
Steelmaking

HND Mineral Engineering Lecture Note,
DEPARTMENT OF MINERAL RESOURCES
ENGINEERING

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1.0 Introduction

Whereas ironmaking is a reduction process producing an impure iron containing carbon, silicon, manganese, phosphorous and sulphur as the main impurities, steelmaking is an oxidizing (fire – refining) process in which the impurities in the pig iron are lowered to acceptable levels depending on the required steel specification. This is the second step in producing steel from iron ore. In this stage, impurities such as sulphur, phosphorus, and excess carbon are removed from the raw iron, and alloying elements such as manganese, nickel, chromium and vanadium are added to produce the exact steel required.

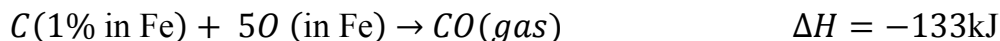
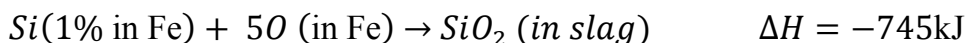
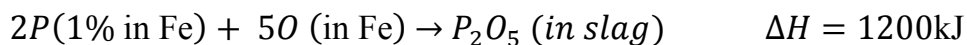
1.1 General Principles of Steelmaking

The general principles of steelmaking process are as follows:

- Removal of all impurities from molten pig iron by oxidation
- Deoxidation,
- Addition alloying element to obtain the desired steel.

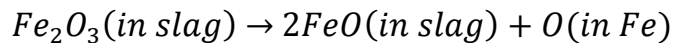
A. Removal of all impurities from molten pig iron by oxidation

The impurity elements in the pig iron oxidize during steelmaking with exothermic reactions.



Under steelmaking conditions, P_2O_5 exist in the slag as a liquid and is not evolved as gas. Atom oxygen (O) is used in above reactions is assumed to have come the dissociation of an oxide of iron at the slag – metal interface:

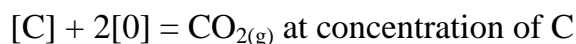
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In oxygen blown processes, there is supply directly into the molten pig iron which causes reaction with *C, Si, Mn, P* and iron oxidizes to *FeO*.

i) Oxidation of carbon

The pig iron contains about 4% C. In steel, we need less than 2% of C hence the main reaction in steel making is oxidation of carbon (burning off). The dissolved carbon in metal is oxidized into CO bubbles. In this, metal is said to be boiling i.e. the carbon boil reaction.



$$\Rightarrow K_C = \frac{P_{CO}}{[C][O]}$$

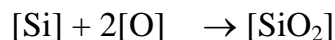
The processes of decarbonation are:

- Supply of reagents (i.e. C & O₂)
- The reaction [C] + [O] proper and
- Evolution of reaction products CO & CO₂

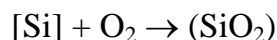
ii) Oxidation of silicon

Silicon is an element which easily oxidizes. The oxidation of dissolved silicon in the metal occurs in the following ways:

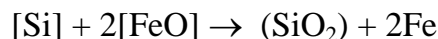
- Dissolve oxygen in the metal



- Oxygen in the gaseous phase



- Iron oxides in the slag



In all these reaction, heat is evolved (i.e.) It is exothermic.

iii) Oxidation of Phosphorous (Dephosphorisation)

The oxidation of phosphorous helps in the removal of phosphorous. The removal of phosphorus from liquid steel is essence due to fact that it is harmful. The procedure of removal of phosphorus from metal is called dephosphorisation. It can be effectively carried out only primary steelmaking operation to achieve phosphorous content of 0.025-0.030wt% in steel.

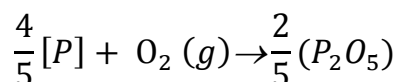
Sources of phosphorus are pig iron charge and scrap iron

The effects of phosphorus in steel are as follows:

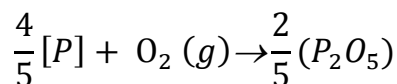
1. Segregation occurs during solidification of ingot or casting
2. It impairs the plastic properties of steel by forming high-phosphorous brittle streaks (interlayer's) between metal grains. This is caused by ratio of diffusion of phosphorus which is low, hence producing in homogeneities.

Desphosphorisation can take place as follows:

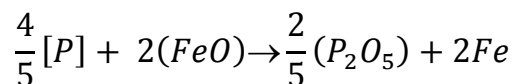
- a. Oxidation of phosphorus with oxygen of generous phase



- b. With nitrogen dissolved in metal

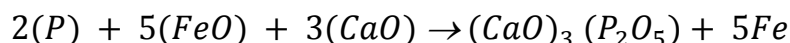
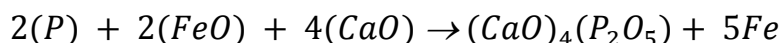


- c. With oxygen present in iron oxides of the slag.



Phosphorus serves as fuel in order to remove phosphorus from metal and it is retained in the slag, the activity of P_2O_5 in the slag must be decreased by adding lime (or limestone).

CaO reacts with P_2O_5 to form stable compound type: $(CaO)_4(P_2O_5)$ or $(CaO) (P_2O_5)$



$$K = a_{(CaO.P_2O_5)}$$

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Condition for Desphosphorisation

1. Formation of an oxidizing furnace atmosphere and respectively of oxidizing slag with a high activity of iron oxides in it (the slag must have a high content of FeO).
2. High basicity of the slag and high activity of CaO in it (the slag must be high in CaO and low in SiO₂);
3. Quick formation of ferruginous –limy slag;
4. A relatively low temperature (especially at moderate and high concentrations of carbon;
5. Low activity (concentration of phosphorus in the slag.

