Increasing Casting Speed of Caster at LD2

Project Details:-This Project Deals with Different Techniques that can be used To Increase the Casting Speed of Caster From 1.20% to 1.24%.This Project is A Study Based Project to Enhance the Caster Production at LD2.

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TATA STEEL: AN INTRODUCTION

Tata Steel is among the top-ten global steel companies with a crude steel production capacity of 27 million tonnes per annum. A Fortune 500 company, the Tata Steel Group is the world's second most geographically diversified steel producer, employing around 80,000 people across five continents in nearly 50 countries with a turnover of US$ 22.8 billion in FY '10. The Group's vision is to be the world's steel industry benchmark in "Value Creation" and "Corporate Citizenship" through the excellence of its people, its innovative approach and overall conduct. Underpinning the vision is a performance culture committed to aspirational targets, safety and social responsibility, continuous improvement, openness and transparency. Tata Steel's global growth began with the objectives of attaining a larger geographic footprint and to service a global customer base, including the mature markets of UK and Europe and the fast-growing South East Asia and China markets. Apart from its Indian operations, the Tata Steel Group today comprises European operations through Tata Steel Europe and South East Asian operations through Tata Steel Thailand and NatSteel Holdings, Singapore.

Indian Operations

Established in 1907, Tata Steel founded and developed India's first industrial city, now Jamshedpur, where the company established one of Asia's first integrated steel plants. The Jamshedpur works currently comprises a 6.8 mtpa crude steel production facility (with plans to grow to 10 mtpa during 2012) and a variety of finishing mills. Tata Steel has a significant presence in allied and downstream areas through its various Strategic Business Units, namely the Tubes Division, Wire Division, Bearings Division, Ferro Alloys and Minerals Division, Agrico Division and Tata Growth Shop. The company also possesses and operates captive iron ore, coking coal, and chrome ore mines.

Products and Brands:-

Tata Steel's Jamshedpur works produces hot and cold rolled coil and sheet, galvanized sheet, tube, wire rod and reinforcing bar. To differentiate its premium quality steel products, Tata Steel has introduced brands such as Tata Steelium (the world's first branded cold rolled steel), Tata

Shaktee (galvanized corrugated sheet), Tata Tiscon (rebar), Tata Bearings, Tata Agrico (hand tools and implements), Tata Wiron (galvanized wire products), Tata Pipes (pipes for plumbing, irrigation and plant processes), Tata Structura (contemporary construction material) and Galvano.

In 2008 Tata Steel India became the first integrated steel company in the world, outside Japan, to be awarded the Deming Application Prize for excellence in Total Quality Management.

INTRODUCTION TO LD2

- L.D. Shop No. 2 (LD-2) is located within the works area of the Tata Steel. Ltd., Jamshedpur. This unit was set up as a part of Modernization Phase-III and commissioned in year 1993-94. It has been further Modernized in 1998-99 during the Ph IV Modernization to augment its capacity to 2.18 m tpa slabs, With three 140 t Basic Oxygen Furnaces (B.O.F) for Steel Making & three Casters.

- Shop Capacity enhanced to produce 3.8 metric ton in 2007 with up gradation of Casters & increasing Vessel capacity to 170t in 2007, three DS units for Hot Metal Desulphurization, two 160 t Ladle Furnace (L.F.) & up gradation of RH degassing units.

- During the erection and commissioning, technical assistance was brought from M/s. Davy Distington of U.K. for Slab caster. Slab Caster have been upgraded in 2004/05 by M/s VAI, UK. M/s Indomag & M/s Demag of Germany for ladle furnace and RH degasser unit, with RH upgradation to – Multi functional Burner by M/s Vacmetal. Up gradation of B.O.F. was done by M/s Voest Alpine of Austria and M/s Demag.

- L.D. Shop No. 2 is engaged in manufacturing of continuous cast slabs of 900-1550 width and 210-mm. thickness. These slabs are sent to the Hot Strip Mill (H.S.M.) for further rolling into strips.

- This LD2 shop consists of 2 DS unit, 3 Vessels, 2 LF unit, 1 RH unit and 3 Casters for manufacturing of Slabs.

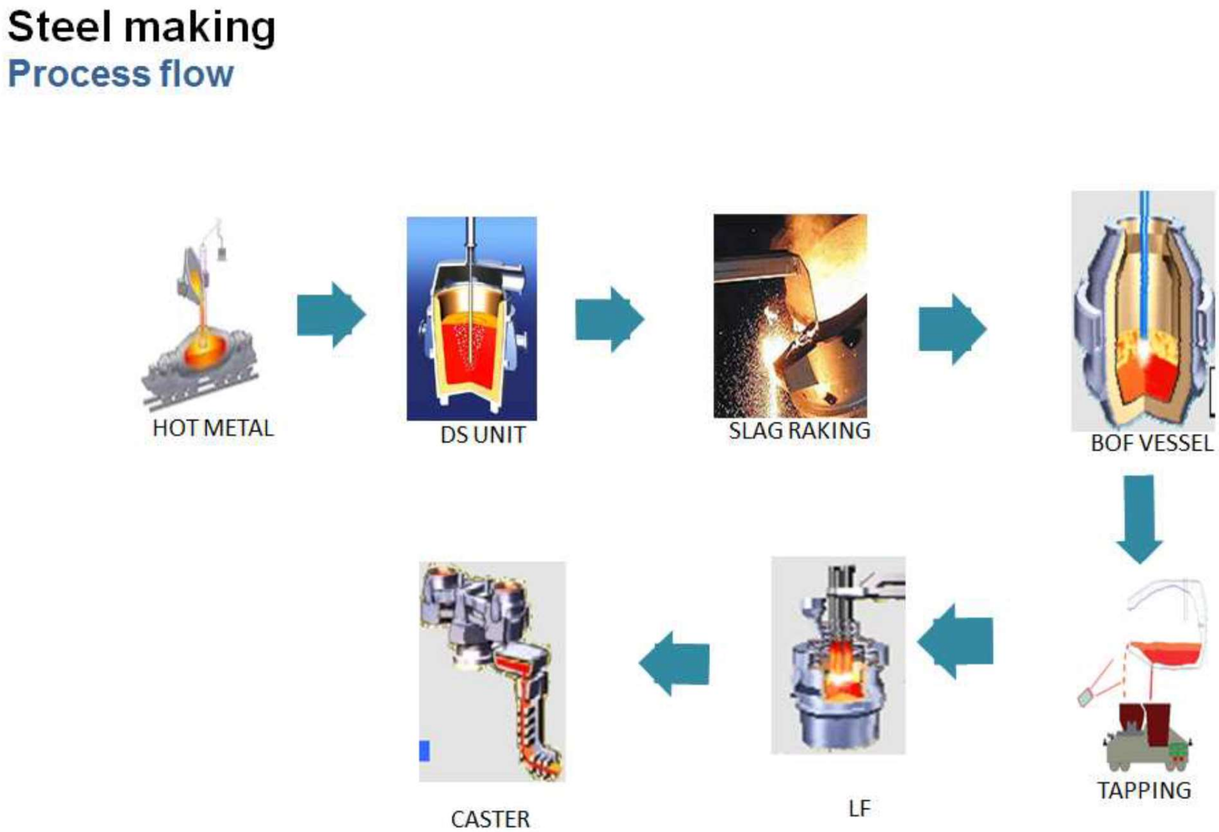
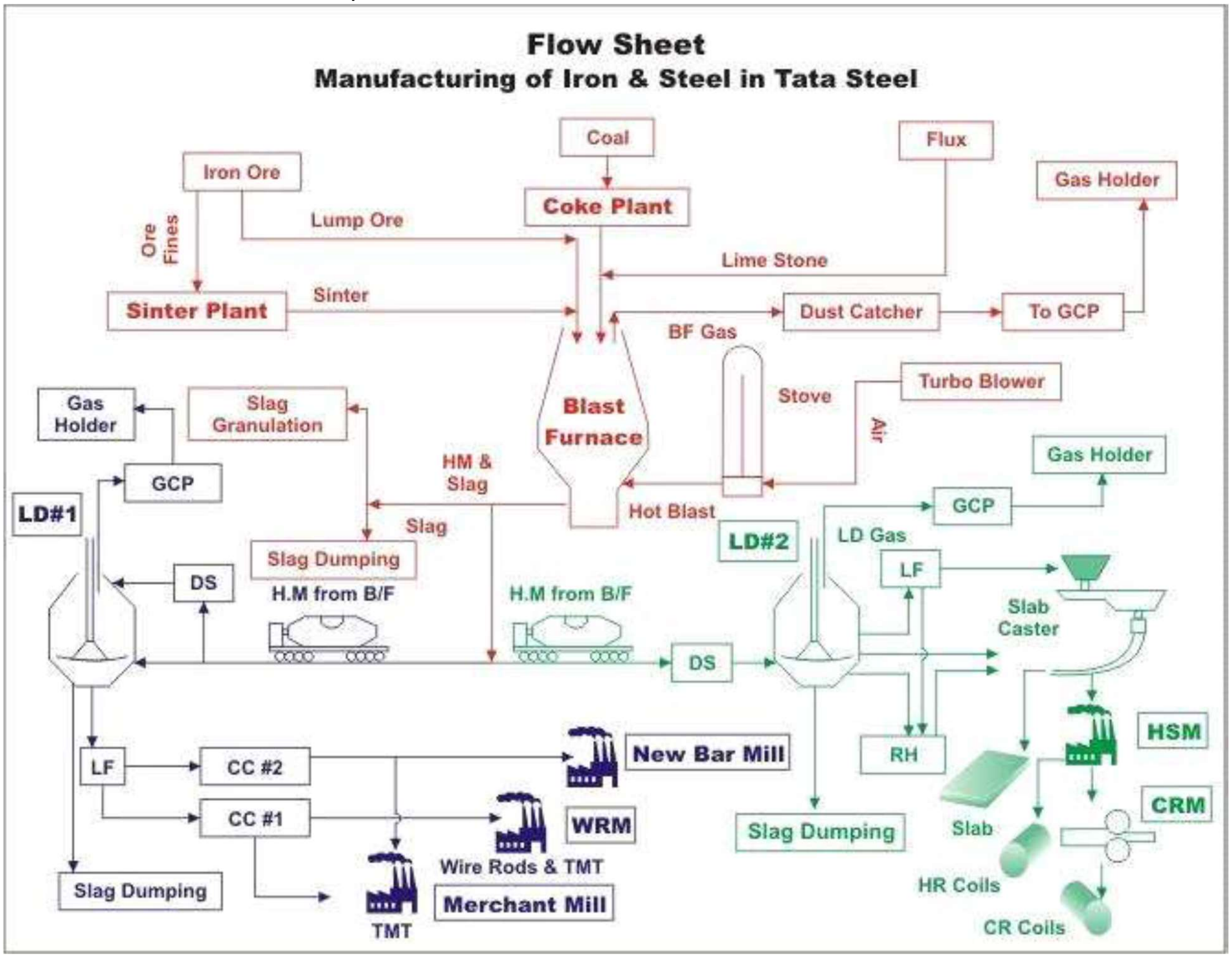


