes fine grain.
- Resists heat.
- Promotes strength at elevated temperatures.

9. Manganese:

- Contributes markedly to strength and hardness.
- Counteracts brittleness from sulpher.
- It lowers both ductility and weldability if it is present in a high percentage with high carbon content in the steel.

10. Copper

- Copper (0.2-0.5%) added to steel.
- Increase resistance to atmospheric corrosion.

- Acts as a strengthening agent.

11. Boron

- Increase hardenability or depth to which steel will harden when quenched.

12. Aluminum

- Acts as a deoxidizer.
- Produces fine austenitic grain size.
- If present in an amount of 1% it helps to promote nitriding.

13. Cobalt

- Improves mechanical properties such as tensile strength, fatigue strength, and hardness.
- Refines the graphite and pearlite.
- It is a mild stabilizer of carbides.
- It improves heat resistance.
- Retards the transformation of austenite and thus increases hardenability and freedom from cracking and distortion.

7.8 Popular Alloy Steel

Nickel Steel

- It contains
- Carbon: 0.35% , Nickel: 3.5%
- The addition of nickel to structural steel results in an increase of strength, without a proportionality great decrease of ductility.
- Nickel steels are used for storage cylinder for liquefied gases and other low-temperature applications.
- Other uses of nickel steels are heavy forging, turbine blades, high stressed screws, bolts, and nuts (40 Ni 3 steel).

Chromium Steel

- Chromium is a less expensive alloying element than nickel and forms simple carbide (Cr7C3, Cr4C) or complex carbides [(FeCr) 3C].
- These carbides have high hardness and good wear resistance.
- It increases tensile strength and corrosion resistance of low alloy steel

% Of Cr in Steel	Use
8	Electrical use
15	Spring ball and roller bearing

Nickel- Chromium Steel

- Chromium – nickel steel combines the effect of nickel (Increasing toughness and ductility) and chromium (Improving hardenability and wear resistance).
- The low carbon nickel-chromium alloy steel is carburized. The chromium supplies the wear resistance to the case, while both alloying elements improve toughness.
- With 1.5% nickel and 0.6%, chromium steel is used for worm gears and piston pins, etc.

- With 3.5% nickel and 1.5% chromium steel used as heavy-duty applications such as aircraft gears, shafts, cams, etc.
- Medium carbon nickel-chromium steels are used in the manufacture of automotive connecting rods and drive shafts.

Molybdenum Steel

- Molybdenum is a relatively expensive alloying element.
- Molybdenum has a strong effect on hardenability and increases the high hardness and strength of steels.
- The plain molybdenum steel with low carbon content is generally carburized and used for alpine shaft and transmission gears.
- With higher carbon, they are used for automotive coil and leaf springs.
- Chromium-molybdenum steels are relatively cheap and posses good deep hardening characteristics, ductility, and weldability. They have been used for pressure vessels, aircraft, structural parts, automobile axles, and other applications.
- Nickel – molybdenum steel has the advantage of the high strength and ductility from nickel combined with deep hardening and improved machinability by molybdenum. They have good toughness combined with high fatigue strength and wear resistance.
- Application: gear, chain, pins, shafts, bearing, etc.
- Nickel – chromium-molybdenum steels are used for the structural parts of wings assembly and loading gears.

7.9 Tool Steel

Tool steel is defined as special steel used for cutting or forming purposes.

Classification

1 According to quenching media

a. Water hardening steel.

b. Oil hardening steel.

c. Air hardening steel.

2 According to the alloy content

a. Carbon tool steel.

b. Low alloy tool steel.

c. Medium alloy tool steel.

3 According to application

a. Hot work steel.

b. Shock resisting steel.

c. High-speed steel.

d. Cold work steel.

Table 7.2 - AISI suggest group and symbol of tool steel

Group	Symbol & Type
Water hardening	W
Shock resisting	S
Cold work	O – Oil hardening A – Medium alloy air-hardening D – High carbon, high chromium
Hot work	H: H1 – H19 Chromium base H_{20} – H_{39} Tungsten base H_{40} – H_{59} Molybdenum base
High speed	T – Tungsten base M – Molybdenum base
High speed	T – Tungsten base M – Molybdenum base
Mold	P – Mold steel
Special purpose	L – Low alloy F – carbon-tungsten

Application of tool steel

- A cutting tool like a drill, reamer, etc. (multi cutting tool).
- Shearing tool use for shear, punch, and blanking die.
- Drawing and extrusion die.
- Thread rolling die.
- Single cutting tool in lathe and planning machine.

