3. METALLURGY OF IRON AND STEEL

OCCURRENCE:

Among the metals, iron comes next only to aluminium in abundance on the earth’s surface. Iron is one of the most widely distributed and abundant metals, constituting about 4.6 % of the earth’s crust. Native iron is found in the meteoritic masses and it is known as meteoric iron. Iron is found in the different forms as follows.

1) Magnetite: Fe₃O₄, Ferroso ferric oxide. It contains 72% iron. This is known as magnetic because it is magnetic in nature. It is reducible with some difficulty. It is a steel gray in colour and rather hard. This ore is comparatively pure and gives iron of high quality

![Magnetite Image]

(ii) Haematite: Fe₂O₃, Ferric oxide. It contains 70% iron. It is red coloured ore and easily reducible. It occurs in large quantities and it is mainly used for the extraction of iron.

![Haematite Image]

(iii) Limonite: 2Fe₂O₃.3H₂O, Hydrated ferric oxide. It has brown colour and it has also called brown haematite. It contains about 60% iron.

![Limonite Image]
(iv) **Carbonate ore**: FeCO₃, ferrous carbonate. When pure it is known as siderite or spathic iron ore. When it is mixed with clay, it is known as clay iron stone. But when it is mixed with clay and coal, it is known as black band iron stone. It may contain about 40 to 45% iron.

(v) **Pyrites**: FeS₂, iron pyrites. Iron sulphide or fools gold are also quite abundant, but they can’t be used as source of iron because sulphur is an objectionable impurity in the final product.
COMMERCIAL FORMS OF IRON

There are three commercial varieties of iron which are put to different industrial uses. These varieties are; i) Cast iron, ii) Wrought iron, iii) Steel. The three varieties differ from each other mainly in their carbon content.

i) **Cast iron**: contains 2.5 to 5 % of carbon as well as other impurities.

ii) **Wrought iron**: contains less than 0.5 % of carbon as well as other impurities. It is the purest form of iron.

iii) **Steel**: its carbon contents are in between cast iron and wrought iron. Its carbon content varies between 0.4 to 1.5 %. Any alloy of iron and carbon, containing more than 2 % of carbon is defined as pig iron. Besides carbon, it also contains varying properties of silicon, which affects the final structure of the solidified product. When this material is being melted for pouring into casting or is in the form of casting, it is called cast iron. Thus, chemically, there is not much difference between pig iron and cast iron.

METALLURGY OF IRON:

The extraction of cast iron from iron ore involves the following stages:

(i) **Concentration**: The ore is associated with sand, clay and other extraneous matter. Hence, the ore is washed on the iron grids under a stream of water to remove clay, sand and other extraneous matter. The washed ore is finely pulverized and passed over powerful magnets which separates iron bearing sand from the nonmagnetic material. Thus the ore is concentrated.

(ii) **Calcination**: The concentrated ore is then calcined (heated in the presence of air) in open heaps or in specially designed shallow kilns. The following changes take place during calcinations.

   a) Moisture is removed and any organic matter present burns off to give carbon dioxide.
   b) Impurities like sulphur and arsenic are removed in the form of their volatile oxides.
   c) The carbonate ore is decomposed to oxide.
(d) The ferrous oxide is converted to ferric oxide. It is necessary to avoid the formation of fusible ferrous silicate in slag during smelting.

(e) The ore becomes porous which is then easily acted upon by reducing agent in the blast furnace.

(iii) Smelting or Reduction: The calcined ore is then smelted i.e. reduced with carbon in presence of flux to remove siliceous impurities. The operation is carried out in a special furnace known as blast furnace.

Blast furnace:

It is a tall cylindrical furnace about 20 to 30 meters high and about 4 to 8 meters wide at the broadest part. It is made up of fireclay refractory bricks and has an outer shell made up of steel plates. The upper part of the blast furnace is known as the throat, middle part is known as body and lower portion is known as hearth. The furnace increases in diameter from the throat downwards until it has attained a maximum diameter at the bosh. From the bosh downwards, diameter of furnace contracts more rapidly up to twyers and then it becomes nearly cylindrical. It remains this form even upon the bottom.
The mouth of the furnace is closed by means of cup and cone arrangement. Large furnaces are provided with double cup and cone feeder, one of them being closed when the other is opened, thus preventing the furnace gases from escaping. About 2.5 meters above the base of the furnace, there are series of tubes called twyers, through which a blast of preheated air, at a temperature of about 800°C, is blown into the furnace. Near the bottom of the blast furnace, there are two outlets one above the other. The upper outlet is used to remove the slag and the lower is used to take out the molten metal. There is exit for the waste gases near the top of the furnace.

