REVIEW OF LADLE FURNACE

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Abstract— This paper gives review of Ladle Furnace. The “Ladle Furnace” means a vessel, lined with refractory material, used for conveying molten metal from the furnace to the ingot mold. The use of Ladle Furnace with refractory linings to hold the molten metal for casting, temperature control, deoxidation, addition of alloys and inclusion floatation. The structure of the furnace consists mainly of refractory bricks and cement, which must be able to withstand the high furnace temperatures and must be carefully selected and constructed. The task conventional design and analysis of ladle furnace is complex and time consuming process. Also the rising demands on the secondary metallurgical processes in steel plants have resulted in an increased awareness of the importance of the steel ladle. Due to awareness and safety the use of software tools used for design and analysis purposes are increased.

Keywords — Ladle Furnace, Ladle Furnace construction & Refractory lining, Types of ladles, Emperature factors & its effects

I. INTRODUCTION

Ladles in the steel plant environment are primarily required to contain and transport molten steel from the melting unit to the casting facility. The use of ladles with refractory linings to hold the molten metal for casting, temperature control, deoxidation, addition of alloys and inclusion floatation. [1] Ladle is a basic tool extensively used in the continuous casting cycle. Ladle is a container used to transport molten steel from the furnace to the casting machine. Ladles are designed to be heat resistant and strong. Moreover it is also necessary that a ladle be heat insulated. Proper heat insulation is required so that the molten steel contained in the ladle remains at a proper temperature. Ladles come in different capacities. The ladle is consisting of ladle housing, thermal insulation, lifting sling and mechanical gear mechanism. [3] The ladle structure is multilayered because of the fact that a ladle should be strong and heat insulated. The inner face of the ladle is built from specialized refractory bricks. These bricks are resistant to high temperature, thus making it possible for the ladle to hold molten steel. Two types of brick are used to construct the inner surface. One type of brick is used to construct part of the surface that will interact with the liquid steel while the other type of brick is used to construct the surface that will interact with the slag layer above the molten steel. Then there is a mass layer. Behind the mass layer is a safety layer. Then comes the insulation layer and all these layers are covered by a steel shell on the outermost side. All these layers are to ensure the ladle will be able to withstand and contain high temperatures. [1]

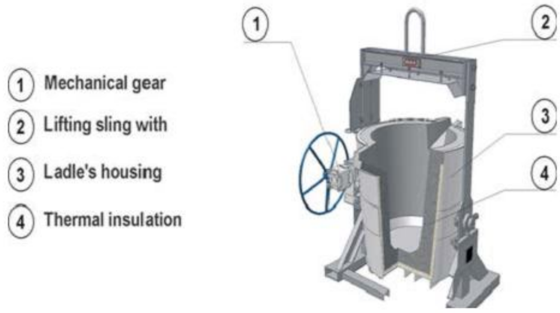

Fig.1 General Construction of the ladle

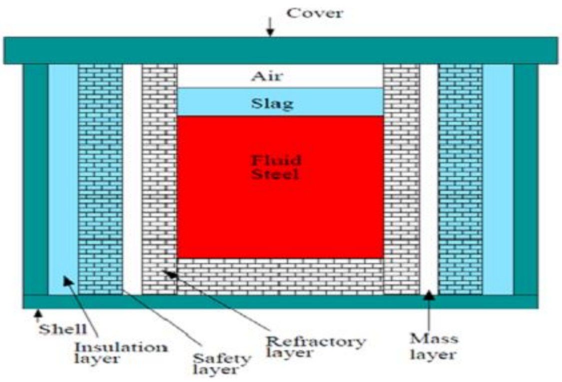

Fig.2 Refractory lining details

II. TYPES OF LADLES

The basic ladle design can therefore include many variations that improve the usage of the ladle for specific tasks. The ladles can be classified depending upon applications. [3] Casting ladle - A ladle used to pour molten metal into moulds to produce the casting. . [1]

Fig.3 Casting Ladle

Transfer ladle - A ladle used to transfer molten metal from a primary melting furnace to either a holding furnace or an auto-pour unit. For the transportation of very large volumes of molten metal, such as in steel mills, the ladle can run on wheels, a purpose-built ladle transfer car or be slung from an overhead crane and will be tilted using a second overhead lifting device. [3]

Fig. 4. Transfer Ladle

Treatment ladle - A ladle used for a process to take place within the ladle to change some aspect of the molten metal.
A typical example being to convert cast iron to ductile iron by the addition of various elements into the ladle. [1]

Fig. 5 Treatment Ladle

LADLE CYCLE

The ladle cycle involves six steps. They are, ladle maintenance, ladle preheating, converter, transportation,
Secondary refining and at last the continuous casting.

