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Added Value Long Steel Products produced at MSSA Newcastle Works

V. Scholtz, D.S. Magudulela, F. van Zyl, A. Coetzee,
A. Humpel, C. Hill, and A.J. Potgieter
Mittal Steel South Africa, Newcastle, South Africa

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Abstract - Located in Northern KwaZulu Natal, Mittal Steel South Africa Newcastle works produces roughly 1.8 million tons per annum, supplying long steel products, locally and overseas. The great extent of local raw material availability and low conversion cost ensures that Mittal Steel South Africa is among the lowest cost, high quality producers of steel. MSSA Newcastle works can be subdivided into two main sections: The iron making side, comprising the coke ovens, sinter plant and blast furnace, and the steel making side, comprising the basic oxygen furnace, ladle furnace, continuous casters, and the medium, rod, and bar mills.

INTRODUCTION

Steel is an alloy of iron and other chemical elements such as carbon (C), manganese (Mn), phosphorus (P), and sulphur (S), that always occur together, or it is alloyed with chemical elements to obtain certain improved characteristics *e.g.* with silicon (Si), chromium (Cr), nickel (Ni), molybdenum (Mo), and copper (Cu).

The most important chemical element in steel is carbon, because it influences the mechanical technological properties most, *e.g.* hardness, tensile strength, and plastic and elastic properties.

Alloy steel contains various chemical elements in varying percentages to obtain desired mechanical or technological characteristics. Steel can also be classified, according to the solidification characteristics, into killed, semi-killed and un-killed steel (rimming steel, effervescing steel). After the steel has been cast, solidified, and rolled or forged, it can be reheated, and rapidly or slowly cooled to obtain certain, even better properties. The latter is referred to as normalising, hardening, or tempering of steel.

In general, steel manufacturing consists of two process parts, *i.e.* iron making and steel making. The iron making process consists of the coke ovens, sinter plant, and blast furnace. In steel making, liquid iron is converted into steel by removing impurities from the hot metal and adjusting the steel to the required composition and temperature before casting into the final product.

History

On 17 May 1969, the South African Government decided that Iscor's (today Mittal Steel SA) third fully integrated steelworks should be erected at Newcastle. The main factor leading to this selection was to decentralize industry away from the Witwatersrand complex and to promote industrial development in Natal, the best watered province of South Africa. Newcastle, as a border area with an adequate supply of labour, and with the Amcor ironworks that could be taken over to save on initial capital costs, as well as to provide an outlet for the iron which was at that time being exported to Yawata in Japan (the contract for which was to expire shortly), was therefore chosen. Further factors were that Newcastle was situated on main rail and road routes between Johannesburg and Durban, essential services such as water and electricity were already well catered for, and the town had a basic established infrastructure with a settled community. While ore would have to be transported 1 000 km from Sishen, coking coal was available nearby, and the overall economics were favourable. It was decided that both profile and flat products would be catered for in a plant with an ultimate capacity of 8 million tons per annum of liquid steel. Subsequent changes in steel market have meant that extension to flat products has been delayed indefinitely and the current capacity is about 2.00 million tons of liquid steel.

The first plant contracts were set only at the beginning of September 1971, although work started on township development in January 1971, and on-site levelling in July 1971. The first coke was pushed on 12 January 1974 and the first steel was made on 17 March 1974 - a truly remarkable performance in world terms for a green-field site. The various other plants for the first phase were brought into operation at intervals up to November 1976, when No. 5 Blast Furnace tapped iron for the first time on the North Works site.

After LNM Ltd became the majority shareholder in 2004, Iscor’s name changed to Ispat Iscor Ltd and shortly after that changed to Mittal Steel South Africa, which is now part of one of the largest steel producers in the world, Mittal Steel.

Newcastle Works

Mittal Steel South Africa Newcastle works is one of the largest producers of long steel products in South Africa. An illustration of the Newcastle works process flow can be seen in Figure 1.

COKE OVENS

Coke, which is produced mainly for a fuel source in the blast furnace, is produced from local and imported coal sources. A coal blend (mixture of local and imported coal), for obtaining the optimum quality properties of the coke, is used. Coke is produced in batteries 3 and 4 at roughly 1.15 Mt per annum.

