Heating control of pouring ladle

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Abstract

In order to effectively manage the process of pouring ladle thermal treating, the predictive model of lining-up heat content change considering the extent of its wear was developed.

Key words: POURING LADLE, LINING-UP HEAT CONTENT, UPPER SHELL TEMPERATURE, WORKING LAYER WEAR

Introduction

At the present stage of steel making the pouring ladle is used not only as a container for melted steel receiving, storing and transporting, but also as a unit, which performs various processing steps - liquid-alloy heating, rabbling, desulfurizing, evacuation etc. [1]. Such conditions of ladle operation affect the lining-up thermal state and resistance.

To decrease the ladle lining-up heat shock during the tapping and reduce the heat loss during the secondary metallurgy the pouring ladles heating on special stands is carried out. This processing step requires considerable amount of energy, as heating is produced by natural gas burning, and the ladle preparation time can take one day or more.

Foreign and home researchers are actively studying the thermal and strength condition of ladles. These studies are connected with considering the influence of lining-up structure, refractory materials properties and operation modes on its resistance. Thus, in works [2, 3] the researches aimed at studying the temperature fields arising in lining-ups of ladle walls and bottom are presented.

To control the heating process of ladles it is necessary to assess the lining-up heat content. Modern technical means do not allow to implement it in industrial conditions. When heating the ladle, as a rule, the lining-up inner side temperature is periodically measured [4]. Some enterprises perform heat control by ladle casing temperature, which is constantly monitored by a pyrometer. However, this control method leads to ladle underheating with increasing its lining-up wear.

Problem statement

Determining the pouring ladle lining-up heat before tapping - is an important technological challenge, because it allows to predict the steel temperature in ladle after the release. This, in turn, is a decisive factor to ensure the stability of secondary metallurgy technology and, ultimately, the steel quality. Ladle heating is accompanied by a significant change in thermophysical properties of lining-up materials. Lining-up thermal state also depends on ladle geometrical dimensions, capacity and configuration, degree of its lining-up wear.

To adequately manage the process of thermal treatment ladle with a temperature-controlled housing is necessary to develop a predictive model of lining-up heat content change during operation.

Substantiation of efficiency criterion

To assess the efficiency of ladle thermal treating it is appropriate to use the ratio of the obtained heat content of ladle multi-layer lining-up to its maximum value at stationary heating mode.

Specific heat content $I(x)$ of ladle wall and bottom in characteristic sections is defined as

$$I(x) = \rho\,\delta\,C(T(x)\;\;T(x),\ \text{J/m}^2. \tag{1}$$

Here ρ – lining-up material density, kg/m^3; δ – thickness of its layer, m; $C(T(x)\;\; = C_0 + b\,T(x)$ – material heat content, depending on its temperature J/(kgK); C_0 – material heat content at 0 °C; b – temperature coefficient; $T(x)=ax+ T_{in}$ – temperature profile over the layer thickness, linearized by modeling results. For each lining-up layer the coordinate x ranges from 0 (inner layer boundary) to δ (outer layer boundary). In this case linearization ratio is defined as $a=(T_{out} - T_{in})/\delta$, where T_{out} and T_{in} – the temperature at the outer and inner lining-up layer boundary, °C , respectively.

The value of specific heat content for the k-th lining-up layer is defined by integral

$$I_k = \int_0^{\delta_k} I_k(x)\,dx_k = \int_0^{\delta_k} \rho_k\,(C_{0k} + b_k\,(T_{0k} + a_k\,x))\,(T_{0k} + a_k\,x)\,dx_k. \tag{2}$$

As a result of integration we will obtain

$$I_k = \rho_k\left[T_{0k}(C_{0k} + b_k\,T_{0k})\,\delta_k + a_k\,(C_{0k} + 2b_k\,T_{0k})\,\delta_k{}^2/2 + a_k{}^2 b_k\,\delta_k{}^3/3\right]. \tag{3}$$

The specific heat content of wall and bottom is equal, respectively, to the sum of specific heat contents of lining-up layers in characteristic sections: for the wall - at the level of the slag belt, and for the bottom -

on the ladle axis.

Initial data for modeling

Temperature distribution, temperature gradients and heat flows are usually of interest when carrying out thermal analysis. Mathematical model contains partial differential equation, boundary conditions, with which these equations are solved, and model of material thermo-physical properties.

The boundary value equation of transient heat conduction, used in mode for axisymmetric body in cylindrical coordinate system *r, z* has the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda(\grave{O})r\frac{\partial \grave{O}}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda(\grave{O})\frac{\partial \grave{O}}{\partial z}\right)=c(T)\rho\frac{\partial T}{\partial t}, \quad (4)$$

where $\lambda(T)$, $c(T)$, ρ – heat conductivity, heat capacity and material density; T – temperature; t – time.

The initial and boundary conditions must be specified to find a particular solution of problem (4).

