Structure Optimization of Ladle Bottom Based on Finite Element Method

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ABSTRACT: *Ladle is an important container in metallurgy industry, and its lifetime is very important for the natural production of enterprise. The stand or fall of refractory lining of ladle decides its lifetime, yet thermal stress is the direct reason of causing refractory lining breakage. In this paper the structure of ladle mainly by changing the structure of bottom with finite element method is designed, and three scheme models are put forward. By analyzing and comparing stress field of the three ladle models, finally an optimization scheme is put forward. The experiment results indicate that the lifetime of ladle gains obvious increasement, and the rationality and practicability of the scheme have been proved. The method is feasible to improve ladle's lifetime.*

Categories and Subject Descriptors:
F.1.1 [Models of Computation] Automata (e.g., finite, push-down, resource-bounded); **G.1.2 Approximation**

General Terms:
Finite element computation, Stress Analysis

Keywords: Structure Optimization, Equivalent Stress, Stress Field, Ladle Bottom, Finite Element Method

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1. Introduction

Ladle is a sort of important container in metallurgy industry, which acts as storing and transporting molten steel. With technology advancement of modern metallurgical industry and unceasingly developing of continuous casting's application, ladle's role is remarkable. At the same time, the quality requirement of molten steel is gradually increasing, therefore ladle's role has had important changed, and ladle gradually becomes refining furnace of twice refining out-furnace from pure storage and transporting molten steel. As can be seen, ladle's status is very important in enterprise and its lifetime directly influences enterprise's regular production and production cost.

In the process of using ladle, the most common destruction is refractory lining's cracking and eroding, thus causing molten steel leakage. The reasons of refractory lining's damage include chemical corrosion and hot mechanical stress, of which hot mechanical stress is the direct reason causing refractory lining's damage. The damage mechanism is that ladle's lining creates thermal stress under sudden temperature's change to cause micro cracks of material's interior gradually to expand, and at last causing lining material flaking and cracking. Destructive phenomenon of lining's cracking and eroding and so on appears after ladle's working for a period of time, and it must be maintained for large, medium and small repairing to guarantee ladle's normal work for different working condition. The work of maintenance consumes massive manpower and material resources, and reduces the production efficiency of enterprise. Therefore, understanding ladle's temperature distribution and stress distribution at different operation conditions have an instructional significance for lengthening maintenance cycle of ladle's lining, increasing service life and reducing the production cost of enterprise [1].

The heat transfer in a steelmaking ladle was studied. The evaluation of heat transfer of the steel was performed by measuring steel temperature in points including all refining steel process. The temperature measurements of the ladle indicate distinct thermal profiles in each stage of steel refining. Moreover, as each stage of the process depends on the previous one, the complexity of the ladle thermal control is incremental [2]. The thermal fields of the refractory linings of metallurgical equipment are investigated. Using as an example the lining of a steel-teeming ladle, mathematical modeling of the thermal fields in preliminary heating of the ladle and during smelting is performed. An approach to the construction of thermal fields, assuming the presence of defects in the lining and in the case of intersecting thermal fields, is proposed [3] .Simulation of stress field was made. Through modeling, loading, restricting and calculating, strain and stress field distribution of the hot metal ladle were acquired. Finally, an assessment of strength and stiffness was made on the hot metal ladle. The method, which is convenient and practical, reasonable and reliable, provides theoretical evidence for checking analysis and further optimal design of the hot metal ladle [4]. To predict the temperature distribution in the ladle wall during the preheating process, a two dimensional model was developed. The model calculated the heat transfer and the velocity field in the gas phase inside the ladle as well as the heat transfer in the solid walls during the preheating process. Measurements of the temperature in an industrial lade were carried out using an infrared radiation (IR) camera. The measurements were made inside and outside the ladle. The model predictions were found to be in reasonably good agreement with the measured temperatures. [5].

Aiming at the performances of ladle composite body in service, three-dimensional model of ladle based on finite element method is built. Simulation of stress field with three different structure f bottom was made by finite element software, so an optimal structure is put forward. The experiment results indicate that the rationality and practicability of the optimal scheme.

2. Establishment the Finite Element Model of Ladle

This paper takes 250-300 tons' ladle of Wuhan Steel Corporation as an example. The finite element model with APDL language is generated after finishing ladle's parameters of geometry model and material model [6].