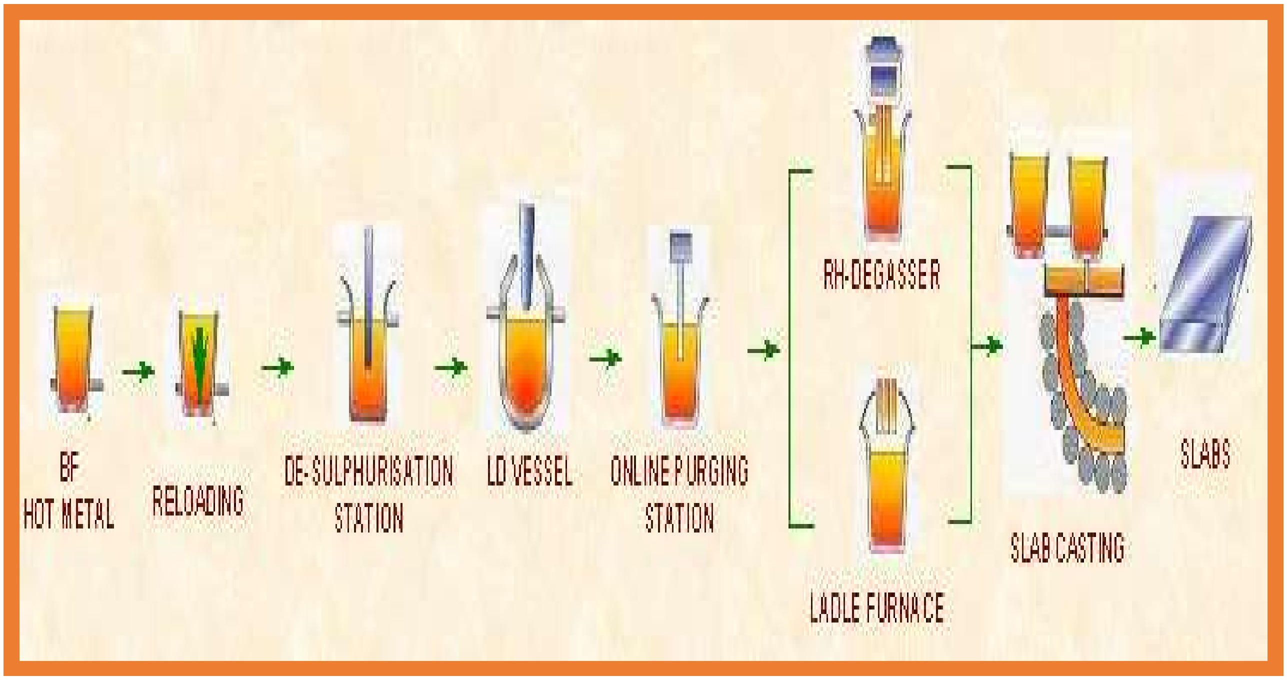
FIG: - PROCESS UNDERGONE FOR MANUFACTURING IN LD#2

MANUFACTURING PROCESS IN STEEL PLANT

Conversion of solids like iron ore into liquid pig iron which is achieved in a blast furnace, refining of liquid pig iron into steel in LD converters, casting of liquid steel into solid forms into slab and billet casters, rolling these sections into finished products like bars, wires, HR coils, CR coils/sheets This is in nut shell a complete process flow of a steel plant. The molten iron produced in the blast furnace is then processed to make steel.



The Main Operations that are done in LD2 includes unloading of the hot metal coming from blast furnace by torpedo's. The temperature of the molten metal at the blast furnace is around 1600 Celsius which reduces to 1420-1420 Celsius when it is carried in the torpedo's to the steel plant. After unloading of the molten metal in a pit which is inside the ground these molten metal is carried by the cranes to the de-sulphurisation unit. In the DS unit the removing of sulphur which is an impurity takes place by addition of some elements. From the DS unit it is taken to SMLP unit where steel making and laddle formation takes place and after the SMLP unit this molten metal is charged to the caster for the continuous casting of slabs.



RAW MATERIALS INPUT IN THE LD2:-

- Coal – West Bokaro, Jharia
- Iron Ore- Noamundi, Joda, Katamandi
- Manganese & Dolomite - Kondbond
- Sponge Iron - Joda
- Chrome Ore - Sukhinda
- Titanium - Tamil Nadu

<u>Overseas Mines</u>

- Low Ash Coal - Queensland, Australia
- Lime Stone - Thailand

<u>Hot metal</u>

Blast Furnaces - A to F, G, H & I

<u>Hot Metal Analysis</u>: Carbon – 4.3 to 4.6, Silicon - 0.70 to 0.80, Sulphur - .05 to .06, Manganese- .04, Phosphorus – 0.18 to 0.20.

DESULPHURISATION UNIT (DS UNIT)

- **Unit – 3 Nos.**
- **Supplier – Thyseen Engineering,**
- **Capacity – 30 heats/ds/day**
- **Operation – Desulphurization by CaC_2 & Mag97 injection, bring down the "S" of Hot Metal < .010 (Treatment time depends on Input 'S' & final 'S' of the product to be made).**

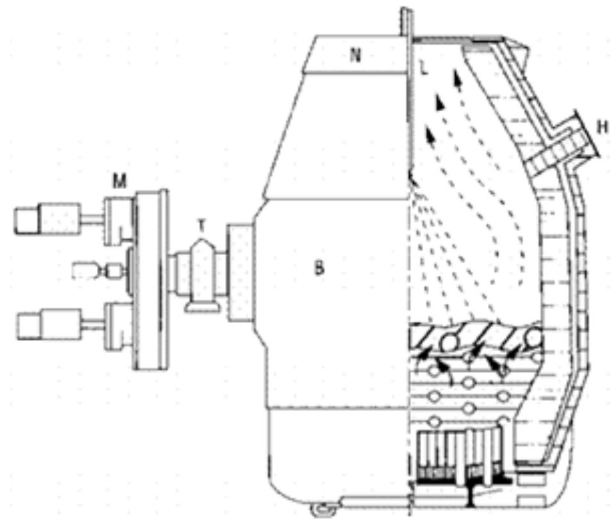
Torpedoes of 320 T Capacity bring hot metal from blast furnaces. These are unloaded in hot metal ladles (170 T) at the torpedo unloading pit. Torpedoes made by Tata Growth Shop / L&T. The MM is then carried to the DS unit where a sample is taken out for testing the impurities in the MM. these sample determines how much CaC_2 and Mg needs to be added to the MM so as the reduce the Sulphur to the required content in the final product. The sample is then tested till then the MM is carried by the cranes to the DS unit. After the required equation is obtained CaC_2 and Mg is added in the MM. First of all CaC_2 is added because if the Mg is added first it melts away. Mg has low Melting point so it is not added alone it is always added with CaC_2 so that it does not melt. The CaC_2 and Mg is injected in the molten metal by the help of Refractory Lances which is –shaped in which N_2 gas acts as carrier of both CaC_2 and Mg. The injection time is around 10-12 minutes. Different types of injection takes place in DS unit. When the CaC_2 is injected it is called **Mono injection** when Mg and CaC_2 is injected together it is called **Co-Injection**. First of all CaC_2 is added then CaC_2 and Mg is added together so that the Mg does not melt away. And then in the last remaining CaC_2 is added. After The injection the impurities float on the top of MM and is black in color, this impurity is then removed by the help of racking machine. This Racking Machine contains a boom and a refractory plate by the help of which the impurity is wiped off.

$CaC_2+S = CaS$;

$Mg + S = MgS$;

VESSELS

Description of the Vessel:-



- Unit – 3 Nos. (2/3 Vessel in Operation)
- Capacity – 38 Heats/day/Converter
- Supplier – V#1& 2 (Voest Alpine, Austria) & V#3 (Demag)
- Operation – Total Charge (Hot Metal + Scrap) 170-175t

The vessel (or reactor, or converter) comprises a steel shell with an internal lining of refractory bricks (magnetite or dolomite), supported by a stout steel ring equipped with trunnions, whose shaft is driven by a tilting system. The internal volume of the vessel is 7 to 12 times greater than that of the steel to be treated, in order to confine the majority of metal projections entrained by the oxygen blast, together with swelling of the slag during periods of foaming. This typical converter geometry shows the nose (N), oxygen lance (L), trunion belt (B), trunnion (T), tilting mechanism (M), and taphole (H).
Typical capacities are 200 to 300 tonnes of liquid steel, and the tap-to-tap cycle is about 30 minutes with a 15 minutes oxygen blowing period.