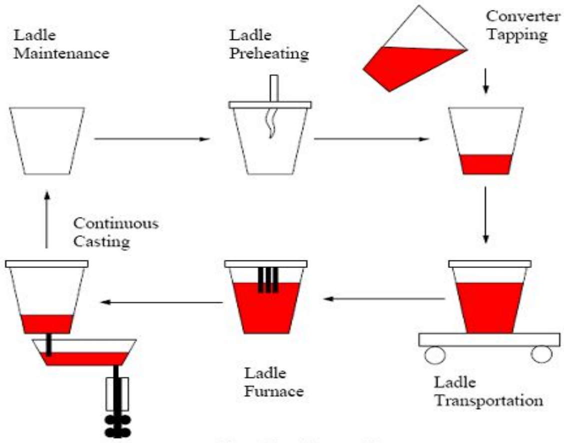

Fig.6 Ladle cycle

1. Ladle maintenance - The ladle has to hold molten steel at temperatures around 1600 oC for long durations. These high temperatures mean that even if the ladle is strong enough to hold them, it is natural for the ladle to ear out after some time. Every ladle needs continuous maintenance to keep it in good shape. So the maintenance station is a place where the ladle arrives after going through the cycle. The ladle is cleaned from any residuals
of the previous heat. [3]

2. Ladle preheating - After the ladle leaves the maintenance station, it arrives at the preheating station. A burner is placed in the ladle which is used to push the ladle temperature to a desirable value. [3]

3. Ladle converter tapping - Once primary refining is done, the liquid steel is poured into the ladle. This pouring of liquid steel is called tapping. The ladle comes from the preheating station or it may come directly from the maintenance station depending on the empty period of the ladle. The temperature of the liquid steel is around 1600
o C. The weight of the liquid steel in a filled ladle is usually up to 90 tons. (Depending upon capacity). [3]

4. Ladle Transportation - Once the ladle is filled, it is placed on the rails for the transportation to begin. The ladle might stay on the rails, waiting to be taken to the ladle furnace for secondary refining, depending on the schedule of the cycle at the facility. It is here at the transportation phase, when most of the temperature loss occurs. To avoiding purpose the molten steel is covered with a layer of slag in order to reduce temperature losses. After this, a lid is used to cover the top of the ladle for further reduction in temperature losses. [3]

5. Ladle Furnace - At the ladle furnace, specified amounts of alloys are added to the steel and excessive carbon is removed. Temperature measurements are taken to ensure the steel is at the correct temperature for casting. Apart from any specific steel grade requirements, it is important for the molten steel to be at the correct temperature

for other reasons too. If the temperature is too high, a breakout can occur and if it is too low, nozzle clogging might be the result. Heat bursts are given to the steel if the temperature is low and scrap metal is added if it is high. Stirring is performed using gas or electromagnetic purging to reduce stratification Hence making the liquid homogeneous. [3]

6. Continuous Casting - In this phase, the ladle is taken to the upper edge of the casting machine where steel from the ladle is gradually tapped into a tundish via the nozzle. The tundish is used to provide the casting machine with a continuous flow of molten steel during the time when an empty ladle is being replaced with a filled one. In this way continuous cycle is going on the industries. [2]