In practice, these conditions are provided by the following techniques:

- (a) Addition of iron oxides to the melt (in the form of the iron ore or scale);
- (b) Addition of CaO (lumpy or powdered lime or limestone);
- (c) Blowing the bath with oxygen (or air);
- (d) Removing most phosphorus at an early stage of the heat when the temperature of the metal is still now high;
- (e) Forming an active free-running slag as early as possible, this can be achieved by bath stirring, adding certain fluidizers to the slag, etc. in cases when it is allowed by the process technology, the fluid final slag from the previous heat, which contains much of CaO and FeO and little phosphorus, is let in the plant;
- (f) Slag renewal (i.e. by slagging – off and the formation of new slag free from phosphorus).

iv) Oxidation of Sulphur (Desulphurisation)

The conditions necessary for sulphur removal during steelmaking are:

1. Basic slag formation
2. Low oxygen potential in the metal
3. High metal temperature

B. Deoxidation

Deoxidation is the process whereby the activity oxygen is lowered to required minimum.

The factors responsible for the presence of dissolved oxygen are:

1. The oxidizing conditions of the heat in a steelmaking plant
2. The presence of oxidizing slag
3. The interaction of the metal with the surrounding oxygen at tapping.

The activity of O₂ lowered by two methods

- By lowering the O₂ concentration
- By combining O₂ into stable compound

Hence, in practice, the methods of deoxidation are:

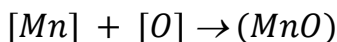
- Precipitation deoxidation or deoxidation in the bulk
- Diffusion deoxidation
- Treatment with synthetic slag
- Vacuum treatment

i) Precipitation Deoxidation (Deoxidation in the bulk)

The method involves adding deoxidizing agent which combines the dissolved oxygen to form an insoluble oxide. The deoxidizing elements must have a higher affinity for oxygen than iron. The product of reaction is a low soluble oxide whose density is less than that of the metal. The precipitate floats up to slag. The deoxidants are:

1. Manganese (as Ferro-manganese)
2. Silicon (as Ferro-silicon)
3. Aluminum

Deoxidation occurs by the following reactions:



All these reactions are exothermic.

Deoxidation by Manganese: Manganese is a relatively weak deoxidation and cannot lower the oxygen content to the derived limit.

Advantages

- a. It has a positive role in eliminating the harmful effects of sulphur
- b. It has a positive effect on the hard ability and strength of stench.
- c. It gives a low interfacial tension at boundaries between molten steel and MnO inclusions, hence helps in the removal of inclusion.

Deoxidation of Silicon: When silicon is added to molten steel, it form liquid iron silicate, with basic slag present in the steelmaking facility, the silicon form an addition of silicon reacts with basic oxides of the slag. This means that iron is readily wettable by silicon, which involves certain difficulties in removable of silicate inclusion from the metal.

Deoxidation of Aluminum: Aluminum is a stronger deoxidant than silicon. It aluminum is added in surplus, it can react with oxides of weaker deoxidant (such as MnO or SiO₂) as well as with the dissolved oxygen. It also reacts with N₂ to form AlN, hence decreasing the harmful effect of nitrogen and making the steel less liable to ageing.

ii) Diffusion deoxidation

The principle of diffusion deoxidation is based on the distribution law. Since oxygen is readily soluble both in slag and in metal, it can be taken that, if there is no both boil, the ratio of the oxygen activities in the metal and slag is constant at constant temperature:

$$L_o = \frac{a_{(O)}}{a_{(FeO)}}$$

Accordingly, $a_{(O)} = L_o a_{(FeO)}$. The metal can be deoxidize in directly by deoxidizing the slag the deoxidants for adding to the slag include coke, broke, electrodes, ferrosilicon.

Advantage

1. It diminishes the concentration of impurities in steel
2. It increases the degree of utilization of easily reducible (from slag) impurities

Disadvantages

1. The making part of reducing mixtures added to the slag would be used not for the reduction of iron oxides in the slag.

iii) Vacuum Treatment of Molten Metal

The equilibrium of the reaction $(C) + (O) \rightarrow CO_g$ is shifted towards the formation of carbon monoxides. The equilibrium constant of this reaction is:

$$k = \frac{P_{CO}}{a_{[C]}a_{[O]}}$$

The deoxidizing effect of carbon increases will decrease pressure P_{CO}

iv) Deoxidation with Synthetic Slag

The metal can be deoxidized if the activity of iron oxides in the synthetic slag is negligible. As in diffusion deoxidation, the oxygen activity in the metal decreases with decreasing activity of oxygen in the slag $a_{(O)} = l_0 a_{(FeO)}$

In synthetic slag treatment of metal tapped from an open hearth furnace or converter into a ladle, it is essential to mix the metal and slag as thoroughly as possible.

Note: slag must contain no iron oxide, i.e. $a_{(FeO)} = 0$

High basic slag is usually employed for purpose, which form favourable condition both for desulphurization and for deoxidation of the metal.

C. Addition of known quantities of carbon and alloying element to obtain the desired steel

The commonly used alloying elements and their effect on steel listed below:

- **Aluminum** (0.95-1.30%): A deoxidizer. Used to limit growth of austenite grains.
- **Boron** (0.001-0.003%): A hardenability agent that improves deformability and machinability. Boron is added to fully killed steel and only needs to be added in

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very small quantities to have a hardening affect. Additions of boron are most effective in low carbon steels.

- **Chromium** (0.5-18%): A key component of stainless steel. At over 12 percent content, chromium significantly improves corrosion resistance. The metal also improves hardenability, strength, response to heat treatment and wear resistance.
- **Cobalt**: Improves strength at high temperatures and magnetic permeability.
- **Copper** (0.1-0.4%): Most often found as a residual agent in steels, copper is also added to produce precipitation hardening properties and increase corrosion resistance.
- **Lead**: Although virtually insoluble in liquid or solid steel, lead is sometimes added to carbon steels via mechanical dispersion during pouring in order to improve machinability.
- **Manganese** (0.25-13%): Increases strength at high temperatures by eliminating the formation of iron sulfides. Manganese also improves hardenability, ductility and wears resistance. Like nickel, manganese is an austenite forming element and can be used in the AISI 200 Series of Austenitic stainless steels as a substitute for nickel.
- **Molybdenum** (0.2-5.0%): Found in small quantities in stainless steels, molybdenum increases hardenability and strength, particular at high temperatures. Often used in chromium-nickel austenitic steels, molybdenum protects against pitting corrosion caused by chlorides and sulphur chemicals.
- **Nickel** (2-20%): Another alloying element critical to stainless steels, nickel is added at over 8% content to high chromium stainless steel. Nickel increases strength, impact strength and toughness, while also improving resistance to oxidization and corrosion. It also increases toughness at low temperatures when added in small amounts.
- **Niobium**: Has the benefit of stabilizing carbon by forming hard carbides and, so, is often found in high temperature steels. In small amounts, niobium can

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significantly increase the yield strength and, to a lesser degree, tensile strength of steels as well as have a moderate precipitation strengthening affect.

