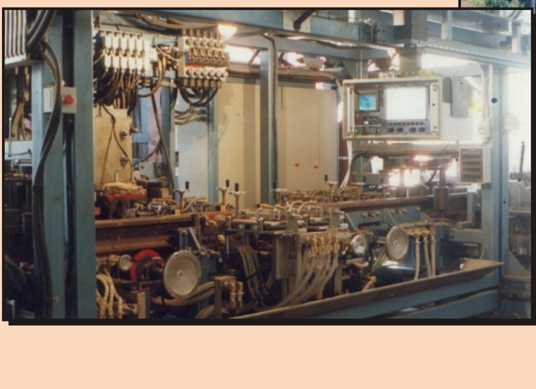
RAIL STEEL



March 2007

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING
PUNE 411 001

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PREFACE TO THE THIRD EDITION

The book on Rail Steel was first published in 1987. Its second edition was brought out in 1997. The book has been found very useful by the field engineers for developing an insight in rail steel.

Rail is the most important constituent of the track structure and plays very vital role in the reliability of railway system as a whole. Quality of rail steel with reference to its chemical composition, especially the hydrogen content has been a matter of serious concern to the manufacturers as well as Indian Railways. In service failure of rail has been a big challenge to the track engineers. Various methods of rail testing and improved chemical composition are being adopted. A lot of new developments have taken place in rail manufacturing industry. Bhilai Steel plant has also done many improvements in rail manufacturing and in post manufacturing inspection process. Proper handling of rails from the stage of its manufacturing up to insertion in track is equally important especially in case of the high UTS rails which are more brittle.

The revised and enlarged edition of the book has been complied by Shri Abhai Kumar Rai, Ex. Professor/ Works and Shri Atul Agarwal, Professor/Track-III. The book is now comprehensive starting from pig iron manufacturing and ending with testing of rails incorporating new developments. RDSO has recently issued 5th amendment to IRS-T-12-96 which has also been incorporated in the book.

I hope this book in the present format will be found more useful by the field engineers.

Shiv Kumar
Director
IRICEN
Pune

ACKNOWLEDGEMENT

The subject of "Rail Steel" is being taught during various courses at IRICEN. Even though a lot of information is available on this subject, yet it was not available at one place especially regarding rail manufacturing in India.

This book is an attempt to compile all the relevant information regarding rail steel starting from manufacturing of the pig iron to rail rolling including its testing and handling.

It would not be out of place to acknowledge the support and assistance rendered by IRICEN faculty and staff in the above efforts. We are particularly thankful to Shri Rajesh Kumar, Professor/Track-1, who has provided logistic assistance for printing of this book. The word processing of the manuscript and its editing has been done by Mrs. Vidya S. Jamma. We also acknowledge the help rendered by Shri Sunil Pophale, in preparing various drawings.

Above all, the authors are grateful to Sri Shiv Kumar, Director, IRICEN for his encouragement and advice for improving the book.

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CHAPTER - I

INTRODUCTION

1.1 Role of rail in permanent way :

The invention of steam locomotives which could run on rail led to the development of a transport system which has changed the life of people in most of the countries of the world. It has facilitated transportation over long distances and immensely contributed to industrial development.

Rail is the defining feature and most important component of permanent way. The primary function of the rail is to provide a smooth and continuous level surface for movement and to provide guidance in lateral direction for movement of the wheels. In process, it transfers the load from the wheels to the track structure below and is subjected to stresses. Function of the rail is shown in Fig. 1.1.

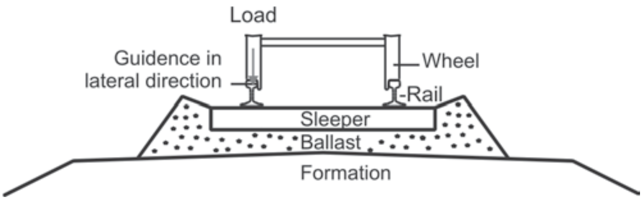


Fig. 1.1. Function of the Rail

The safety and reliability of railway system, to a great extent, depends on proper functioning of rail. On Indian Railway, a large number of accidents take place on account of rail/weld failure. Also wear and tear of permanent way necessitates its periodical renewal in which, rail renewal is a major component.

The design of rail is a complex process. The features like cross section, chemistry, process of manufacturing, handling & utilization each have bearing on its life and these aspects are to be decided depending upon the expected traffic, speed, axle load etc.

1.2 Historical background :

The history of rail transport is about 500 years old and includes systems with human beings or horses pulling wagons running on rails made of wood or stone. The wagonways were developed in Germany in the 1550s which made use of wooden rails and the wagons drawn by horse. In 1600s these were popular in Britain also. The Wollaton Wagonway drawn by horses is the earliest, proven, surface railway. It is recorded as running from Strelley to Wollaton near Nottingham and was completed in 1604. Subsequently in the late 1760s the fixing of cast iron plates through the wooden rails started. The wagons were having flanged wheels. Another system having flanged ('L') shaped metal plate fitted to the wooden rails and the wheels without flange was used. However, over a course of time it was realized that flanged wheels with flat rails worked better than the 'L' shaped rails with flat wheels. The 'flanged wheel' on 'flat rail' arrangement continues even today.

The strip iron rails having thin strip of iron fixed on wooden rails were very fragile and not suitable to carry heavy loads. However, their use continued for quite some time because of the fact that initial cost of construction was low and so the railway lines could be completed faster at a cheaper rate. The main problem associated with these rails was separation of iron strip from the wooden rails, which increased maintenance requirement making it expensive over the life cycle.

In 1767, first all iron rail was manufactured with cast iron. These rails were manufactured by casting process. These rails were three feet long.

Subsequently rolling of rails started. The steel rails were first made in 1857 and laid at Derby station in England. Steel being a better and stronger material than cast iron, in due course, it replaced the cast iron as the material for use in making rails.

1.3 Evolution of rail steel :

The first use of iron in the making of rail was in the form of a cast iron plate fitted over wooden rail. As its maintenance was becoming expensive, the next stage in development was use of cast iron rail, which was replaced by steel. As the know-how in manufacturing of steel developed, the chemical composition of rail steel also changed over the years and the percentage of various constituents particularly carbon, manganese and silicon changed. Adding of expensive alloys such as chromium etc. were also tried to improve steel quality. Carbon content in the steel has a major bearing on its properties and hence various percentage of carbon contents are tried to produce different types of rail steel. This will be discussed in detail subsequently.

1.4 Evolution of rail section :

The rail section also got evolved over time from a simple cast iron plate to today's flat footed rail. The basic principles which govern the design of section are that it should have required strength in bending, the head should provide a smooth running surface and should interact with the wheels so as to have minimum wear. It should have a base, which is wide enough to provide stability.

One of the early iron rail was double headed which has a dumb-bell type shape. The reason for using this shape was that during service one side head gets worn out and it can be turned for other side use. However, in practice, this could not be done because of the fact that once the one side gets worn, it was not possible to re-use it. The next stage of development of rail section was bull headed rails which has two heads but the one head was larger than the other. This type of rail was difficult to fix to the sleepers. This has resulted in the development of flat footed rails which is easy to fix to the sleepers because of the shape of the foot. The use of flat-footed rails still continues. The finer point of head profile was further refined so as to match the wheel profile. Weight of the rail section also got increased over years in line with increasing axle load and speed of the trains.

CHAPTER-2

STEEL MAKING

2.1 Introduction :

Iron, like most other metals is not found in elemental stage. It is found in combination with oxygen or sulphur, in the form of ore. Pure iron is relatively soft material not suitable for structural purposes. Therefore, for most structural needs steel is used which is an alloy of iron. The principle ores from which iron and steel are manufactured are magnetite (Fe_30_4) and hematite (Fe_20_3). Iron is extracted from these ores by removing the oxygen.

There is archeological evidence to show that iron ore has been reduced to usable iron as early as 400 B.C. Prior to 14^{th} century, this reduction was accomplished by heating iron ore and charcoal in a shallow hearth, which produced a spongy mass of iron, which was shaped directly by forging.

A brisk charcoal fire was sufficient for the ancient man to produce lumps of hot metal from iron ore. This can be accomplished at fairly low temperature (say 600^0F). The metal can not be produced in a liquid condition but it can be dragged out of the fire in the form of spongy mass which in hot condition can be welded to another piece of spongy mass and when enough iron mass is welded like this, then it is hammered in hot condition to convert into useful tools. This process results in production of wrought iron.

In India, good quality steel was being produced as early as 200 A.D. by crucible technique wherein high purety wrought iron, charcoal and glass were mixed in crucible and heated until the iron melted and absorbed the carbon. The solid pillar of rust resistant iron made in 4th century A.D. which has stood for many centuries next to the Kutub Minar in Delhi is a testimony of this.

Subsequently, it was understood that iron could be produced soft or hard, ductile or brittle, depending upon the carbon content and cooling rate. Melting temperature of iron depends on it carbon contents. Pure iron melts at a temperature of about 1535^0C. When it has carbon content of 1%, the melting can begin at 1150^0C. However, the melting completes at a temperature of 1450^oC. Similarly, with 3% carbon, the melting is completed at 1320^0C. This shows that the melting temperature varies with the carbon content. The lowest melting temperature is corresponding to a carbon content of 4.25% when it melts at 1130^0C. If carbon content is more or less than 4.25% the melting temperature will be more than 1130^0C. Iron containing 3 to 4 % of carbon, which can be easily melted, and cast into mould, is known as cast iron. Because of higher carbon content it is very brittle and so could not be worked either hot or cold and any attempt to work it results in cracking. This means, the cast iron can not be wrought and wrought iron can not be casted.

2.2 Pig Iron :

Around the year 1350, a method was developed for producing molten high carbon iron in a furnace and for casting the molten iron into shaped moulds. This was the basis for the present day blast furnace process for manufacturer of pig iron. The original process utilized charcoal, lime stone and ore. The charcoal was later on replaced by coke around the year 1600 and hot blast was introduced about 200 years later. The capacities of the furnace had been increased to 100 tons a day by the late 1800's and in the present day, it has further increased to over 1400 tons a day.

Pig iron, besides being used directly in the form of castings, is the intermediate form of iron through which all commercial ferrous products must pass. The name pig iron was derived from the manner of casting molten metal from the furnace in sand. The molten metal runs from a main runner into smaller ones on both the sides resembling a sow with a litter of suckling pigs.

The pig iron is manufactured from iron ore in blast furnace. The chemical reaction which takes place is as follows:

Iron ore + Sinter + Coke + Limestone $\rightarrow$ Pig Iron + Carbon Mono-oxide

$2Fe_2O_3 + 6C \rightarrow 4Fe + 6CO\uparrow$

2.2.1 Blast furnace

The process of smelting iron ore in a blast furnace consists of charging a mixture of ore, fuel and flux in proper proportion through a specially constructed opening in the top of a tall cylindrically shaped furnace. This furnace has firebricks while heated air is continuously blown near the bottom through openings called tuyeres. A typical blast furnace is shown in Fig. 2.1.

Blast furnace is a refractory lined steel shell which is about 90 to 100 ft.high. The cylindrical bottom of the furnace is called the Hearth having a dia. of 24' to 28'. This is where the molten iron and slag are collected. The inverted truncated core above the hearth is called the BOSH where the melting of iron and slag occurs. Above the BOSH is the tall-truncated cone, where the burden is heated and where the reactions start. On top of the furnace, the double bell and hopper system is located for charging the raw materials without allowing the gases to escape. Inside this furnace is a 90ft. column of material consisting of coke, ore and

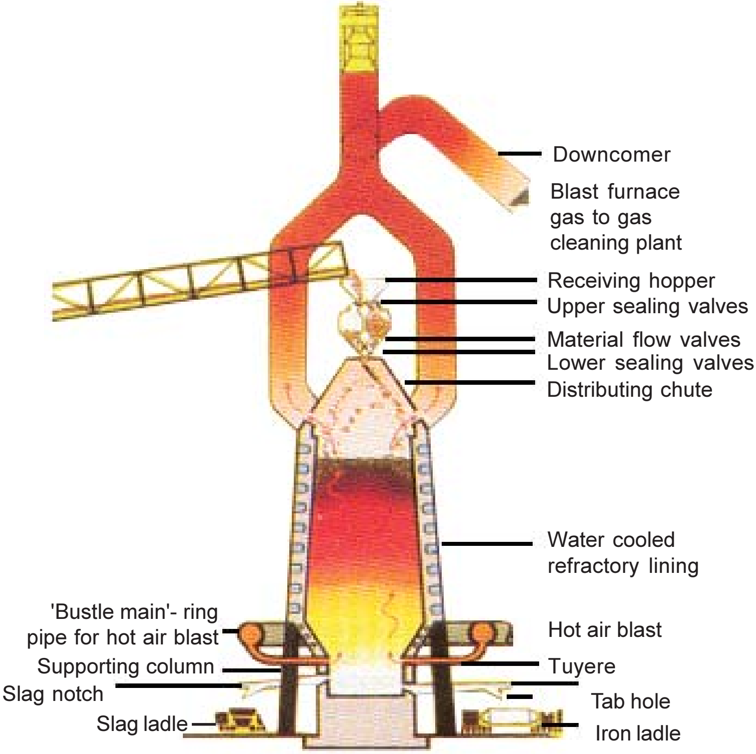


Fig. 2.1 : Blast Furnace

limestone in which temperatures vary from 3000^{0}F at the bottom to about 300^{0}F at the top. Average capacity of a modern blast furnace is about 1200 tons per day.