The initial temperatures field in the wall and bottom of pouring ladles is determined by given boundary conditions of the I-st kind - temperature values of the internal surface of ladle lining-up and the outer surface of its upper shell, adopted in accordance with industrial research data.

The study was carried out on the ladle thermal state computer model [5], which takes into account heat losses through the ladle side surface and bottom.

A 120-ton steel ladle is taken as test sample. Ladle lining-up structure, and thermal properties of its components correspond to those in [5].

Sequence of modeling

To investigate the effect of lining-up wear on ladle thermal state two options were considered:

1) Heating the newly lined ladle with working layer thickness of lining-up from corundum of 150 mm.

2) Heating the ladle with half spent working layer (corundum thickness is 75 mm).

For each option, four stages of ladle operation were modeled:

stage 1 – heating-up the ladle for 24 hours at the constant temperature of lining-up internal wall of 1100 °C and environment of 30 °C;

stage 2 - liquid-alloy staying with initial temperature of 1620 °C in the ladle for 60 minutes;

stage 3 - ladle cooling for six hours at an ambient temperature of 30 °C;

stage 4 - heating the ladle at the internal wall constant temperature of 1100 °C until reaching the lining-up heat content when heating.

Modeling results

Figure 1 shows the change in lining-up wall specific heat content at heating-up (curve 1) and heating (curve 2) the ladle according to option 1, as well as at heating the ladle with half developed working layer (curve 3) - option 2. The dotted line shows maximum values of lining-up heat content at stationary heating mode (4 - for option 1 and 5 - for option 2).

Figure 2 shows the change in upper shell temperature at heating the ladle according to option 1 (curve 1) and heating the ladles (curve 2 - for option 1 and curve 3 - for option 2).

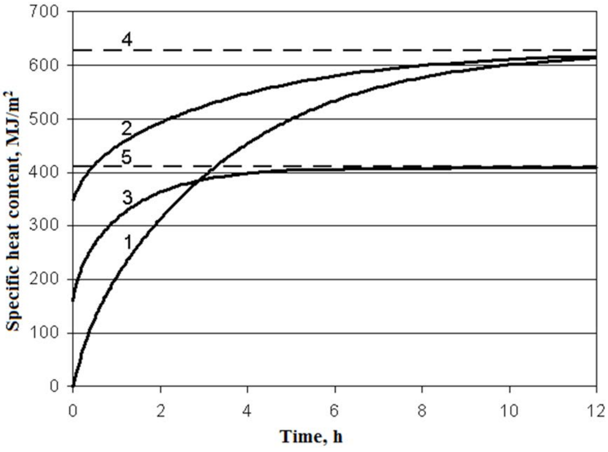

Figure 1. Change in specific heat content of ladle lining-up when it is heated

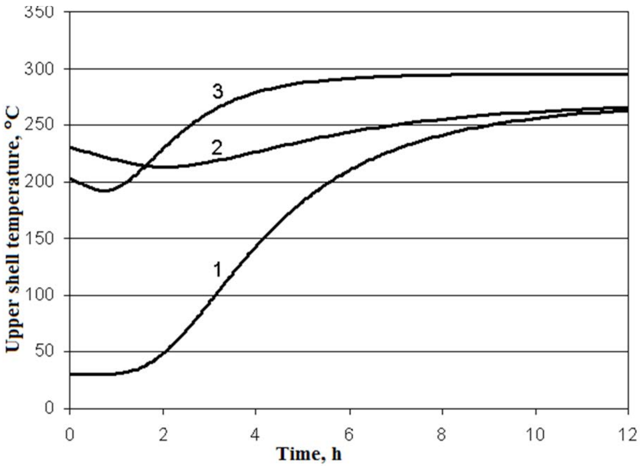

Figure 2. Change in ladle upper shell temperature when it is heated

Research on the computer model showed that the time to reach maximum lining-up heat content depends not only on the stage of ladle heating, but also on the degree of working layer wear. When heating the maximum heat content of ladle with half developed working layer of corundum is achieved 2.4 times faster than heating the newly lined ladle.

Results of modeling show that the control of ladle heating degree on its upper shell temperature justifies itself for the newly lined ladle. Thus, when its thermal treating almost similar lining-up heat content is achieved at the same upper shell temperature.

However, the attempt to use the same temperature value to control the heating of ladle with worn working layer will lead to significant lining-up underheating: the ratio of obtained heat content to its maximum value, implemented with stationary heating mode, will be only 91%.

Conclusions

The possibility of reliable control of the lining-up thermal state on the upper shell temperature is demonstrated only for newly lined ladles. Control system setting up by heating stand for the specific upper shell temperature will lead to ladles underheating with worn lining-up.

To control the process of pouring ladle thermal treating with upper shell temperature control the predictive model of lining-up heat content change, taking into account its wear must be used.

Application of the proposed efficiency criterion makes it possible to reduce energy costs for the ladles preparation and operation.

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