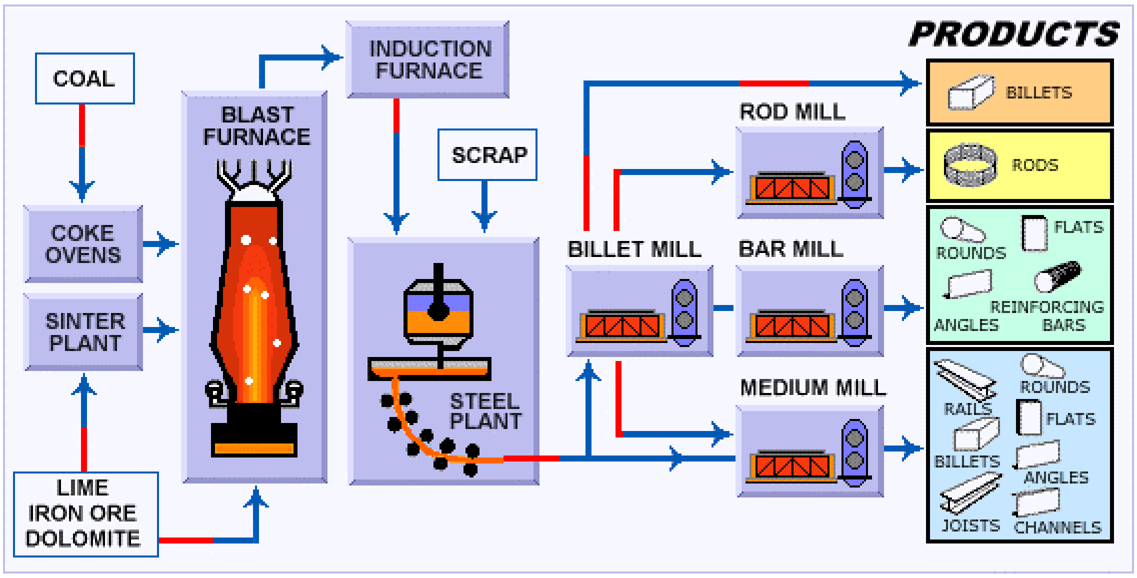

Figure 1: Process flow of MSSA Newcastle Works

In this process, the coal blend is heated up, driving off all the volatile matter and coke to plasticize. Each batch of coal takes roughly 24 hours to be transformed to coke.

The off-gas gets sent to the by-products plant, where the impurities in the gas are removed, and sold as by-products. The by-products, which are produced, are as follows: tar, crude benzole, ammonium sulphate, sulphuric acid, and NaOH. The clean gas is used as a fuel source at different sections in the Newcastle works.

Main purpose of coking and gas purification

1. To produce metallurgical coke and separate the different sizes by screening *i.e.* lump, medium, and fine coke.
2. To clean the coke oven gas which is utilized as a fuel by the works.
3. To produce by-products, such as crude tar, sulphuric acid, ammonium sulphate, and crude benzol from the coke oven gas.

The coke ovens section consists of three sub-sections *viz:*

1. Coal and Coke Handling Plant
2. Coke Oven Batteries
3. Gas Purification Plant

Currently, the coke ovens are busy with a R900 million project on Battery 2 to increase the coke production. This extra coke will then be sold on the open market.

COAL HANDLING

Types of Coal

Coking coal, the main raw material, is imported from Australia, New Zealand, and the United States of America, and the local coal utilized is from Grootegeluk.

Coal Receipt
Coal is received at the tipplers in block loads consisting of 50 rail trucks. The capacity of each rail truck is 50 tons. The maximum coal throughput of the 2 x 50 oven batteries is 3 200 tons of wet coal per day. The coal trucks are tipped at the tipplers at a rate of 12 trucks per hour.

Storage of Coal
The coal is stored in silos or stockpiled in the coal stockyard. Each type of coal is stacked on a different heap in the coal stockyard by a stacker/reclaimer machine. The coal is utilized on the FIFO (First in First Out) principle to prevent the ageing of coal.

The coal handling section has 20 silos available for the storage of coal. There are 18 silos with a capacity of 1 600 tons each, *i.e.* double rows of 9 silos per row. Situated next to the two bigger rows of silos are two smaller silos with a capacity of 300 tons each. The different types of coking coal are stored in the silos. The number of silos used for each different type of coal is determined by the blend that is crushed for coking purposes.

Blending of Coal
Each type of coal has different coking qualities, and effective blending is critical to produce a good quality coke. The coal is drawn out of the silos by constant weigh-feeders that are pre-adjusted to feed the required blend.
The blend, which is at present being crushed, is:

- High quality imported coking coal: 65%
- Blend coal (local): 35%

This blend is adjusted to accommodate the variance in the coal supply.

Crushing of Coal
The purpose of the crushers is to crush the coal blend that is conveyed from the silos so that 80% is smaller than 2.8 mm. There are three crushers. Each crusher can crush 400 tons of coal per hour. The main reasons for crushing the coal are:

- Uncrushed coal produces weak coke.
- Crushing the coal promotes the blending of the different types of coal.
- Crushing of coal limits the internal gas pressure during the coking process in the oven that can damage the oven walls.

COKE HANDLING

Coke Wharf
The coke wharf can be described as an off-loading point or a transfer station for the quenched coke from where the coke is conveyed by means of conveyor belts to the coke screening plant. There are two coke wharfs serving the batteries and each wharf can accommodate five quenched coke loads. The coke wharf slopes at an angle so that the coke can slide down, enabling the plough feeder to plough it onto a conveyor belt. Conveyor belts from the coke wharf to the coke screening plant transport the coke.

Coke Screening Plant

The purpose of the coke screening plant is to screen all the wharf coke into the different fractions for use at the blast furnace and sinter plant. The coke is screened into the following sizes:

- Lump Coke: (-80+32) mm fractions that are consumed as metallurgical coke at the blast furnace.
- Medium Coke:(–32+15) mm fractions are also used at the blast furnace.
- Fine Coke (Breeze): –15 mm fractions are conveyed to the sinter plant where it is crushed, mixed with fine iron ore, and put through a baking process to form sinter.