2.2.2 Modern blast furnace

A modern blast furnace for smelting iron consists of (i) blast furnace (ii) hoisting appliances for hoisting ore, flux and coke to the top of the furnace (iii) the blowers for supplying hot air blast (iv) stoves for heating the blast (v) the pumping plant for supplying the large quantities of water needed for cooling the furnace walls and steam raising (vi) gas cleaning plant (viii) appliances for disposal of slag and pig iron and (ix) pig casting machine. The components of a modern blast furnace are shown in Fig. 2.2.

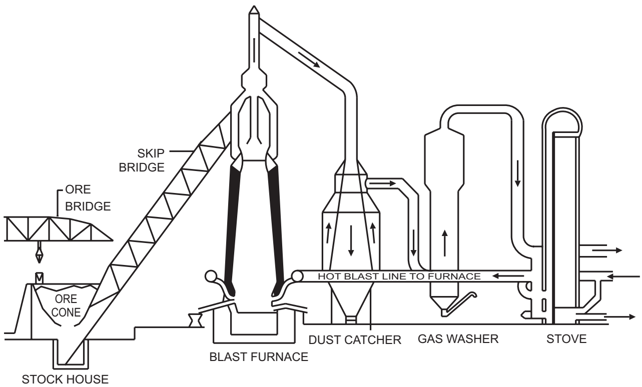


Fig. 2.2. Modern Blast Furnace

2.2.3 The reduction process

The raw materials except air are charged through the top of the furnace. They proceed by force of gravity down against rising air and gases. The reducing reactions start near the top of the furnace and increase in intensity as the charge settles in the stack. The charge remains a mixture of solids and gases until it descends to the upper region of the Bosh where the iron starts to become a pasty mass. Simultaneously, the calcium oxide in the limestone forms fusible slag with the impurities in the iron ore and the ash of the coke. The pasty mass of iron absorbs more carbon and both the slag and metal become molten and trickle down to the hearth over the remaining un-burnt incandescent coke. In the hearth, since the slag has a lower specific gravity than iron, it floats on top of the molten metal from where it is drained at regular intervals. The molten high carbon iron is tapped regularly and is then cast in the pigs or used in the molten condition in the manufacture of steel.

2.2.4 Reaction in blast furnace

The oxygen in the pre-heated air, that is blown through the tuyeres reacts quickly with the carbon in the incandescent coke forming carbon dioxide which in the presence of excess carbon at high temperature is reduced to carbon monoxide according to the following reactions:-

$O_2 + C = CO_2$
$CO_2 + C = 2\ CO$ or
$O_2 + 2C = 2\ CO$

The first and third of these reactions are exothermic and provide most of the heat for initiating and accelerating the reactions of the furnace. They also produce the CO that is responsible for approximately 80% of the reduction in the furnace. The reduction of the ore proceeds according to the following reactions:

$3Fe_2O_3 + CO = 2\ Fe_3O_4 + CO_2$
$Fe_3O_4 + CO = 3FeO + CO_2$
$FeO + CO = Fe + CO_2$

The reduction of iron ore, therefore, occurs progressively i.e., Fe_2O_3 is first reduced to Fe_3O_4, then to FeO and finally to iron. The first reaction is predominant at 200^0C and the second begins approximately at 650^0C. The latter is not completed till the oxide is completely reduced to iron in the Bosh zone.

Under the reducing conditions in the furnace, all easily reducible oxides get reduced along with the iron and produce an impure pig iron having picked up approximately 4 to 5% carbon from the coke, 0.5 to 2% silicon from the slag, 0.4 to 2% manganese from the ore, 0.04 to 2.5% phosphorus from the ore and 0.020 to 0.2% sulphur mostly from the coke.

2.2.5 Recent development in the blast furnace technology

Blast furnace technology and operations have progressed extensively during the recent years. Improvements are mainly in relation to the furnace design and preparations of the burden. A direct result of technological advances in furnace design is the marked increase in size. The present day furnaces are about 29' hearth in dia. and produce upwards of 1400 tons of iron per day. Along with increase in size, the furnace productivity is continuously being improved by other means such as the replacement of the reciprocating blowers with turbo blowers, improving the design of the top applications and the use of high top pressures in the blast furnace. Some of these developments have been incorporated in the blast furnaces in the new steel plants in India. In the matter of burden preparation, screening of ores and washing of the coal to reduce sulphur and ash content are the most important.

2.3 Steel making :

The strating point for the manufacture of steel is pig iron. As explained earlier, the pig iron is produced by reducing iron ore (the most common ore being hematite Fe_2O_3) with the help of coke into blast furnace. Pig iron contains, carbon, silicon, phosphorous, etc. far in excess of percentage desired in steel, as will be evident from the comparison given in table 2.1.

Element	Typical percentage in pig iron	Percentage usually present in steel
Carbon	3.5 to 4%	Upto 1.2%
Silicon	Upto 2%	Upto 0.3%
Manganese	Upto 1%	0.3% & above
Phosphorous	Upto 2%	0.05% max.
Sulphur	Upto 0.08%	0.05% max

Table 2.1

By suitably altering the operating conditions in the blast furnace, silicon, manganese and phosphorous in pig iron are kept within predetermined limits to suit the subsequent steel making process.

To convert pig iron into steel, the various methods being used are as follows:

i) Bessemer Process
ii) Open hearth process
iii) Basic oxygen method
iv) Electric Arc furnace

Regardless of the process, the essential principle in the conversion of pig iron into steel is oxidation – oxidizing agent being Oxygen in air for the Bessemer process, pure oxygen in LD (ladle degassing), and iron ore (which contains oxygen in chemical combination with iron) in open hearth and electric process. By oxidation, Carbon gets converted into gaseous carbon monoxide and escapes whereas the other elements get converted into their respective oxides in which form they combine with the fluxing materials used in the charge, such as lime, to form slag that floats on the molten steel.

2.3.1. Bessemer process

Bessemer process was the first process for the mass production of the steel from molten pig iron. It was invented by Henry Bessemer in 1855. The basic principle used in this process is removal of impurities from pig iron by oxidation for which air is blown through the molten iron. There are two methods available, one is Acid Bessemer and the other is Basic Bessemer.

2.3.1.1 Acid Bessemer Process

The acid Bessemer converter is a pear-shaped steel vessel lined with silica bricks and is mounted on two trunions. One of these trunions is hollow and is connected with the air pipe and the wind box, to which it conveys air supplied by suitable air blowers. The other trunion is attached to a toothed wheel which works in a rack and enables the converter to be turned through an angle of at least 200^0 to meet the various stages of process – charging, blowing and pouring. The bottom contains the wind box and a number of tuyeres to admit the air blast. The molten pig iron is poured into the converter in an horizontal position, the blast is turned on and the converter rotated into a vertical position. Oxygen in the air blast oxidizes carbon, silicon and manganese together with some iron. The carbon escapes as a gas, while the silicon and manganese along with any iron that may be oxidized form a mixed ferrous manganese silicate slag. The chemical reactions occurring are exothermic and so no external source of heat is needed. The progress of the heat is followed by observing the flame, which is characteristic for the elements being consecutively eliminated, viz., silicon, manganese and carbon. The blow is stopped after the flame drops and the refining is complete in about 15-20 minutes. The converters used in the process usually have a capacity of about 25 tons. Alloy or finishing additions are limited and are usually made as the metal runs from the converter into the casting ladle. As already explained, on account of the acid lining of the converter, sulphur and phosphorus are not eliminated in this process and, therefore, the process can be used only for raw materials, i.e., pig iron containing very low percentage of these elements. The chief disadvantage of the process is that the nitrogen from the air gets into the steel which is undesirable for many applications.

2.3.1.2 Basic Bessemer Process

Basic Bessemer process which is also known as Thomas process in the European continent is used when the phosphorus content of the pig iron is between 1.8 and 2.5%. In many continental countries the pig iron available contains about 2% phosphorus and hence this process is widely used in those countries. This process utilizes a basic lined converter similar to the one used for Acid Bessemer process. The purification is effected by oxidation by blowing air as in the case of Acid Bessemer process but in conjunction with a strong base such as burnt lime to maintain a basic slag, which helps elimination of phosphorus. In the process, the blowing is prolonged after the flame drops and this period is known as the after-blow. It is during the after-blow that the phosphorus is eliminated. Like the Acid Bessemer steel, this steel also contains high nitrogen, which is a disadvantage for certain classes of work. Indian pig iron rarely contains as high as 2% phosphorus and, therefore, this process is not likely to be used in India.

In the recent years various modifications of this process have been tried to keep nitrogen at a minimum. These modifications have been directed at using a mixture of air and steam or air and oxygen for the blast.

2.3.2 Open Hearth Process

In 1858, William Siemens discovered the regenerative system for preheating the gas and air for refining pig iron in a reverberatory type of furnace. A few years later on, the Martin Brothers introduced the practice of charging scrap along with the molten pig iron and the ore as part of the raw materials charge in the process discovered by Siemens. The combined process came to be known as Siemens-Martin process and more commonly as open hearth process. In this method excess carbon and other impurities are burnt out from the pig iron. As the steel has a very high melting point, Open hearth furnace were used. These furnaces could have capacity even upto 500 tonnes. This method is slow and easier to control. Open hearth furnace can further be classified as (i) basic open hearth furnace and (ii) acid open hearth furnace. There are discussed below in detail :

2.3.2.1 Basic open hearth furnace

The modern basic open hearth furnace is a brick chamber about 80’ long by 18' - 20’ wide. The furnace has two essential parts – (i) the hearth and (ii) the air and fuel-heating system, including firing ports, regenerative chambers and reversing valves. etc. Its main constituents and the process involved are explained below :

The Hearth

The hearth is an elliptically shaped vessel 25 to 35 inches deep, with a foundation of closely spaced steel beams covered with steel plates. On top of the steel bottom plate is an insulating concrete pad, followed by insulating brick and firebrick. The hearth is finished with succeeding layers of chrome and magnetic bricks, upon which is rammed a magnesite bottom. An opening called tap-hole about 6” in dia. located midway between the ends of the hearth and at the middle of the back bank, is provided from which molten metal is drained from the furnace.

Heat source

The charge which is placed in the hearth is heated by radiation from a long sweeping flame that passes over it. The fuel used may be liquid such as oil or tar or it may be gas. The firing is alternately from one end of the furnace, then from the other, the reversals being made every 15 to 20 minutes.

Regenerator (Checker) Chambers

In order to obtain sufficient flame temperature and economies in fuel consumption, the air for combustion is preheated. When gas is used as a fuel, this is also preheated. For this purpose, there are two large rectangular brick chambers one at each end of the furnace, beneath the charging door firebricks arranged in a criss-cross, or checker fashion occupy 60 to 70% of the volume of the chambers. The hot exhaust gas, leaving the furnace at one end of the hearth, travels downward through the two uptakes and enters the checker chambers. During the passage through the chambers the hot gas gives off most of its heat to the checker brick before passing through the reversing valve on its way to the stack. At the same time, the air for combustion and gas when used as fuel are drawn in through the reversing valve and directed through the checker chambers at the opposite end of the furnace. The air and the fuel gas pick up heat from the hot checker brick before entering the firing end of the furnace. When the firing is reversed the flame passes through the furnace in the opposite direction and the functions of the two checker chambers are interchanged. This is known as the regenerative system of preheating.

Raw materials

The raw materials used in the basic open hearth consist of the following:

1. Solid and liquid pig iron
2. Steel scrap
3. Iron ore
4. Lime stone
5. Burnt lime

The pig iron should be low in silicon i.e., below 1.25% to prevent reaction of $Si0_2$ with the basic lining. Manganese is preferred high (1-2%) because it aids in the removal of sulphur and increases fluidity of slag. Phosphorus can be any amount but for economy it is restricted to a maximum of 1%. Sulphur should be as low as possible preferably below 0.05%.

The quality of steel scrap used is based on two properties (a) its physical form and (b) its chemical composition. The chief function of the iron ore is to supply oxygen. Two types of ore additions are used in the basic open hearth namely charge ore and feed ore. Charge ore is included in the initial charge and supplies oxygen during the melting period. Feed ore is added to the bath after melt to hasten oxidation during the refining period. The process is flexible in that the furnace may be charged with various combinations and proportions of these raw materials and produce a quality product to a specified requirements. The relative amounts of steel scrap and pig iron in a charge and the proportionate parts of pig iron in the liquid and solid state are controlled by economic considerations.