After the furnace has been tapped and then later slag has been poured out from the mouth of the vessel into slag pots. Certain amount of slag is retained in vessel for next heat. Lime/Dolomite is added to Slag for making slag viscous and to provide coating to the lining of the vessel on both charging and tapping pad areas by providing slag wash. After slag wash the slag is completely dried by addition of lime and dolomite. The vessel is inspected by the Regulator to ensure that slag is completely dry. Ensuring dryness of the slag is necessary to prevent blast during Hot Metal (HM) charging. The vessel is rotated into position for scrap charging. The scrap is charged from the scrap charging box which is brought in front of the vessel by scrap charging crane. When the scrap charge is completed, which generally requires less than 2 minutes for a one box charge, the vessel is rotated past the vertical position to level the scrap in the furnace vessel.

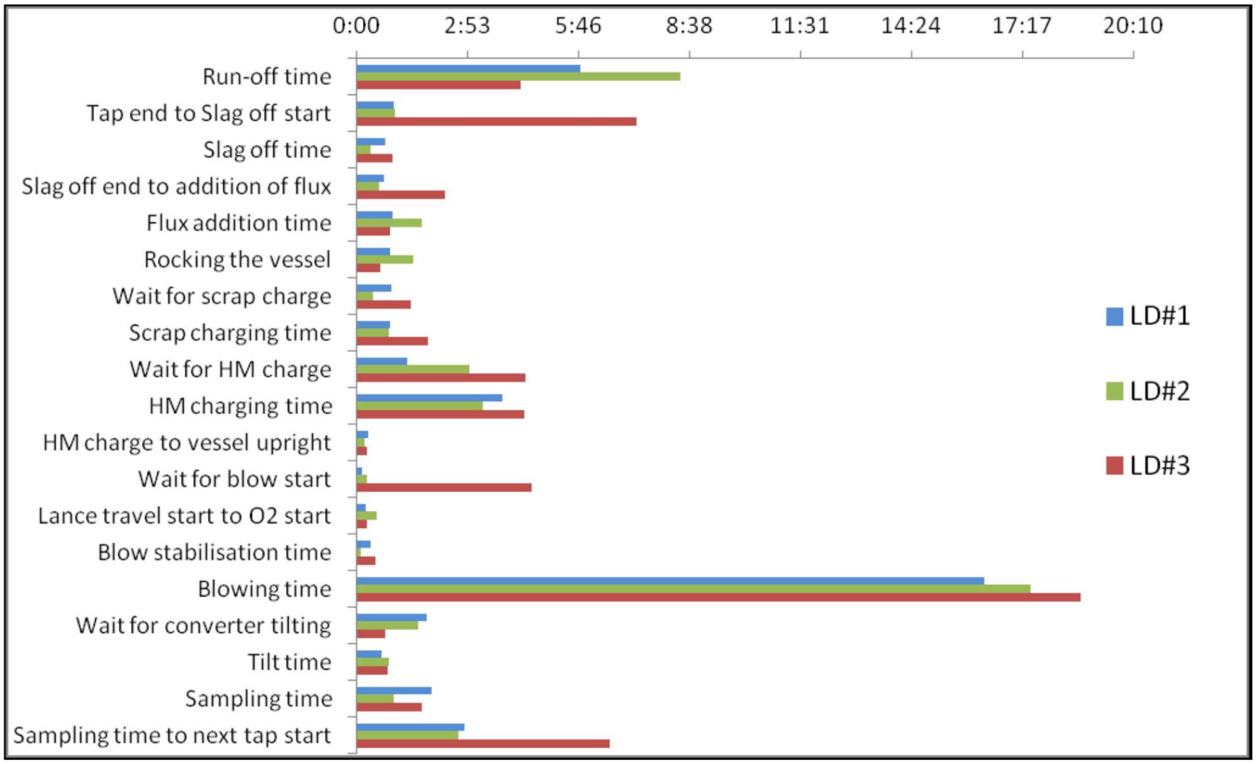


FIG: Time distribution for different activities involved during a heat

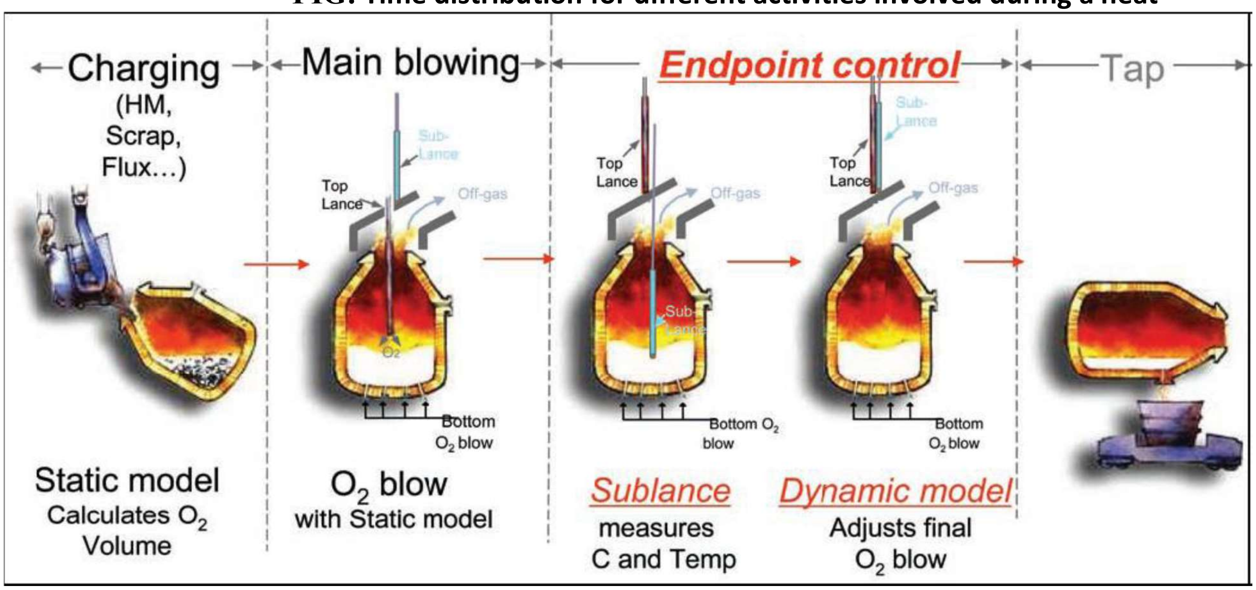


FIG: - Process control by sublance system

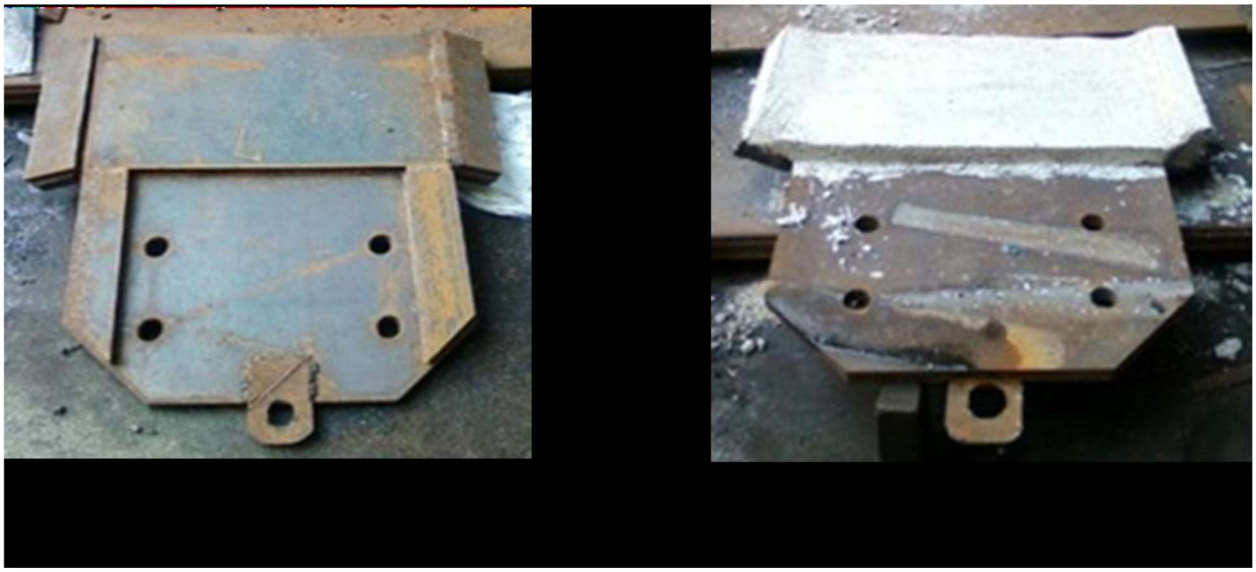


FIG: - RAKE DESIGN AT LD#2

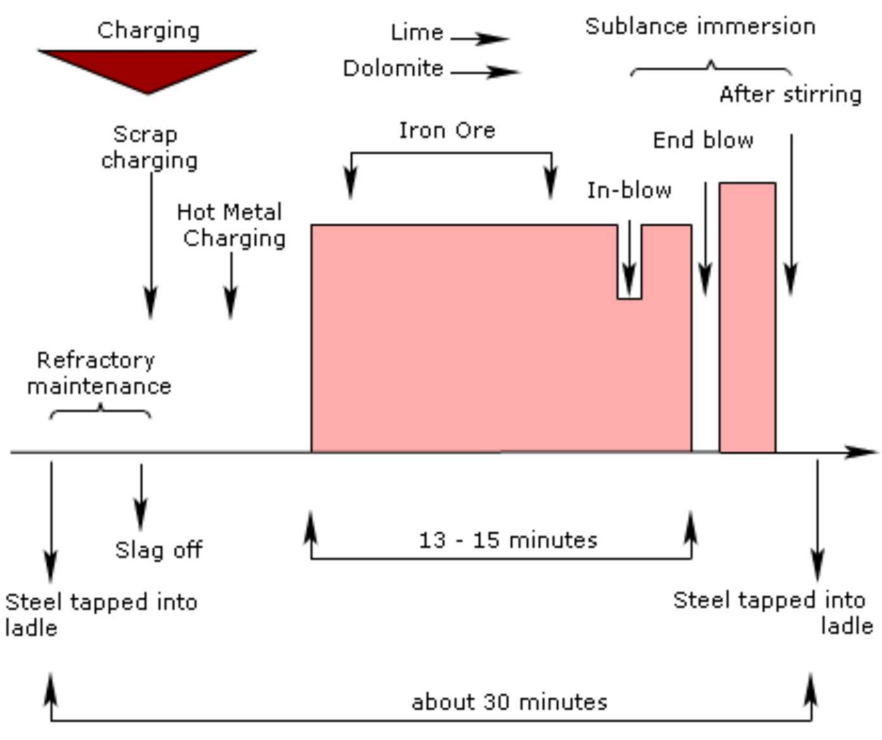


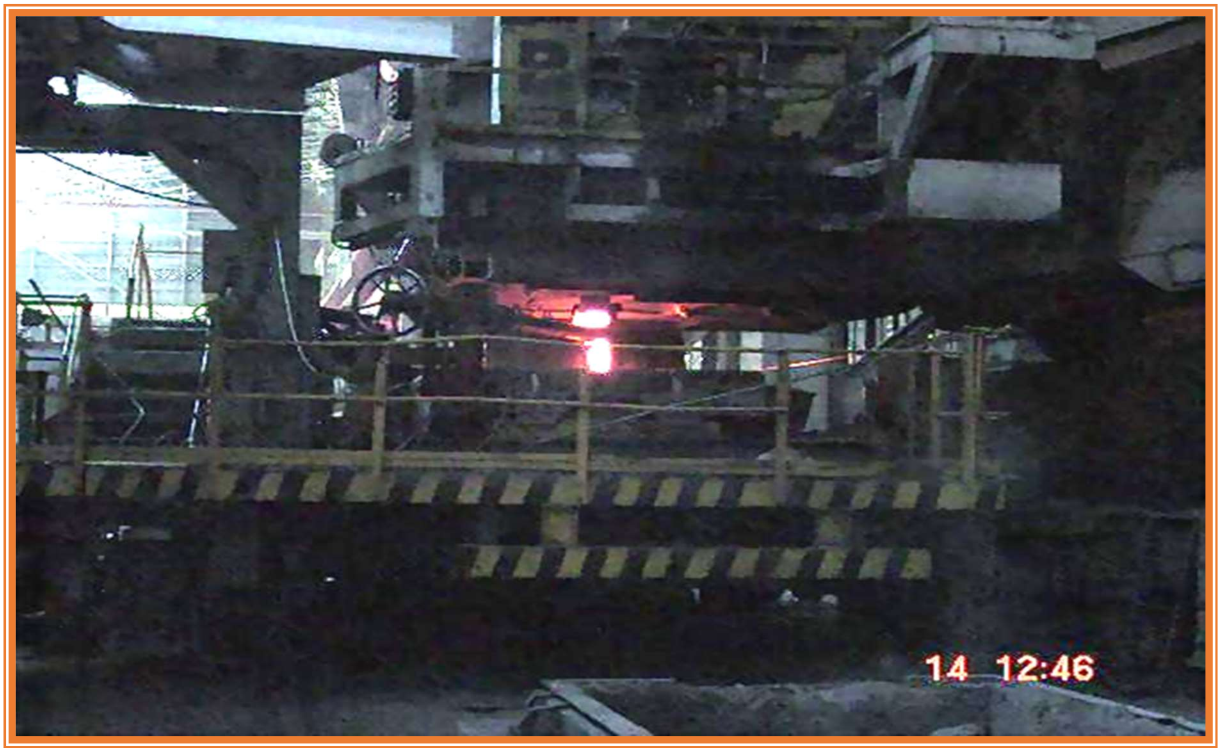
FIG:-SCHEMATIC OPERATION OF THE VESSEL

RH-UNIT

- Unit – 1 Nos.
- Capacity – 24 Heats/Day
- Supplier – Demag, Germany
- Treatment Time – 15-30 mins
- Process – Recirculating type
- Grades – Al killed fine grained steel, deep drawing steel, IF Steel, Electric grades steel, medium carbon and high carbon strip steel.