- **Nitrogen:** Increases the austenitic stability of stainless steels and improves yield strength in such steels.
- **Phosphorus:** Phosphorus is often added with sulphur to improve machinability in low alloy steels. It also adds strength and increases corrosion resistance.
- **Selenium:** Increases machinability.
- **Silicon (0.2-2.0%):** This metalloid improves strength, elasticity, acid resistance and results in larger grain sizes, thereby, leading to greater magnetic permeability. Because silicon is used in a deoxidizing agent in the production of steel, it is almost always found in some percentage in all grades of steel.
- **Sulphur (0.08-0.15%):** Added in small amounts, sulphur improves machinability without resulting in hot shortness. With the addition of manganese hot shortness is further reduced due to the fact that manganese sulphide has a higher melting point than iron sulphide.
- **Titanium:** Improves both strength and corrosion resistance while limiting austenite grain size. At 0.25-0.60 percent titanium content, carbon combines with the titanium, allowing chromium to remain at grain boundaries and resist oxidization.
- **Tungsten:** Produces stable carbides and refines grain size so as to increase hardness, particularly at high temperatures.
- **Vanadium (0.15%):** Like titanium and niobium, vanadium can produce stable carbides that increase strength at high temperatures. By promoting a fine grain structure, ductility can be retained.
- **Zirconium (0.1%):** Increases strength and limits grains sizes. Strength can be notably increased at very low temperatures (below freezing). Steel's that include zirconium up to about 0.1% content will have smaller grains sizes and resist fracture.

2.0 Manufacture of Steel

There are three major routes for the production of plain carbon steels, namely;

1. The integrated Blast Furnace (BF) – Basic Oxygen Furnace (BOF) also called LD process).
2. The scrap/direct reduction iron or sponge Iron – Electric Arc Furnace (EAF)
3. Open hearth process

2.1 Raw Materials in Steelmaking

Raw materials used in steel making are:

- (i) Pig iron or
- (ii) Sponge iron
- (iii) Scrap iron/scrap steel
- (iv) Fluxes
- (v) Oxygen
- (vi) Alloying element

i) MOLTEN PIG IRON (HOT METAL)

Hot metal is liquid iron from the blast furnace saturated with up to 4.3% carbon and containing 1% or less silicon, Si. It is transported to the BOF shop either in torpedo cars or ladles. The hot metal chemistry depends on how the blast furnace is operated and what burden (iron-bearing) materials are charged to it. The trend today is to run at high productivity with low slag volumes and fuel rates, leading to lower silicon and higher sulfur levels in the hot metal. If BOF slag is recycled, P and Mn levels rise sharply since they report almost 100% to the hot metal. U.S. iron ores are low in both elements.

The sulfur level from the blast furnace can be 0.05% but an efficient hot metal desulfurizing facility ahead of the BOF will reduce this to below .01%. The most common desulfurizing reagents, lime, calcium carbide and magnesium - used alone or in

combination - are injected into the hot metal through a lance. The sulfur containing compounds report to the slag; however, unless the sulfur-rich slag is skimmed before the hot metal is poured into the BOF, the sulfur actually charged will be well above the level expected from the metal analysis.

ii) SCRAP

In autogenously BOS operation, scrap is by far the largest heat sink. At 20 - 25% of the charge it is one of the most important and costly components of the charge.

Steel scrap is available in many forms. The major categories are "home scrap", generated within the plant. With the advent of continuous casting, the quantity of home scrap has diminished and it is now necessary for integrated mills to buy scrap on the market. Flat rolled scrap is generally of good quality and its impact on the chemistry of BOF operations can almost be ignored. There is a yield loss of about 2% due to the zinc coating on galvanized scrap. "Prompt scrap" is generated during the manufacturing of steel products. It finds its way into the recycling stream very quickly. Many steel mills have agreements with manufacturers to buy their prompt scrap. "Obsolete" or "post-consumer" scrap returns to the market after a product has ended its useful life. Cans return to the market very quickly but autos have an average life of 12 years.

Scrap also comes in many sizes, varying chemical analyses and a variety of prices. All of which makes the purchase and melting of scrap a very complex issue. Very large pieces of scrap can be difficult to melt and may damage the vessel when charged. Some scrap may contain oil or surface oxidation. Obsolete scrap may contain a variety of other objects which could be hazardous or explosive. Obviously the chemical analysis of obsolete scrap is imprecise.

Scrap selection is further complicated by the wide variety of steel products. Deep drawing steels limit the maximum residual (%Cu +%Sn + %Ni +%Cr +%Mo) content to less than 0.13%, while other products allow this to range as high as 0.80%. Since these elements cannot be oxidized from the steel, their content in the final product can only be reduced by dilution with very high purity scrap or hot metal. The use of low residual hot

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metal in the BOS, with its inherent dilution effect, is one of the features that distinguish BOF from EAF steelmaking.

iii) FLUXES

Fluxes serve two important purposes. First they combine with SiO_2 which is oxidized from the hot metal to form a "basic" slag that is fluid at steelmaking temperatures. This slag absorbs and retains sulfur and phosphorus from the hot metal.

Lime (95+% CaO) and dolomite (58%CaO, 39% MgO) are the two primary fluxes. They are obtained by calcining the carbonate minerals, generally offsite in rotary kilns. Calcining Ca CO_3 and Mg CO_3 liberates CO_2 leaving CaO or MgO. Two types, "soft" and "hard" burned lime, are available. A lump of soft burned lime dissolves quickly in a cup of water liberating heat. Hard burned material just sits there. Soft burned fluxes form slag more quickly than hard-burned, and in the short blowing cycle, this is critical for effective sulfur and phosphorus removal. The amount of lime charged depends on the Si content of the hot metal.