III. TEMPERATURE FACTORS AND IT'S EFFECTS

The temperature of the molten steel at casting plays an important role in the quality of the steel. To keep the casting temperature at the desired level, the temperature needs to be monitored and controlled throughout the process. The first step in designing a control system for a process is to understand the behavior of the system. In case of secondary steel casting, it is necessary to understand the general behavior of the ladle and the effects of temperature on the ladle process. [3] During the ladle cycle, some heat is lost to the refractory layers by conduction while some of the heat is lost to the atmosphere by radiation. The radiated heat is reduced by the usage of slag layer and the lid. The addition of ferrous alloys also adds to the heat loss. The heat loss is directly related to the thermal status of the ladle. If the ladle has high heat content at the instant of tapping, less heat loss from the molten steel will occur but if the ladle has lower heat content, then heat losses from the molten steel will be higher. The amount of heat content a ladle can carry depends upon the construction of the ladle and its thermal properties. [2] At the preheating station, the inner ladle refractories absorb heat from the gas flame. Some of the heat from the flame is lost to the ambience. Heat absorbed by the inner ladle refractories is gradually passed to the outer refractories by conduction. Heat is also lost to the ambience by radiation from the ladle shell. If the ladle remains empty for longer periods, then preheating will be necessary because the ladle will lose its heat content to the environment. But if the ladle's empty time is short then the ladle can be utilized without preheating. This is because the ladle has inherited a suitable amount of heat content from the previous cycle that is enough to provide a suitable metal delivery temperature for the next heat. Ladles with short empty times have higher heat content in their lining and relatively low surface temperature while ladles that undergo a long preheating have lower heat content in their lining and a higher surface temperature. Heat loss also occurs by radiation from the inner and outer face of the ladle when the ladle is being brought for tapping. During tapping, the molten steel loses some of its heat to the ambience by radiation and some of its heat is lost by convection to the refractories of the converter's mouth. If an inadequately heated ladle is brought for tapping, the molten steel poured into it will lose heat at a higher rate. [3] During the phase when the ladle is being transferred towards the casting machine, the ladle has to wait depending upon the schedule at the facility. The molten steel continues to lose heat to the refractories and to the ambience. Stratification occurs during this phase and increases with holding time. [3] When the ladle reaches the secondary refining stage, ferroalloys are added to the melt which results in more heat loss. Heat loss due to the addition of ferroalloys depends upon the quantity of the added material and its chill factor. Arc heating is then used to compensate for all the heat losses and bring the melt's temperature into a desired range. Upon reaching the casting machine, the casting starts and the melt is poured from the ladle to a tundish. More heat is lost during casting by radiation and conduction from both the ladle and the tundish. [3] A study has estimated that typically 55 to 60 % of the total heat is lost through the ladle wall refractories. 15 to 20 % is lost through the ladle bottom and 25 to 30 % is lost through the slag layer. Achieving any desired quality of steel depends upon many factors. Controlling the carbon content and the alloy proportions in molten steel is important, but equally important is the control of molten steel temperature. Unlike the alloys and carbon content control, temperature control is difficult. This is because the desired temperature must not only be achieved; it must be achieved at a specific time. The control of such processes is called time-temperature control problem. [2] The combined heat transfer by convection and conduction takes place between the liquid steel and the ladle lining. The steel flowing in ladle is unsteady in view of the time and, depending on the sequence of the technological processes, even multiple transitions encounter from the forced convection to free convection and vice versa. [2]

IV. DESIGN PARAMETERS

The ladle is intended to deliver the molten metal to the molds evenly and at a designed through put rate and temperature without causing contamination by inclusions. The main causes for inclusion formation and contamination is deoxidation of the melt by air. [1]Good design of a ladle must be directed toward minimizing the formation of the macro inclusions and alumina cluster. The designing of ladle is consisting, of mainly Structural design of ladle and Refractory selection for lining. [1] 1. Structural design of ladle – The Structural design of ladle are intended to cover only Materials (by reference) and the more important structural design features, such as thickness of sidewalls and bottom, proportions of stiffener rings, gear tilting mechanism, trunnion pin, miscellaneous forged fittings and the designing of welded joint such as sidewall & bottom, stiffener rings and shell. [4] [1] The AISE Standard N0. 9 are intended to cover the following specifications of ladle,

a) Design Assumptions and Allowable Stresses,
b) Material selection,
c) Design of Bottom Plates & Side wall Plates.
d) Design of Stiffeners, Design of Trunnion Block and Pin