This RH unit is basically used to mix the different alloys in the hot metal and then stirring it with argon and nitrogen gas. Different alloys which are useful in steel making are mixed in the molten metal by the help of the vessels. Alloys which are used are carried with the help of Belt drives to the vessels and the mixing Process is carried out in it. After the mixing of the alloys the ladle formation takes place which is useful in casting. This ladle is of the same shape as we require the slabs. There is a specific dimension of this ladle. We can vary the height and thickness of the slabs to be manufactured. These alloys are carried through belt drives and pressure gates to the vessel.

Introduction to Caster:-



- Unit – 3 Nos.
- Capacity – 80 heats; with 285 to 295% metal in mould
- Supplier – Davy Dingston
- Type – C#1,Vertical bending (7.5met radius), C#2 & C#3, Curved with Continuous unbending (10 met Radius)
- Ladle Turret – Two arms slewing type; Lift/lower hydraulically
- Casting Speed– 1.8 m /min (Max.), 1.25 m/min (avg)
- Tundish - Capacity 40 T

In the caster, continuous casting process takes place. The caster has a mould cavity which is vertical in position. This mould cavity stores the ladle and is used in the casting process. The molten metal is passed through the ladle which is in the shape of the flat slabs, the molten metal when passes through the ladle takes the shape of the slabs and then the continuous casting takes place.
A single caster in a day produces around 150-160 slabs which means around 500 slabs are manufactured in a day by the 3 casters. These casters are vertically kept. The slabs formed in the casting process are cooled by the air and water mixture. These mixtures are passed through a nozzle and then they are sprinkled on the slabs. Since continuous casting takes place the slabs formed are continuous and they need to be cut. For cutting of these slabs a torch flamed is used which is controlled by the CNC machine.

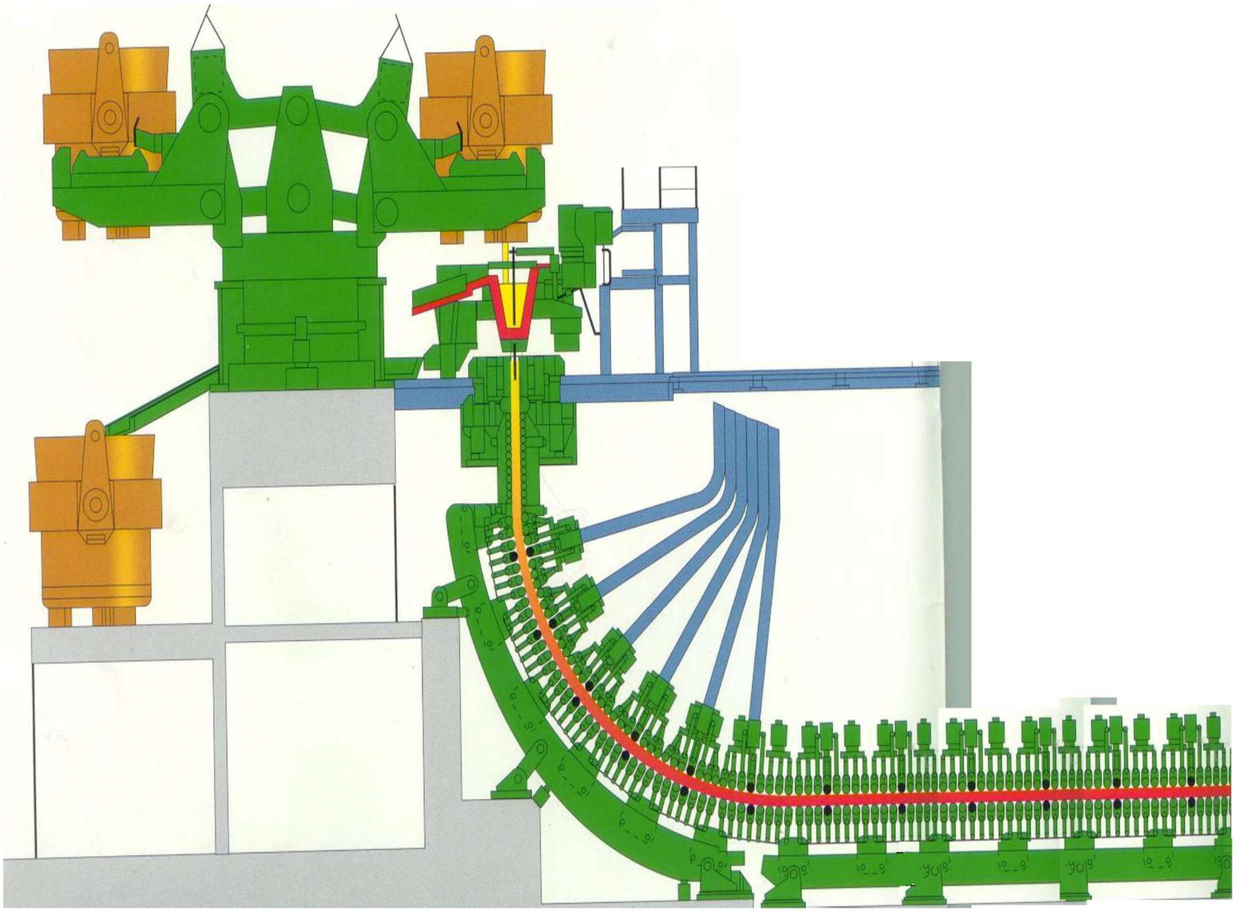
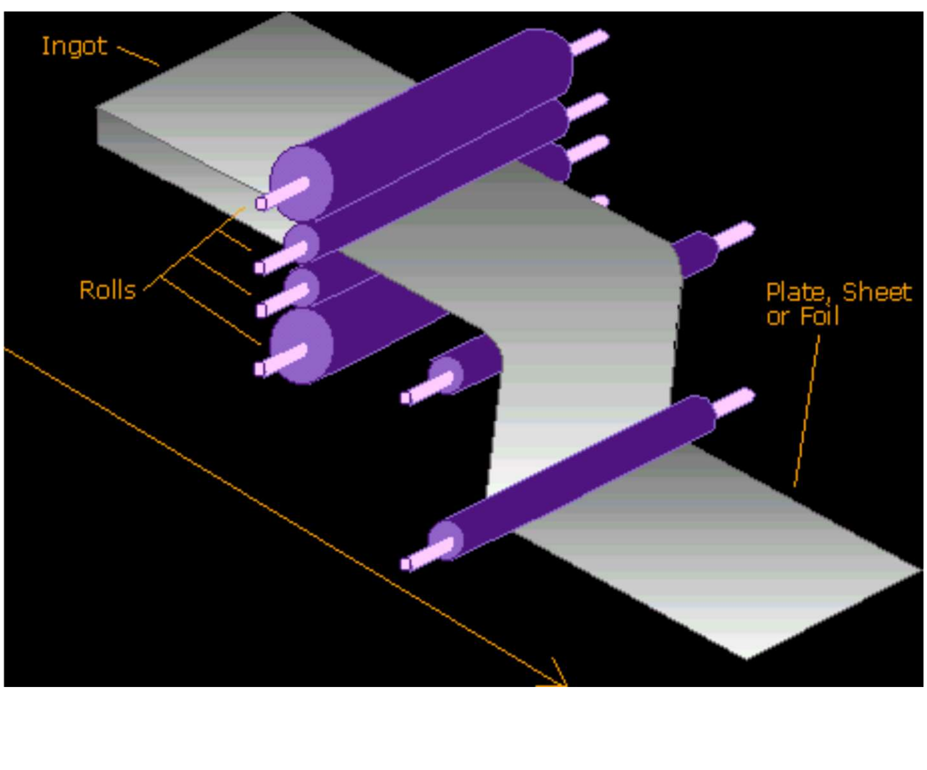