In BOS steelmaking a high CaO/ SiO_2 ratio in the slag is desirable, e.g. 3. A rule of thumb is 6 X the weight of Si charged. The MgO addition is designed to be about 8 to 10% of the final slag weight. This saturates the slag with MgO, thus reducing chemical erosion of the MgO vessel lining.

iv) COOLANTS

Limestone, scrap, and sponge iron are all potential coolants that can be added to a heat that has been overblown and is excessively hot. The economics and handling facilities dictate the selection at each shop.

v) ALLOYS

Bulk alloys are charged from overhead bins into the ladle. The common alloys are ferromanganese (80%Mn, 6%C, balance Fe), silicomanganese (66%Mn, 16%Si, 2%C, balance Fe), and ferrosilicon (75% Si, balance Fe). Aluminum can be added as shapes

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and/or injected as rod. Sulfur, carbon, calcium, and special elements like boron and titanium are fed at the ladle furnace as powders sheathed in a mild steel casing about 1/2 inch in diameter.

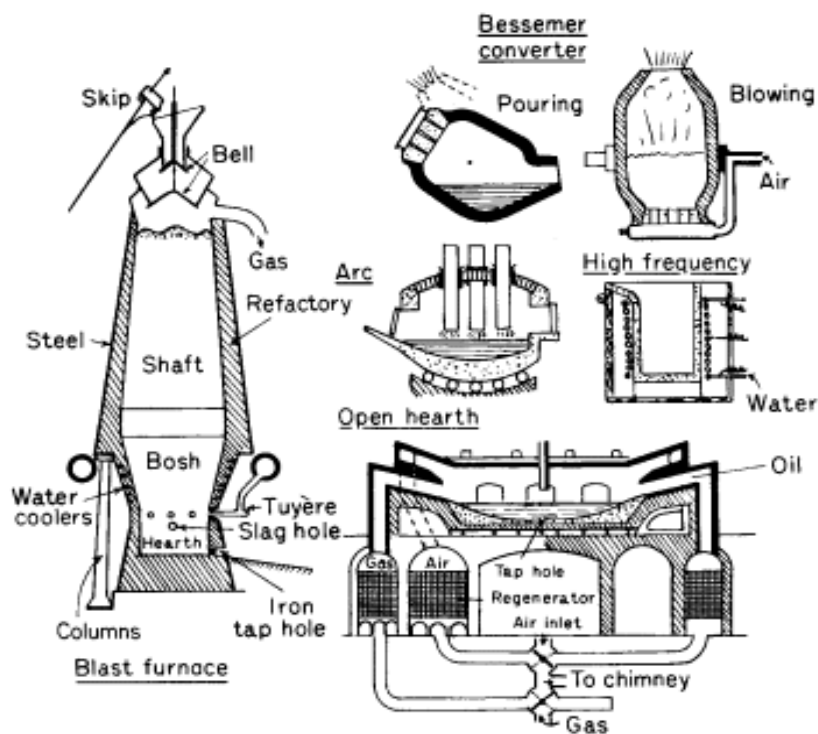


Fig. 1: Overview of Steelmaking Process

2.2 Manufacture of Steel by Bessemer processes

The evolution of modern steelmaking started from Henry Bessemer's invention of converter. The original Bessemer process (i.e.) Acid Bessemer was invented in 1856, while the basic Bessemer (i.e.) Thomas process patented in 1879.

The Bessemer process uses a cylindrical vessel (called converter). The converter shown below was originally lined with silicon refractory (it can withstand attack from acidic oxides). Liquid iron (i.e.) molten iron from blast furnace is poured into the converter and air is blown through the bottom tuyeres. The oxygen in the air is blown and reacts with Si, C, and Mn to form oxide such as; SiO_2 , MnO etc. These oxides alongside with FeCO

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form an acidic slag and, CO and CO₂ escape into the atmosphere. The oxidation reactions are exothermic, hence the temperature of the liquid bath rises and there is no need of external fuel. The process is economic because it is fast (refining there is about 20 meters)

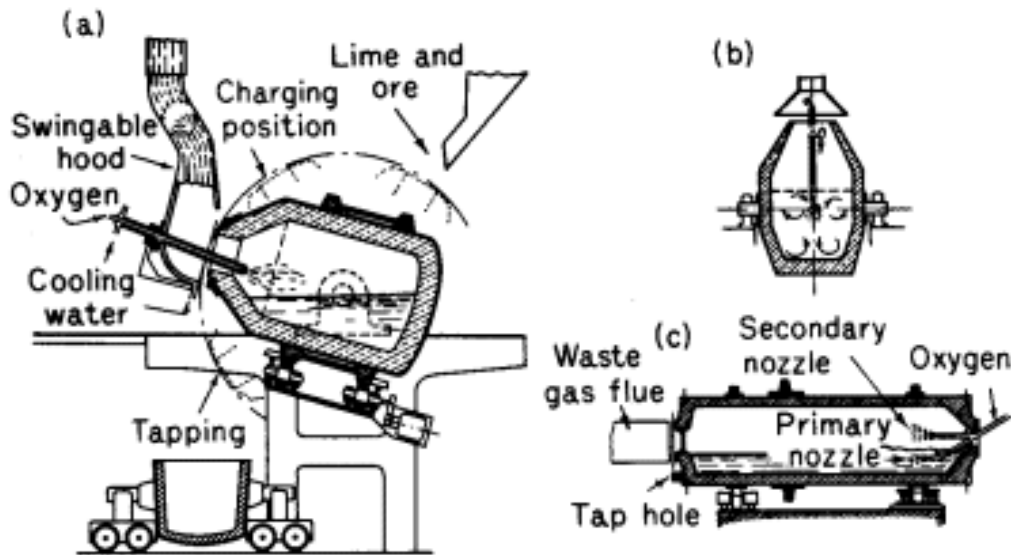


Fig.2: Steel is made by the Bessemer, Siemens Open Hearth, basic oxygen furnace, electric arc, electric high-frequency and crucible processes.