V. DESIGN ASSUMPTIONS AND ALLOWABLE STRESSES

Design Assumptions:
The design assumptions are considered as below,
Assumption for dead weight: -
The specific weight of molten metal varies with the grade of the steel. For Ladle Furnace of about 150-ton net capacity, the lining weight is ordinarily 80-85 per cent of the total steel dead weight. [1]

Assumption for Bottom Plate:-
A dished bottom is recommended as advantageous in several ways as compared to the flat type. The dished bottom is usually of the shallow dish type tank head, shaped like a spherical segment with a smaller knuckle radius giving an arch tangent to the head flange (sometimes called torispherical). [1] The maximum deflections of flat plates were six to seven times as large as the maximum measured for the dished bottom, and exceeded the thickness of the bottom including the cover plate. The bottom should be furnished with a removable cover plate for protection against heat radiation during the pouring process. The cover plate is spaced away from the bottom by means of washers, and can be renewed or removed to allow inspection. [1] For a Ladle Furnace of 150-ton capacity the empirical diagram in Figure indicates a 1.3 in. (33.020 mm) thick bottom plate. [4]

Assumption for Side wall Plate:
The thicknesses commonly used for Ladle Furnace side shells are within 10% either way. [4] The model shell thicknesses were made as small as possible, considering available materials, the model corresponds to ~ 3/4 in (19.050 mm), thickness on the 150 ton capacity of Ladle Furnace. But practically in operation considerations probably require a thicker Ladle Furnace shell than required by stress analysis. [4]

Assumption for Trunnions & Trunnion pin:-
The trunnions on Ladle Furnace of 100-ton capacity or more are usually of welded construction. Castings are now mostly used for smaller Ladle Furnace. The trunnions should be connected to thestiffener rings which are usually provided above and below the trunnions in order to minimize local shell stresses due to the trunnion reaction. The combined center of gravity of the Ladle Furnace and the molten metal when full shall be safely below the centerline of the trunnions, and trunnions shall be located at least 65 per cent of the overall vertical height above the lowest point of the shell. [1] If trunnions must be located lower due to crane clearance, trunnions should be provided with lock bars or other means to prevent accidental tilting of the Ladle Furnace. [1] [4]

Allowable Stresses on Ladle Furnace:-
The following stresses will not be exceeded in the design of Ladle Furnace. In members where the axial stress through the thickness is nearly constant, the stress shall not exceed 8000 psi. (27679.9 kg/m3) i.e. direct stress in Ladle Furnace wall or dished bottom. [1] Stresses in members which are subject to bending or combined ending and direct load shall not exceed 16,000 psi. (442878400 kg/m3) i.e. Stress in stiffener ribs. An exception is the trunnion pin. [4] Stresses in members which do not help appreciably in carrying load, but which are secondary stresses or due to stress concentrations at discontinuities shall not exceed 24,000 psi. (664317600 kg/m3) i.e. Normal stress due to bending at juncture of sidewall and bottom of dished bottom Ladle Furnace. [1] [4] the maximum allowable shear stress shall be 0.6 times the allowable tensile or compression stress.
The maximum normal stress in the trunnion pins due to bending, neglecting stress concentrations in fillets, shall not exceed 8000 psi. (27679.9 kg/m3) [1] [4]

MATERIAL SELECTION

A Material for the following parts of the Ladle Furnace shall be in accordance with the latest revision of the Following specifications:

Bottom plate:
For bottom plates, ASTM, Standard Specification for low and intermediate tensile strength carbon steel plates with firebox qualities, A-285, Grade C type Steel used. [1]

Side wall plate:
For Side wall plates, ASTM, Specification for Steel for Bridges and Buildings, A-7. If the A-7 steel used exceeds
1-in. and does not exceed 2 1/2-in. thickness. [1] The steel must also meet the requirements of AWS Specification No.D2-0-47 Standard Specification for Welded Highway and Railway Bridges. If specified on the information sheet, material shall meet the requirements of A-285, grade C firebox quality for thicknesses up to and including 2 in. For thicknesses

over 2 in., if specified on the information sheet, the material must meet requirements of specification ASTM A-201; Grade a, f1angc quality type Steel used. [4]