Charging

The charging cycle for the furnace starts after tapping the previous heat. As steel flows from the furnace, the banks and the bottom are examined; steel and slag trapped on the bottom is blown out and holes if any are patched. This period is called 'fettling time' which should be kept to a minimum to prevent chilling furnace. Thereafter, the charging machine places the solid portions of the charge in the furnace as quickly as possible. If plate scrap is available it is charged first so that the abrasion shock to the hearth due to charging can be kept to a minimum. When plate scrap is not available, limestone is charged first followed by steel scrap and solid pig iron, if available. During the melting of the charge, the burners are adjusted to give a short intense flame, which melts the charge in about two hours oxidizing the scrap and the pig iron, and subsequently molten pig iron is added.

Melting and refining

The melting period begins when steel scrap is charged into the furnace and refining begins when molten pig iron is added. Oxygen of the ore reacts with carbon in the pig iron and produces carbon monoxide, which bubbles through the bath. Evolution of the carbon monoxide causes the molten bath to boil and this stage of the heat is called 'ore boil'. During this period, the silicon, manganese and the phosphorus in the pig iron are oxidized and enter the slag. The phosphorus is oxidized to P_2O_5 and being acidic in nature combines with ferrus and manganese oxide to form a phosphatic slag. With a higher pig iron charge, the slag volume becomes sufficient to flow out of the furnace.

As the ore is consumed the ore boil subsides, the temperature of the bath rises and calcination of lime stone commences. The limestone decomposes as per reaction: $CaCO_3 = CaO+CO_2$ and the evolution of the carbondioxide results in further boiling of bath which is termed 'lime boil'. As the limestone is decomposed, the lime rises to the slag to form calcium phosphate $\{Ca_3\ (P0_4)_2\}$. Thus, the slag becomes more basic and is capable of taking more phosphates and silicates into solution. When the calcination of the limestone is complete and all the lime has risen to the top of the bath, the heat of the steel is considered to be melted.

The end of the lime boil marks the beginning of the refining or working period. At this point, there is sufficient carbon in the heat to permit proper refining but without an excess of carbon to cause a longer heat time for its removal. Samples of steel are taken from the bath for chemical analysis. Further refining at this stage is accomplished by adding feed ore to supply oxygen for oxidation. Feed ore is added to the bath in carefully controlled amount to promote carbon removal at controlled rate. During the refining period, the removal of silicon, phosphorus and carbon to a level suitable for the desired analysis is completed. Removal of sulphur is not controllable since it goes into the slag as manganese suphide and some as SO_2 with the waste gases. When the desired effects of the refining period have been attained, the heat is ready to tap. The steel flows out of the tap hole into a refractory lined runner which directs the steel into a ladle.

2.3.2.2 Acid open hearth process

The acid open hearth furnaces are similar to basic open hearth furnaces but are usually smaller and are lined with silica refractories. The slag produced contains excess silica (SiO_2), instead of excess lime (CaO). In the acid slag, however, the iron oxide is mostly combined with silica as ferrous silicate. Consequently, there is much less free oxide in the slag to migrate into the metal. Thus acid open hearth steel usually contains less oxide than basic open hearth steel and therefore, this process is used for making high grade carbon and alloy steels. Again since phosphorus and sulphur cannot be removed in this process, costlier raw material containing very low percentage of these impurities only can be used in this process.

2.3.3 Basic oxygen method

The basic oxygen method popularly known as BOS i.e. basic oxygen steel making, is an improvement over the Bessemer process. In this method oxygen is blown through molten pig iron and the carbon content is lowered. So this process of steel making is used to convert carbon rich molten iron into steel. The basic oxygen method is used by LD converter, which has got its name from Austrian place names Linz and Donawitz, where this method was first used. This process has assumed a great importance as a steel making process because it possesses some of the economic advantages of Basic Bessemer process combined with the qualities of open hearth steels. Generally, the process is suitable for pig irons having the same composition as those used in basic open hearth practice.

In this process refining is carried out in a Basic lined converter by blowing 98% purity oxygen, vertically downward by a water cooled nozzle in the surface of the bath of hot metal. The oxygen jet impinging on the surface of the liquid bath instantaneously starts reactions leading to the formation of Fe0, part of which diffuses rapidly through the bath. Carbon monoxide is immediately evolved which gives rise to a vigorous boiling action and accelerates the refining reactions. Slag forming fluxes such as burnt lime are added during the blow. The blow usually lasts 18 to 20 minutes.

Unlike the basic Bessemer process, this process employs a refining agent which is nitrogen free and, therefore, the steel produced have low nitrogen content, i.e., of the same order as in open hearth process. The steel exhibits good cold forming properties and good weldability. In Bhilai Steel Plant, basic oxygen method is used for making steel for rails.

The steps involved in this process are as follows:

I. Molten iron from a blast furnace is poured into a large container called a ladle.

II. The metal in ladle is sent directly for basic oxygen steelmaking or to a pretreatment stage. Pretreatment of the blast furnace metal is used to reduce the refining load of sulphur, silicon, and phosphorus. In desulphurising pretreatment, a lance is lowered into the molten iron in the ladle and several hundred kilograms of powdered magnesium are added. Sulphur impurities are reduced to magnesium sulphide in a violent exothermic reaction. The sulphide is then raked off. Similar pretreatment is possible for desiliconisation and dephosphorisation using mill scale (iron oxide) and lime as reagents. The decision to pretreat depends on the quality of the blast furnace metal and the required final quality of the BOS steel.

III. The BOS vessel is tilted and one-fifth filled with steel scrap. Molten iron from the ladle is added until the vessel is full. Filling the furnace with the ingredients is called charging.

IV. The vessel is then placed upright and a lance is lowered down into it. The lance blows 98% or more pure oxygen onto the steel and iron, causing the temperature to rise to about 1700^0C. This melts the scrap, lowers the carbon content of the molten iron and helps remove unwanted chemical elements. It is the use of oxygen instead of air that makes for the improvement on the Bessemer process, for the nitrogen (and other gases) contained in air does not react with the charge as oxygen does.

V. Fluxes (burnt lime or dolomite) are fed into the vessel to form slag, which absorbs impurities of the steel making process. Near the end of the blowing cycle, which takes about 20 minutes, temperature reading and samples are taken. The samples are tested and the composition of steel is checked.

VI. The BOS vessel is tilted again and the steel is poured into a giant ladle. This process is called tapping the steel. For making steel having special properties, required alloys are added in the ladle furnace. Sometimes argon or nitrogen gas is bubbled into the ladle to make sure the alloy mix correctly. The steel now contains 0.1-1% carbon. The more carbon in the steel, the harder it is, but it is also more brittle and less flexible

VII. After the steel is removed from the BOS vessel, the slag, filled with impurities, is poured off and cooled. The basic oxygen method is explained in Fig. 2.3.

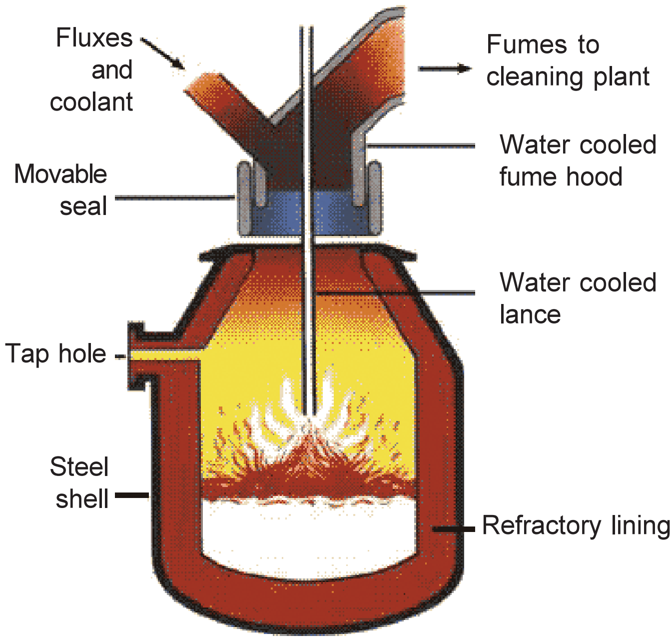


Fig. 2.3 Basic Oxygen Method

2.3.4 Electric Arc Process

The shell of a modern electric furnace is usually cylindrical and is constructed of steel plates. The shell has a circular flat bottom which is laid first with clay, magnesite or silica brick as required. The roof is a simple dome with three openings near the center for the electrodes. Two doors are usually placed in the shell of the furnace one the charging door diametrically opposite to the tap-hole and other the working door 90^0 away.

2.3.4.1 Operation

The charge generally consists of about 40% heavy scrap, 40% medium scrap and 20% light scrap. Ferro alloys, alloying oxides and virgin alloys, which are not easily oxidized, can be and usually are charged in the furnace prior to melting down. The charge usually contains excess carbon in the bath to permit proper shaping of the heat. The ore is added to lower the carbon. This ore may be added with the initial charge or when the charge is completely melted. When charging is completed, electrodes are lowered to about 1" above the scrap and with proper current setting when the arcs are struck under automatic control, the melting of the charge starts. The first period in the heat is the oxidation period during which the reactions taking place in the basic electric furnace are similar to those in the basic open hearth furnace. During this period, the phosphorus, silicon, manganese, carbon, chromium and some sulphur are oxidized and at the end of the oxidizing period, the initial oxidizing slag is removed from the furnace. This is now replaced with reducing slag by adding burnt lime fluorspar, coke and silica sand. Small amounts of crushed ferro silicon are also added. During the reducing period, a strongly reducing slag containing calcium carbide is formed and is maintained through out the refining period. Carbide cannot exist in the presence of oxides reducible by carbon and, therefore, carbide slag is free of such oxides. Carbide slags return reducible oxides such as those of Mn, Cr, V, W, Fe, from the slag to the metal. Consequently, such oxides may be added for direct reduction as soon as carbide slag is formed. The slag also serves to reduce the oxides in the bath and facilitates the removal of sulphur as calcium sulphide. After the reducing slag has been formed, sample of steel is taken for analysis and the necessary additions for adjustment of carbon and alloys are made. When all the additions are in solution, ferro silicon is added for silicon content and deoxidation and the steel is ready for tapping.

The electric furnace provides several advantages among which the following are the most important:-

i. The electric arc is a source of pure heat, which minimizes contamination by elements normally present in the liquid or gaseous fuels.
ii. Permits temperature control within close limits.
iii. The slag can be better-controlled permitting high efficiency of recovery of alloys in scrap and additions, through slag manipulation and, therefore, can make practically all the known grades of steel and is used exclusively for the high alloy steels.
iv. The oxidizing and reducing conditions can be more effectively attained and removal of sulphur to a very low level is possible.

The disadvantage of the electric arc furnace relates to the higher cost of auxiliary equipment, power, electrodes and refractories etc. when compared to the open hearth process.

2.4 Provision of IRS T-12–96 :

As per the Indian Railway Standards specification for flat bottom rail (IRS-T-12-96), the steel used for the manufacture of rails shall be made by basic oxygen or electric arc furnace process. In case of steel made by electric arc furnace process secondary ladle refining is mandatory.

CHAPTER - 3

RAIL MANUFACTURING

3.1 Introductionm :

Whatever process of steel making is used, the steel produced contains some residual iron oxide dissolved in the steel. In addition, molten steel can dissolve a large amount of hydrogen, the source of hydrogen being moisture combined or free in the materials added to or coming in contact with molten steel. Rails fail in service by what is now well known as transverse fissure. Intensive investigation showed this type of failure to occur due to hydrogen present in steel. In the molten steel, excess hydrogen easily escapes, but in the solid state, escape of excess hydrogen can take place by the process of diffusion, which is temperature and time dependent.

The excess hydrogen produces cracks which are called flakes or shatter cracks. The harmful effect of hydrogen is well recognized and therefore attempts are made to controll all the possibilities of excess hydrogen taking place in the production of steel. It is a standard practice to take necessary precautions such as drying all materials used for manufacturing of steel. Despite such steps, transverse fissures traceable to hydrogen in steel occur, thus emphasizing the need for steps to further reduce the hydrogen content in steel.

For making the steel fit for rolling of rail, the steel so made is further processed and treated to bring various elements in the permissible and desirable limit. This is called secondary refinement. Earlier the reduction in hydrogen content was being achieved through controlled cooling. Subsequently, the use of vacuum degassing and argon flushing started which made the process of slow cooling as avoidable. The latest of the degassers is RH degasser and the same is being used at Bhilai steel plant for rail steel making.