The charge, consisting of calcined ore (8 parts), CO (4 parts) and limestone (1 part), is taken to the top of the furnace and allowed to fall upon the upper cone which is lowered to admit the charge into the air-lock. The upper cone is then raised, furnace top and the lower cone is lowered to admit the charge into the furnace. The loss of hot gases during the process of charging is thus minimized. The hot blast of air, at a temperature of 800°C, is blown into the furnace through the twyers at the rate of about 20,000 cu.meter of air per minute and at a pressure of 1 kg/sq. cm. if the hot blast of air contains some water vapours, there is a considerable absorption of heat on account of the following endothermic reaction that may take place in the lower part of the furnace.

\[
C + H_2O \rightarrow CO + H_2 - 29 \text{kcal}
\]

Hence dried blast should not contain more than 2 % moisture. 9 to 10 % saving of fuel is reported to be affected by drying the blast.

**Physico-chemical principle involved during reduction of iron oxide**

The concentrated and calcined hematite ore is mixed with limestone and coke, and melted in a blast furnace to obtain cast iron. A hot blast of air is introduced into the furnace through the twyers. The adjacent layer of the coke burns vigorously in the presence of oxygen of the hot blast. In other words, oxygen of the hot blast of air oxidizes coke to carbon dioxide with the evolution of a considerable amount of heat. It is an exothermic reaction.

\[
C + O_2 \rightarrow CO_2 + 97 \text{Kcal}
\]

The hot gases containing CO\(_2\), then pass up through the hot layer of coke when CO\(_2\) is reduced to carbon monoxide as
\[ \text{CO}_2 + \text{C} \rightarrow 2\text{CO} - 41.2 \text{ Kcal} \]

The above reaction is endothermic. The part of the furnace where this reaction occurs is known as the zone of heat absorption. The temperature of the furnace is, therefore, not constant at all levels. It is maximum at the hearth and diminishes slowly towards the throat of the furnace where it is about 300 °C. In the above reaction, the volume of the product is more than that of the reactants. Hence an increase of the temperature and a decrease of pressure leads to a greater formation of carbon monoxide. It has been found experimentally that at 1000 °C the gas phase contains 99% CO and 1% CO\(_2\).

Theoretically, at lower temperature, i.e. in the upper part of the furnace, CO should decompose to CO\(_2\) and carbon. However, because of the pressure of iron oxide, the reduction of oxide by CO takes place, and decomposition of CO is prevented. In other words, equilibrium of the reaction, shifts towards right as CO is removed for the reduction process.

\[ \text{CO}_2 + \text{C} \rightarrow 2\text{CO} \]

It has been experimentally found that below 700 °C, CO is the best reducing agent and above 700 °C, C is the best reducing agent. Since the lower part of the furnace has a temperature above 700 °C, the reduction of iron oxide will takes place by carbon in this part. In the upper part CO will reduce iron oxide. In order to achieve maximum reduction by CO in the upper part of the furnace, the mixture of CO and CO\(_2\) should be richer in CO. This can be achieved by increasing the total pressure of the mixture by putting a valve in the upper part of the furnace and also by making the shape of the furnace, tapering at the top.

The reduction of iron oxide with CO is possible at low temperature, provided the total pressure is low. The reaction may be represented as follows.

\[
\begin{align*}
\text{(a) } 3 \text{Fe}_2\text{O}_3 + \text{CO} & \rightarrow 2\text{Fe}_3\text{O}_4 + \text{CO}_2 + 16.2 \text{ kcal} \\
\text{(b) } \text{Fe}_3\text{O}_4 + \text{CO} & \rightarrow \text{3FeO} + \text{CO}_2 - 4.16 \text{ kcal} \\
\text{(c) } \text{FeO} + \text{CO} & \rightarrow \text{Fe} + \text{CO}_2 + 3.4 \text{ kcal} \\
\text{(d) } \text{Fe}_3\text{O}_4 + 4\text{CO} & \rightarrow \text{3Fe} + 4\text{CO}_2 + 6.04 \text{ kcal}
\end{align*}
\]

Since the dissociation pressure of the Fe\(_2\)O\(_3\) is comparatively high, the reaction (a) is practically irreversible. Therefore it gets completed even in the presence of a small amount of CO. The study of graph of percentage of CO in CO + CO\(_2\) mixture Vs temperature leads to the following observations. According curve AB, if a limited quantity
of pure CO is in contact with FeO and Fe at 900 °c, iron oxide will be reduced until the gases contain 68% CO and 32% CO₂. in the other word only one third of CO is available for reduction purposes. At the same temperature according to the curve AE, the equilibrium mixture over FeO and Fe₃O₄ is 18% CO and 82% CO₂. Whereas the equilibrium mixture over Fe₃O₄ and Fe₂O₃ is under 1% CO.