BATTERIES

Construction of a Coke Oven Battery

A coke oven battery is a firm silica brickwork construction. A battery is built on a concrete foundation and supported by a steel construction. The brickwork is firmly held in position by a steel bracing system. The ovens are built adjacent to one another, with the combustion chambers into which coke oven gas or blast furnace gas is fired, situated in between. The battery is also designed so that the waste gas and the volatile coke oven gas that is generated during the coking process are completely separated. A coke oven battery consists of a number of cells (ovens) separated by heating walls. At the Newcastle works there are two batteries consisting of 50 ovens each.

Coking of Coal

Coking is the removal of the volatile matter from the coal during heating at high temperatures, in the absence of oxygen, to form metallurgical coke. Coke is a physically strong and dense carbon structure with no volatiles. The coking time of an oven is from the time the oven is charged with coal until the time that the coke is ready to be pushed from the oven and is approximately 20 hours. The end temperature of the coke is approximately 1100^{0}C when pushed from an oven. On a coking cycle of 24 hours, a particular oven is pushed 1.2 times per 24 hours.

Coal Service Bunker

There is a coal bunker situated between the two batteries. The coal blend that is ready for charging is conveyed from the coal-handling section and stored in the coal service bunker. The coal bunker has a capacity of 4 000 tons, which is sufficient coal to keep two batteries in production for 24 hours. There are five rows of sliding gates under the coalbunker, through which the charging car draws the coal for charging purposes.

Charging Car

The purpose of the charging car is to charge the ovens of the battery according to a pre-planned schedule. Each oven is charged with a blend of coal totalling a wet mass of 28 tons. The charging car is a steel construction, with four coal bins, that is designed to execute the charging process from one position when correctly lined up. From this position, the charging car automatically removes the four charging lids, where after the oven is charged and the lids replaced.

Pusher Machine

The function of the pusher machine is:

- To remove the oven door on the pusher side of the battery and clean the sealing edges.
- To push the coke out of the oven and clean the oven frame before replacing the door.
- To level the coal in the oven after the oven has been charged.

The pusher machine consists of a steel construction on which the pusher beam, door extractor, door and frame cleaner, and the leveller beam are mounted.

Guide Car

The function of the guide car is:

- To remove the door on the coke side and clean the sealing edges.
- To position the steel coke guide through which the coke is to be pushed, across the coke side platform into the quenching car, hard up against the oven doorframe.
- To clean the oven frame before replacing the door.

The Quenching Car

The hot coke from each oven is pushed into the quenching car that transports it to the quenching tower where the coke is quenched with water. The quenched coke is then transported and offloaded at the coke wharf. When pushed, each oven yields approximately 19 tons of coke.

All the machines are equipped with control cabins from which the drivers execute the various functions. All the machines travel on rails and are electrically driven by motors that draw power from power rails installed over the full length of the batteries.

GAS PURIFICATION PLANT

The main purpose of the gas purification plant is to clean the raw coke-oven gas that is released during the coking process at the batteries and to supply the rest of the works with clean gas that is utilized as fuel. The components extracted from the raw coke-oven gas are converted into saleable products.

To achieve this the following equipment is used at the gas purification plant:

- Tar Separators
- Primary Coolers
- Detarrers
- Hydrogen Sulphide Scrubbers, Stills, and Sulphuric Acid Plant
- Ammonia Scrubbers, Stills, and Ammonium Sulphate Plant
- Exhausters
- Secondary Coolers
- Naphthalene Scrubbers
- Wash-oil Regeneration Plant
- Cooling Towers

Tar separators

The coke-oven gas released during the coke making process at the batteries is cooled down from approximately 900ºC to approximately 80ºC with process water from the plant (flushing liquor) sprayed in the collecting mains.

During this process most of the tar condenses and tar and flushing liquor mixture flows to the gas purification plant where the tar and flushing liquor is separated in the tar separators.

The separated tar collects at the bottom of the tar separators from where it flows to one of the three storage tanks. Tar is pumped or dispatched to the following places:

- The loading zone for external dispatches either by road or rail.
- To the boiler house where it is burned for steam generating purposes.
- To the blast furnace for tar injection purposes.

Primary coolers

The purpose of the primary coolers is to further cool down the raw coke gas from the batteries from approximately 80^0C to approximately 25^0C. This eases the pressure on the gas exhausters and increases the effectiveness of the absorption process.

Detarrers

The purposes of the electrostatic detarrers are to effectively and uninterruptedly remove the last traces of tar mist from the coke oven gas. A transformer creates a high-tension electrical field. The gas flows through this tension field and the tar particles are electrically charged, causing them to precipitate on a highly charged surface from where the tar flows down and is removed by means of a seal pot.

Hydrogen sulphide scrubbers, stills, and the sulphuric acid plant

The purpose for the removal of the hydrogen sulphide from the gas is:

- During combustion hydrogen sulphide is converted into sulphur dioxide that causes air pollution when set free into the atmosphere.
- The hydrogen sulphide is scrubbed out of the main gas stream with ammonia liquor. Thereafter, the hydrogen sulphide is stripped out of the ammonia liquor in the hydrogen sulphide stills. The hydrogen sulphide vapours are then burnt at the Sulphuric Acid plant burner and converted to sulphuric acid. The sulphuric acid is then used to produce ammonium sulphate.