The process of controlled cooling and various types of degassers are discussed below:

3.2 Controlled Cooling :

From solid steel, hydrogen can be removed only by diffusion, which is dependent both on time and temperature. In the controlled cooling method, excess hydrogen is sought to be removed by choosing a high enough temperature at which the hydrogen content normally present in steel does not cause cracking and cooling the rails from this temperature to room temperature very slowly thus allowing sufficient time for hydrogen to diffuse out. Controlled cooling came into general practice in 1937 and was especially developed to prevent formation of shatter cracks, also called internal thermal ruptures, flakes or internal thermal cracks. Rails from the hot saw are allowed to cool to about 500^0C on the hot banks and then are transferred to the insulated containers. The containers are such that the rails cool from 500^0C to nearly room temperature in a period of about 15 hours.

3.3 Vacuum Degassing :

Like the controlled cooling process, this process also aims at solving the shatter crack problem. Its approach however is to reduce the hydrogen content in the liquid steel to a harmless level by exposing the liquid steel to a low pressure atmosphere created by vacuum treatment. The time consuming controlled cooling method can therefore be dispensed with resulting in corresponding saving. An accidental advantage is that the mixing action taking place during vacuum treatment gives greater uniformity of composition.

In vacuum degassing process, a vacuum chamber is made above a ladle containing liquid molten metal. Low pressure in the evaboration chamber allows the entrapped gases to expand and rise to the surface.

There are several processes for carrying out vacuum degassing. However RH degassing is the latest and generally preferred owing to the metallurgical advantage of downstream refining processes to produce large tonnages of high quality low cost continuously cast steel.

Various methods of vacuum degassing are discussed below:

3.3.1 Ladle degassing

The Ladle containing the molten steel to be degassed is kept inside a gas-tight tank, the outlet of which is connected to a vacuum pump. Evacuation of the space within the tank causes hydrogen from molten metal to escape with accompanying boiling action. It is necessary to agitate the molten metal to hasten removal of hydrogen and this is done either by induction stirring (which will necessitate use of non magnetic stainless steel for construction of the ladle) or by bubbling an inert gas such as helium or argon, into the molten metal. On completion of degassing and before the tank is opened to atmospheric air, the tank is purged with an inert gas in order to avoid the possibility of ignition of flammable gas and metallic dust that may have collected inside the tank. The degassed steel is teemed in the usual manner. Fig. 3.1 shows the sketch of ladle degassing.

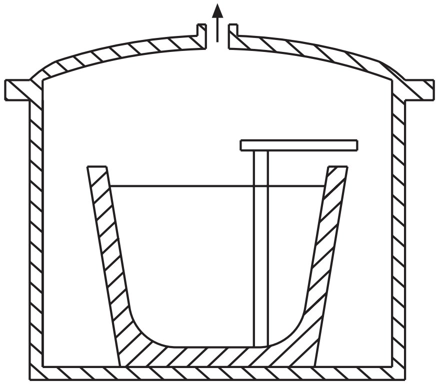


Fig. 3.1 Ladle degassing

3.3.2 Steam degassing

A bottom pour ladle, containing the molten metal is set on the top of the vacuum tank to which it is sealed to prevent entrance of air. A second ladle to receive the degassed steel is set inside the tank. After creating vacuum inside the tank, the stopper of the ladle containing the molten steel is lifted when molten steel flows down, it melts the metal diaphragm that seals the opening to the tank and falls into the ladle inside the vacuum tank. Because of the vacuum, the molten steel breaks up into the droplets, thus exposing a large surface to the degassing action of vacuum. After letting in an inert gas to replace inflammable gases inside the tank, the tank is opened to atmospheric air and the ladle metal teemed in the conventional manner. Fig. 3.2 shows the sketch of steam degassing.

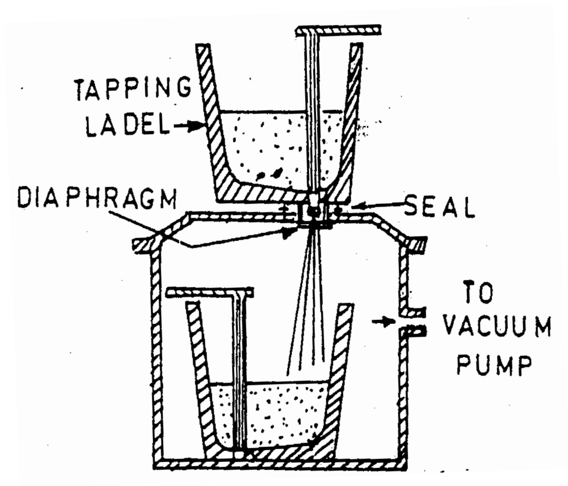


Fig. 3.2 Steam degassing

3.3.3 Dortmund-Horder Degaser (D-H Degasser)

To start with, the vacuum vessel is lowered until its nozzle extends through the slag into the molten steel in the ladle (Fig. 3.3A). Pressure is lowered to the order of 1mm of mercury when the liquid steel rises into the chamber with violent evolution of gas, on account of which the molten steel entering the vacuum vessel is in the form of the droplets, thus exposing an enormous surface to the influence of vacuum.

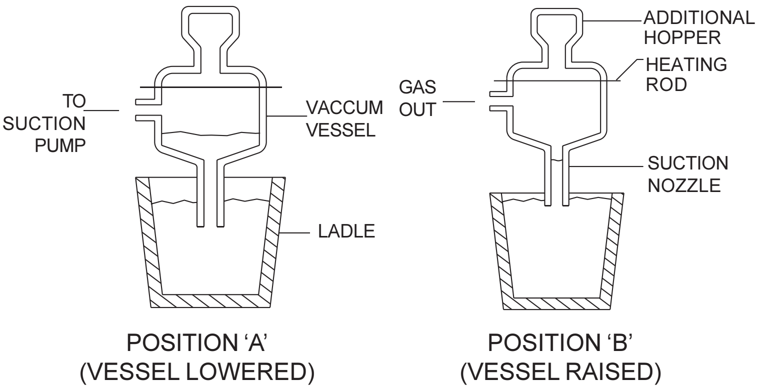


Fig. 3.3 D.H. Degassing

The vacuum vessel is then raised (Fig. 3.3 B) without removing its nozzle from the liquid metal which permits the degassed metal in it to flow back into the ladle. The vessel is again lowered and metal degassed. By repeating the operation sufficient number of times, the entire contents of the ladle can be degassed to the required level. A graphite electric resistance heating element is provided at the top of the vacuum chamber which can be used to offset any heat losses. Additions to the molten steel to bring it to the desired composition may be made without destroying the vacuum by using the addition hopper provided at the top of the vacuum vessel. After degassing is completed, the vacuum vessel is purged with nitrogen before lifting it from the molten steel.

3.3.4 Ruhrstahl-Heraeus Degaser (R.H.Degasser)

The vacuum vessel has two tubular extensions, on one of which there is an inlet for injection of an inert gas. The vessel is lowered to have the ends of both the tubular extensions submerged in the molten steel to be degassed. On evacuation of the vessel, molten steel rises in both extensions. Argon, an inert gas, is now continuously injected into one extension, on account of which, in that extension, the density of liquid steel is decreased and therefore, the level of molten steel rises. Because of the imbalance in the liquid levels thus created molten steel flows from this extension into the other, thus producing a pumping action. By the action of vacuum and the argon bubbles, hydrogen leaves the metal with boiling action and the degassed metal returns to the ladle by way of the other extension. Thus there is continuous circulation of the metal from the ladle into the vacuum chamber. When the dissolved gases have been brought to the desired level, the molten metal is teemed in the conventional manner. The schemetic diagram of R.H. Degasser is shown in Fig. 3.4.

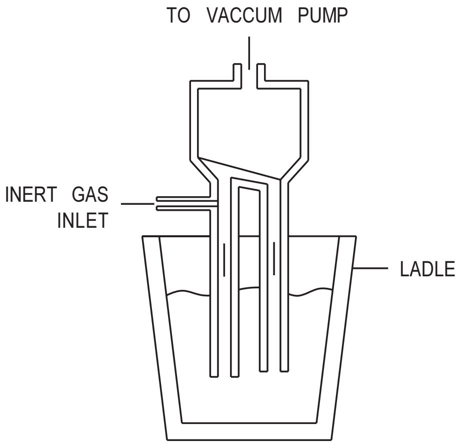


Fig. 3.4 R.H. Degasser

3.4 Casting

After the steel of desired quality for making rails is prepared at the end of degassing process, its casting is done. Earlier, ingot casting was being done which had many disadvantages.

A pre-requisite to faultless finished material is perfect ingots, free from all cavities or openings and made up of material, that is uniform. Unfortunately, the natural process that govern the solidification of the liquid metal operate against both these requirements and defects called piping, blow-holes, segregation, columnar structure and internal fissures are pesent in ingots. To these may be added defects such as checking, scabs and slag inclusions attributable to the incorrect pouring practice. A number of defects in the finished products can be directly traced to the defective ingots. So the ingot casting method has been subsequently replaced by continuous casting. Both these methods are discussed below:

3.4.1 Ingot Casting

Ingot moulds in which liquid steel is poured are made of cast iron. Two methods of pouring (teeming) are employed. The more common is top pouring in which the nozzle of the ladle is spotted over the center of the mould and the stopper opened gradually to minimize splashing. When the mould is filled to the proper point, the stopper is closed and the ladle is advanced to the next mould. Bottom pouring is employed for some products such as boiler and other high grade plates and heavy forging steel because a better surface results. This method avoids splashes that adhere to the mould and form scabs on the ingots.

3.4.2 Continuous casting process

This process comprises the direct solidification of liquid steel into a solid bloom which is continuously extracted from the casting machine and cut into required lengths.

Figures 3.5 A, B, C show the arrangements of the principal components of a continuous casting machine. While the arrangement in A will require a tall structure of height above 21m with attendant material handling difficulties, B & C show arrangements where a structure of shorter height will suffice.

3.4.2.1 Working

In order to conserve heat and to control the temperature, insulated ladles are used, and these, as also the pouring vessel are preheated. Where more than one billet production stand are in operation, the same pouring vessel may be used for pouring the moulds simultaneously by providing as many nozzles in the bottom of the pouring vessel. During casting, the mould oscillates over a small predetermined distance and this prevents sticking of the solidifying steel on to the mould. Molten steel is continuously poured from the ladle through the pouring vessel into the water-cooled mould. The withdrawal rolls control the speed of withdrawal of the billet. Because of the high melting point, high specific heat and low thermal conductivity of steel, only partial solidification occurs at the mould stage and much of the steel inside is still in molten condition. Solidification is completed as the steel mass passes through the vertical cooling chamber which is cooled on the outside by water sprays. The billet is flame cut to the required length, as it emerges out of the withdrawal rolls and received by the tilting mechanism and rolled out.

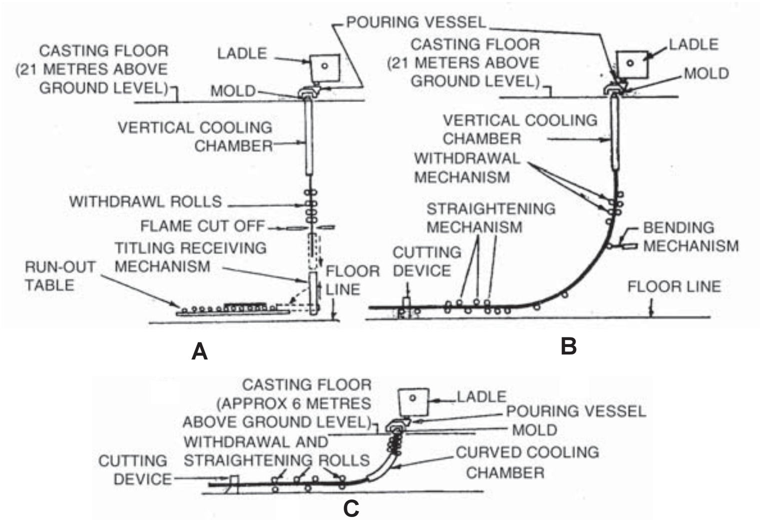


Fig. 3.5 Continous casting

3.4.2.2 Advantages

i) This process produces blooms of required length straight from liquid metal and thus eliminates the necessity to pour the liquid steel into ingot, stripping the solidified ingot from the mould, reheating it for rolling, rolling into blooms and cutting the blooms to the required length. Thus economy is achieved.

ii) Pipe, large and numerous inclusions and segregations are known to give rise to cracks during upsetting in flash butt welding and similar processes. The faster and more uniform bloom cooling rates which occur during solidification in this process greatly reduce the occurrence of macro segregation and minimize the occurrence of pipe. Therefore, troubles during welding arising from these factors are eliminated.

iii) Since there is no need to discard a portion of ingot to remove the piped portion, steel yield from molten metal is greater.