Establishing ladle's model adopts the modeling way from bottom to top. At first a surface is generated in XOY plane, and then the surface is stretched along Z axis to form a body, at last each element is divided into hexahedron element with the method of stretching. In addition, in order to assign different material attribute and boundary conditions to generated surfaces and bodies, which are separately named, in the process of modeling. Finite element model generated is shown as Figure 1.

3. Structural Optimization of Ladle's Bottom

Because ladle's lining is composed of many materials, the structure of bottom and the materials of wall are adjusted to obtain a smaller stress structure of bottom and wall. But considering from the angle of structure, the structure of wall is relatively fixed, not suitable changed. When designing the structure of ladle, the structure of bottom is mainly considered together with the materials of wall.

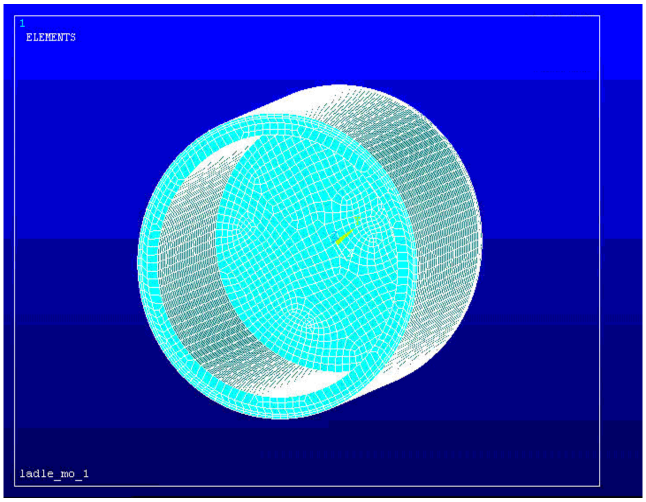

Figure 1. Three dimensional finite element model of ladle

3.1 Experimental Scheme

Because the disappearing heat near the wall is more than that of near the center, as causing the gradient of temperature here to be bigger than that of near the central, thus the stress of bottom's hot surface in the crossing between the bottom and the wall is generally bigger than that of near the center. But the thermal-expansion coefficient of micro-expansion and high aluminum bricks, which locate in the permanent lining, is small in the lining materials of ladle, so increasing a cirque of high aluminum lining in the periphery of bottom can be helpful to reduce the thermal stress value of bottom. The impact block firstly contacts molten steel when receiving molten steel, so the thermal stress value which is caused by instantaneous inflation also reduces by adding high aluminum lining in the periphery of the impact block [7]. According to the above analysis, three following model plans of ladle are obtained. Their structures are shown as figure 2, figure 3 and figure 4.

No.1 scheme is shown as figure 2. A cirque of high aluminum lining bricks is added in the periphery of bottom. The outer diameter of this cirque is the inside diameter of ladle's bottom, and the difference between the outer diameter and the inside diameter is 300mm.

The following are equivalent stress distribution figures of three schemes in bottom, shown as Figure 5, Figure 6 and Figure 7.

No.2 scheme is shown as figure 3. A cirque of high aluminum lining bricks is added in the periphery of impact block. The length of lining bricks is 2200mm, the width 360mm, and the length extends to the wall of ladle.

No.3 scheme is shown as figure 4. A cirque of high aluminum lining bricks is added in the periphery of impact block. The length of lining bricks is 2200mm, the width 360mm, And a cirque of high aluminum lining bricks is added in the periphery of bottom. The outer diameter of this cirque is the inside diameter of ladle's bottom, and the difference between the outer diameter and the inside diameter is 300mm.