Ammonium scrubber, stills, and the ammonium sulphate plant

The purpose for the removal of ammonia out of the coke-oven gas is:

- When ammonia is uncontrollably burnt in any combustion chamber, it forms nitrogen oxide that causes air pollution.
- Ammonia also causes excessive corrosion in gas pipelines.

The ammonia is scrubbed out of the main gas stream with soft water. The ammonia vapours are then stripped out of the ammonia liquor with steam in the ammonia stills. The ammonia vapours then flow to the ammonium sulphate plant where the vapours react with diluted sulphuric acid in the saturators to form ammonium sulphate. The latter is marketed as fertilizer.

Gas exhausters
A gas exhauster can be described as a gas pump which is designed to transfer 90 000 cubic metres of gas per hour. The gas exhausters can be seen as the heart of the coke ovens and is situated in the middle of the gas purification plant. The purpose of the gas exhausters is to remove the gas that is produced during the coking process at the batteries under controlled suction and to transfer the gas to the various consumer points after the gas has been purified. Cleaned coke-oven gas is a rich fuel gas used at the mill for the heating of the reheating furnaces. The gas purification plant has three gas exhausters, of which two are normally in operation. The third serves as a standby unit.

Secondary coolers
The purpose of the secondary coolers is to cool the gas again after a temperature rise caused by the compression through the exhausters, thus making optimum absorption of naphthalene possible in the naphthalene scrubbers. The secondary coolers are of the direct contact sprayer type in which the gas is cooled from approximately 55ºC to 28ºC. There are two secondary coolers that cool the gases of both the stages at the gas purification plant.

Naphthalene scrubbers and wash-oil regeneration plant
The purpose of the naphthalene scrubbers is to effectively remove the naphthalene out of the main gas stream by means of an absorption process with wash oil, thus preventing naphthalene blockages in the gas pipelines, especially during the winter months.

After scrubbing, the naphthalene-rich wash-oil is pumped to the wash-oil regeneration plant. The purpose of the wash-oil regeneration plant is to continuously and effectively strip the naphthalene out of the naphthalene rich wash-oil and to pump back naphthalene-stripped wash-oil at the correct temperature for scrubbing purposes.

Cooling towers
The purpose of the cooling towers is to re-cool the cooling water for use at the gas purification plant.

SINTER PLANT

Sinter is a mixture of 'fine' iron ore, and fluxes, which are sintered (fused) to form agglomerates, suitable for the use in the blast furnace. The raw materials, mixed with fine coke, are passed over a strand where the coke is ignited by coke-oven gas. Air is then sucked from the bottom of the stand, enabling the combustion zone to slowly move to the bottom. High temperatures, up to 1400°C are found, causing partial fusion of the particles.

A basic illustration of the process flow can be seen in Figure 2.