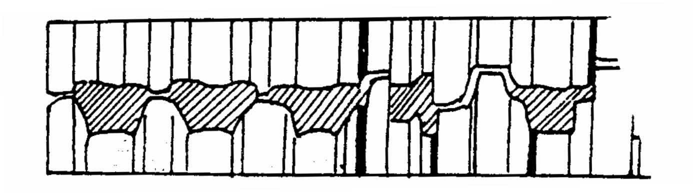
According to para 5 of the IRS-T-12-96 "Standard Specification for flat bottom rails", all blooms used in the manufacture of rails shall have a cross sectional area not less than 10 times that of the rail to be produced.

3.5 Rolling of Rails :

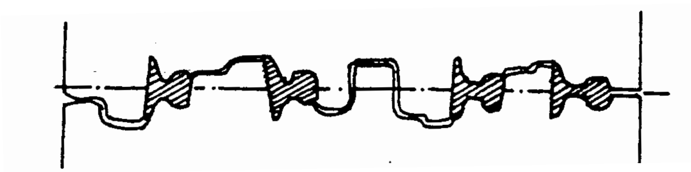
From pig iron to bloom making it is a continuous process. After blooms are prepared, these are rolled into the rails. For this, the cut blooms which are still hot are taken for rolling into rail lengths. Alternatively, these are allowed to cool and stored to be taken up for rolling later, in which case the pieces are reheated before rolling.

In Bhillai Steel Plant, the blooms are allowed to cool and are reheated to 1250^0 C before cooling.

The blooms are rolled in a series of roll passes to form the rail to template dimensions. In the first few passes, called roughening, a large amount of work is done to reduce the section size and elongate the piece. In the next stage known as first finishing, actual shaping of the rail takes place in a few passes. The third stage is the finishing pass in which the rails are formed exactly to template dimensions without reduction in section. A typical series of section changes occurring during the rolling process is shown in figure 3.6.



Roughing roll



Finishing roll

Fig. 3.6

While rolling is done, spraying of water at 200 bar pressure is done to remove furnace scale. By the time, rolling is complete, the temperature of rails comes down from 1250^0C to 800^0C. Rolling of rails have many advantages as detailed below **:**

(i) To break down coarse grains

In the as-cast condition, the ingot/billet shows columnar structure towards the mould surface to varying depths and very coarse grained structure in the interior. Both are undesirable structures and in order to develop the mechanical properties to the maximum extent, the structure should be broken, mixed and refined. When the rail is rolled, the change in section size elongates the grains, of which the ingot is made up, in the direction of rolling by shear along characteristic atomic planes. The shearing force increases the internal energy of the grains and immediately therefore, the elongated grains recrystalise giving rise to a new sort of grains. This process of elongation of grains and recrystallisation occurs every time the process of rolling changes the section size. The facility with which grains grow depends on temperature. At a high temperature, several small grains initially formed during recrystallisation form large grains. At a lower temperature, however, this is limited and therefore, the grain size is smaller. Because of the lower temperature at the time the rail is finally rolled, the recrystallised grain tends to be much smaller than in the ingot.

(ii) To make composition uniform

When steel is in liquid state, carbon, manganese silicon, etc. are uniformly distributed throughout. When the steel solidifies from liquid state, the composition of nucleus is different from the liquid from which it crystallizes. Also, the composition of different layers of solid crystallizing on the nucleus progressively differs. In other words, there is difference in concentration of elements in each grain and this is called "micro segregation". Though some equalizing of concentration occurs due to diffusion even as the ingot solidifies, complete uniformity is not achieved. With micro-segregation optimum properties cannot be achieved. The high temperature employed and the work put in during rolling facilitates diffusion of the elements to result in uniformity in concentration.

(iii) To close down internal blow holes

Blow holes are formed by evolution of gases during solidification of steel. Unless the blow holes are exposed to atmospheric oxygen, their walls remain clean. During rolling, the blow holes elongates, the clean walls come together and weld up. Thus the blow holes are completely eliminated.

(iv) To break down inclusion and render them harmless.

Inclusions are non-metallic materials, such as, sulphides, complex silicates, etc.

Steel making process is essentially oxidizing process. When the elements have been brought down by oxidation to the level planned, even though no further oxidation occurs, some oxygen still remains in equilibrium in the molten steel. When the steel solidifies, because of the lower equilibrium concentration, oxygen reacts with carbon to give carbon monoxide gas and so makes the solid steel full of blow holes. The oxygen in the molten steel has therefore to be removed (deoxidization) before the steel can be taken for pouring. Ferro manganese, ferro silicon and aluminum are used for this purpose, which by reaction with oxygen produce their respective oxides. This is one source of inclusion of steel. Other sources are accidental entrapment of slag or refractory particles from runners, ladle and furnace lining etc. in the ingot during solidification. Being weak and brittle, these act as weak spots. Inclusions cannot be completely eliminated, but should be minimized. Large inclusions or inclusions in a row (stringers) are particularly objectionable. The enormous lengthening of billets during rolling of rails, not only breaks the large inclusions into tiny bits but also disperses them.

3.6 Cutting of rails :

Rails are then cut to standard lengths by hot saws. The rails while they are still hot are allowed to cool to about 500^0C and are then transferred to well-insulated chambers or to closed containers where they are allowed to cool very slowly to room temperature, occupying a minimum time of the order of 15 hours. This process is called controlled cooling However now a days at Bhilai Steel Plant, slow cooling is not being done as purpose of slow cooling is achieved in vacuum degassing. So the cooling is done in 4 hrs. instead of 15 hrs. earlier.

3.7 Precambering and Straightening :

Rails have asymmetrical shape. It is a well known fact that the thinnest part of the section cools the fastest. In case of rail, the had contains the larger mass, and therefore, retains the heat to the greatest degree. Consequently the contraction in the head is greater than at the flange with the result that in cooling, the rail would naturally sweep or pull towards the head, causing a very great bow in the rail, which would make it extremely unwieldy for further processing. To overcome this condition rails are given a pre-camber in opposite direction while they are hot so that in the process of cooling rails straighten themselves. At Bhilai Steel Plant, the reverse camber is given to rails by a set of 29 position controlled carriages. The programming of the carriages produces pre-cambering of the rails. The rails are clamped firmly, lifted from roller table and placed on to the walking beam cooling bed with the help of hydraulic cylinders. All these hydraulic operations are synchronized with the help of flow control valves. Hydraulic actuators of all the 29 carriage for a particular operation are actuated with a common solenoid valve. The travel mechanisms of the carriages are independent.

The various precamber curves are set based upon temperature, rail length and profile parameters. The residual stress in the rails in this process are very small and well within norm after straightening. Cooling of full length rails on walking beam beds prevents localized bends in rails.

To meet straightness requirement, roller straightening machine wherein the rails are passed through series of rollers straightens the rails at Bhilai Steel Plant, the cooled rails are passed through most advanced bi-planar straightening machine, having 9 horizontal rollers and 8 vertical roller machines which are collectively capable of straightening in vertical as well as horizontal plane. The machine with off-line straightening model enables development of straightening parameters and straightening models. This machine is capable of minimizing residual stress during roller straightening process by computing the bending pattern and elasto-plastic stress strain correlation with the help of mathematical model. Such model helps in optimizing the deflection pattern under different rollers to achieve favorable internal stresses across the rail profile. The straightening machine also communicates online with laser straightness machine such that timely corrective action for straightness can be optimized. The biplaner straightning machine used in Bhilai steel plant is shown in fig. 3.7.

Fig. 3.7. Biplaner rail roller straightning machine

After straightening, the rail are checked and inspected in continuous operation for internal defects, dimensional accuracy and running surface straightness. This will be dealt in Chapter 5 & 6.

CHAPTER-4

EFFECT OF DIFFERENT ELEMENTS IN PLAIN CARBON STEELS

4.1 Introduction :

Apart from the iron, which is obviously the main constituent in any steel, ordinary plain carbon steel contains carbon, manganese, phosporus, sulphur and silicon. Carbon, manganese and in some steels silicon are essential ingredients while sulphur and phosphorus are unavoidable impurities. In addition, steel may contain oxygen (if not completely oxidized), traces of nitrogen and hydrogen etc. The effects of all these elements are discussed below. However, at this stage we are not discussing the effects of special alloying materials like chromium, which are added to the special and alloy steels.

4.2 Carbon :

In steel, carbon is present as iron carbide, a compound of iron and carbon also called cementite. In normalized plain carbon steels, at room temperature, upto 0.8% carbon, which is called eutectoid composition, the carbide and ferrite (alpha iron in which elements such as silicon, manganese etc. are in solid solution) form alternate lamellae, a structure known as "pearlite". At 0.8% carbon content, the structure of steel is fully pearlitic; at lower carbon contents, the normalized structure shows proportionately lower amounts of pearlite with free ferrite areas. Above 0.8% carbon, free cementite occurs generally in the form of a fine net work at the grain boundaries, sometimes it also precipitates in the form of needles inside grains of pearlite.

Upto a little above 0.8%, carbon increases hardness, yield point and ultimate tensile strength. This it does, by increasing the amount of pearlite. However, the increase is accompanied by reduction in percentage elongation and percentage reduction in areas i.e. loss of ductility. Beyond this percentage, however, the cementite network forming in the grain boundaries tends to make the steel brittle.

Gamma iron (austenite) has a high solubility for carbon, the maximum solubility being 2% at 1130^{0}C whereas alpha iron which is the room temperature allotrophic form of iron, has a solubility for carbon less than 0.1%. This difference in the solubility for carbon is the basis for a variety of heat treatment given to steel to obtain a very wide range of physical properties. For example, the carbon may be taken into solid solution by heating the steel into its austenite range and then cooling precipitates the carbon as cementite. Increased rates of cooling produces finer and finer cementite (and ferrite). Hardness, yield point, and ultimate tensile strength increase with fineness of cementite, with accompanying decrease in ductility. When the rate of cooling exceeds a particular limit, all the carbon is retained in supersaturated solution in alpha iron, in which form (called martensite) the material is hardest and brittle for that carbon content. Heating martensite to successively higher temperature reduces tensile strength and hardness with increased ductility.

The effect of increasing carbon can be summarized as increase in the tensile strength and hardness and decrease of ductility and more responsive to heat treatment. As per IRS-T-12-96, the permissible range of carbon content in rail steel is 0.60% to 0.80%.

4.3 Manganese :

Manganese is used for deoxidating the molten steel since it has greater affinity for oxygen than iron. Also this element combines with sulphur present in steel to form the insoluble manganese sulphide which is present as inclusions. If sulphur is not present as manganese sulphide, a condition which will arise if sufficient manganese to combine with all sulphur is not present, it participates as a network of iron sulphide in the grain boundaries. Since this has a low melting point, it makes the steel susceptible to cracking (hot shortness) during forging and in this sense, manganese overcomes hot shortness in steel. Manganese in excess of that required for combining with sulphur is present mainly in the form of solid solution in iron at all temperatures. Some of it combines with carbon to form a carbide similar to iron carbide and precipitates along with iron carbide as a complex carbide. Above about 0.8%, manganese influences the properties of steel as an alloying element enabling higher tensile strength with no loss of ductility and better hardenability. It gives rise to finer pearlite and finer grained structure in normalized steel. As per IRS-T-12-96, the permissible range of managnese content in 880, 1000 & 1080 HH grade rails is 0.80% to 1.30% and in 1080 Cr. grade, it is 0.80% to 1.20%.

4.4 Silicon :

Silicon has great affinity for oxygen. It is better in this respect than manganese and is therefore, used as a deoxidizing agent in the production of steel. In the combined conditions as silicates, it is present as tiny inclusions in the steel matrix but the major portion is present as solid solution in iron at all temperature. It is present less than 0.1% in rimmed steels and 0.1% to 0.3% in killed steel, it does not affect the physical properties of steel to any useful degree. As per IRS-T-12-96, the permissible range of silicon content in 880, 1000 & 1080 HH grade rails is 0.10% to 0.50% and in 1080 Cr grade, it is 0.50% to 1.10%.

4.5 Phosphorous :

Phosphorous is a harmful element in steel as it produces cold-shortness i.e. makes steel brittle and liable to crack when cold worked. Its content therefore is restricted to 0.05% (max.) in most of the steels. Phosphorous segregates to a considerable extent during solidification of steel, the segregation being due to the selective freezing of steel leading to the concentration of the phosphorous rich metal which has a lower freezing point, in the portions of the ingot which solidifies last, i.e. the pipe. The segregation portions, are, therefore less ductile. By removing the pipe, the high phosphorous regions may be largely but not entirely eliminated. Because of the embrittling effect, the restriction in phosphorous content is called for more in the case of high carbon steels (which have less ductility) than in low carbon steels. Also, where only static loading is encountered, more phosphorous may be tolerated than in dynamically stressed components. Phosphorous is usually restricted to 0.07% in ordinary steels, 0.05% in quality steels and 0.04% in high quality steels. It increases the tensile strength, hardness and yield point, but reduces sharply the impact strength.. The improvement in yield strength is made use of in the production of high strength structural steels containing upto 0.2% phosphorous in combination with small amounts of other alloying elements such as chromium copper, silicon, etc. As per IRS-T-12-96, the permissible limit of Phosphorous content in 880, 1000 & 1080 HH grade rail steel is 0.030% (max.) and 0.035% (max.) in finished rail. For 1080 Cr grade, it is 0.020% (max.).