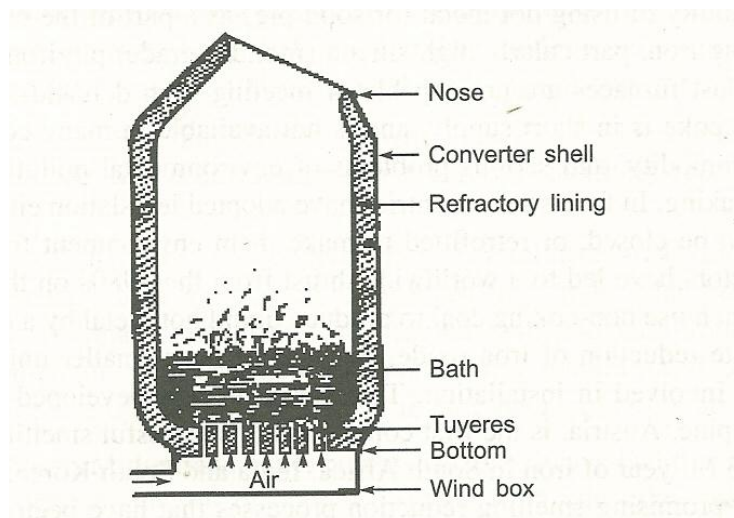


Fig. 3: Bessemer converter steel making process

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The major limitation of this process, it could not remove Sulphur and Phosphorus which are harmful impurities to steel. The introduction of basic Bessemer process of the Thomas process involving the use of a basic oxide (burnt dolomite or magnetic) lining in the vessel tackled the removal of phosphorous, basic oxides (e.g.) CaO as flux were added during the blow to form a basic slag of high 60 content. This type of basic slag was capable of removing phosphorus in the form of calcium phosphate. Both acid Bessemer and basic Bessemer steel suffered from the problem of high level nitrogen introduced the air blow.

Advantages of Basic Oxygen Steelmaking over Acidic Bessemer process

- It is rapid-the cycling time is about 45min
- Nitrogen contamination is very low so that deep-drawing quality mild steel is produced
- The thermal efficiency is high because heat is not carried away by N₂ as in the former Bessemer process. Hence, the change may include 40% and in the some circumstances 50%
- Scrap
- A wide variety of both scrap and pig iron can be used.

2.3 Basic Oxygen Steel Making

The general basic oxygen steel-making process is as follows:

1. Molten pig iron from a blast furnace is poured into a large refractory-lined container called a ladle;
2. The metal in the 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,

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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 pre-treat depends on the quality of the blast furnace metal and the required final quality of the BOS steel.

3. Filling the furnace with the ingredients is called *charging*. The BOS process is autogenous: the required thermal energy is produced during the process. Maintaining the proper *charge balance*, the ratio of hot metal to scrap, is therefore very important. The BOS vessel is one-fifth filled with steel scrap. Molten iron from the ladle is added as required by the charge balance. A typical chemistry of molten pig iron charged into the BOS vessel is: 4% C, 0.2–0.8% Si, 0.08%–0.18% P, and 0.01–0.04% S.
4. The vessel is then set upright and a water-cooled lance is lowered down into it. The lance blows 99% pure oxygen onto the steel and iron, igniting the carbon dissolved in the steel and burning it to form carbon monoxide and carbon dioxide, causing the temperature to rise to about 1700°C. This melts the scrap, lowers the carbon content of the molten iron and helps remove unwanted chemical elements. It is this use of oxygen instead of air that improves upon the Bessemer process, for the nitrogen (and other gases) in air does not react with the charge as oxygen does. High purity oxygen is blown into the furnace or BOS vessel through a vertically oriented water-cooled lance with supersonic speed.
5. Fluxes (burnt lime or dolomite) are fed into the vessel to form slag, which absorbs impurities of the steelmaking process. During blowing the metal in the vessel forms an emulsion with the slag, facilitating the refining process. Near the end of the blowing cycle, which takes about 20 minutes, the temperature is measured and samples are taken. The samples are tested and a computer analysis of the steel given

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within six minutes. A typical chemistry of the blown metal is 0.3–0.6% C, 0.05–0.1% Mn, 0.01–0.03% Si, 0.01–0.03% S and P.

6. The BOS vessel is tilted again and the steel is poured into a giant ladle. This process is called *tapping* the steel. The steel is further refined in the ladle furnace, by adding alloying materials to give the steel special properties required by the customer. Sometimes argon or nitrogen gas is bubbled into the ladle to make sure the alloys 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.
7. After the steel is removed from the BOS vessel, the slag, filled with impurities, is poured off and cooled.

There are three types converter process, namely: this process can be referred to as LD (i.e.) Linz and Donawitz process, BOF, BOP (basic Oxygen process) or BOS (Basic Oxygen Steelmaking) it involves the top blown converter steel making.

1. Top-blown converter process
2. Bottom-blow converters
3. Combination process (hybrid process)

2.3.1 Top-blown converter process

Pure oxygen at supersonic (high) speed is blown vertically the lance into the surface of molten hot metal contained in a cylindrical shaped converter. In this process, a water coolant lance (with several opening at the tip) is introduced at

the top of the converter to blow oxygen at supersonic speed on the surface the molten iron for about 10 to 20 minutes. The total time required for the process about 40 to 60 from charging to discharging. Due to the exothermic nature of the reaction, at beginning of each heat scrap is charged into the converter along with hot metal to act as a coolant.

Low carbon steel (0.03-0.03% c) are tapped from converter at 1620-1600L of line and other slag forcing agents are added during the blow in order to form a slag capable of holding the impurities.

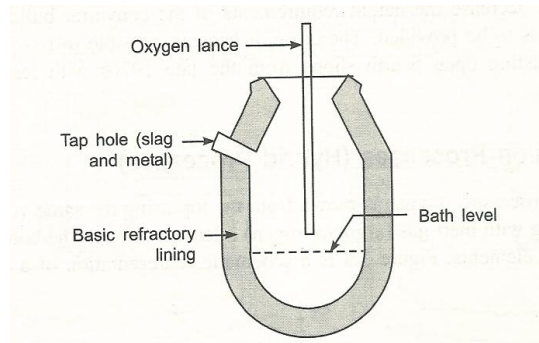


Fig.4: Top – Blown Converter process.