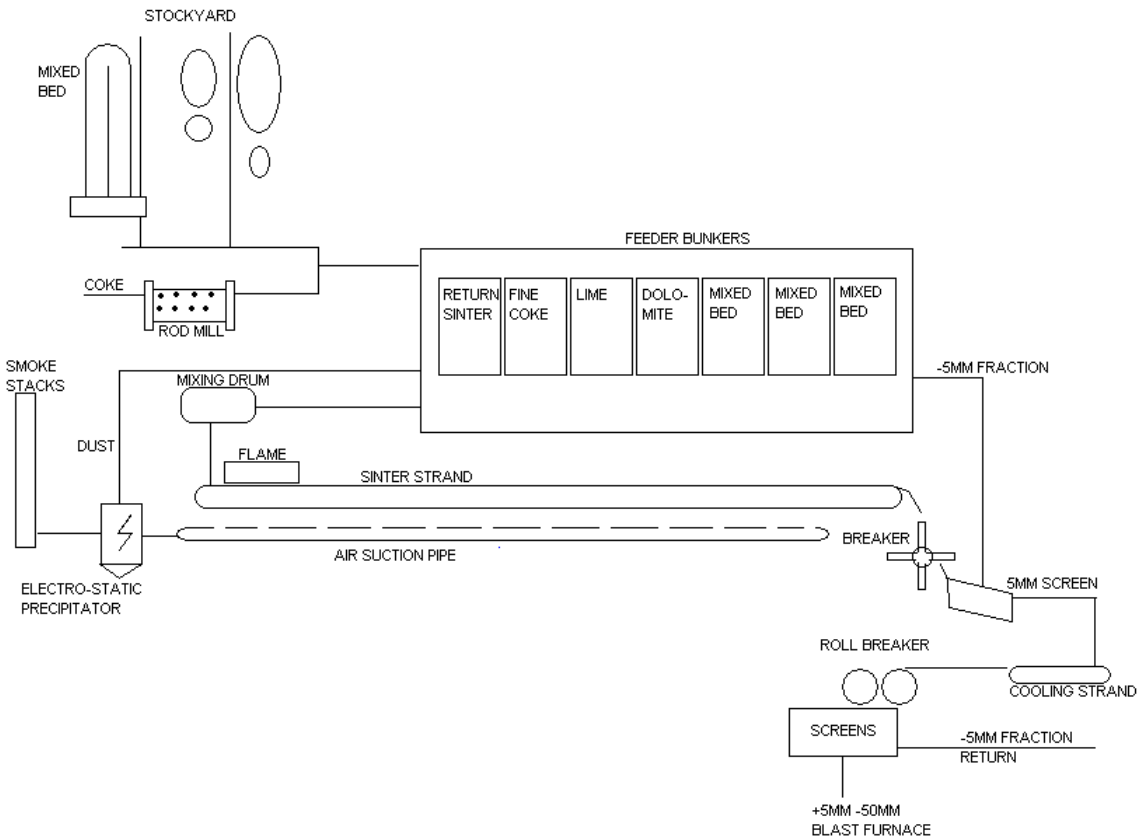

Figure 2: Sinter plant raw process flow

The sinter plant uses a mixture of local iron ores (Sishen, Thabazimbi, and Beeshoek), silica, lime, and manganese ore on a mixed bed, which is then reclaimed, to the sinter plant. Depending on the quality specification required at the blast furnace, dolomite or lime could be added from the feeder bunkers for 'fine tuning'. Before the sinter mix is placed on the strand for sintering, fine coke is mixed into the mixture at the mixing drum. After sintering, the sinter is sent through a breaker and screened. The +5 mm fraction is sent to the blast furnace, whereas the smaller fraction is mixed into the next sinter bed.

Roughly 2.3 Mt sinter is produced each year. Excess sinter is sent to the Vanderbijlpark works by rail.

Average sinter composition and technical information can be seen in Tables I and II, below.

Table I: Average sinter composition

Na_2O %	0.075
K_2O %	0.18
MgO %	2.9
SiO_2 %	5.4
Al_2O_3 %	1.6
CaO %	9.99
Fe (total) %	55.8
FeO %	8.8

Fe_2O_3 %	69.7
CaO/SiO_2	1.84
T-Index(ISO +6.3mm)	75.1
A-Index(ISO –0.5mm)	5.6
Avg. mm	18.9
+25 mm	24.9
-5 mm	3.2

Table II: Technical information of sinter plant

Date commissioned	26 November 1976
Type	On Strand Cooling
Strand width	4.5 m
Sintering Area	248 m^2
Cooling Area	150 m^2
Sintering	2 Fans
Production Capacity	7 200 t/24h
Number of Pallet Cars	183 (4.5m x 1.2m)
Gas Cleaning - Sintering	Electrostatic (Lurgi)
Gas Cleaning - Cooling	Multi-cyclones
Ignition Hood	Coke-Oven Gas Fired (Lurgi Design)
SINTER PLANT STATISTICS AFTER	THE 1993 CAMPAIGN
DAY	7 410 ton 2003-09-07
WEEK	48 201 ton 2005-06-27
MONTH	196 121 ton Oct 2005
FINANCIAL YEAR	2 185 757 ton

BLAST FURNACE

A blast furnace is a shaft type furnace used to produce liquid iron from iron ore sinter (mainly iron oxides) and coke (fuel). A basic representation of a blast furnace can be seen below.

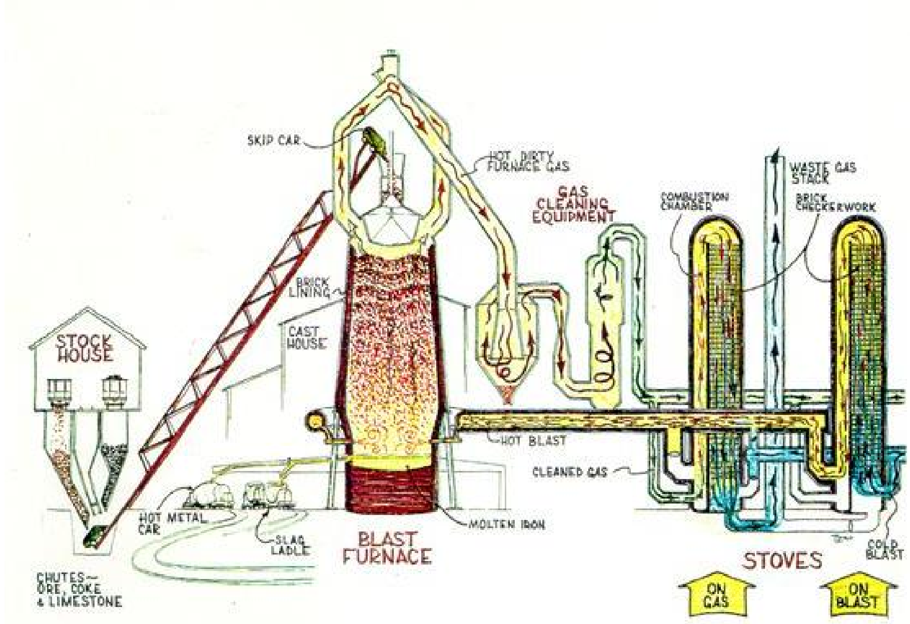

Figure 3: Basic illustration of a blast furnace

The iron-containing material (iron ore and sinter) and fuel (coke) is charged in layers at the top of the furnace. Hot air, with oxygen enrichment, is blown into the furnace through tuyeres at the bottom, roughly 3 metres above the tapholes. Pulverized coal (fuel) is also injected through the tuyeres. The hot air combusts the coal and coke in the bosh area to produce energy and CO gas for reduction of the iron-containing material. As the CO gas and coke reduces iron oxides, iron droplets will form and collect in the hearth. This molten iron (hot metal) is then semi-continuously tapped out of the furnace, separated from the slag and sent to the steel plant for further processing.