FIG:-OVERVIEW OF SLAB CASTER



For the continuous casting to occur, we need a mould which is of a specified dimension. Dimension of this mould can be changed according to the need of the time. These mould provides a basic shape to the slabs. These moulds are regularly shaken by the help of an electro-magnetic shaper so that the molten metal does not get stick to the copper walls of the mould.

- The main function of the mould is to establish a solid shell sufficient in strength to contain its liquid core upon entry into the secondary spray cooling zone.
- Key product elements are
  1) Shape,
  2) Shell thickness,
  3) Uniform shell temperature distribution, and defect-free internal and surface quality
- The mould is basically an open-ended box structure, containing a water-cooled inner lining casted and machined from a high purity copper alloy. Mould water transfers heat from the solidifying shell.
- The working surface of the copper face is often plated with chromium or nickel to provide a harder working surface, and to avoid copper pickup on the surface of the cast strand, which can facilitate surface cracks on the product.

MOULD FLUX FOR STEEL CONTINUOUS CASTING:-

- Mould fluxes are mixtures of different components (mainly minerals) used during the continuous casting of steels.
- Mould flux are designed for specific steel grades and casting parameters. The required characteristics for the mould fluxes are adjusted by the chemical composition. The main constituents are: SiO2, CaO, Al2O3, Na2O, F, C, and sometimes small amounts of MgO, K2O, Li_2O, Fe_2O_3, MnO, B2O3, BaO, TiO2,
- The carbon is added to control the melting rate of the powder, there is no carbon in the liquid slag.
- These fluxes, continuously added into the mould, melt on the liquid surface of the steel and flow between the mould and the solid shell.

FUNCTIONS OF A MOULD FLUX

- Lubrication of the strand.
- Transfer heat from the strand to the mould.
- Thermally insulate the top surface of the molten steel.
- Protect the liquid steel against re-oxidation by the air.
- Absorb non-metallic inclusions rising to the metal surface.

BASIC FUNCTIONS

- Thermally insulates the molten steel meniscus to prevent premature solidification.
- Protects the molten steel in the mould from reacting with atmospheric gases.
- Absorbs products of de-oxidation from the molten steel.
- Provides a lubricating film of molten slag to prevent the steel from adhering to the mould wall and to facilitate strand withdrawal.
- Modifies thermal heat removal in the mould.

