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AN OVERVIEW OF THE DEVELOPMENT OF CONTEMPORARY STEEL MAKING PROCESSES

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Abstract

The manufacture of steel is essentially an oxidation process that decreases the amount of carbon, silicon, magnesium, phosphorus and sulfur in a mixture of molten pig iron and steel scrap. The impurities such as nitrogen, sulphur, silicon, phosphorus and excess carbon are separated out from the raw iron and alloying elements such as nickel, manganese, vanadium, molybdenum and chromium are added to impart different properties to steel. This paper has reviewed the modern technologies used in a steel plant such as Bessemer process for steelmaking, open-hearth process for steelmaking, Basic oxygen converter, ingot casting, continuous casting and electric arc furnace steelmaking. In this study, the production procedure, advantages, and limitations of each of the steelmaking process have been discussed. The application of steel materials in various

Keywords: Carbon, Impurities, Manufacture, Scraps, Steel, Oxidation.

industrial purposes has been explored.

Introduction

Scientists are reengineering steel's molecular structure creating new forms with the potential to build higher, further and stronger than the World has ever seen. Steel is an alloy of iron and carbon. It is the world's most useful and inexpensive metal. Steel is made of crystals and the dislocations inside the crystals helps to deform. [Kenneth CB. (2016)] Steel is tough and has high tensile and compression strength. Steel is divided up into a patchwork and each individual patch is a crystal. Inside these crystals are iron atoms which are arranged in a regular way. The dislocations that are available in steel is what make its crystal so special and because they can move. When they move they change the shape of the crystal and thus they change the shape of steel. Thus, it finds its various applications like in construction, automobile, food preservation, aircrafts, ships, utensils, etc.

Iron ore is found near the surface of the earth and open pit mining methods are used. Giant shovels scoop up huge bites of ore. The trucks are quickly loaded and the ore is on its way. Underground mining methods are also used, while Rocks are blasted and the stones are transported to the steel industry. Bituminous or soft coal is converted into coke. This takes the place of charcoal previously used as fuel. The coal is first crushed and then heated in ovens until the moisture and volatile matter has been driven off. After all the by-products have been extracted from the non-volatile matter, the gas that remains can be used as fuel. After 16-24 hours the red hot coke is pushed out. It usually contains 91-92% Carbon.

The use of steels is continuously gaining share of worldwide over the past 30 years. Steel is an important material which is directly related to industrial and economic development of any country [Meyer PB. (2005)]. In the present study, the review has been planned to study the development of steel and its allied steels in the initial stages of development of engineering materials.

The steel is basically derived from the iron material. Iron is a chemical element, which possesses good mechanical properties like strong, hard,

stiffness, etc. It contains heavy gray metal. The iron materials are basically produced by melting iron ore and removing other impurities. The earth's crust contained almost 5% iron among other minerals. Steel is produced from iron; it is simply a purer form of iron with lower carbon content. Steel can be produced by molten iron ore with blast of air (BOF) using different processes. Steel material is a mixture of pig iron, wrought iron, and carbon (limited to 2% only). Steel was the first material that possesses more elastic property compared to other iron materials available around 1850's. Elastic property is defined as a property which returns its original shape and size after removing load applied on it. Steel materials were started to use in various applications like cutlery, railroad ties, armor plating, structural elements of buildings, etc., but the usage of steel was limited at that time, because of its high production cost per product Pehlke RD. et al (2007) . In a blast Furnace, the charge is fed into the blast furnace continuously Robert AC. (2013)]. One ton of iron requires approximately two tons of iron ore, one ton of coke, half a ton of limestone and four tons of air. Hot blast stoves and powerful blowers which force huge amounts of preheated air into the furnace. Heating the air increases production and decreases fuel consumption. In striking contrast to primitive methods the modern blast furnaces are controlled scientifically.

METHODS

The methodology focuses on understanding existing technologies used in the production of steel, their implementation status, challenges, and recommendations for improvement through the analysis of secondary data sources. A literature review was conducted to gather secondary data on the history, development, and current state steel production in Nigeria. The various technologies for modern steel making are discussed below.

1. **Bessemer Converter**

   This technology was discovered by Henry Bessemer about 150 years ago and it was the first method in which steel can be produced on a large scale. The Bessemer process removes impurities from pig iron.

$Fe + O_2 \rightarrow 2[FeO]$

Silicon and manganese is oxidised first.

$2[FeO] + Si \rightarrow SiO_2$

$[Mn] + [FeO] \rightarrow MnO + Fe$

The carbon oxidation starts only after silicon and manganese is oxidised.