4.6 Sulphur :

Like phosphorous, sulphur is also a deleterious element since it makes steel "hot short" i.e. liable to crack when hot. Sulphur upto about 0.6% is generally allowed in steels, though in high quality steels, not more than 0.04% is permitted. It is present in steel in the form of dovegray manganese sulphide inclusions. Much larger amounts (0.18% to 0.3%) are intentionally introduced in the grade of free-cutting steels in which the large amount of sulphide inclusions makes the steel burnings fall off in the form of chips during machining, enabling faster rate of production. In these cases, the manganese contents also has to be high (of the order of 1.5%). In these steels, the ultimate tensile strength of steel is only very slightly effected. In steels required to be weldable, not more than 0.06% of sulphur is permitted since excessive amounts of manganese sulphide inclusions causes porosity during welding. Also, the presence of inclusions brings down the fatigue strength of steels, where the steels are to be used under conditions of alternating stresses. As per IRS-T-12-96, the permissible level of Sulphur in 880, 1000 & 1080 HH grade rail steel is 0.030% (max.) and 0.035% (max.) in finished rail. For 1080 Cr grade, it is 0.008%-0.025%.

4.7 Oxygen :

Although oxygen is considered as detrimental to steel, it has been usefully employed in steel making, for example, in producing rimmed, semi killed and killed steels. The oxygen may be dissolved in steel to a maximum of 0.15% even in overblown Bessemer steel. Oxygen has no effect on tensile or ultimate strength, but slightly increases the hardness and considerably decreases the ductility and resistance to impact. Low carbon steel containing oxygen are susceptible to what is known as age hardening.

4.8 Nitrogen :

Nitrogen is introduced into the steel from the air used in melting furnaces. Steels made in open hearth, electric and LD processes contain only little nitrogen i.e., less than 0.005%. This amount does not have any deleterious effect on the steel. Steels made in Bessemer processes however may contain upto 0.015% of nitrogen. Nitrogen exists in the steels in the form of nitride Fe_4N, and renders the steel susceptible to age hardening. On this account Bessemer steels are not generally suitable for dynamically loaded components. In the steels having the same carbon content, those with higher nitrogen exhibit better wear resistance. The better wear resisting properties sometimes claimed for rails made from Bessemer process are attributed to this. As per IRS-T-12-96, the Nitrogen contents for 1080 Cr grade steel is 0.009% (max.).

4.9 Hydrogen :

Hydrogen is introduced into the steel during the melting and refining, from the dissociation of water vapour. Hydrogen is insoluble in steel at room temperature and if allowed sufficient time to escape during cooling does not cause any harm to low carbon steels. In very thick section and in high carbon and alloy steels, minute internal cracks known as hydrogen flakes or shattered cracks are formed, particularly when the steels are quickly cooled. In rail steel, control of hydrogen content is very important. As per IRS-T-12-96, the pemitted hydrogen countent in liquial steel is 1.6 ppm (max).

4.10 Permitted chemical composition as per IRS-T-12-96 :

The permitted chemical composition (in percentage) of various elements in the steel to be used for making rails is specified in IRS-T-12-96. By amendment number 5, dtd. 02.02.2007, these limits have been revised and the revised limits are as follows :

TABLE - 4.1

Grade	Chemical Composition (percentage)											
	C	Mn	Si	S (max.)	P (max.)	Al (max.)	Mo (max.)	Cr	V max.	N max.	O 10^{-4}% (ppm) max. by mass	H in liquid steel (max.)
880	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	---	---	---	---	---	1.6 ppm
1000	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	0.25	---	---	---	---	1.6 ppm
1080 Cr	0.60-0.80	0.80-1.20	0.50-.1.10	0.008-0.025	0.020	0.004	---	0.80-1.20	0.18	0.009	20	1.6 ppm
1080 HH	0.60-0.80	0.80-1.30	0.10-0.50	0.030*	0.030*	0.015	---	---	---	---	---	1.6 ppm

*0.035 maximum for finished rail

The chemical compositions specified as above are applicable to Ladle analysis and Product Analysis. Manufacture shall ensure that chemical composition at ladle analysis should be such that product analysis also satisfies the requirement of chemical composition as above.

CHAPTER – 5

TESTING OF RAILS

5.1 Introduction :

Testing of iron and steel products is necessary for ensuring conformity and quality in the manufactured product, checking up conformity with the prescribed specifications and to serve as a guide for the engineers for designing.

Testing of rails includes dimensional checks, chemical analysis and physical tests. On Indian Railways, rails are accepted as per IRS -T-12-96 which covers flat bottom rails. In this chapter, the chemical and physical tests shall be discussed and dimensional checks will be covered in sixth chapter alongwith other important stipulations of IRS -T-12-96.

5.2 USFD Testing :

The rails shall be of uniform section throughout and shall be free from all detrimental defects such as cracks of all kinds, flaws, piping or lack of metal etc. having unfavourable effect on the behaviour of the rail in service. The absence of harmful internal defects shall be ensured by the continuous on-line ultrasonic examination.

The limits of permissible defects for ultrasonic testing of rails shall be as follows.

Head :	1.5mm dia through hole
Web :	2.0mm dia through hole
Web & foot junction :	2.0mm dia through hole
Foot :	0.5mm deep, 12.5mm long and 1.0mm wide notch (inclined at 20^0 with vertical axis)

Bhilai steel plant is using on-line ultrasonic rail testing system. Test equipment is calibrated using a test rail with artificial defects. Ultrasonic system in Bhilai steel plant is as per table 5.1 given below :

Zone	No. of probes	Diameter of Artificial Defects
Head	6	1.5mm
Web	4	2.0mm
Foot bottom	1	2.0mm
Foot-inclined	2	1.5mm

Table 5.1.

The inspection is carried out at a line speed of 1.5 m/sec. The rails after passing through the Rail Roller Straightener Machine (RRSM) are fed into the descaling station where a high pressure water system is used. An encoder defines the speed of the rail on entry to the online automatic ultrasonic inspection system. Photoelectric cells (PEC) define the front and rear end of the individual rail to determine the defective position. The rail then passes into the on-line automatic ultrasonic inspection system. The system is totally automatic and needs no manual involvement. The ultra sonic testing

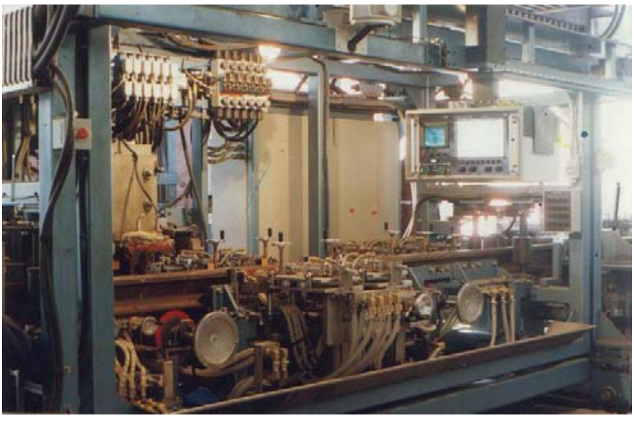


Fig. 5.1. Ultra sonic testing machine

machine being used in Bhilai steel plant in shown in fig. 5.1.

The system provides that any flaw detected will be located against its position within the rail and along the rail length. Also, such defect events are automatically logged by type and position on a printer in the control cabin and a defect is marked on rail automatically by paint sprays on the top head of the rail at the paint gun section. Three different colour codes are being used to identify the defect zone i.e. head, web & foot. Status marking O.K. rail is done by fourth paint spray gun with white colour. The defects marked rails are segregated in a separate bed by automatic tilter. These rails are then manually tested for confirmation of the genuine defect or false signals arising due to high noise level, mechanical vibration, rough surfaces etc.

5.3 Surface Quality :

5.3.1 Hot marks

Depth of rolling guide marks anywhere on the rail should not exceed 0.5mm. A maximum of two guide marks are allowed per rail. The width of each rolling guide mark should not exceed 4.0mm.

Depth and width of guide marks must conform to table 5.2 :

Depth (mm)	Minimum width (mm)	Maximum width (mm)
0.5	1.5	4.0
0.4	1.2	40
0.3	0.9	4.0

Table 5.2

5.3.2 Cold marks

Depth of longitudinal or transverse cold-formed scratches anywhere on the rail should not exceed 0.5mm.

5.3.3 Seams

Rails with seams greater than 0.2mm in depth are not acceptable and shall be ground. On the running surface of the rail, dressing shall be limited to 0.3mm deep and in other places, it shall be limited to 0.5mm deep.

5.3.4 Protrusions

All protrusions in the head or foot of the rail shall be ground to match the parent contour. Protrusions on web greater than 1.5mm high and 20mm square shall be ground. All protrusions affecting the fitment of the fishplate shall be ground.

During examination on the inspection banks, any shrinkage cavity, inclusion & segregation visible to the naked eye shall result in rejection of such rail or cutting out of the defective portion and re-examination.

Any operation carried out either in the hot or cold state with the object of hiding a defect is strictly forbidden.

5.3.5 Eddy Current Testing

In Bhilai steel plant, on-line Eddy current testing system is used to inspect surface defects at the foot bottom, the most critical area. As per specification each and every rail is being inspected for all the surfaces for visual inspection. Foot is most critical because base of the rail is subjected to tensile stresses. Defects on the surfaces are detected by the system at a line speed of 1.5 metres/sec.

The surface is scanned by the Probes/Coils without physical contact as the rail passes over the probe. The test electronics power the excitation windings of probes and generates eddy currents in the surface. If there is a flaw / defect in the foot surface of the rail, the homogeneity of the flow path of eddy current is disturbed and is sensed by the receiver windings of the probes and consequently signal is displayed for flaw/defect The machine is set on predetermined threshold level above the normal noise level on rails and any abrupt signal beyond this level is marked & automatically recorded. Sometimes some spurious defect signals are also observed which arise from some other sources. Thus it is not fool proof system. Visual inspection is required and on-line eddy current system aids/helps the inspectors in concentrating more on defect signals received from eddy current testing machine. The eddy currant testing machine being used in Bhilai steel plant is shown in fig. 5.2.

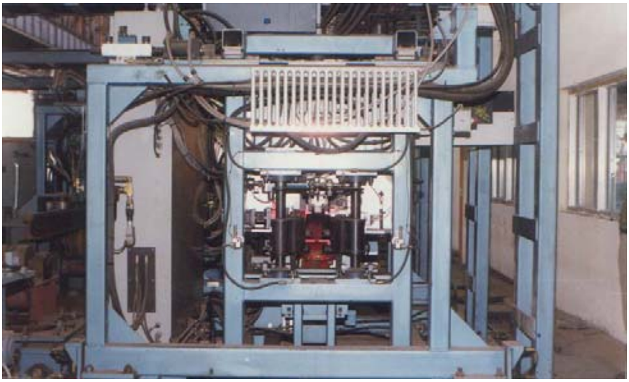


Fig. 5.2. Eddy currant testing machine

5.4 Chemical Analysis :

5.4.1 A complete ladle sample analysis of each cast from which the rails are to be rolled is done. The percentage of each specified element shall conform to the limits specified in Table.4.1 in Chapter 4.

5.4.2 Extent of test (Product)

For casts < 150t, one test per cast
For casts > 150t, two tests per cast, one sample taken from first half of the cast and the other from the second half and different strand. If chemical analysis of any cast fails to conform to the provisions as given in Table 4.1 in Chapter 4, the cast shall be subjected to the retest as per provisions given below.

5.4.3 Retest

Two additional chemical analysis shall be made. If both analysis pass, the casts shall be considered as complying . If one or both of the analysis fail, the cast shall be rejected.

If a cast does not satisfy the conditions of the specification, the intermediate metal belonging to preceding and succeeding cast shall be rejected or subjected to a retest.

The chemical analysis for specified elements shall also be made either from drillings taken from a hole drilled in the rail, or by spectrography or any other approved method, rolled from the same cast or from the tensile test piece or piece selected by the inspecting agency and the percentage of each specified element shall be within the range specified in table 4.1 of chaper 4.

In Bhilai Steel Plant, two lollipop samples from each heat, one at 20 M casting and other at 40 M casting from the Tundish is collected and analysed. The average of the two is reported as ladle sample analysis.

5.4.5 Determination of Hydrogen Content in Liquid Steel

As per IRS-T-12-96, the measurement of hydrogen shall be done by hydris method. The method of measurement as prescribed by the manufacturer of HYDRIS system shall be adopted with approval of the purchaser. Any other alternate method of determination of hydrogen will require prior approval of the purchaser.

The level of hydrogen measured by the method described above shall be 1.6 ppm max. for acceptance of a heat for production of rail.