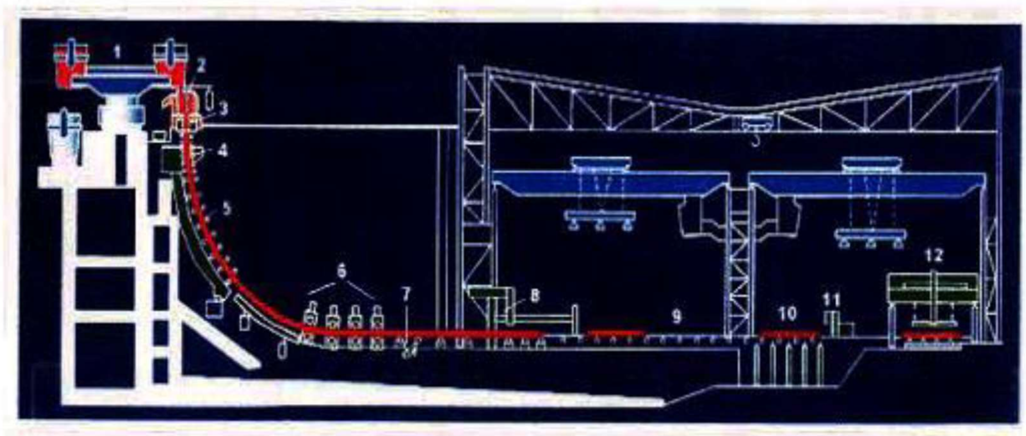


FIG:-CONTINUOUS CASTING PROCESS

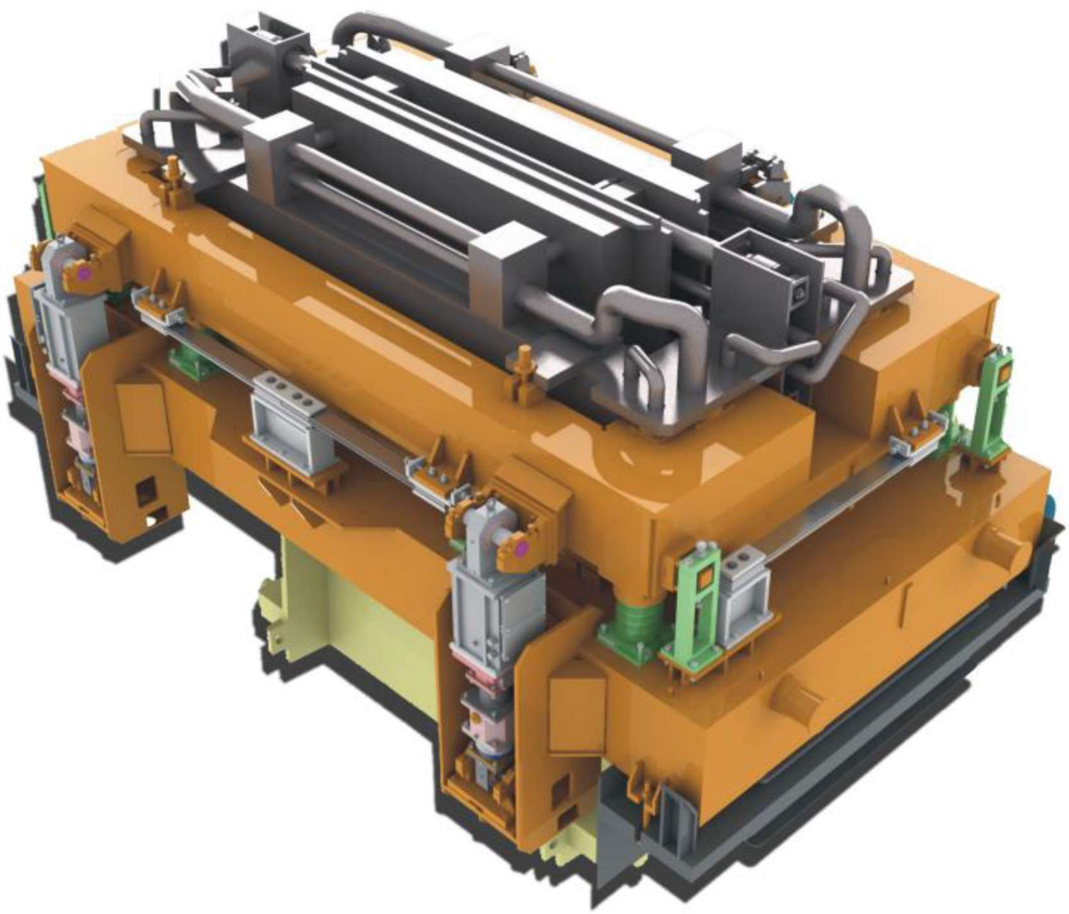


FIG:-MOULD

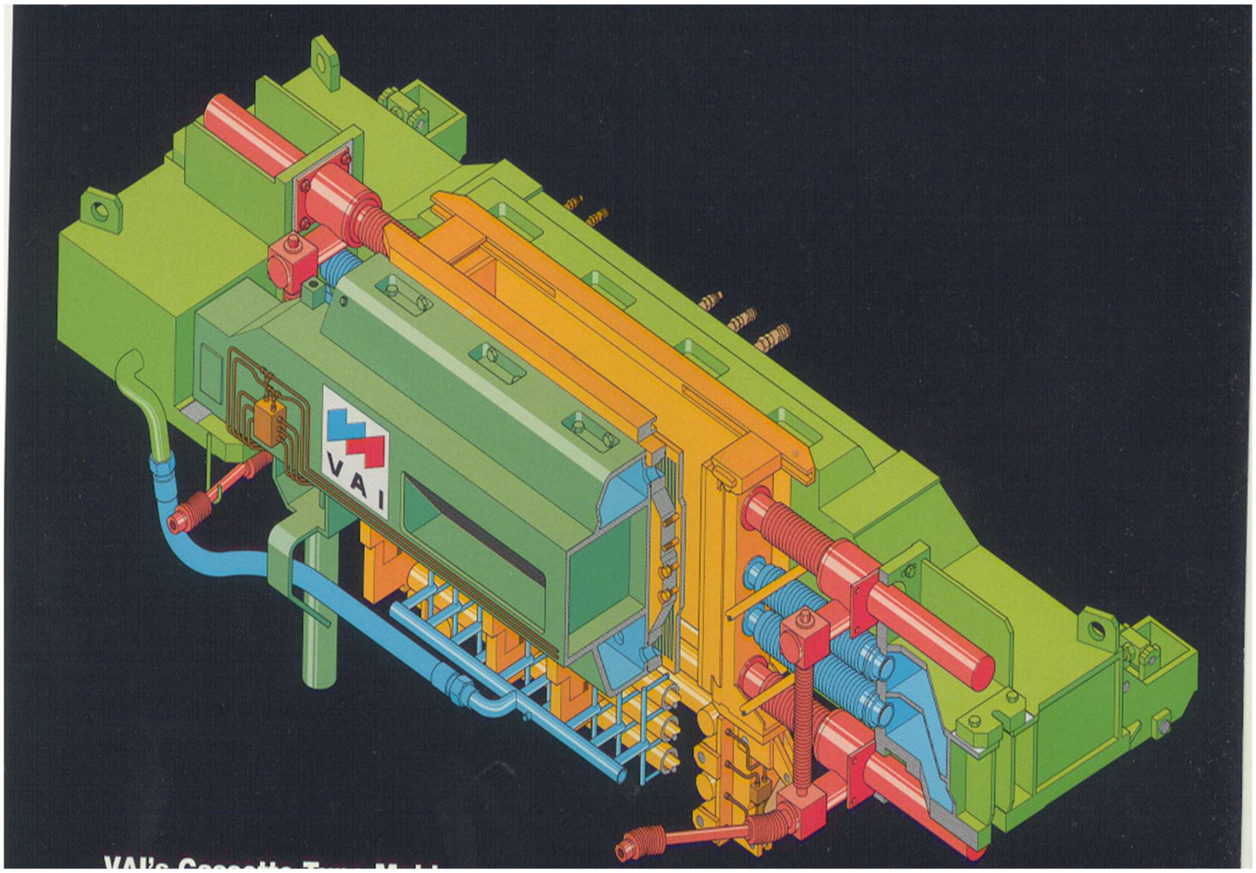


FIG:-MOULD ASSEMBLY

MOULD OSCILLATION

- **Purpose: The oscillator provides necessary movement of the mould to prevent sticking of the strand shell to copper plates .**
- **Oscillation is achieved either hydraulically or via motor-driven cams or levers which support and reciprocate (or oscillate) the mould.**
- **Mould oscillating cycles vary in frequency, stroke and pattern.**

Type of Oscillators

A Electro mechanical Oscillation

B Hydraulic Oscillator

A common approach is to employ what is called "negative strip", a stroke pattern in which the downward stroke of the cycle enables the mould to move down faster than the section withdrawal speed.

This enables compressive stresses to develop in the shell that increase its strength by sealing surface fissures and porosity.

SLAB CASTER

- **Mould – 900 mm (Copper Alloy, open ended, Indirect Cooling), oscillated by motor driven cams to reduce mould strand adhesion and the risk of breakouts.**
- **RAM –Width change online 10 mm/min/side. The adjustment could be made either by electromechanically or hydraulically. The mould taper adjusted by gear mechanism.**
- **Sec. Cooling – Spray type (Air Mist)**
- **Section size – 900-1550 mm Wide; 210 mm Thick**
- **Slab Length – 8-11 m (full)**
    - **4.8-5.1 m (half)**
- **Slab Cutting – TCM**
- **PINCH ROLL – Inserting dummy**
- **bar and withdrawal during casting.**
- **DUMMY BAR – Provides base in the**
- **Mould Before casting & withdraw slab**
- **Segment. Design – Split Roll**
- **Metallurgical. Length– 27.9 m**
- **Deburring – Knife type**
- **Slab Marking – On line 11 digit aluminum spray marker (Stacking code-'2' numbers, Width code-'1' character (A to Z), Heat no- '5' digits, Caster no. & Slab sl.no.).**


14 12:42


14 12:43

<u>SYMS</u>

SYMS keeps an automatic tracking of the slab. The inspection of slab is done and surface defects if any, removed by scarfing. Slabs are stacked cast wise and sent to HSM as and when required. Slabs are transferred in CTRT car and send to HSM on roller table. Some grades which does not require inspection & some High 'C' grades are hot charged. 50-60% slabs are hot charged.

Slab Dispatch – Avg. 10000-12000t / Day, & Inventory – 25000-30000ts

FACTORS EFFECTING SPEED OF CASTER

FACTORS THAT AFFECT CASTER:-

- **SPEED**
- **AVAILABILITY**
- **WIDTH**

FACTORS THAT EFFECT CASTING SPEED:-

- **QUALITY OF SLABS TO BE MANUFACTURED**
    1) **Low carbon steel has more casting speed.**
    2) **High carbon content steel has more casting speed.**
    3) **Peritectic steel are also manufactured in the caster.**

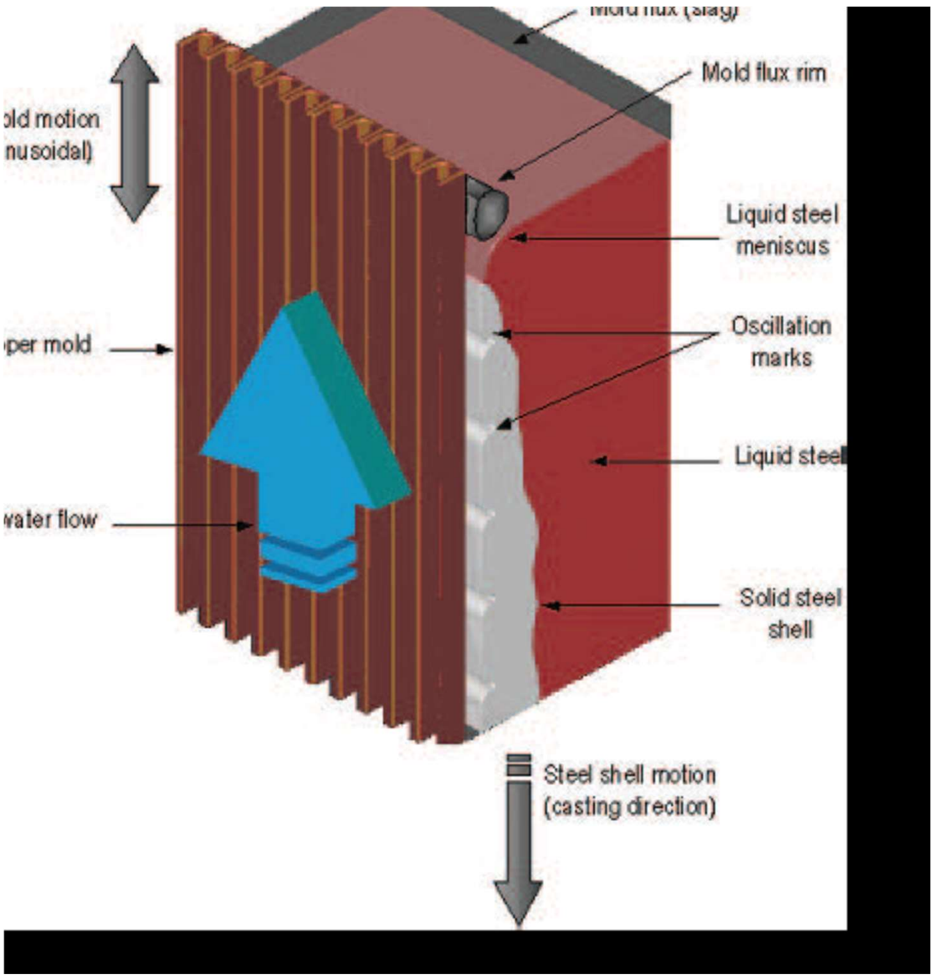


FIG: LIQUID STEEL IN CONTINUOUS CASTING MOULD

FIG: - Scrap charging crane hook design at LD#3 and LD#2

According to the trials conducted in LD#2, making the raking plate as curved will yield following benefits:

- 33% reduction in raking time observed (12 mins → 8 mins)
- Increase in life of the plate (30 heats →100 heats)

So increasing the casting speed has got many benefits:

- Reduction in the cost of steel making.
- Reduction in the slag formation
- Casting time decrement will lead to more production of slabs which will be a huge benefit for the industry.
- If the casting time decreases it will lead to formation of slabs with less defects. As there will be less impurity the cost of removing these impurities will be less and the slabs will be more profit giving for the industry.
- Due to impurities in the slab the slab are sold at low cost but increment in the casting speed will result to more profit to the industry.