2.3.2 Bottom-Blown converter

The essential feature of bottom-blown steelmaking is that the entire requirement of oxygen ($50-55\text{Nm}^3$ per tonne liquid steel) is introduced through the bottom of steel making converters using tuyeres, carried porous elements, or refractoriness with control porosity. At times, lime is also introduced along with oxygen through the tuyeres.

There are different types of oxygen bottom-blowing process:

1. Oxygen Bottom Maxlmette (OBM)
2. (Q-BOP) Quiet – BOP
3. LWS – BOP (LWS = Liore, Wendel and Sprinck)

In the OBM/Q-DOP process, the oxygen tuyeres are cooled by injecting hydrocarbon gas (such as methane or propane) through an outer pipe surrounding the oxygen pipe but in LWS converter, fuel oil is used.

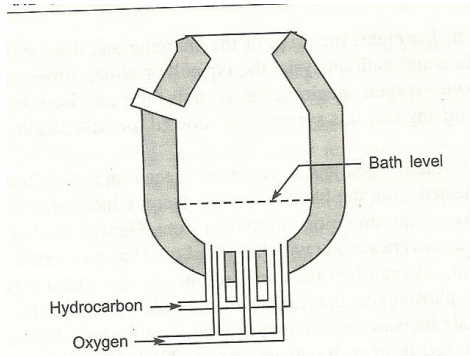


Fig.5: Bottom – Blown Oxygen Converter.

Advantages

1. They operate closer to equilibrium,
2. Encourage early formation of a fluid slag,
3. Reduce the oxygen content of the steel tapped
4. Decreased the height requirements of the converter building

2.3.3 Combination Process (Hybrid Process)

This combines both bottom and top blowing processes. Oxygen is blown from the top using vertical lance along with inert gas (argon/nitrogen) injection through the bottom using tuyeres or permeable elements.

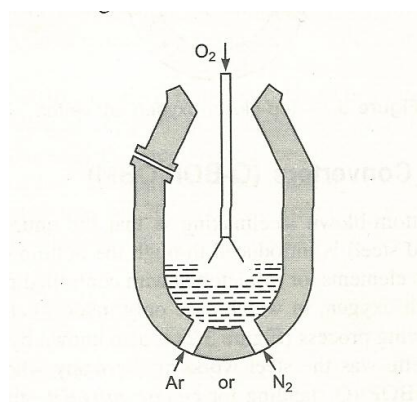


Fig. 6: Hybrid Process

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Advantages

1. It enables the production of ultra-low carbon steels
2. It has flexibility in gas-slag metal interaction
(i.e.) Top blown \Rightarrow gas – metal reaction,
Bottom blow \Rightarrow slag – metal reaction

Basic Oxygen Furnace steelmaking has started replacing open hearth furnace because of:

1. The simplicity and flexibility of the process in producing high quality steels it takes less than 60 minutes to get required carbon content in BOF, while OHF takes 6-8hours.
2. No exchange heat is required due to the heat generated by oxidation of carbon and other impurities (mainly silicon/phosphorous)
3. High productivity (uninterrupted process/cycle)

Manufacture of Steel by Electric Arc Furnace (EAF)

This mainly depends on availability of scrap/sponge iron. This involves external heating of the metal. Graphite electrode are used to supply the power and arcing take place between the metal both and the electrodes as shown below.

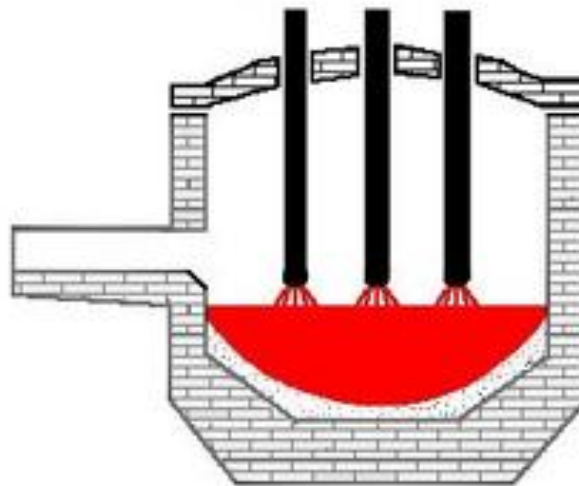


Fig. 7: Electric Arc Furnace

Steelmaking

An electric arc furnace used for steelmaking consists of a refractory-lined vessel, usually water-cooled in larger sizes, covered with a retractable roof, and through which one or more graphite electrodes enter the furnace. The furnace is primarily split into three sections:

- the *shell*, which consists of the sidewalls and lower steel "bowl";
- the *hearth*, which consists of the refractory that lines the lower bowl; the *roof*, which may be refractory-lined or water-cooled, and can be shaped as a section of a sphere, or as a frustum (conical section). The roof also supports the refractory delta in its centre, through which one or ore graphite electrodes enter.

The furnace is classified into low high power or ultra high power (UHP) using AC or DC technology.



Fig. 8: An arc furnace pouring out steel into a small ladle car. The transformer vault can be seen at the right side of the picture. For scale, note the operator standing on the

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platform at upper left. This is a 1941-era photograph and so does not have the extensive dust collection system that a modern installation would have, nor is the operator wearing a hard hat or dust mask.

Advantages

1. Ability to accept scrap, DRI and etc
2. Provide external energy
3. Furnace efficiency can be improved by the combined injection of carbon and oxygen through the lances.
4. It is an ideal melting unit for the production of all steel grades (from carbon grades up to high alloyed special and stainless steel grades).