$2C + O_2 \rightarrow 2CO$ (Burns with a blue fame)

$CO + [FeO] \rightarrow \{CO\} + Fe$

$MnO + SiO_2 \rightarrow MnSiO_3$ (Slag)

This technology is no longer used as it wastes a large amount of heat. Also N_2 content of steel is high which makes the steel brittle. Also it is hard to maintain.

BP (Sir Henry Bessemer) is an industrial process for the manufacture of steel from molten pig iron. BP has changed the world by making steel materials with cheap cost [Robert AC. (2013))]. It added steam to the already ongoing industrial revolution that hit the world. It allowed men to build new products and build structures toward the heavens. The BP allowed the mass production of steel, a material that shaped our modern world.

Bessemer Production Procedure of Steel

(1) The principle involved in BP is to make oxides of the impurities in the pig iron by passing the air through molten metal. Due to oxidation process,

the temperature of the mass increases which keeps molten metal during operation.

(2) The BP is performed in a large container which is made of steel material with lining of materials like silica or clay/dolomite. The container used for the BP is known as Bessemer converter.

(3) Bessemer converter is made to handle a maximum capacity of 30 tons. But it used 15–18 tons per production.

(4) An egg-shaped converter is used for steelmaking in the BP. The narrow upper end in the egg-shaped converter is used to load and unload the iron and finished product, respectively.

(5) The bottom end of the Bessemer converter provides a number of perforations to pass the air in upward direction forcefully.

(6) The converter has a facility (i.e. pivots) to tilt at certain angle to certain angle to perform the operations such as loading and unloading of raw material and finished materials before starting the process and after completing the operation.

(7) The impurities like silicon, manganese, etc. are present in the pig iron from an oxide whenever the air passes in upward direction in the converter.

(8) The carbon monoxide present in the converter is burned off and some other impurities present form slag.

(9) If the content of phosphorus is high, dolomite is used as the converter-lining material. Then this process is called the basic BP.

(10) If phosphorus is not present or the content is very less, then silica and clay materials are used for the lining purpose.

Open Hearth Furnace

The hot metals from the blast furnace is tapped into ladles. Iron must be further refined to become steel. Tailor-made steel can be produced in large quantities using this method. First, the limestone is dumped in the furnace.

Limestone removes impurities from the steel. The furnace is then charged with a predetermined amount of scrap steel. As the scrap is already refined steel it's a helpful ingredient. Lastly, a huge overhead crane dumps huge ladle of hot metal as it comes from the blast furnace. The usual charge is about half scrap steel and half blast furnace iron [Abernathy WJ, et al.(2018) .An open hearth furnace consists of what might be described as an upstairs and a downstairs. Upstairs is the hearth in which the steel making materials are refined. Downstairs are heating chambers containing firebrick made in checker board pattern. One chamber for heating the fuel which may be oil, gas or oil and tar and another chamber for heating air.

The preheated air and fuel move upward and pass into the space above the hearth; combustion instantly takes place. Currents of flaming fuel sweep over the hot metal creating temperatures above 3000OF. Excess carbon and impurities are burnt out.

$Si + 2FeO \rightarrow SiO_2 + 2Fe$

$Mn + FeO \rightarrow MnO + Fe$

The hot exhaust gases pass down to another set of checker chamber heating the bricks as they pass between them. Every fifteen minutes the direction of flow of fuel and air is reversed. In this way the air and gas is heated in one set of chambers while hot exhaust gases are heating the others. This mechanism continues for nine to twelve hours. The molten metal is oxidised and undergoes desulphurization and dephosphorization.. Gordon RB. et al 2020.)

From time to time samples are taken for laboratory analysis to make sure the steel meets the rigid requirements test are carried out in every step in the production of steel. The metal is then tapped into ladles. The slag being lighter overflows from the ladle. The nitrogen content of the steel is low. The OHP is a heating process, in which scrap metals are also added along with pig

iron in blast furnace to produce steel materials Gordon RB. et al 2020. The OHP is also called as Siemens–Martin process.

Open-Hearth Procedure of Steelmaking

(1) In the OHP, the temperature was made to increase in a metallurgical furnace, resuscitated for using the waste heat passed from the furnace through bricks .

(2) Heating the bricks of furnace to a high temperature, and then air was used to enter the furnace, and the same pathway resulted in increase of flame temperature because of preheated air.

(3) The steel materials produced in OHP were of superior qualities than the steel produced in Bessemer converter.

(4) Natural gas or atomized heavy oils were used as fuel in OHP.

(5) The preheated air and fuel were used for combustion process in OHP.

(6) The furnace was made with liquid blast-furnace iron and steel scrap together with iron ore, limestone, dolomite, and fluxes.

(7) The furnace (like hearths, roofs, lining materials, etc.) used in OHP was made with highly refractory materials such as magnesite bricks.