The three blast furnaces in South Africa, at Newcastle works and Vanderbijlpark, are the only furnaces in the Mittal group which run with a high 'unprocessed' iron ore burden, compared to other furnaces using only pellets ore sinter.

Table III provides a summary of some of the blast furnace parameters.

The blast furnace produces roughly 1.8 Mt hot metal per annum.

Table III: Blast furnace parameters

Area	Units	BF N5
General		
Year commissioned	Date	1975
Year of last reline	Date	1993
Working volume	Cubic metres	2 017
Inner volume	Cubic metres	2 500
Hearth diameter	Metres	10.14
Gas system		
Top pressure		
Design pressure	Kilopascals	175
Control system	Description	Automatic
Equalization medium	Type of gas	Semi clean BF top gas
Furnace stack		
Number of tuyeres	Number	30
Hearth side wall cooling	Description	Cast iron staves
Hearth side wall refractory	Type	Micropore carbon
Hearth bottom cooling	Description	Water cooled
Hearth bottom refractory	Type	Al bricks, graphite blocks, carbon blocks
Cast-house		
Number of tapholes	Number	3
Number of cast-houses	Number	3
Slag-pots or pits/ number	Description	5 Slag bays
Injections		
Maximum wind rate	Cubic metres per minute	4 200
Blast Temperature	Degrees C	1 140
Fuel injection capacity	Kilograms per ton HM	160 (PCI)
Oxygen injection capacity	% Enrichment	4.75
Fuel		
Coke	Kilograms per ton HM	350
Medium Coke	Kilograms per ton HM	41
PCI	Kilograms per ton HM	160
Iron bearing material		
Iron Ore	Kilograms per ton HM	561.3
Sinter	Kilograms per ton HM	952.4
Stoves		
Number of stoves	Number	3

STEEL MAKING

COMMON USES FOR STEEL

Steel products have a very wide application and form part of almost every aspect of our everyday lives. Common uses for steel produced at Mittal steel Newcastle are:

- Construction – steels are used for the building of bridges, houses and buildings.
- Manufacturing – steels are used for the manufacturing of tools etc.
- Automotive - steels are used for the manufacturing of many parts of motor vehicles.
- Transportation - steels are also used to manufacture rail tracks.
- Mining – steels are used extensively in the mining industry for ore grinding applications in ball mills.

CLASSIFICATION OF STEEL

Steel can be classified into five main types with respect to the percentage of carbon in the steel;

Table IV: Classification of steel

% Carbon	Classification
< 0.03%	Ultra low carbon steel
0.03 to 0.08%	Low carbon steel
0.08 to 0.18%	Peritectic steel
0.18 to 0.25%	Medium carbon
> 0.25%	High carbon

High-Carbon Steel (> 0.25%C)
The most notable thing about high-carbon steel is the high strength and hardness.

Medium-Carbon (0.18 to 0.25%C)
Medium carbon steels have relatively higher carbon contents.

Low-Carbon Steels (0.03 to 0.08%C)
The low-carbon steels made at Newcastle are generally used in applications like general machining steels and welding wires.

Peritectic Steels (0.08 to 0.18%C)
Peritectic steels made at Newcastle are used for commercial, bolt and nut, and welding wire applications.

Ultra Low-Carbon Steels (< 0.03%C)
Ultra low-carbon steels are made through the vacuum degasser, in order to reduce the carbon content to levels lower than 0.03% carbon. Typical applications for these materials are armoured wiring around telephone cables, steel-wool, *etc.*

ALLOYING OF STEEL

Many of the alloys used during steelmaking have an influence on the solidification properties of steel including castability. Nevertheless, alloys are added to achieve specific mechanical properties. Various alloys affect mechanical properties of steel differently and the effect of each alloy used is discussed below:

Manganese (Mn)
Manganese is one of the most cost-effective alloying elements and is used in most steels to remove oxygen remaining after the BOF blowing practice *i.e.* as a de-oxidiser. Manganese also enables hot rolling of the steel when its content in the steel is higher than 0.8%. Manganese does also improve the strength and hardness and is especially effective in high carbon steels where it acts as a carbide former.

Nickel (Ni)
Nickel and iron are completely soluble together in the liquid phase and solidify as a single entity. Nickel enhances the graphite and delays the austenite transformation. Nickel improves toughness.

Aluminium (Al)
Aluminium reduces the gamma iron area and also acts as a de-oxidant and nitrogen binder because of the high affinity of aluminium for both oxygen and nitrogen. Aluminium steels are applied where a fine-grained structure is required and are generally used in electrical equipment.

Silicon (Si)
Silicon also reduces the gamma iron area and thereby changes the structure of the steel. This leads to an increased ability to conduct electricity but also causes steel to become more brittle. Silicon is used for steels needing oxidation and corrosion resistance. These steels also have better erosion resistance and improved machinability. High silicon content steels also find application in welding wire rods.