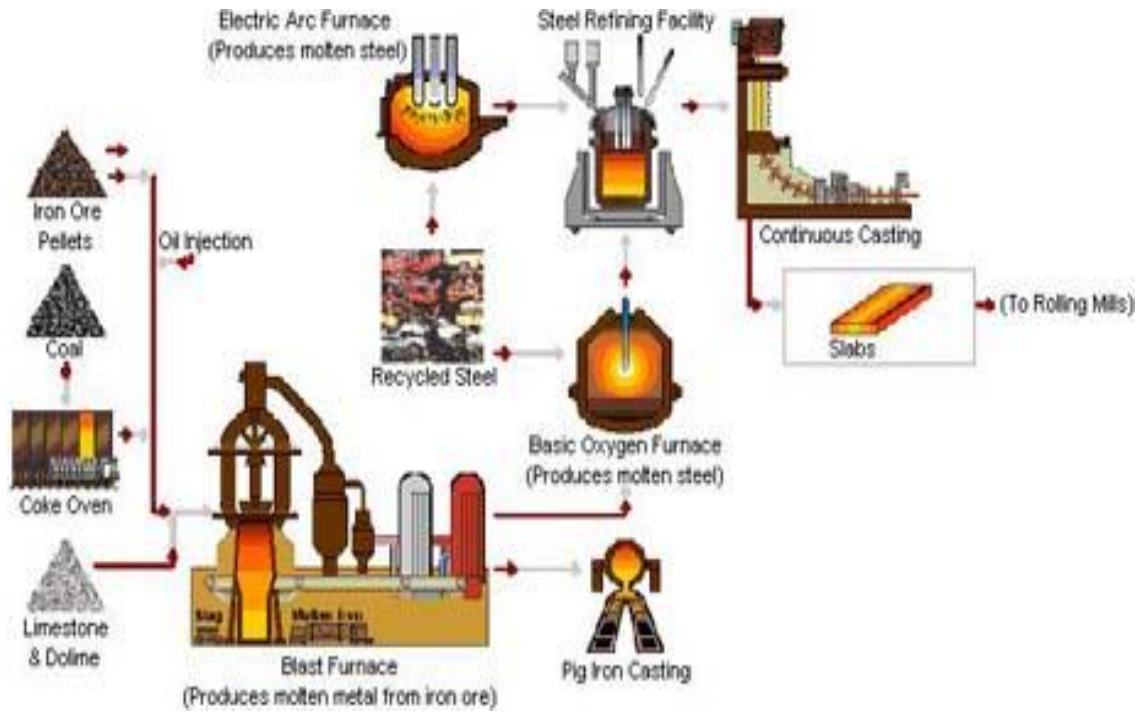
Disadvantages

1. It requires a stable electricity supply
2. The considerable of noise is emitted
3. It causes flickering in the grid

Electric Induction Furnace

It can also be used for melting a solid charge through induction. It helps in the production of high quality steels such as stainless steel.

Steelmaking



Manufacture of Steel by Open Hearth

3.0 Secondary Steelmaking

Introduction

Steelmaking can be completed in BOFs and EAFs in less than 60 minutes if the furnaces are pushed to the limit. Hence, there is used for further refining ((i.e.) second stage of refining). For exact control of chemistry and/or temperature, molten steel tapped from furnace producing a large number heat can be further processed in the ladle.

Secondary processing steel decreases the concentration of gases dissolved in liquid steel (degas) such as O₂, N₂, H₂ as well as sulphur. All this are harmful for the production of quality steel. It also reduces harmful non-metallic inclusions, allow adjustment of composition and temperature and can aid the production of ultra-low-carbon steels.

These are various methods of post-treatment of liquid steel

- a. Stirring processes (by gas injection through the bottom of the ladle, or by means of a top lance On-line Lance Purging, OLP)
- b. Injection processes (including powder injection through a lance or wire feeding).
- c. Vacuum processes (tank degassing or stream degassing)
- d. Refining-cum-heating process (with or without vacuum)

3.1 Ladle Stirring

After molten steel is tapped from the primary steelmaking furnace into a ladle, a lid is placed over the ladle and conserves heat, then inert gas (e.g. argon) is introduced to stir it. Homogenization is achieved causing the oxide inclusion to float either by blowing inert through a top submerged lance or through a porous plug. If before stirring, the ladle is covered with a synthetic slag, then stirring promotes slag-metal reaction like desulphurization and deoxidation

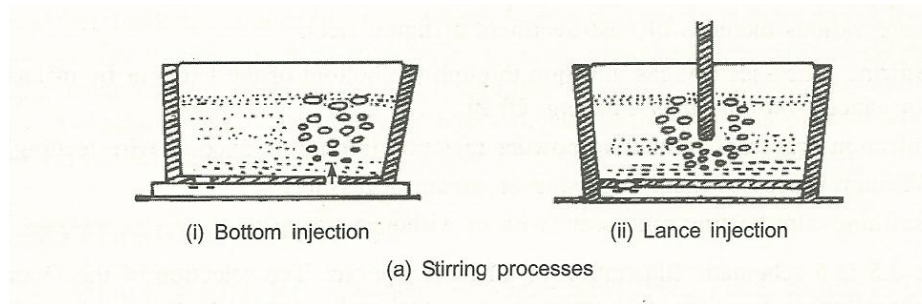


Fig.9: Ladle Stirring process

3.2 Injection Process

This process helps to carry out deoxidation, desulphurization and inclusion modification. This can be done by introducing suitable materials in the form of a powder. The powder material is blown into molten steel in a ladle using a submerged top lance at a high pressure with the aid of a carrier gas. Also, encasing the same material in the form of a clad wire (i.e. wire feeding), can be introduced.

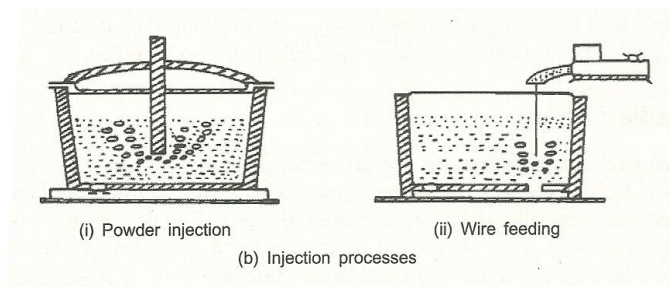


Fig.10: Injection process

3.3 Vacuum Process

In this case, molten steel after tapping into ladle is transported to a vacuum station. A tight cover is attached before vacuum is induced to reduce the partial pressure of hydrogen, nitrogen and carbon monoxide in the ambient atmosphere above the ladle. The degassing, decarburization and deoxidation are achieved in this process.