METHODS BY WHICH WE CAN INCREASE THE CASTING SPEED OF CASTER:-

- **Mould Powder Requirements for High-speed Casting**

Mould powders play an important role in the stability of the continuous casting process of steel. The main functions of mould slag (i.e. molten powder) are to provide sufficient lubrication and to control the heat transfer between the developing steel shell and the mould. Sufficient lubrication requires an undisturbed melting of mould powders and uniform infiltration of mould slag. Based on the casting practice in IJmuiden, it is found that these demands become even more important for the applied high casting speeds in thin slab casting at 5 to 6 m/min. At Corus RD&T, mould powders were characterized by X-ray diffraction and subsequent fully quantitative Rietveld analysis. Additionally, the melting of mould powders has been studied in-situ using high-temperature X-ray diffraction, to gain crucial knowledge about melting relations. Slag rims obtained from the thin slab caster mould were characterized using extended microscopic techniques in order to describe the mechanisms of rim formation and growth. Finally, slag films obtained after casting were characterized. As a result, not only the melting process of mould powder, but also the mechanism of formation and growth of slag rims is much better understood. This knowledge will be applied to define the demands on the composition and properties of mould powder for even higher casting speeds.

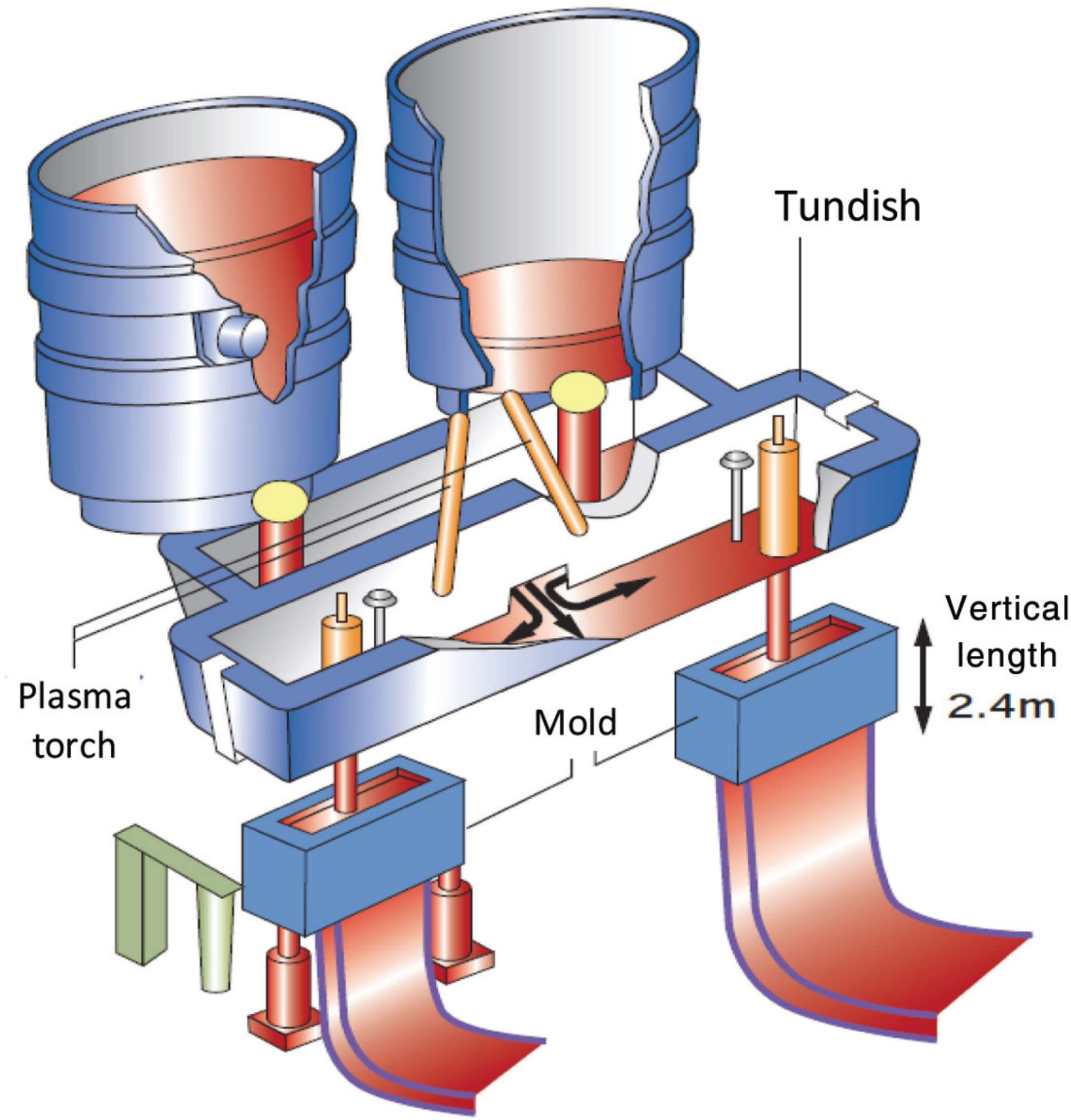
Mould powders play an important role in the stability of the continuous casting process of steel at all casting speeds. The main functions of mould slag (i.e. molten powder) are to provide sufficient lubrication and to control the heat transfer in horizontal direction between the developing steel shell and the copper mould.

Several authors have reviewed the composition, properties and operational experience of mould powders for conventional slab casting [1-2]. However, only a few publications have been issued on the design and use of mould powders for thin slab casting [3-4]. Compared with conventional slab casting, process control in thin slab casting is more critical and it can be assumed that mould powder demands for thin slab casting become more critical as well [5-6]. Thus a more extensive understanding of mould powder properties and functions is needed to meet the increasing demands of high-speed thin slab casting.

Nevertheless, a lot of improvements (mould powder developments) are based on trial and error and are focusing on casting speeds up to 2 m/min (conventional slab casting). A general approach is to relate the chemical composition of a mould powder to the operational behavior (in-mould behavior) during casting. In doing this, some physical properties of the mould slag like the viscosity and the melting point are addressed as well. However, this approach will not automatically result in a suitable mould powder or an in-depth knowledge on powder design and required slag properties.

At Corus Ijmuiden, a project started in the framework of the Netherlands Institute for Metals Research with the aim to develop mould powders suitable for high-speed thin slab casting with a maximum casting speed up to 8 m/min. For this work, a fundamental understanding and quantification of the melting and solidification behavior of mould slag as well as the functions of mould powder is needed.

- **MINIMISING INCLUSIONS**



Minimizing inclusions in the mould is one of the most important quality issues of continuous casting. Inclusions deteriorate the mechanical properties of steel under tension, bending, hole expanding, press forming, and other types of working, and cause surface defects. Therefore, it is of great importance to minimize contamination of steel and remove inclusions from it in the CC process. This subsection relates the technologies for preventing inclusions from being entrapped in the surface layers and the center of cast slabs/blooms. Measures to minimize inclusions in surface layers Because of conspicuity, the steel sheets for automotive outer panels must be free of surface defects. The typical surface defects originating in steelmaking processes are those due to inclusions of alumina and mould powder. They are caught in initial solidification shells, and when the steel is rolled either in hot or cold, they are stretched and form defects in streaks at the surface;

they are called spills, scabs, or slivers. Such inclusions near a surface of slabs can be removed by scarfing, but since scarfing involves costs and decreases yield, it is preferable to minimize their entrapment during the initial solidification in the CC mould. The M-EMS mentioned earlier was introduced for this purpose; it makes steel immediately inside the solidification shells to flow at a prescribed speed or faster to prevent inclusions from being entrapped in the help the floatation of inclusions; either plasma heating or electric induction is used for this purpose.

- **Stabilizing initial solidification:-**

Break-out (BO) is one of the operation troubles that most adversely affect the production of continuous casters. It occurs as follows. During the initial solidification of molten steel in a CC mould, the solidification shell may not form adequately at some position for whatever reason, and when that position comes out of the lower end of the mould, molten steel flows out through the defective part of the shell. BO does not merely decrease production, but inflicts heavy damage to the equipment, calling for intensive repair work. To prevent BO, therefore, it is essential to make sound initial solidification shells form stably in the mould. The principal factors that affect the initial solidification of steel in a CC mould are steel temperature, mould powder (flux), mould copper plates, and primary cooling water. Various improvements and modifications of mould powder have been conducted so that it liquefies and gets between the initial solidification shells and the copper plates evenly and stably, even at high casting speeds, and thus serves for homogeneous heat removal and lubrication. While there were some reports on the mechanism of hydrogen- induced BO, 2) the mechanism of BO of silicon-killed steel remained unclear. Later, the mechanism was finally clarified,3) and the occurrence of this type of BO has been decreased by use of high-basicity powder. The copper plates on the mould surfaces are cooled by water from the back side, thus removing heat from the steel to accelerate its solidification. Since the shells contract as the solidification advances, the copper plates, especially those on the mould short faces that contact slab sides, are tapered downward to ensure the contact areas. However, because the contraction does not progress linearly, if the copper plates are dead flat, gaps are likely to form between the plates and shells, heat is not removed well there, and the solidification becomes uneven, possibly leading to BO. As a countermeasure, a multistep tapered mould was proposed and commercially applied, wherein copper plates on the short sides are tapered in different angles according to the contraction of the shell; it proved effective at dissolving the problem of uneven solidification and preventing the BO due to the cause. Besides the above, in-mould magnetic stirrers (named M-EMS), which control the steel flow in a mould to make the steel temperature homogeneous at the meniscus and thus make the shell thickness even (to be explained later), have been effectively used for commercial production. As a result of the above measures to stabilize the initial solidification of steel, the incidence of BO of Nippon Steel Corporation’s continuous casters decreased significantly.