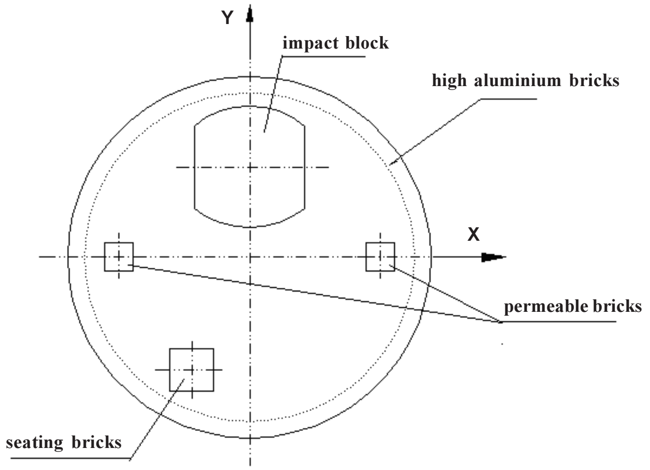

Figure 2. No.1 Scheme model of ladle's bottom

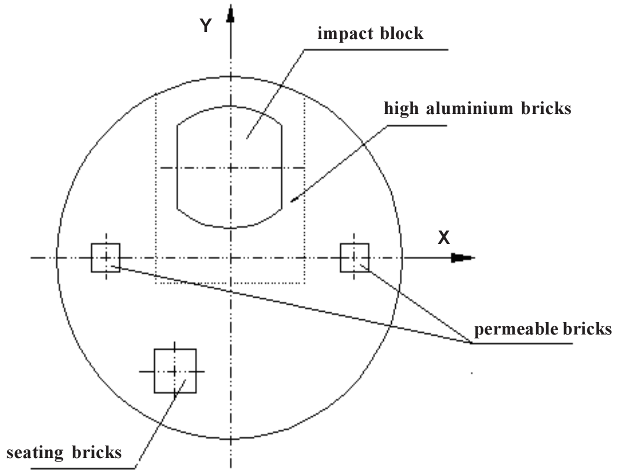

Figure 3. No. 2 Scheme model of ladle's bottom

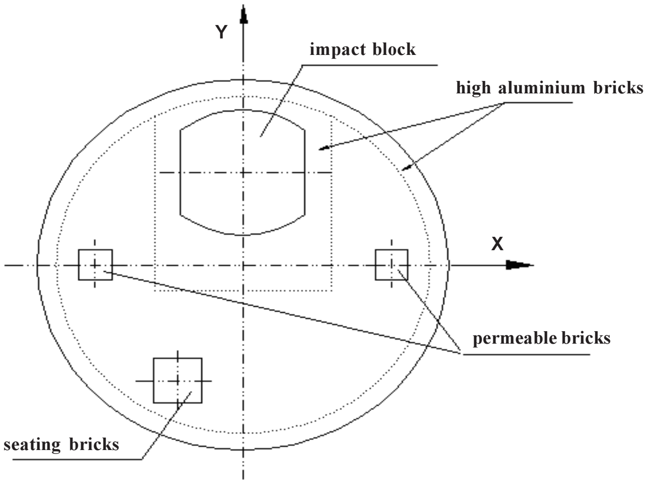

Figure 4. No. 3 Scheme mode of ladle's bottom

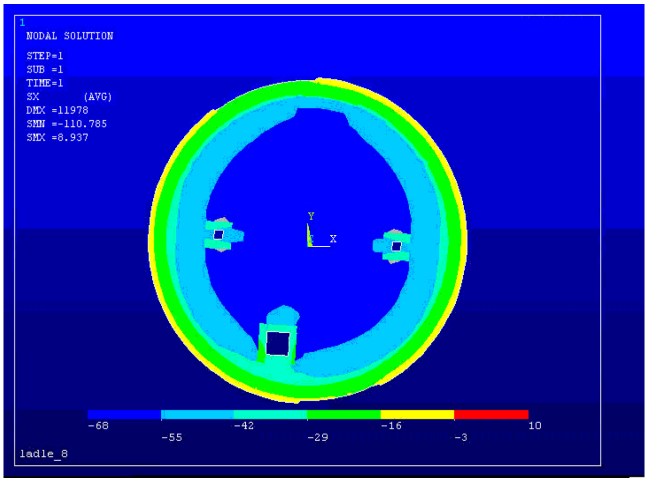

Figure 5. Equivalent stress distribution of scheme 1 in bottom

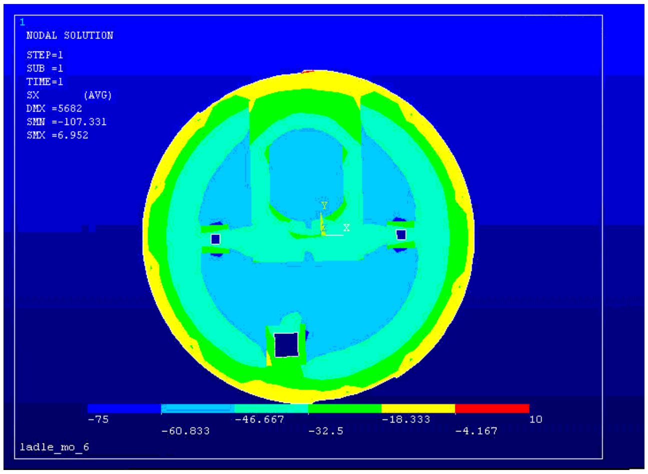

Figure 6. Equivalent stress distribution of scheme 2 in bottom

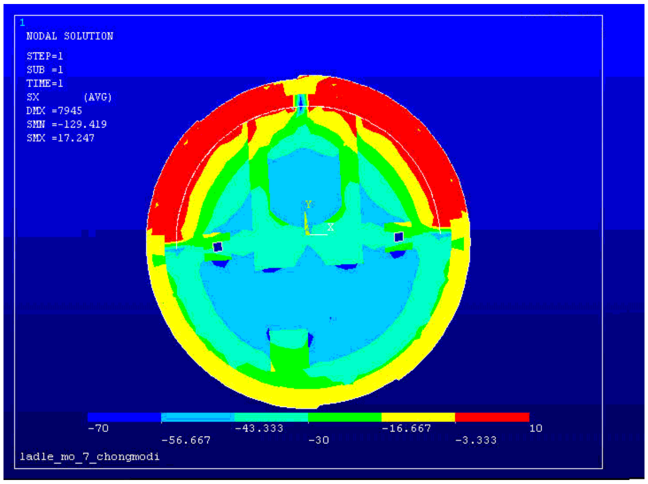

Figure 7. Equivalent stress distribution of scheme 3 in bottom

3.2 Calculating Results and Analysis

A cirque of high aluminum lining bricks whose thermal-expansion coefficient is small is added in the periphery of bottom for the structure of bottom 1, so the equivalent stress value in high aluminum region is smaller than that in the middle region of aluminum-magnesium-carbon lining. It accounts for reducing bottom's stress that medium-grade precast block is added in bottom.

A circuit of high aluminum lining bricks is added in the periphery of impact block for the structure of bottom 2,as reduces stress in the cirque region between permeable bricks and sidewall, but increases stress among permeable bricks, eating bricks and impact block, the maximal stress adding up to 100Mpa.