Any iron oxide, which escapes reduction by CO in the upper part, undergoes direct reduction by carbon at the high temperature prevalent in the lower region of the furnace.

\[
\text{Fe}_2\text{O}_3 + 3 \text{ C} \rightarrow 2\text{Fe} + 3\text{CO} + 108\text{ kcal.}
\]

Most of the iron oxide is reduced in the upper part of the furnace. It is, therefore, called the zone of reduction; here the temperature limit is from 300 °c to 800 °c. Below this, is the region where heat is absorbed and it is due to the changes of CO₂ to CO. it is known as zone of heat absorption.

![Equilibrium concentration of CO in reduction of iron oxides](image)

Here the temperature limit is between 800°c to 1200°c. Near the hearth is the zone of high temperature whereas the slag as well as the metal are obtained in the molten condition. It is therefore known as the zone of fusion. Here the temperature limit is from 1200°c to 1500 °c.
Reactions in the blast furnace:

The charge consisting of calcined ore, coke and limestone in the proportion of 8:4:1 is admitted into the blast furnace through the cup and cone arrangement feeder. It takes appreciable time in descending the furnace. As the charge descends, it meets the reducing gases, mainly carbon monoxide ascending from the lower part of the furnace. The ascending gases warm up the descending charge. The reactions in the various zones are as follows.

(A) Zone of Reduction: (300 °C to 800 °C i.e dull red heat)

CO reduces ferric oxide to the metallic stage.

\[ \text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2 \]

This reduction of ferric oxide continues with increasing speed as the charge descends to the hotter part of the furnace. The reaction is not so simple but it is a sum of the various reactions taking place in stages.

(i) At the top of the furnace, where the charge is heated between 300 °C to 500 °C, Fe₂O₃ is converted into Fe₃O₄.

\[ 3\text{Fe}_2\text{O}_3 + \text{CO} \rightarrow 2\text{Fe}_3\text{O}_4 + \text{CO}_2 \]

This Fe₃O₄ is stable up to 650 °C in presence of CO, CO₂ and free coke.

(ii) At temperature between 650 °C to 700 °C, Fe₃O₄ is converted into FeO.

\[ \text{Fe}_3\text{O}_4 + \text{CO} \rightarrow 3\text{FeO} + \text{CO}_2 \]

(iii) At temperature between 700 °C to 800 °C, FeO is reduced to metallic iron.

\[ \text{FeO} + \text{CO} \rightarrow \text{Fe} + \text{CO}_2 \]

And simultaneously the limestone, present in the charge, is also decomposed to produce lime.

\[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]

In short, iron oxide gets reduced in stages as follows,
The metal produced is at first spongy. But simultaneously with the process of reduction, a part of metallic iron reacts with CO to form ferric oxide or ferroso- ferric oxide.

\[
\begin{align*}
2 \text{Fe} + 3 \text{CO} & \rightarrow \text{Fe}_2\text{O}_3 + 3 \text{C} \\
3 \text{Fe} + 4 \text{CO} & \rightarrow \text{Fe}_3\text{O}_4 + 4 \text{C}
\end{align*}
\]

(B) Zone of heat absorption: (800 °C to 1200 °C i.e. bright red heat).
Iron oxide is reduced by red hot carbon,

\[
\text{Fe}_2\text{O}_3 + 3 \text{C} \rightarrow 2\text{Fe} + 3 \text{CO} + 108 \text{ kcal}
\]

The hot spongy iron meets the ascending carbon monoxide and decomposes a part of it to produce a finely divided carbon.

\[
2 \text{CO} \rightarrow \text{CO}_2 + \text{C}
\]

This finely divided carbon thus remains enclosed in the spongy iron. In this zone, lime obtained at the end of the first zone by the decomposition of limestone, combines with silica and forms calcium silicate, a slag.

\[
\text{CaO} + \text{SiO}_2 \rightarrow \text{CaSiO}_3 \text{(slag)}
\]