Chromium (Cr)
Chromium reduces the gamma iron area but it also promotes the formation of carbides. By adding chromium, the critical cooling rate is also lowered and the hardenability is improved. The carbides formed as a result of the chromium addition diffuse less readily, leading to an improvement in hardenability.

Molybdenum (Mo)
Molybdenum combines with the iron to form ferromolybdenum molecules (Fe_3Mo_2). The solubility of these molecules is reduced as the temperature falls, leading to precipitation of the molecules. These precipitates enhance the hardness of the steel. Addition of molybdenum also improves corrosion resistance.

Vanadium (V)
Vanadium forms carbides whose solubility varies with temperature, which means that it has a tendency to give precipitation hardening. The bonding between carbon and vanadium causes the steel to be not very sensitive to heating and hence is not very brittle which makes it suitable for welding applications.

Copper (Cu)
Copper enlarges the gamma area and also encourages precipitation hardening. Copper also improves the steel's corrosion resistance.

Niobium (Nb)
Niobium forms an intermediate bond with iron, resulting in a narrowing of the gamma iron area. The solubility of niobium in steel reduces with decreasing temperature, which results in precipitation hardening. Niobium also imparts creep resistance.

THE INFLUENCE OF IMPURITIES IN STEEL

Nitrogen
The presence of nitrogen in steel causes brittleness. Nitrogen enlarges the austenite zone. However, nitrogen can be used to give steel a high surface hardness and wearing resistance via a process of surface nitriding.

Sulphur
The presence of sulphur in steel, particularly clean steel, can be seen as an unwanted residual element unless purposefully added to improve final product properties *e.g.* machinability. Sulphur can be hazardous in the sense that it causes hot ductility during hot working processes like a Hot Strip Mill. As a residual element, sulphur has the strongest tendency to segregate because of its a low solidification temperature.

Phosphorus
Phosphorus is an unwanted residual element in noble steel. To eliminate the negative effect on the mechanical properties of steel, the phosphorus content in these steels should be kept under 0.03%. Phosphorus has a strong tendency to segregate and the solubility of phosphorus decreases in steel with increasing temperature. A phosphorus content in excess of 0.05% lowers the toughness of steel.

Oxygen
Different steel types react differently towards oxygen. This is controlled by the oxygen equilibrium of the steel. If this equilibrium oxygen is exceeded, the oxygen will react with certain alloying elements in the steel and will result in a solid oxide particle forming, referred to commonly as an inclusion. As an example, in a steel containing aluminium, the oxygen will react with aluminium and form alumina (Al_2O_3). Alumina, if trapped in the solid steel during solidification, results in the steel having low mechanical strength.

Hydrogen
Hydrogen diffuses through steel faster than any other element. The solubility of hydrogen in steel is dependant upon the steel composition or chemistry. The difference in solubility has different effects and decreases as the steel temperature decreases. Whenever rapid cooling occurs such as in the continuous casting process, the hydrogen does not have sufficient time to diffuse. Therefore, the hydrogen molecules generate high internal pressures in the steel, which could lead to internal cracking.

STEELMAKING PROCESSES

Hot metal handling
Hot metal is delivered from the blast furnace to the steel plant by rail using 250-ton torpedo cars. On arrival, hot metal is desulphurised in the iron ladle using soda ash. The sulphur-rich slag produced is removed mechanically by de-slagging, and thereafter the cleaned hot metal charged into the furnace. This process is accompanied by sampling to determine the chemistry of the hot metal loaded, and cooling requirements during the carbon oxidation process in the furnace.

Table V: Typical hot metal analysis from blast furnace, mass %

C	Mn	P	S	Si	Ti	Fe
4.50	0.50	0.10	0.08	0.60	0.07	bal.

Basic oxygen furnaces
Mittal Steel Newcastle operates three furnaces, each with a capacity of about 165 tons. All furnaces are equipped with a bottom stirring facility and slag-free tapping technology that is coupled to a slag stopper.

The production cycle/time for these furnaces is ~ 55 minutes. A typical cycle is described below:

First the furnace is charged with steel scrap, typically 10 - 15% of the total charge, thereafter 150 to 160 tons of hot metal depending on various factors such as, for example, ladle life. After charging, oxygen is blown in the furnace for ~17 minutes through the lance at very high speed (Mach 2). During the blow, lime and other fluxes are added. Typically, per blow, about 9 000 cm^3 of oxygen is used.

A reaction takes place, in which sulphur and phosphorus are oxidized and absorbed in the slag formed by the fluxes, and most of the carbon and silicon are oxidized and energy is liberated.

Liberated energy is used to raise the temperature of the liquid, and melt the scrap. The gas leaving the vessel comprises mainly carbon monoxide with some carbon dioxide. The gas is collected and treated in the waste-gas handling system.

Once the blowing process is complete, a steel sample and slag sample are taken from the furnace. The analysis thereof is used to calculate the required alloy additions in order to produce the desired composition of steel being made. On receiving the sample analysis and conditions satisfied *i.e.* the tap chemistry being aimed for after blowing is achieved and temperature correct, the steel is tapped and the calculated alloy additions are made during tapping into the ladle.