(8) The maximum capacities of open-hearth furnaces were 600 tons, which is so many times higher than the capacity of Bessemer converter.

(9) It can handle solid and liquid steel efficiently.

(10) The schematic working diagram of open-hearth furnaces is shown in Figure 5.

Advantages of Open-Hearth Process

- • The open-hearth furnace allows alloying elements to be mixed into the batch.
- • This process is economical because the usage of regenerative firing heat produces less fuel consumption.

- • It can produce steel with maximum of 600 tons per batch.
- • This process is cost effective, because the usage of regenerative firing heat produces less fuel consumption.

Disadvantages of Open-Hearth Process

- • Production was very slow.
- • It cannot eliminate harmful effects of nitrogen.
- • Quality of the steel was not enough.
- • It requires external source of heat.

Basic Oxygen Converter

It most abundantly used process for procuring steel from pig iron. BOC can produce 250 tons of steel in a matter of hours. The iron is first oxidised to iron oxide by direction oxygen at the molten metal at supersonic speeds.

$2[Fe] + O_2 \rightarrow 2FeO$

$4(FeO) + O_2 \rightarrow 2Fe_2O_3$

The iron oxide then reacts with the impurities in metal and slag.

$FeO + [Si] \rightarrow Fe + SiO_2$

$SiO_2 + 2FeO \rightarrow 2Fe.SiO_2$

$[Mn] + FeO \rightarrow MnO + Fe$

$2MnO + SiO_2 \rightarrow 2MnO.SiO_2$

The iron oxide rich slag dissolves lime.

$2MnO.SiO_2 + 2CaO \rightarrow 2CaO.SiO_2$

The dephosphorisation of the metal takes place.

$2[P] + 5FeO \rightarrow P_2O_5 + 5Fe$

$P_2O_5 + 4CaO \rightarrow 4CaO.P_2O_5$

The basic oxygen converter or LD converter is a refined version of Bessemer converter where air has been replaced by oxygen. BOC reduces capital cost of plants, time of smelting and increases labour productivity.[Gordon RB. et al 2020]

Alloying

Molten metal from the Basic Oxygen Furnace is tapped into the ladle. The steel under goes alloying in the Ladle Metallurgical Furnace (LMF). Then the specific elements are mixed with the metal at the molten state to get the desired properties. Tungsten added to low carbon steel can withstand cold temperatures and has high resistance to pressure. A little chromium can increase the tarnishing resistance and erosion. Manganese increases strength and flexibility. Molybdenum makes steel wear resistant and extra tensile. It is a suitable replacement for tungsten in high speed steels. Vanadium increases elastic limit and tensile strength in steel without any appreciable decline in its ductility. It helps by obtaining finer grain structure.

Ingot Casting

Molten steel from Basic Oxygen Furnace or the Open Hearth Furnaceis tapped into a teeming ladle. Ingot casting process of steel making has greatly been replaced by continuous steel casting process. Only about 5% of the total steel is manufactured using this process. There are two types

of teeming practices associated with ingot casting- bottom pouring and top pouring. There are three types of ingots produced based on oxygen content- killed steel ingot, semikilled steel ingot, rimming steel ingot. Killed ingots are completely deoxidised ingots. Semi-killed ingots are
partially deoxidised ingots. Rimming ingots are ingots with excess oxygen.[Gordon RB. et al 2020]

Continuous Casting of Steel

Continuous casting solidifies a major part of the 750 million tons of steel produced every year. In this process, the ladle is positioned on top of the holding bath called a tundish to ensure continuous metal feed . Metal is transported through another shroud into a copper mold which is water cooled. This solidifies the metal. Gordon RB. et al 2020]. It also oscillates vertically to prevent metal from sticking to the mold walls. Hot rolling may be carried out on the metal coming out from the casting machine.

CONCLUSIONS

Steel's versatility is evident in engineering and in architecture. But this metal also has another quality that makes it even more dispensable- resiliency. Steel is the most recycled material on earth. It has 71% recycled rate which is approximately four times the combined amount of both aluminium and plastic. Fire, explosion may bend or break steel but seemingly nothing can destroy it. Even when steel lies in ruins it can be melted down, recast and remolded for another purpose. Its recyclability has changed the way that steel industry operates. For steel there is no self-life. No longer confined to iron ore, steel industries now use cans, guard rails or even an old dish washer as raw material. In recent years, scrap metal has drastically cut down the cost of production and reducing environmental impact.

RECOMMENDATIONS.

It is recommended that further advancements should be made to reduce energy consumption in steel plant. Reduction of waste production by using the waste from one industry as a raw material for another industry. For example, slag from the steel plant can be used in the cement industry as a raw material.

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