If the ore originally contains phosphates, these are also reduced to elementary phosphorus which then alloys with iron.

\[
\begin{align*}
\text{Ca}_3(\text{PO}_4)_2 + 3 \text{SiO}_2 + 5 \text{C} & \rightarrow 3 \text{CaSiO}_3 + 2 \text{P} + 5\text{CO} \\
3 \text{Fe} + \text{P} & \rightarrow \text{Fe}_3\text{P}
\end{align*}
\]

A little sulphur obtained by the reduction of iron sulphide present in coke also mixes with iron. Manganese is also formed by reduction of manganese compounds present in the ore.

\[
\text{Mn}_2\text{O}_3 + 3\text{C} \rightarrow 2 \text{Mn} + 3 \text{CO}
\]

At high temperature, some elementary silicon is formed by the reduction of silica by carbon in presence if iron and alloys with iron.

\[
\text{SiO}_2 + 2 \text{C} + (\text{Fe}) \rightarrow \text{Si} + 2 \text{CO} + (\text{Fe})
\]

Thus, in this zone of bright red heat, iron is mixed with C, P, S, Mn and Si and becomes impure.
(C) Zone of Fusion: (1200 °C to 1500 °C i.e white heat):

The melting point of this impure iron is lower (1250 °C to 1300 °C) than that of pure iron (1530 °C). The temperature of the blast furnace is not sufficient to melt pure iron but it is sufficient to melt this impure iron. Therefore, impure iron melts in the zone of fusion and the molten iron trickles down and is collected into the well of the furnace below the tuyers.

Calcium silicate, CaSiO$_3$ (slag) that is formed in the zone of absorption also melts at a temperature of 1200 °C to 1250 °C and is also collected in the well of the furnace. This molten slag floats over the molten metal as it is lighter than the molten iron. The slag, when it, forms the upper layer, automatically protects molten iron from oxidizing action of the hot air blast.

The molten metal is withdrawn at the regular intervals through the lower tap hole and is sent into sand moulds or is sent to the steel furnaces directly. This iron is known as pig iron or cast iron and is the most impure form of iron. The molten slag is removed periodically through the upper tap hole.

At regular intervals, the air blast is stopped and the furnace is allowed to let off the molten metal and the molten slag.

**WROUGHT IRON**

Wrought iron is the purest form of iron. It is also known as malleable form of iron. It contains not more than 0.5% impurities. A typical quantity of wrought contain 0.1% C, 0.1% Mn, 0.08 to 0.16% P, 0.02 to 0.035% S and 0.1 to 0.2% Si.

**Manufacture of Wrought Iron:**

It is obtained by purifying cast iron by the process known as ‘puddling’ (meaning-stirring). The cast iron is heated on the hearth of reverberatory furnace lined with hematite (Fe$_2$O$_3$). This reverberatory furnace is also known as puddling furnace. Heat supplied by reflection from the roof of the furnace falls upon the charge placed on the hearth. The cast iron is melted and stirred. The impurities in the pig iron namely C, Si, Mn & P are oxidised to CO, SiO$_2$, MnO$_2$ and P$_2$O$_5$ respectively by oxygen supplied by haematite.
CO escapes. MnO₂ and SiO₂ combines to form MnSiO₃ (slag)

Phosphorus pentoxide combines with haematite to form ferric phosphate slag.

\[
\text{Fe}_2\text{O}_3 + \text{P}_2\text{O}_5 \rightarrow 2\text{FePO}_4 \text{ (slag).}
\]

**Fig: Reverberatory furnace for wrought iron manufacture**

Due to removal of impurities, the melting point of the iron rises and it becomes a pasty mass. It is obtained in the form of balls, weighing about 70 pounds. These balls are beaten under steam hammers or squeezed between the jaws of mechanical squeezer, to remove as much as possible. The iron so obtained is called wrought iron.

**PROPERTIES OF WROUGHT IRON:**

i) Wrought is gray in colour.

ii) It is fibrous in structure.
iii) It is soft, ductile and malleable.
iv) It can be forged as well as welded.
v) The presence of small amount of slag gives strength and toughness to the metal and makes it resistant towards rusting and corrosion.
vi) It does not harden when heated to redness and quenched in water.