At Bhilai steel plant, for measurement of the hydrogen content by HYDRIS method, pin sample of 6mm dia & 150mm length is drawn from the ladle after degassing by using imported probe and analysed with the help of LECO analyzer. The analysis is reported within 4 to 5 minutes. If the value is more than permissible limits, the heat is returned to degasser and fresh sample is collected.

5.5 Qualifying Criteria :

As per IRS-T-12-96, 4th amendment, the following tests shall be done for each rail section, grade and class after any change in the process of manufacture which may affect the results or annually for the first three years and if results of these three years are consecutively found satisfactory, the frequency may be relaxed to three years.

a) Residual stress measurement
b) Fracture toughness measurement
c) Fatigue test
d) Inclusion rating level

The samples for these tests shall be collected from finished rails. These samples shall not be subjected to any further mechanical or thermal treatment. The method for carrying out these tests is given in detail in IRS-T-12-96.

Although these tests are to be conducted once in a year as per the specification, but in order to have close monitoring, it is done four times a year in Bhilai Steel Plant. Samples for fracture toughness, fatigue strength and residual stress are sent to RDCIS (Ranchi), for testing as Bhilai steel plant does not have the facilities for such testing whereas inclusion rating test is conducted at Bhilai Laboratory.

5.6 Acceptance Tests :

The following acceptance tests are conducted for 880, 1000 and 1080 Cr grade rails :

a) Chemical Analysis
b) Tensile test
c) Sulphur Print
d) Hardness test (for information & record)
e) Falling weight test
f) Hydrogen content

For 1080 HH rails, the tests to be conducted are as follows :

I. Before Heat treatment

All tests stipulated for grade 1000 rails except tensile and hardness tests.

II. After Heat treatment

The following tests shall be carried out :

a) Tensile test
b) Hardness test
c) Macroscopic test

Chemical analysis including test of hydrogen content have been discussed in para. 5.4. Other tests are discussed below :

5.6.1 Tensile Test

One of the most widely used tests in engineering is the tensile test. It is used either to determine the load carrying capacity or the amount of deformation before fracture. The tensile test consists of applying gradually increasing force of tension at one end of the test piece, the other end being anchored in a rigid support so that the bar is slowly pulled into two. The testing machine is equipped with a device for indicating and sometimes recording the magnitude of the force throughout the test. Simultaneous measurements are made of the increasing length of the selected portion at the middle of the specimen called the gauge length. After the specimen has been pulled into two, the halves are removed from the machine and the fractured ends fitted together. Measurements are made of the now extended gauge length and of the average dimension of the minimum cross section. The extent of test as per IRS-T-12-96 is as follows.

For casts	<	150 t, one test per cast
For casts	>	150 t, two tests per cast one sample taken from the first half of the cast and the other from the second half and from different strand.

5.6.2 Sulphur Print Test

In this test, a Baumann-type impression is obtained by the application of bromide paper, previously impregnated with a solution of sulphuric acid, to the clean rail sections drawn from a location within the cast at the discretion of the Inspecting Agency.

The sections intended to be used for these tests are cold sawn and are then sufficiently cleaned on one surface in order to eliminate completely all machining marks and to obtain a sharp impression.

Extent of Tests

Sulphur print tests shall be carried out at the rate of one each per cast for casts < 150 t and two per cast for casts> 150 tonnes.

Results to be obtained

The prints obtained must not reveal macrographic defects more marked than those of the limit prints shown in (or equivalent to those shown in) the album of macrographic print given in IRS-T-12-96.

5.6.3 Hardness

The accepted definition of the hardness is that it is a measure of the ability of a material to resist deformation, indentation or abrasion. The indentation methods are most commonly employed and the hardness is determined as the resistance offered by the material to the penetration of an indenter of specified material, shape, dimensions and underlying principles in this test is to cause an indentation under specified conditions and to measure the diameter, diagonal or depth of the indentation. In the first two cases, the area of indentation is taken as proportional to the hardness of the material, while in the third method the depth of indentation is taken as proportional to the hardness.

In Brinell a load of 3000kg for ferrous materials Hardness tester and a spherical hardened steel indenter of 10mm dia. is used. The Brinell Hardness Number is defined as the ratio of the load to the spherical area of indentation.

Test on 10% of the casts shall be carried out in case of 880 and 1000 grade rails. The hardness values should preferably be as under:

Grade 880	Minimum 260 BHN
Grade 1000	300 to 350 BHN
Grade 1080 HH	340 to 390 BHN

Results of the test should be the average of five observations on the same test piece.

5.6.4 Falling weight test

The test is primarily intended to ensure that the rail is not in any way brittle and is sufficiently tough. One test per cast is carried out. The method of carrying out test is detailed in IRS-T-12-96.

Chapter-6

IMPORTANT STIPULATIONS OF IRS-T-12-96

6.1 Introduction :

IRS-T-12-96 provides standard specification for flat bottom rails. The provisions related with testing of rails for chemical and physical properties have been discussed in Chapter 5. Its other important provisions are being discussed in this chapter.

6.2 Manufacture :

The steel used for the manufacture of rails shall be made by basic oxygen or electric arc furnace process and continuously cast. In case of steel made by electric arc furnace process, secondary ladle refining is mandatory. The cross sectional area of the bloom shall not be less than ten times that of the rail section to be produced.

6.3 Grade, chemical composition and Mechanical properties :

IRS-T-12-96 stipulates 4 grades of rails viz. 880, 1000, 1080 Cr and 1080 HH rails. The grade being its minimum UTS in Mpa. The percentage elongation on gauge length prescribed is 10% (minimum) for all the grades.

The steel for rails shall be of fully killed quality and shall conform to chemical composition given in Table 4.1 in Chapter 4. The mechanical properties required for various grades of rails are given in Table 6.1.

Grade	Mechanical Properties		
	UTS (MPa) (Min.)	Elongation % on gauge length $5.65\sqrt{So}$ (min.)	Running surface hardness (BHN)
880	880	10.0	Min 260**
1000	1000	10.0	300-350
1080 Cr	1080	9.0	320-360
1080 HH	1080	10.0	340-390

** Desirable Value.

So = Cross sectional area of tensile test piece in mm^2

TABLE - 6.1

6.4 Marking :

Brand Marks : Brand marks shall be rolled in relief on one side of the web of each rail at least every 3.0 meters.

The brand mark shall include:

a) Rail section
b) Grade of steel. e.g. for grade 880 - "880"
c) Identification mark of the manufacturer.
d) Month (using Roman numbers) and last two digits of year of manufacture.
e) Process of steel making :
   e.g. for Basic oxygen – "O", for Electric - "E"

6.5 Hot Sampling :

Each rail shall be identified by a numerical, alphabetical or combined alphabetical and numerical code which will be distinctly hot stampled at least once every 4.0m on the web in figures and letters at least 15mm high from which following information can be obtained :

i) The caste number alongwith letter "C"

ii) Strand number

iii) For change over blooms, cast number should be the preceding cast number with prefix letter 'B'.

6.6 Colour Code :

Rails shall be painted as per colour code given in IRS-T-12-96. Paint of good quality should be used with the prior approval of the Inspecting Agency.

6.7 Permissible Variations in Dimensions :

The dimensional tolerances are as given below. The actual weight computed by weighing short pieces of rail, not less than 300mm in length, shall fall within 0.5 percent below and 1.5 percent above the calculated weight for each rail section.

Tolerances in Sectional Dimensions :

Overall height of rails	: +0.8 mm -0.4mm	
Width of head	: $\pm$0.5mm	Measured 14mm below the rail top.
Width of flange	: $\pm$1.0mm	For sections less than 60kg/m.
	: +1.2mm - 1.0mm	For sections 60kg/m and above
Thickness of web	: +1.0mm - 0.5mm	Measured at the point of minimum thickness.
Verticality/asymmetry	: $\pm$1.2mm	

Base	:	The base of the rail shall be flat, but a slight concavity not exceeding 0.40 mm shall be permissible.
Fishing surfaces	:	The standard template for rail fishing surface shall not stand away from the contour of web by more than 1.20mm and the clearance at the fishing surfaces shall not exceed 0.2mm at any point.

For class-II rails, the tolerances in sectional dimensions are as given below :

Overall height of rails	: +1.6mm -0.8mm	
Width of head	: +1.2mm - 0.6mm	Measured 14mm below the rail top.
Width of flange	: $\pm$1.0mm	For sections less than 60kg/m.
	+1.2mm - 1.0mm	For sections 60kg/m and above
Thickness of web	: +1.6mm - 0.6mm	Measured at the point of minimum thickness.
Verticality/asymmetry	: $\pm$1.2mm	

Base	:	The base of the rail shall be flat, but a slight concavity not exceeding 0.40 mm shall be permissible.
Fishing surfaces	:	The standard template for rail fishing surface shall not stand away from the contour of web by more than 1.20mm and the clearance at the fishing surfaces shall not exceed 0.2mm at any point.

Note : i) Class-II rails shall be used only on loop lines/ private sidings and shall be of length equal to or less than 13m.

ii) A cold punching of "II-Q" at the middle of the web on the center length of rail on non branding side should be done for clear indentification of such rails. Size of these letters should be 15 mm high.

iii) Class-II rails should be painted with orange colour on both sides of the web for a distance of 1 meter from each end, for easy identification.

iv) Class-II rails should be loaded in one wagon and should not be mixed with other rails for dispatch.

6.8 Length of Rails :

The standard length of rails shall be 13 metres or 26 metres. However, incase, rails are to be procured to longer lengths, the same shall be prescribed by the purchaser.

The manufacturer shall be entitled to supply in pairs short upto 10% by weight of the quantity contracted for or ordered. Such shorter length shall not be less than 8.0m in length for standard length of rails of 13m and shall not be less than 24m in lengths for standard length or rails of 26m. The short length shall multiples of 1.0m. Tolerances in length of all rails shall be +20.0mm and -10.0mm.

6.9 End squarness :

The deviation from square in both horizontal and vertical direction shall not exceed 0.6mm on a length of 200mm.

6.10 Straightness :

The straightness of the whole rail shall be judged by naked eye but incase of doubt or dispute, the affected portion shall be checked using 1.5 metre straight edge. The maximum permissible deviations shall be 0.70 mm measured as the maximum ordinate on a chord of 1.5 metre. Wavy, kinky and twisted rails shall not be accepted.

6.11 End straightness :

The tolerances for end straightness are prescribed in table 6.2 as given below :

Straightness	Tolerances	
	Class 'A' rails	Class 'B' rails
Horizontal	Deviation of 0.5 mm measured as maximum ordinate from the chord of 2.0 metres standard straight edge.	Deviation of 0.7 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge.
Vertical a) Up sweep b) Down sweep	Deviation of 0.4 mm measured as maximum ordinate from the chord of 2.0 meters standard straight edge. Nil	Deviation of 0.5 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge. Nil

Table-6.2

The method of measurement of end straightness are shown in figure 6.1 and 6.2 given below:-

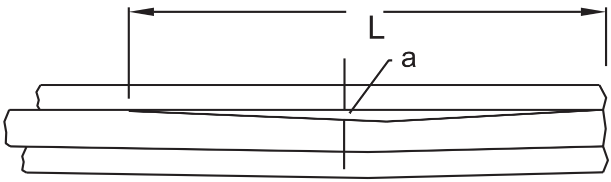


Fig. 6.1 Top view of Horizontal Tolerance at Rail Ends

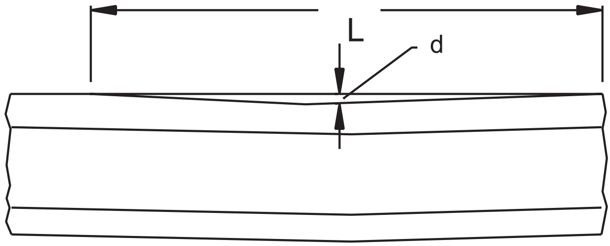


Fig. 6.2 Side view of Vertical Tolerance at Rail Ends

Note :

L = Length of straight edge specified in Table. 6.2

D = Maximum tolerance specified in Table. 6.2

CHAPTER – 7

HANDLING OF RAILS

7.1 Introduction :

Earlier, 72 UTS rails were being used on Indian Railways. These rails were having less tensile strength and wear resistant property. At the same time these rails were more ductile. This was so because of less carbon content. The effect of carbon on strength and ductility of steel has been studied in chapter 4.

As these rails were having more ductility, they were less fracture prone. However, with the introduction of BOX'N' -wagon and higher axle load, 72 UTS rails were having alarming wear. To overcome this problem, the use of higher UTS i.e. 90 UTS and above rails were started. 90 UTS rails are having higher tensile strength and more wear resistant property but are brittle as the carbon content is more. This increased brittleness makes these rails more susceptible to fracture. Because of this reason proper handling of 90 UTS rails is very important.