The structure of bottom 3 synthesizes the structure of above two bottoms. It reduces the stress of majority region n bottom, having a better effect than the first two schemes.

High aluminum lining can effectively reduce the thermal stress of bottom lining from the above stress analysis. While the difficulty of masonry for lining bricks will increase due to the arc structure of impact block in the process of masonry. Therefore the fourth optimized structure of bottom is put forward. Namely original aluminum-magnesium-carbon is substituted for corundum castables in bottom lining, and a circuit lining bricks of aluminum-magnesium-carbon are added around permeable bricks and seating bricks so as to replace them. This way not only reduces the thermal stress of bottom lining, but also solves the masonry problem due to the arc structure of impact block. The structure of bottom is shown as Figure 8. The stress distribution of the modeling structure is obtained by calculating, shown as Figure 9.

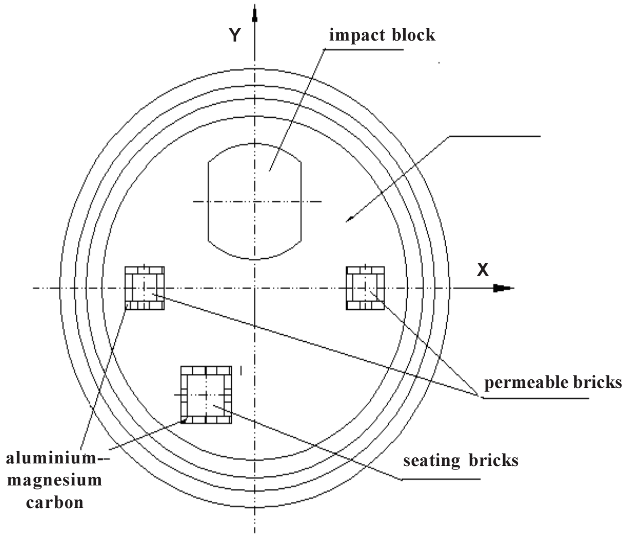

Figure 8. No.4 Scheme mode of ladle's bottom

By comparing the above four stress distribution of bottom, the maximum value of equivalent stress in the fourth bottom is only 42.4MPa, and the average equivalent stress is about 19MPa smaller than that of the above three bottom. The equivalent stress of bottom is greatly reduced.