Trunnion pin & Trunnions:
ASTM, Specification for Carbon Steel Forgings for General Industrial Use, A-235, Class C, normalized or annealed type Steel used. (Unless integral part of cast steel trunnion band or pad). [1] Also ASTM, Specification for Mild to Medium Strength Carbon Steel Castings for General Application, A-27, Grade 60-30 or ASTM, A-2I6, WCA, type Steel used. [1]

Stiffener rings, Trunnion block:
For Side plates, ASTM, Specification for Steel for Bridges and Buildings, A-7. If the A-7 steel used exceeds 1-in. and does not exceed 2 1/2-in. thickness, [1] The steel must also meet the requirements of AWS Specification No.D2-0-47 Standard Specification for Welded Highway and Railway Bridges. [1]

VI. DESIGN OF BOTTOM PLATES AND SIDE WALL PLATE

Designing of Bottom Plate:-
The formulas given here in for thickness of flat bottom plates have been arrived at on the basis of the bending theory of circular plates, considering the restraint of the sidewalls as being intermediate between supports and fully fixed edges. [1] Figure 7 shows the agreement for circular bottom ladles between the proposed design formulas and a number of ladles built by various manufacturers over a period of many years. The design formulas give thicknesses on the safe side of existing practice. [1] The greatest discrepancy between the proposed design formula as and existing practice appears to be in the case of the flat bottoms with no reinforcing plates. These are used only for relatively small capacity ladles and only a few designs were available for this comparison. Bottom plate thicknesses in these cases would have had to be appreciably thicker if the present specification had been
applied. [1]

Designing of Side wall plate:
The Minimum side wall plate thicknesses are in accordance with usage requirements, and in addition it is specified that the sidewall thicknesses shall not be less than 0.75 (19.050 mm) times the bottom plate thickness. For intermediate capacities, sidewall thicknesses may be interpolated to nearest 1/16 in. (0.0625 in = 1.5875 mm). Between the Ladle Furnace bottom and the bottom rib, the sidewall thickness should preferably be the same as the bottom plate thickness. [1]

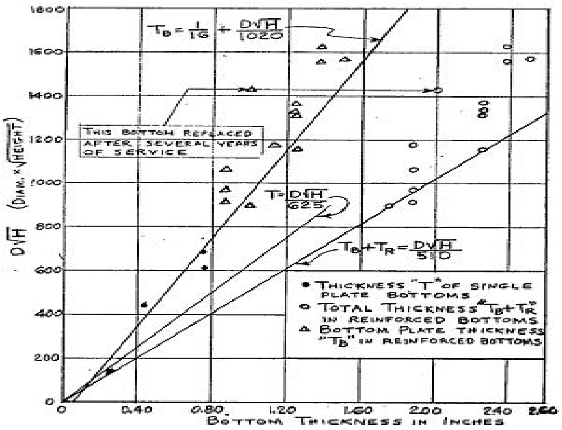

Fig. 7 Proposed design formulas

VII. DESIGN OF STIFFENERS, DESIGN OF TRUNNION BLOCK AND PIN

Design of Stiffener rib or rings:
The tendency of the Ladle Furnace to collapse when suspended by the Ladle Furnace hooks may be resisted by two stiffener ribs or rings, one above and one below the trunnion pad or framing, designated, for top and bottom, respectively. The lip reinforcement of the Ladle Furnace is not to be considered in calculating the stresses in the Ladle Furnace ribs. The strength of each rib is to be determined on the basis of allowable stress, as calculated by the following procedure, which stress is not to exceed 16,000 psi (1125 kg/cm2). [4] Each "effective rib" shall consist of the stiffener ring together with a portion of the adjacent Ladle Furnace sidewall of "effective width" provided however that the rib or band be welded or riveted to the Ladle Furnace sides. Welding is recommended and should be continuous. [4]