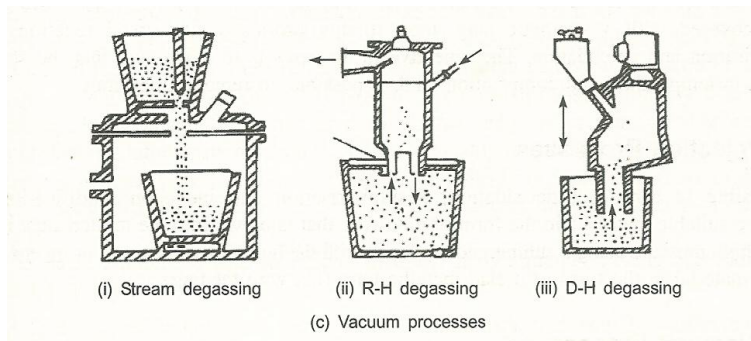
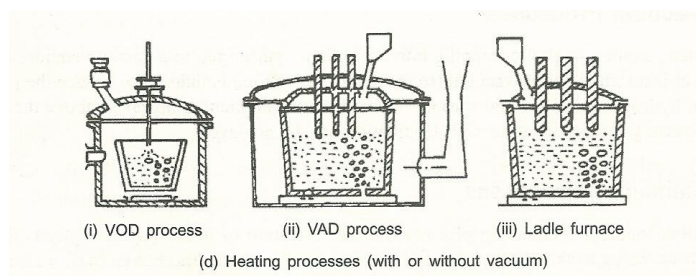


Fig.11: Vacuum process

3.4 Reheating Processes

In all secondary steelmaking process, the temperature of molten steel tends to fall due to heat losses to the atmosphere and additives (gas or solid). To compensation for the drop in temperature, there should be additional heating. This can be done either as an isolated operation or during the vacuum treatment. In most cases, electrical energy is employed. However, chemical heating is also resorted to by blowing oxygen with addition of aluminum.



3.5 Continuous Casting

Continuous casting involves the finished product of molten steel in which the liquid steel is directly casted into slabs/blooms/billets of appreciable lengths. This saves energy and reduces the complexities involved in ingot stripping/reheating.

The basic equipment and operations involved in continuous casting are illustrated below:

1. A source of liquid steel
2. A ladle for transferring and holding the liquid steel

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3. A tundish for distributing the metal into the continuous casting moulds made of copper.
4. The mould(s) to freeze outer skin.
5. Water sprays to complete the solidification.
6. A drive system to control the rate of withdrawal of the cast product from the mould.
7. A cut-off and discharge system

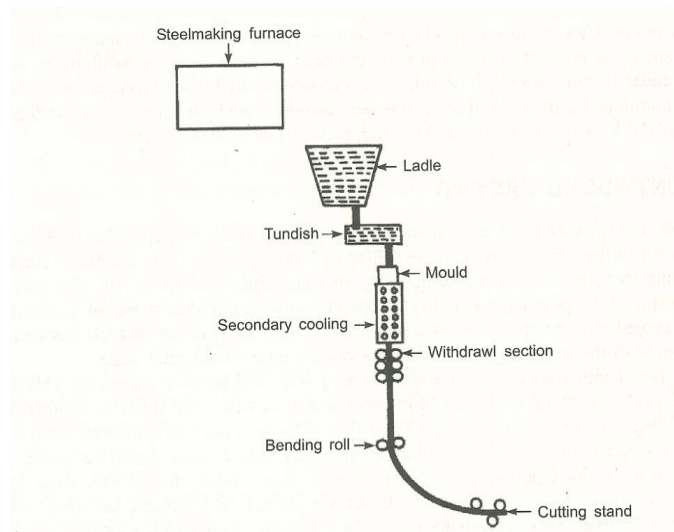


Fig.12: Continuous Casting process

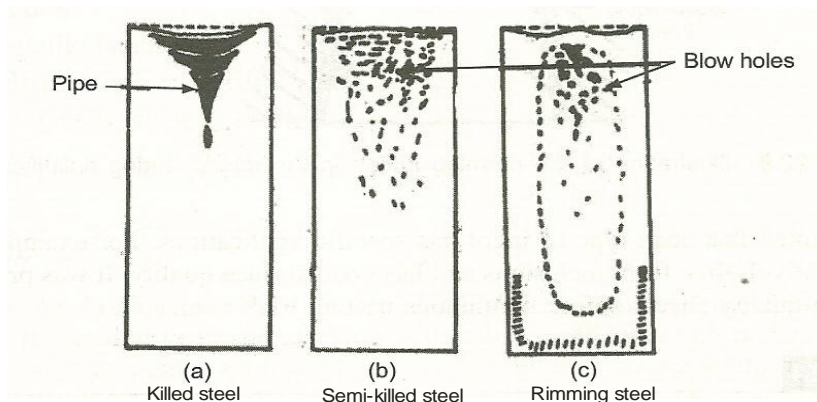
Ingot Casting Techniques

3.5.1 Types of Ingots

Ingots can be classified into three groups:

1. Killed steel
2. Semi killed steel
3. Rimming

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- (a) In well-deoxidized steel in which strong deoxidizer(s) such as aluminum is added, $[O]$ and hence P_{CO} is very low with no gas bubbles. Due to solidification shrinkage and volume contraction, a hollow cavity (pipe) is formed at top of the ingots.
- (b) For semi – killed ingots, deoxidation is carried out by Mn and some Si and hence the extent deoxidation is weak. There are gas – bubbles formed and trapped in the solid ingot to form blow hole.
- (c) In rimming steels, very little deoxidation is carried out in the ladle hence leading into many blow hole.

A rimming steel ingot is relatively free from inclusion and has good surface quality. It was principally used to produce high-quality sheet before continuous casting.

When solidification occurs with nitrogen's evolving is called killed steel if the metal is tapped and teemed without being deoxidize, the reaction $[O] + [C] \rightarrow CO(g)$ occurs. Bubble CO evolve from the solidifying metal carrying boiling, such steel is called mild, when solidified it is called rimming steel. Semi killed steel is oxidized to the O_2 content of metal at the equilibrium level with carbon.