The service life of this bottom achieves about 250 stove times by scene testing, yet the service life of bottom which hasn't been improved achieves only 90 stove times. It confirms that the bottom model adopted by this paper has a better rationality and practicability.

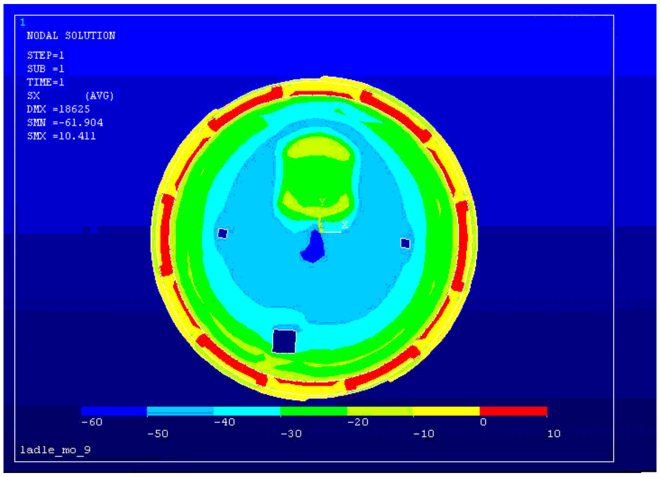

Figure 9. Equivalent stress distribution of scheme 4 in bottom

4. Application

The theoretical research and calculation indicated that the fourth ladle structure was an optimum scheme. According to the optimum scheme in conjunction with the actual production conditions, five ladles in the normal operation (No.5 ladle, No.9 ladle, No.10 ladle, No.17 ladle and No.5 ladle) were randomly selected to carry out the preliminary test and application.

The masonry was conducted from building the ladle in strict accordance with the fourth optimum structure and refractory lining material. Nozzle seat bricks and permeable bricks were constructed after achieving the masonry of wall bricks and slag line bricks. Two rows of alumina-magnesite carbon bricks were constructed along the periphery of the permeable bricks and gate bricks in order to conveniently replace the permeable brick and gate brick during the minor repairing. Impact bricks were laid in the lashed area and then the corundum castable was poured. The ladle was in the natural curing for 24 hours at the end of the pour and then it was provided with the pre-bake for 24 hours. The ladle was baked on the baking bench according to the current baking regulation (Stage of ladle heating after constructing the permanent layer, Stage of ladle heating after constructing the working layer and Stage of ladle holding after the masonry). The ladle was transferred to the hot repair package for the turnover after reaching the specified time. The ladle entered into the stage of receiving molten steel when the ladle heating ended. Filled with the molten steel, the ladle was conveyed to a continuous casting plant. Moreover, the molten steel was poured into the tundish. The ladles subjected to the hot repair turned into the next working recycle stage when the ladle heating ended.

From the application, the experimental ladles could satisfy the actual production requirements and the ladle service life increased apparently: the service life of the No.5 ladle was 239 stove times on the spot, the service life of the No.9 ladle was 254 stove times on the spot, the service life of the No.17 ladle was 239 stove times on the spot, the service life of the No.20 ladle was 255 stove times on the spot, the service life of the No.10 ladle was 252 stove times on the spot. They were shown in detail in Table 1.

Ladle No.	5	9	10	17	20	Average
Service Life (stove times)	239	254	252	239	255	248

Table 1. Statistics on Service Life of Ladles on the Spot

As seen from the preliminary test research data, it indicated that the average service life of the optimized ladles was 248 stove times. However, the average service life of utilized ladles in the original design was only about 90 stove times. Therefore, the intended purpose was achieved.

5. Conclusions

Thermomechanical stress is the main factor causing damage of the inside lining of refractory material. It can effectively reduce the stress of bottom by substituting for corundum castables in bottom lining. By adopting the fourth bottom structure, not only the masonry problem of lining is solved, but also the equivalent stress of bottom is reduced. It basically controls the phenomenon that bottom is destroyed, and greatly increases the service life of bottom.

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