USES OF WROUGHT IRON:

Wrought iron is used in manufactured of articles which are to be subjected to sudden stresses, such as chains, wires, anchors, bolts, nails, the coupling for railway carriages. It is also used in making cores of electromagnets

STEEL:

Manufacture of steel from pig iron: There are three methods for manufacture of steel.
i) Bessemer process
ii) Open-hearth process
iii) L.D. process

I) BESSEMER PROCESS:

This process was first introduced in steel industry by Henry Bessemer in 1856. The process is carried out in a large egg shaped vessel called as Bessemer converter. The converter is made up of steel plates. It is provided with a number of holes at the base to admit a hot blast of air. It is mounted on trunion so that it can be tilted into different positions:

(a) For charging (b) For blowing (c) For pouring out the product.

Bessemer converter is lined with silica (Acid Bessemer process) or with lime and magnesia (Basic Bessemer).

(A) Acidic Bessemer process:

In the Acidic Bessemer process, the converter is lined with silicious refractory material which is acidic in nature. To start with, the converter is turned into the horizontal position and molten pig iron from the blast furnace is introduced into it.
A hot blast of air is introduced through the holes of the bottom of the converter and it is then thrown back into the vertical position. The blowing of air is continued. As the air passes upwards through the molten metal, the oxidation of impurities present in pig iron takes place as,

\[
\begin{align*}
2 \text{Mn} + \text{O}_2 & \rightarrow 2 \text{MnO} \\
\text{Si} + \text{O}_2 & \rightarrow 2 \text{SiO}_2 \\
2 \text{C} + \text{O}_2 & \rightarrow 2 \text{CO} \\
2 \text{S} + \text{O}_2 & \rightarrow 2 \text{SO}_2
\end{align*}
\]

The oxides of silicon and manganese combine to form a slag of manganese silicate.

\[
\text{MnO} + \text{SiO}_2 \rightarrow \text{MnSiO}_3 \text{ (slag)}
\]

A little amount of iron is also oxidized to ferric oxide but it gets readily reduced by carbon present in the cast iron.

\[
\begin{align*}
4 \text{Fe} + 3 \text{O}_2 & \rightarrow 2 \text{Fe}_2\text{O}_3 \\
\text{Fe}_2\text{O}_3 + 3 \text{C} & \rightarrow \text{Fe} + 3 \text{CO}
\end{align*}
\]

Ferric oxide formed above also oxidizes manganese and silicon to their respective oxides.

\[
\begin{align*}
3 \text{Mn} + \text{Fe}_2\text{O}_3 & \rightarrow 3 \text{MnO} + 2 \text{Fe} \\
3 \text{Si} + \text{Fe}_2\text{O}_3 & \rightarrow 3 \text{SiO}_2 + 4 \text{Fe}
\end{align*}
\]

The two oxides combine with each other to form slag MnSiO\textsubscript{3}. The CO produced in the above reaction burns at the mouth of the converter with a blue flame with orange red tinge and throwing out showers of sparks. When whole of the carbon is oxidized, the blue flame suddenly dies down. The requisite amount of carbon in the form of spiegeleisen (an alloy containing iron, Manganese and Carbon) is added to the molten metal. The blast is continued for a moment to ensure complete mixing. C and Mn first act as oxidizers and reduce any ferrous oxide present.

The excess of C & Mn dissolves in the molten iron to form steel. Sometimes, a little Al is added to the molten steel. Al & Si serves as scavengers. Their function is to reduce any dissolved CO in the molten steel to C. Aluminium removes nitrogen by forming AlN. Hence defects like ‘blow hole’ in the casting can be avoided. The scavenger elements are oxidized and finally removed as slag. The converter is then tilted and the molten steel
poured out and separated from the slag. The process complete in about 20 minutes. Phosphorus if present in the cast iron, is not removed.

(B) Basic Bessemer (Thomas Gilchrist) Process:

This process is used to treat pig iron containing phosphorus. In this process, the converter is lined with magnesia and lime prepared by calcinations of dolomite ($\text{CaCO}_3$.MgCO$_3$). Some limestone is added into the converter. Molten pig iron from blast furnace is then run into the converter and the blast continued. C, S & Mn are oxidized first as usual, but if the blast is continued even after the flame sinks down, then the phosphorus forms phosphorus pentaoxide.

$$4 \text{P} + 5 \text{O} \rightarrow 2 \text{P}_2\text{O}_5$$

For the complete removal of impurities other than P requires twelve min and further removal of P requires four min. phosphorus pentaoxide combines with lime and forms calcium phosphate slag.

$$3 \text{CaO} \rightarrow \text{Ca}_3(\text{PO}_4)_2 \text{ (slag)}$$

The slag also known as thomas slag, is used as a valuable fertilizer.