Design of Trunnion Block and Pin:-
The maximum normal stress in the trunnion pins due to bending, neglecting stress concentrations in fillets, shall not exceed 8000 psi (562 kg/cm2). The average shear stress in the trunnion pins shall not exceed 2400 psi (169 kg/cm2), computed by dividing the total shear by the area of the pin. (Maximum, shear stress will be about double average shear stress in a circular section). [1] In calculating the bending moment in the trunnion pins, the lifting force shall be assumed to act 1 in. in from edge of collar of trunnion pin. The average bearing stress between the trunnion pin and trunnion block in the Ladle Furnace shell shall be calculated. The trunnions on Ladle 6 Furnace of 100-ton capacity or more are usually of welded construction. Castings are now mostly used for smaller Ladle Furnace. The trunnions should be connected to the stiffener rings which are usually provided above and below the trunnions in order to minimize local shell stresses due to the trunnion reaction. Tests show a beneficial effect of comparatively wide trunnions. [4]

2. Refractory selection for lining –

Refractory selection is an important issue for the successful design of molten metal transportation Ladle Furnaces. The material selected should be thermodynamically stable when in contact with molten metal. [3] Insulation is used in manufacturing processes to prevent heat loss or heat gain. Although its primary purpose is an economic one, it also provides more accurate control of process temperatures and protection of personnel. It prevents condensation on cold surfaces and the resulting corrosion. Such materials are porous, containing large number of dormant air cells. [2] Thermal simulations are helpful when selecting which refractory system has the best performance in terms of heat flow, cold face temperature and metal temperature decay, though not always the most efficient thermal solution gives the best mechanical properties. [2] The refractory selection is depending upon the following properties of the refractory material. [3]

Thermo mechanical Properties:-

A refractory, which is selected based on a proper pore-size distribution and on thermodynamics, might be Less subjected to mechanical impact because the cleaning operation is not so frequent. Conversely, corroded and infiltrated refractories may resist less to impact (crack initiation) because of the disruption in their original microstructure. [2] The cold-crushing strength (CCS) and modulus of rupture (MOR) values are the only mechanical properties usually considered for refractory selection. Although MOR correlates well with impact resistance, 6 it does not take into account other fracture mechanisms relevant for thermal shock resistance (TSR) optimization. [3]

Thermal Properties:

The thermal diffusivity indicates how fast a material can reach the steady-state condition whenever its surrounding temperature varies. Therefore, materials with high thermal diffusivity should be selected. In addition to the thermal diffusivity, the amount of heat stored when the refractory temperature is increased also can be a useful parameter to predict the amount of energy necessary to preheat the Ladle Furnace Therefore, there are six thermal parameters that can be calculated and used to compare various refractory systems for Ladle Furnace lining: thermal diffusivity; heat storage; heat flux; cold-face temperature; freezing point; and metal temperature decay rate. [3] The ideal material presents high thermal diffusivity and low stored heat, which allows a fast preheating schedule; low heat flux and cold-face temperature, which provides less heat exchange and good insulation; freezing point far from the steel shell, for safety reasons; and low metal temperature decay rate, which enables metal transportation for longer distances .[2] In the Ladle Furnace heat transfer by a combination of thermal conduction and thermal convection can be analyzed using conductive thermal resistance and convective thermal resistance. These thermal resistances are functions of thermal conductivity, convective heat transfer coefficient(s), and geometrical parameters. [3]

CONCLUSION

Ladle is a basic tool extensively used in the continuous casting cycle. Ladle is a container used to transport molten steel from the furnace to the casting machine. The ladle is consisting of ladle housing, thermal insulation, lifting sling and mechanical gear mechanism. The ladle cycle involves six steps. They are, ladle maintenance, ladle preheating, converter, transportation, secondary refining and at last the continuous casting. During the ladle cycle, some heat is lost to the refractory layers by conduction while some of the heat is lost to the atmosphere by radiation. The amount of heat content a ladle can carry depends upon the construction of the ladle and its thermal properties. The Structural design of ladle are intended to cover only Materials (by reference) and the more important structural design features, such as thickness of sidewalls and bottom, proportions of stiffener rings, gear tilting mechanism, trunnion pin, miscellaneous forged fittings and the designing of welded joint such as sidewall & bottom, stiffener rings and shell. Refractory selection is an important issue for the successful design of molten metal transportation Ladle Furnaces. The material selected should be thermodynamically stable when in contact with molten metal.

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