- ## Optimum relationship between steel temperature and casting speed:-

What is essential for increasing CC production on the basis of stable initial solidification is maintaining an adequate balance of the steel temperature in the mould, heat removal, and casting speed. When both steel temperature and casting speed are high, the solidification shell does not develop sufficiently, and there may be a case where molten steel breaks through the shell immediately below the mould (remelting BO). This indicates that, to increase production without BO, the steel temperature and casting speed must be controlled adequately.

Casting temperature is one of the most important control parameters; it is defined on the basis of solidification temperature according to the steel chemistry and dictates retroactively the end point Temperature of the secondary refining and the tapping temperature from the converter. For adequate control of casting temperature, induction heaters, plasma heaters, and other heating devices have been provided for tundishes. On the other hand, an excessively slow casting speed at a period of high steel temperature, such as at the middle of a charge, causes a loss of production. Steel temperature is measured at different positions in different casters and the throughput is also different; therefore, each continuous caster had its own standard temperature–speed table that defined the relationship between casting temperature and maximum casting speed on the basis of past experience and the calculation method of each work. The working group for CC re-examined the steel solidification in the mould using the solidification simulation models developed by Plant Engineering & Facilities Management Center (PFC), and accordingly revised the temperature-casting speed tables of all casters of the company.

- ## Break-out prediction:-

How to predict and prevent the occurrence of BO: technology whereby thermocouples are embedded in a mould to continuously monitor the temperature of the copper plate surfaces and to detect insufficient initial solidification, or the occurrence of BO, has since long been given, and if such solidification is detected while the thermocouple is still within the mould, casting speed is decreased to prevent the position from passing to the lower end of the mould, thus preventing the occurrence of a BO. However, the time allowance for the deceleration became limited because of higher casting speed of the latest operation practice to increase productivity, and the initial solidification behavior changed owing to the change in the kind of steel produced. It became, therefore, necessary to review the technology for initial solidification control and prediction of BO. Another problem lately is that, because of the scarce incidence of BO and generation change of casting operators, few operators have the experience of actually dealing with BO, and should one occur, they may fail to take adequate measures immediately and allow the damage to spread. On the other hand, because of the rapid advance in computer technology, it is now possible to process considerable information from many thermocouples in a sophisticated manner, and visualize and display the situation on monitoring screens near operators' positions. Accordingly, by combining information from thermocouples with solidification calculation, a system is being developed to detect any abnormal formation of initial solidification shells and to notify it to the operators before the BO occurs. These developments will be mentioned later. What is important for continuous casters that frequently change the cast width during high-speed casting is the control of the side shifting and taper angles of the mould short faces. Slab cooling at the edge rolls immediately below the mould also poses a problem. Efforts have been made to enhance the operation control according to characteristics peculiar to individual casters under different casting

Conditions. Nippon Steel Corporation is developing an improved method for measuring the mould taper and a precision positioning system for the mould short faces that can replace the conventional Stepping cylinder mechanism. Thus, the company is looking for effective measures to prevent BO, one of the most long-standing and toughest problems of continuous casting.

➢ Decreasing preparation time between casts:-

The preparation work between the casts includes extraction of the final piece, insertion of the dummy bar, tundish change, and mould sealing. The final piece of the previous cast is carefully extracted to prevent bleeding, a trouble of molten slag or steel flowing out from the upper end, where solidification is often insufficient. To do this quickly is important to shorten the preparation tie; the present field practice represents an optimum method established through many trials and errors. As for the dummy bar insertion, the downward-inserting type is presently the main stream because the dummy bar can be inserted while the final cast piece is being extracted. In case of using the upward- inserting type, in contrast, dummy bar insertion must wait until the final piece gets out of the caster completely, which increases the preparation time by 10 to 20 min. Thus, most dummy bars of the upward-inserting type were modified into downward-inserting type on the occasions of revamping.

➢ Sequential casting of more charges:-

The number of charges cast through a continuous caster without interruption between insertions of the dummy bar differs from caster to caster depending on factors such as the size of a production lot of the same steel chemistry, service life of submerged entry nozzles, and occurrence of nozzle clogging and other troubles in the teeming system. There used to be cases such as the following: when it was necessary to cast many small lots of different steel grades, they were cast without interruption, allowing for yield loss due to scrapping of joints between two steels where they were mixed; and with some other casters in which the number of charges cast continuously was limited mainly by the service life of submerged entry nozzles, they were quickly changed together with the tundish without stopping the caster. At present, mass-produced steels are grouped into large lots of 10 to 15 charges (3,000 to 5,000 t) for casting without interruption. This was made possible by improvement of countermeasures against clogging of teeming systems taken at different works. Nagoya. Works developed a method whereby submerged entry nozzles were changed during casting without tundish change; this has been put into actual practice. Small-lot steels are cast continuously by using sequence blocks or inserting steel plates at the joints of different grades to minimize the mixing of steels. Various measures were established to decrease the amount of scrap around the joints, such as optimum casting sequence of steel grades and more flexible utilization of slabs/blooms containing the steel joints; these measures increased the casting yield by 2% to 3% from what it was around 1990.

- ## Measures to minimize internal defects:-

Tinplates are drawn to a thickness of 0.1 mm or less during can making. There are many similar cases, and such products are subject to strict control of internal defects due to inclusions. In continuous casting, every measure against inclusions must be taken on slabs for these products at the tundish and the mould. The most common countermeasure is revamping the caster from the curved-mould type into the VB type; making cast steel follow a vertical line of 2 - 3 m from the mould is effective at letting inclusions float up to the molten steel surface and be removed from the cast. Additionally, it is necessary to control the downward flow of Steel in the mould. To this end, level magnetic field electromagnetic brakes (EMBs) have been introduced to some casters. When a static magnetic field is applied to the inside of a mould, a force in the opposite direction of the steel flow arises, which is used for decelerating the downward flow to facilitate the floatation of the inclusions. Some curved-mould casters not having EMBs are equipped with strand electromagnetic stirrers to make steel flow upward and prevent inclusions from going down and being caught in the cast.

Technologies Supporting High-speed Casting of High-quality Steels:-

Since steelmaking processes deal with molten metal at high temperatures, it is not easy to accurately follow the molten steel behavior, for example, the surface properties of hot slabs/blooms in detail during the CC process. However, to improve the quality of slabs/ blooms and increase casting speed, it is necessary to accurately understand the bulk flow, the inclusion behavior in molten steel, and the nature of cast pieces, which cannot be seen directly, and reflect them in the field actions of quality improvement and operation stabilization. To this end, Nippon Steel Corporation has improved technology for directly measuring actual phenomena, as well as for analyzing them, using model calculation.

- **ANALYSIS TECHNOLOGY**

  CC is a complicated process dealing with the behavior of microscopic inclusions in a mixed flow of molten steel, slag, and gas, and therefore, it is not easy to monitor and control all that occurs in the process that stretches across tens of meters. Recently, however, because of advances in simulation models, it has become possible to understand various mutually correlated process phenomena. For example, optimum tundish shape was defined through analysis of the difference in the behavior of inclusions of different sizes in tundishes of different shapes using coupled models that could handle gas and liquid. As mentioned in 4.2.2, Nippon Steel Corporation has improved the shape of mould copper plates and defined the optimum casting speeds for different steel temperatures using solidification simulation models. Furthermore, operation conditions ideal for preventing gas bubbles and inclusions from being caught in the solidification shells were defined, using coupled models for molten steel and gas bubbles in the mould, and such ideal operation conditions have actually been applied to daily practice. In addition, the formation mechanism of center segregation was made clearer by simulation models of the cast bulging between segment rolls and the formation of center segregation due to steel flow at the dendrite tips at the final solidification stage, and it became possible to quantitatively predict how different factors would influence the formation of center segregation. These findings were reflected in the design guidelines for equipment and operation, and center segregation decreased significantly. More recently, attention was paid to the behavior of secondary cooling water to cool casts in the segments, and calculation models made it clear that falling water got together between the bearings, where the segment rolls were divided, over-cooled the cast steel, and caused uneven cooling in the width direction. Nippon Steel Corporation has effectively applied the thermodynamic equilibrium calculation program, SOLGASMIX, to the prediction of the composition of de-oxidation products, oxide metallurgy, etc.

- **Measurement technology:-**

  Since CC is a process for solidifying molten steel, temperature measurement is of basic importance. Continuous temperature monitoring in tundishes, a common practice nowadays, is indispensable for stable caster operation and quality assurance. To continuously monitor the lateral temperature homogeneity of cast steel, surface temperature is measured between segments using radiation thermometers. For quality assurance of slabs/blooms, defect detectors are provided at transfer tables at the exits from casters; they effectively prevent defective slabs/blooms from going downstream by spotting small defects in hot, which is difficult for human eyes.

Closing

The CC technology for high-speed casting of high-quality steels and efficiency enhancement has been outlined herein. As stated earlier, the Japanese steel industry is facing stagnant domestic demand and competition from developing economies, and to strengthen its position in the world market in such a situation, the industry must further enhance its technology that it has fostered and accumulated. As described in other articles of the present issue, Nippon Steel Corporation has developed wide varieties of CC technologies for high-speed casting of high-quality steels. In addition, helped by the advances in analysis technology, causes of problems have been made clearer and clues to their solution found, and as a result, it is now possible to take effective measures to minimize the occurrence of inclusions and remove them. Thus, we have come closer to producing defect-free slabs/blooms, free of center segregation or cracks that form during solidification, and will continue to challenge this target. It is often said that the strength of the Japanese steel industry lies in its technical capability and the people on the work floor. In the CC process, which still depends much on human labor, operators' skill and technology that support it form synergistically the foundation for stable production of high-quality products. In the present situation where we face tough competition in a global market, enhancing our technical capability and the power of the people on the work floor is the only way to make our future brighter.

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