Rails of 90 or higher UTS require extra care for handling as compared to 72 UTS rails while loading or unloading, transporting, inserting into track or any other handling related to track maintenance.

Research design and standard organisation (RDSO) has issued manual of instructions on handling of rails. The manual provides precautions and methods to be followed for handling and stacking of the rails.

The important precautions to be taken while handling rails are as follows :-

i) maintaining perfect straightness
ii) avoiding surface notching

iii) preventing metallurgical damage
iv) isolating from injurious substances
v) protecting personnel

7.2 Maintaining perfect straightness :

Barely visible straightness deviations, for example a deflection of 0.50 mm over 2.0 m span, renders a rail unacceptable since even a small deflection can cause heavy impact on rail in service under running wheels. Because of higher strength, 90 UTS rails have lesser toughness and there proneness to fracture on account of such impact is more. These impacts can cause higher stresses and higher the stresses, lesser is the number of cycles to failure i.e. the fatigue life will be less. Therefore, special care should be taken to avoid loss of straightness during all handlings, stacking and transport operations as detailed below :

- Heavy static loading and sudden impact (or dynamic) loading should be avoided
- Single point slinging should be avoided and minimum two point slinging should be ensured. More slings should be used for longer rails.
- Rails should be kept horizontal and straight when lifting, carrying or placing them.
- End drop and flange overlap should be avoided.
- Localized point or line contact loading, when stacking, should be avoided.
- Rails should be aligned uniformly, avoiding flange overlap or crossing.
- Rails of the same length should be stacked together on a firm level base providing uniform support.
- Subsequent layers should be separated with consistently and uniformly placed spacers or dunnage in vertical alignment with the base supports.
- All necessary precautions should be taken to protect rail ends.
- Extra care should be exercised with longer rails.

7.3 Avoiding surface notching :

90 UTS rails are highly notch sensitive and more fracture prone. The triaxial state of stress exists at a notch. In engineering practice, the common notches or stress raisers are holes, any change in section of material, metallurgical defects like cavities, blow holes, slag or inclusions etc. The changes produced by the introduction of a notch have important consequences in fracture process. A notch creates a local stress peak at the root of the notch. Plastic flow begins at the root of the notch when this local stress reaches the yield strength of the material. The plastic flow relieves the high elastic stress and limits the peak stress to the yield stress of the material. However, more important effect of the notch is to produce a triaxial state of stress at the notch rather than introducing a stress concentration and ultimately reducing the fatigue strength.

Surface notches of even less than 0.25mm in depth may cause rail fracture in service. Therefore, insufficient care in handling and transport operations can lead to serious rail surface damage. To prevent rail surface from any damage, the following precautions should be taken:

- Impact or abrasion of rails and rail bundles against structures, buildings, ships, hatches, wagons, vehicles etc. should be avoided.
- Perfect straightness of rails in each layer should be ensured.
- Crossing or flange overlap should be avoided
- Use of round-link chain sling should be avoided. Ideally, the rails should be lifted by using electro-magnetic lifting devices.
- Where conventional slings are employed, use of fabric, e.g. polypropylene slings and sleeves are recommended. As an alternative, if flat link chains are used, these must be fitted with fabric sleeves.

- Bruising, notching or scoring of surface should be avoided
- Rail support, handling or clamping device and rail pinch rollers should not apply localized or point contact to the rail. These items should be profile contoured to match the rail profile as appropriate.

7.4 Preventing metallurgical damage :

High UTS rails are thermally very sensitive and any localized heating may cause a hard, brittle and cracked metallurgical structures which may lead to sudden failures. Therefore,

- All heatings, flame cutting, welding and spot welding operations must be strictly prohibited during rail handling or transit.
- Every precautions must be taken to protect rail from electric arc from adjacent cables or molten metal splashes from nearby welding operations.

7.5 Isolating from injurious substances :

High UTS rails can withstand normal degree of rusting. However in unfavourable environments, this normal rusting may be accelerated. A more serious risk is posed by localized corrosion. The effect of corrosion is to form pits on surface, which become sharp notches in due course of time and cause stress concentration. The stress concentration gives rise to fracture proneness of the rails.

To avoid this, following precautions are required:

- Contact with injurious substances which are known to, or likely to react with and produce high levels of corrosion in steel should be avoided. Special attention should be given to acids, alkalis, salts, fertilizers, sulphates, chlorides and nitrates. The rails should not be stacked adjacent to such harmful substances.

- Rail stockpiles should be built on a well drained base of inert material with uniform supports and preferably above ground level on concrete as per Drawing No. RDSO/T-4962.

7.6 Protecting personnel :

To protect persons from injuries, special attention should be given with respect to following :

- Use of effective protective gloves and clothing to reduce risk of skin abrasions and lacerations. Gloves will also mitigate against the effects of extremes of temperature experienced when rails are exposed to either very cold or very hot climatic conditions.
- Steel toe-capped protective footwear should be used. Distinctive coloured helmets and clothing should be used to provide ease of identification and location of personnel by machine or crane operators.
- Standing under suspended rails should be avoided.
- Sudden dropping or impact on rails should be avoided
- Use of bundle strapping in lifting, slinging or handling of rails should be forbidden
- Safe working in the vicinity of electrical conductors and wiring should be ensured to avoid contact with rails.

7.7 Stacking :

7.7.1 Base preparation

Stacking of rails shall be done on proper concrete base as per drawing No. RDSO/T-4962. Base supports and dunnage should be evenly spaced along the rail length, with special care to support near rail ends. Rails forming the bottom layer should be carefully aligned and care should be taken to avoid overlapping of rail flanges.

7.7.2 Subsequent Layers

- Rails of the same length should be kept in a stack. Where this is not possible, the shorter rails should be placed in the upper layers.
- A leaning stack should be avoided.
- When dunnage is used, layers should not be crossed. The rails should be kept in a uniform lengthways direction.
- Good vertical alignment of dunnage should be ensured
- Timber dunnage should be of a uniform and adequate thickness (say 100 mm) to withstand loading and allow for sling removal without 'ripping out'.
- Each succesive layer of rails should be either of of a constant or decreasing width.

7.8 Handling of Rails :

Mainly the handling of rails is involved at production unit, flash butt welding plant (FBWP) and at site. The precautions required while handling rails at different locations are discussed below :

Production Unit

At production unit, the handling of rails should be done using magnetic lifting devices which are suspended from a lifting spreader beam.

At Bhillai Steel Plant, the rails are loaded in flat bottom wagons. There are 13 rails per layer & 4 layers separated by rollers. These rakes are called EUR (End unloading rakes). The long rails are handled by automatic rail handling system controlled by a computerized map of the storage yard. The system makes it possible to assign and record the position of individual rails in the yard. The stacking, loading and dispatch of rails from the storage area is controlled by the mapping system. Loading reports are generated automatically.

Handling of Rails in Flash butt welding plant (FBWP)

At FBWP, the rails should be unloaded by using magnetic lifting beams. If the same is not available than the unloading may be done using electric hoist and spreader beam. After unloading, the rails should be stacked at a proper concrete base as per Drawing No.RDSO/T-4962. The base support and Dunne should be evenly spaced along the rail length and rail end should be properly supported. In a particular stack, rails of same length, if possible, should be stacked. In case of all the rails are not being of a equal length shorter length should be in upper layer. Each successive layer should be having consistent or decreasing width.

Handling of Rails at Site

Proper rail handing at work site is very important. In Open Line at track renewal sites single rails should be unloaded by providing a ramp of two wooden sleepers kept at 6.5m apart.

3 rail panels should also be unloaded using ramp of un-serviceable wooden sleepers.

10/20 rails panels should invariably be unloaded from special end unloading rakes.

At construction site, for loading and unloading of rails in road vehicle, the road crane should be used. In case of doubling project, rails should be taken by BFRs and unloaded using unloading rakes.

Immediately after unloading of rails, these should be kept in upright and straight alignment. In case of long girder bridges, the rail panels should be supported on bridge timbers and not allowed to sag over the opening.

CHAPTER-8

NEW DEVELOPMENTS IN RAIL MANUFACTURING

8.1 Introduction :

The material for rail has to fulfill two primary requirements. The material must not be brittle so as to minimize the risk of breakage under heavy loads. At the same time it has to be hard enough to resist wear. These two requirements are contrasting. Therefore, the design of rail steel involves certain trade offs. At the same time efforts have continued to be made to develop rail steel, which can meet the requirements in a better way, and these efforts have resulted in a number of developments, which are being discussed in this chapter.

8.2 Head Hardening of Rails :

Wear is one of the factors restricting serviceability of rails, particularly on curves. A large number of rails have to replaced every year on account of wear. It is therefore important to improve the wear resistance of the rail. Head hardening of rail has been found to be an economical and effective way of increasing the wear resistance of the rails.

The technology for head hardening was developed in 1970s. The top of the rail is heated upto 900^0C as shown in Fig. 8.1 and then cooled quickly to create a fine pearlite microstructure at the top of the rail. Earlier mist was used as coolant but the new techniques use compressed air as coolant. The latest equipment makes use of induction heating to ensure uniform heating. With this the variation in temperature can be limited to 50^0C to 60^0C as against 100^0C earlier.

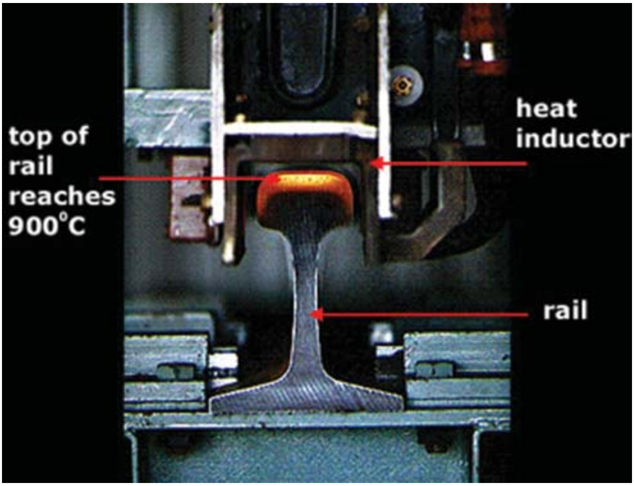


Fig.8.1 Head Hardening

The head hardened rail show hardness of the order of 360 to 400 BHN on the running surface.

8.3 Premium Rails :

Premium Rails is a term which refers to the rail made of high tensile strength steel. The ultimate tensile strength of these rail steel is around 1300 N/mm^2. Such high strength is achieved by reducing the spacing between the pearlite lamellae by controlling growth rate of pearlite. Another way of improving the properties is through alloying elements such as chromium and nickel.

The hardness rating of these rails is in the range 340 to 400 BHN. The premium rails can also be made to undergo head hardening so as to further improve the hardness.

8.4 Corrosion-Resistant Rails :

The corrosion resistance of steel is substantially improved by the addition of elements such as copper, aluminum, silicon and chromium. These elements form thin but dense and adherent oxide films which protect the surface of the steel from further attack. Chromium is the most suitable additive if mechanical properties are also to be improved.

Steel Authority Of India Limited (SAIL) has produced corrosion resistance rails for use on Indian Railways which are under trial. The rail steel under trial typically contains about 0.33 percent Copper and 0.15 percent Molybdenum.

8.5 Banitic steel :

A variety of steel called Banitic steel is being tried for manufacture of rails. These steels are low carbon steels and contain chromium and molybdenum. The manufacturing process includes moderate quenching. The microstructure consists of non-laminar aggregate of cementite and plate shaped ferrite.

These rails have strength comparable to conventional heat treated rails. However, these are superior as far as toughness is concerned. The improvement in toughness significantly increases the size of crack which can be tolerated in service without causing fracture.

For steel having comparable hardness, the banitic steels show much less wear. The trials have also indicated that in case of banitic rails the development of rolling contact fatigue is much delayed in comparison with conventional rails.

This material is under trial since 1980s and has been found to have higher resistance against wear and rolling contact fatigue defects.

8.6 Longer rails :

As per IRS-T-12-96, the standard length of rails shall be 13m or 26m. However, in case rails are to be procured in longer lengths, ths same shall be prescribed by the purchaser.

Bhilai steel plant has commissioned its long rail finishing line to cater to the demand for long rails from Indian Railways. Taken up at a cost of Rs. 400 crore, Long rail finishing line produces rails upto 80 meter length and welded rail panels of upto 260 meter lengths. This results in ready to use welded panels being sent to site directly. Concerns of safety and economy of operations have necessitated railroads world over, to switch to long rails with very few weld joints. The longer the length of the rail, the lesser the number of welds per kilometer length.

The Long rail finishing line of Bhilai steel plant has the most modern rail processing equipments. The rail straightening machine, the ultrasonic and eddy current rail testing systems, the laser based straightness measurement and 4 directional hydraulic press, precision cut to length carbide saws and the computer controlled automation and rail mapping systems. The Bhilai steel plant has already started supplying 260m long rails to Indian Railways.

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