**MERITS AND DEMERITS OF BESSEMER PROCESS:**

**MERITS:**

i) The process is useful for rapid production of steel.

ii) Since the molten pig iron obtained from blast furnace, is directly taken in the converter, no extra fuel is required for melting of pig iron.

iii) The cost of the operating the process is low.

**DEMERTIS:**

i) Steel produced is of inferior quality.

ii) The loss of iron in the slag is comparatively more (15%).

iii) Comparatively small quantity of (5 to 8 tons) of iron can be converted into steel at a time.

iv) The process is not continuous and charging is rather tedious.
LINZER-DUSEN PROCESS (L.D. PROCESS):

This process was developed in Australia in 1953. It was discovered by Linzer-Dusen verfarhen. In this process, highly pure oxygen (99.5 to 99.7%) is blown from the top of the converter, which is lined usually with magnesite. The converter has a solid closed bottom as shown in fig.

The converter is charged with scrap steel, lime stone and the hot cast iron. A jet of pure oxygen is blown vertically on the hot metal surface through a water cooled copper lance, at a pressure of about ten atmospheres. The distance between the lower end of the copper lance and the surface of the charge, is about 40 to 50 cm.

Oxygen passed on the charge, rapidly oxidizes the impurities and the heat liberated gives rise to a temperature of about 2500 °C at the center of the top of the charge. The impurities combine with lime, forming a lime. The metal thus purified has a higher density than the impure metal and hence it sinks to the bottom of the converter. As a result of this, convection currents are produced. Due to these currents, the impure or unrefined metal is brought to the center of the top of the charge. When purification is completed, the convections current stop. The process lost for about 20 min. A large quantity of CO burns at the mouth of the vessel with blue flame. This process is very suitable for obtaining low carbon steel.

![Fig: Converter for L.D. process](image)
ADVENTAGES OF L.D. PROCESS:

i) The intense heat enables the use of iron scrap in the process.

ii) Both carbon and phosphorus gets removed simultaneously. Due to intense heat, lime dissolves in the slag at an early stage and thus binds $P_2O_5$ at low activity.

iii) It gives steel of very superior quality.

iv) The investment and capital cost are low.

v) The finished steel of this process contains low nitrogen.

vi) The energy requirements of this process are low.

vii) This process has more productivity than the other processes.

SPECIAL ALLOYS OF STEEL:

They contain in addition to carbon, at least one other element like Mn, Cr, Ni etc. in sufficient quantity. Due to presence of these elements, the properties of steel are modified. Some important alloy steels and their characteristic properties are given below.

**Table: Important alloys of steel**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name</th>
<th>Composition</th>
<th>Properties</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manganese steel</td>
<td>9-13 % Mn</td>
<td>Very hard, tough and resistant to water</td>
<td>Grinding machinery, steel helmets.</td>
</tr>
<tr>
<td>2</td>
<td>Stainless steel</td>
<td>12-13% Cr 1 % Ni</td>
<td>Resists corrosion</td>
<td>Utensils, ornamental pieces</td>
</tr>
<tr>
<td>3</td>
<td>Tungsten steel</td>
<td>10-22% W</td>
<td>Retain hardness even at high temp.</td>
<td>Cutting tools for high speed lathes.</td>
</tr>
<tr>
<td>4</td>
<td>Chrome steel</td>
<td>2-4 % Cr</td>
<td>High tensile strength</td>
<td>Ball bearing, cutting tools</td>
</tr>
<tr>
<td>5</td>
<td>Nickel steel</td>
<td>2-4 % Ni</td>
<td>Very hard, tough, rustless &amp; elastic</td>
<td>Wires, cables, gears etc.</td>
</tr>
<tr>
<td>6</td>
<td>Molybdenum steel</td>
<td>0.3 -3 % Mo</td>
<td>Resists corrosion even at high temp.</td>
<td>Cutting tools &amp; axels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7</td>
<td>Silicon steel</td>
<td>15% Si</td>
<td>Extremely hard &amp; resistant to acid</td>
<td>Pumps &amp; pipes carrying acids.</td>
</tr>
<tr>
<td>8</td>
<td>Cobalt steel</td>
<td>5% Co</td>
<td>Very hard, resists wear &amp; corrosion, power of retaining magnetism</td>
<td>High speed tools, permanent magnets.</td>
</tr>
</tbody>
</table>