High-speed tool steel

- These steels are the most highly alloyed of the tool steel usually contain a large amount of tungsten or molybdenum along with chromium, vanadium and sometimes cobalt. Carbon content varies from 0.7 – 1.0% and sometimes up to 1.5%.
- Application of high-speed steel is for cutting tools also they are used for making extrusion dies, burnishing tools and blanking punches and dies.

Properties

- Excellent red hardness (tool can operate at high temperatures).
- Good shock resistance.
- Good wear resistance.
- Fair machinability.
- Fair to poor resistance to decarburization.

Types

1. Molybdenum base (Group M).
2. Tungsten base (Group T).

- Tungsten base is known as 18 – 4 – 1
- 18% tungsten, 4% chromium, 1% vanadium.
- Molybdenum base is known as 6 – 6 – 4 – 2
- 6% molybdenum, 6% tungsten, 4% chromium, 2% vanadium.
- Molybdenum steel is lower in price, so over 80% of H.S.S. is produced of molybdenum type steel.
- When better than average red hardness is required, steel containing cobalt is recommended.
- Higher vanadium content is desirable when the material cut is highly abrasive.
- In T-15 steel, a combination of cobalt and vanadium provides red hardness and abrasion resistance.
- Application: cutting tools such as tool bits, drills, reamers, broaches, milling cutters, hobs, saws, woodworking tools, etc.

7.10 Stainless Steels

- Concept: When 11.5% or more chromium is added to iron, a fine film of chromium oxide forms spontaneously on the surface exposed to air. The film acts as a barrier to retard further oxidation, rust or corrosion. As these steel cannot be strained easily it is called stainless steel.
- A three numerical numbering system is used to identify stainless steel. The last two numbers have no particular significance but the first number indicates the group as follows.

Table 7.3 - Significance of stainless steel

Series Designation	Groups
2XX	Chromium, nickel – manganese, not hardenable, austenitic, nonmagnetic
3XX	Chromium – nickel, non hardenable, austenitic, non magnetic
4XX	Chromium, hardenable, martensitic, magnetic
4XX	Chromium, not hardenable, ferritic, magnetic
5XX	Chromium, low chromium, heat-resisting

1. Martensitic Stainless Steel

- These steels are primarily straight chromium steel containing 11.5 – 18% chromium.
- Example: 403, 410, 416, 420, 440, 501 and 502.
- 410 and 416 are the most popular alloys in this group and used for turbine blades and corrosion-resistant casting.
- Martensitic stainless steel is identified by its martensitic microstructure in the hardened condition.
- The heat treatment process for martensitic steel is the same as for plain carbon or low alloy steel where strength and hardness depend upon carbon content.
- These steels are magnetic in all conditions and possess the best thermal conductivity of the stainless steel types.
- Application: springs, machine parts, pumps, shafts, ball bearings, aircraft fittings, valve parts, and surgical instruments.

2. **Austenitic Stainless Steel**

- These are chromium-nickel stainless steel (type 3XX) and chromium-nickel – manganese stainless steel (type 2XX).
- These types are austenitic and non-magnetic in the annealed condition and do not harden by heat treatment.
- They can be hot worked and cold worked.
- Extremely shock resistance and difficult to machine (303, 303E).
- Best high-temperature strength and resistance to scaling of the stainless steel.
- The corrosion resistance of austenitic steel is usually better than that of martensitic or ferritic steels.
- Application: aircraft industries, chemical processing industries, food processing industries, household items, transportation industries.

3. **Ferritic Stainless Steel**

- This group of straight chromium stainless steels contains approximately 14 – 27% chromium and includes types 405, 430 and 446.
- Low in carbon content and higher in chromium than martensitic grades.
- Not hardened by heat treatment.
- They are magnetic and can be cold work or hot worked but they develop their maximum softness, ductility and corrosion resistance in the annealed condition.
- The only heat treatment applied to truly ferritic steel is annealing. This treatment serves primarily to relieve welding or cold working stresses.
- Application: lining for petroleum industries, heating element for furnaces, interior decorative work, screws and fitting, oil burner parts.

7.11 References

Sidney H Avner " Introduction to Physical metallurgy 2nd Edition 2011 Tata Mc Graw- Hill Publication.

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