The energy required to raise the temperature of the bath and melted scrap is derived mainly from the following reaction:

$$2C + O_2 \dashrightarrow 2CO \qquad [1]$$

Once the Basic Oxygen Furnace treatment is complete, the ladle is dispatched to secondary metallurgy for further processing or perhaps directly to the continuous caster for casting into final product.

Secondary metallurgy

In the secondary metallurgy area, the steel is desulphurised further if necessary. Slag is made for inclusion removal, and acts as a thermal insulator during treatment and reheating of the bath to homogenise the system. The composition of the steel is adjusted to the required specification.

To achieve this, the secondary metallurgy plant is equipped with two Ladle Furnaces that consist of the following units:

- Additive and alloy handling system
- Hydraulic station
- Water-cooled roof
- Ladle transfer car for moving ladle in and out of furnace, with the aid of overhead cranes
- Temperature measuring and sampling lance
- Ladle stirring facility
- Wire feeding machines
- De-dusting system

Furthermore, the Secondary Metallurgy plant is equipped with a vacuum degasser. A vacuum degasser typically consists of a chamber equipped with two downward-facing snorkels. The chamber is evacuated using pumps and high-pressure steam jets. The typical vacuum achieved during operation is approximately 0.1 kPa.

With vacuum degassing, gases in steel namely hydrogen, oxygen, and nitrogen can be flashed out of the steel, and the carbon contained in the liquid steel is decreased by reacting with dissolved oxygen in the steel. In this way, steels with ultra low carbon contents, *e.g.* <0.05% carbon, can be produced. The vacuum degasser is equipped with an alloy chute for alloy trimmings if required.

Continuous casting

The continuous casting plant has the following capability:

Capacity	2 million tons/a
Casting speed	0.80 – 1.1 m/min
Number of machines	2
Casting strands per machine	6
Size of blooms	260 x 260 mm
Cutting machines	Automatic: Oxy & Sasol synthetic gas
Casting radius	12.485 m
Casting ladle	Bottom-pour slide gate
Casting mode	Tundish slide
Ladle capacity	165 tons
Max. bloom length	14.2 m
Min. bloom length	4.97 m
Turret	Rotatable, with hydraulic lifting arms

The casting machines have curved moulds with a machine radius of 12.485 m. The bloom size is 260 mm x 260 mm. The two casting machines are identical. A tundish slide-gate system is used with submerged entry nozzles.

Each machine is equipped with two tundish pre-heating stations for preheating the tundish refractory lining before ladle teeming.

Both machines have a turret with two support arms that can lift and lower independently and are designed for loading and unloading of casting ladles by means of overhead cranes.

When the 165-ton ladle is placed on to the turret, hydraulic and air pipes are connected to the slide gate mechanism.

The tundish car, which runs on rails, is used to move the pre-heated tundish and tundish shrouds into the casting position above the moulds and back to the pre-heating position. After the cast, the turret is rotated anti-clockwise where a ladle shroud is fitted to the ladle and finally rotated into the casting position.

When casting commences, liquid steel is conveyed by gravity from the ladle to the tundish, through the slide gate. The tundish distributes the steel through tundish shrouds and slide gates into the moulds. The ladleman (operator) controls the flow of steel from the ladle to the tundish by opening and closing the ladle slide gate with a pendant control. When the tundish is filled up to approximately 20 tons, the strands will start automatically.

Solidification takes place very rapidly against the water-cooled mould walls through the primary cooling zone, resulting in the formation of the outer wall or shell of the bloom.

The dummy bar withdraws the partially solidified bloom from the mould and moves it downwards at a radius of 12.485 m through the secondary cooling zone where it is sprayed directly with water and where it eventually solidifies completely. In this zone, the strand is supported by guide rollers and is then bent in a horizontal direction by a straightener and levelling rollers.

The dummy bar is separated automatically from the hot bloom by the dummy bar ramp, and parked in its home position by means of the dummy bar receiver. The solidified strand downstream of the straightener is cut into the desired bloom lengths and weight by means of a flame cutter.

After the cut, each bloom is weighed on the bloom-weighing table, and discharged to the cooling banks where its identity is stamped by the bloom-marking machine and inspected. Cranes are used to move the blooms from the cooling banks to the primary rolling mill.

Refractories

Steelmaking is a high temperature process. Thus refractory materials are used throughout the process where a barrier is required between molten steel and the outer shell of industrial furnaces and molten metal containers *e.g.* casting ladles. The primary purpose of refractories is that of resisting high temperatures. In addition, they need to withstand destructive actions associated with steelmaking, *i.e.* abrasion, slag attack, gas erosion, and spalling. Since refractories are non-metallic materials, they are capable of enduring high temperatures, and are suitable as construction materials with an insulating character.

Common refractories used in steelmaking are basic as opposed to iron-making refractories that are acidic. Magnesite, dolomite, and magnesite chrome are among the most prevalent for steelmaking applications.

CONCLUSIONS

Almost all Mittal Steel SA Newcastle works processes are strongly dependent on pyrometallurgists. The company, therefore, has bursars in metallurgy, as well as in electrical and chemical engineering, studying at all the top universities across South Africa.

It is also clear that steel is still one of the most widely used alloys, and with continuous developments to decrease costs and increase quality, the road ahead for steel producers and consumers is surely paved with gold.

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