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UTILIZATION OF CASTING LADLE LINING ENTHALPY FOR HEATING GAS SAVINGS IN THE COURSE OF LADLE PREHEATING

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During the long-term staying of steel in ladle within the period from the tap until the end of continuous casting takes place a great amount of heat accumulates in lining. For its utilization is necessary to optimize heat operation of ladle lining. The demanded enthalpy of ladle before tap and the real enthalpy of ladle as things stand are needed for heating gas savings during the preheating. The enthalpy changes of ladle lining are in the course of their cycling in steelworks solved by the model of lining thermal state. For that purpose were conducted the operation measurements to find out the ladle lining thermal field within the whole technological flow.

Key words: ladle, enthalpy, lining, steelworks

INTRODUCTION

In the framework of automated control system of the steelworks are utilized partial technological models, both for monitoring of the ladle cycling and determination of the thermal state of the ladle lining during the operation. Present technological conditions of the steelworks are characterized especially with the operation of three mechanisms for continuous steel casting including ladle furnaces and utilizing of the new device for preheating of the ladle lining. Two continuous casting mechanisms (no. 2 and 3) were put into the operation and therefore were in the ladle cycle new technological sections that were necessary to include into the models of steelworks control system. On the base of the plant monitoring of the ladle cycling were these new sections specified, algorithms for solving the thermal state of ladle lining were derived and the constants were calculated. Functions for ladle preheating control were also created. Because of the long time of steel in the ladle and high enthalpy of the ladle lining at the end of casting were some functions of ladle preheating under new conditions changed. Summary of the shown projects guarantee conditions for optimization of ladle thermal operation in the connection with high quality of the continuous steel casting.

For the project and optimization of the ladle furnaces and other thermal devices are as well used mathematical models and computer programs concentrated on the minimization of the lining thermal losses [1-2].

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Experiment

To set the data necessary for determination of the ladle lining enthalpy change and heat losses through lining was during all the technological operations that come to within the ladle operation cycle utilized measurement.

The operation measurements included the whole ladle cycle from heating the new lining and following technological section "tap of the heat - secondary processing of steel in ladle furnace - continuous casting" all for 15 heats. The sensors for temperature measuring of the lining were created from thermo elements type B and thermo elements with housing type K. The sensors were placed so to get the data characterising the lining thermal field during the whole operation cycle of ladle. Most of the measuring places occurred close to the working surface of the lining because its thermal field was in deciding way influenced by the thermal processes in working area of the ladle [3].

The allocation of the thermal sensors is shown in Figure 1. To record the measurement results were used memory systems GRANT Squirrel. The measuring exchanges in cooled thermal insulating boxes were placed on the steel coat of ladle.At Figure 2 there are presented temperatures which were measured inside of ladle lining during first free melts with new lining [4].

MODEL OF THERMAL LOSSES OF LADLE

At aggregates working continually there can be determination of losing thermal flows through the lining much more complicated, because of thermal field in lining is non-stationary. In this case a losing thermal flow through lining is determinate by the thermal flow from

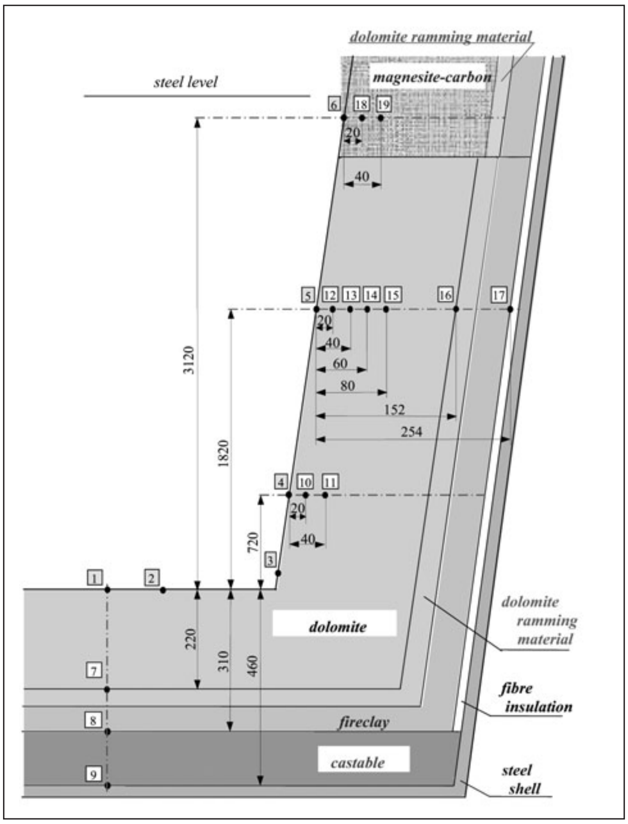

Figure 1 Allocation of thermoelements on the surface and inside the ladle lining

outer lining surface to surrounding environment and by change of losing thermal fl ow due to accumulation of heat inside of lining, and therefore:

$$P_{lo,lin} = P_{lo,sur} + P_{lo,ac} \quad (1)$$

where:

$P_{lo,sur}$ is losing thermal flow from surface / W,

$P_{lo,ac}$ - losing thermal fl ow by accumulated heat in lining / W.

The losing thermal flow from outer lining surface to the surrounding environment $P_{lo,env}$ can by calculated from this relation:

$$P_{lo,env} = \alpha_c \cdot (t_{sur} - t_{env}) \cdot S \quad (2)$$

where:

α_c is total coefficient of heat transfer from outer surface of ladle to surrounding environment / $W \cdot m^{-2} \cdot K^{-1}$,

t_{sur} - mean value of surface temperature of lining / °C,

t_{env} - surrounding temperature / °C,

S - total surface, where there is thermal change / m^2.

At evaluation of thermal losses through the ladle lining in order to results of operating experiment there is used the model for simulation of thermal processes in ladle. For evaluation of enthalpy changes through the lining and thermal losses through lining there is used the same fi le of input data and solution is carried out parallel.

Heat loss through the lining is determinate as an integral value which depends on the time, for the entire ladle lining. At its calculation there is used the whole file of measured temperatures in measuring planes of ladle wall. In fi le of input data of model for simulation of thermal processes in ladle there is directly given the quantity of temperature decrease of steel, which is caused by thermal losses through ladle lining [5]. Decrease of temperature of steel caused by heat loss through the lining in a specific time period is defined by relationship:

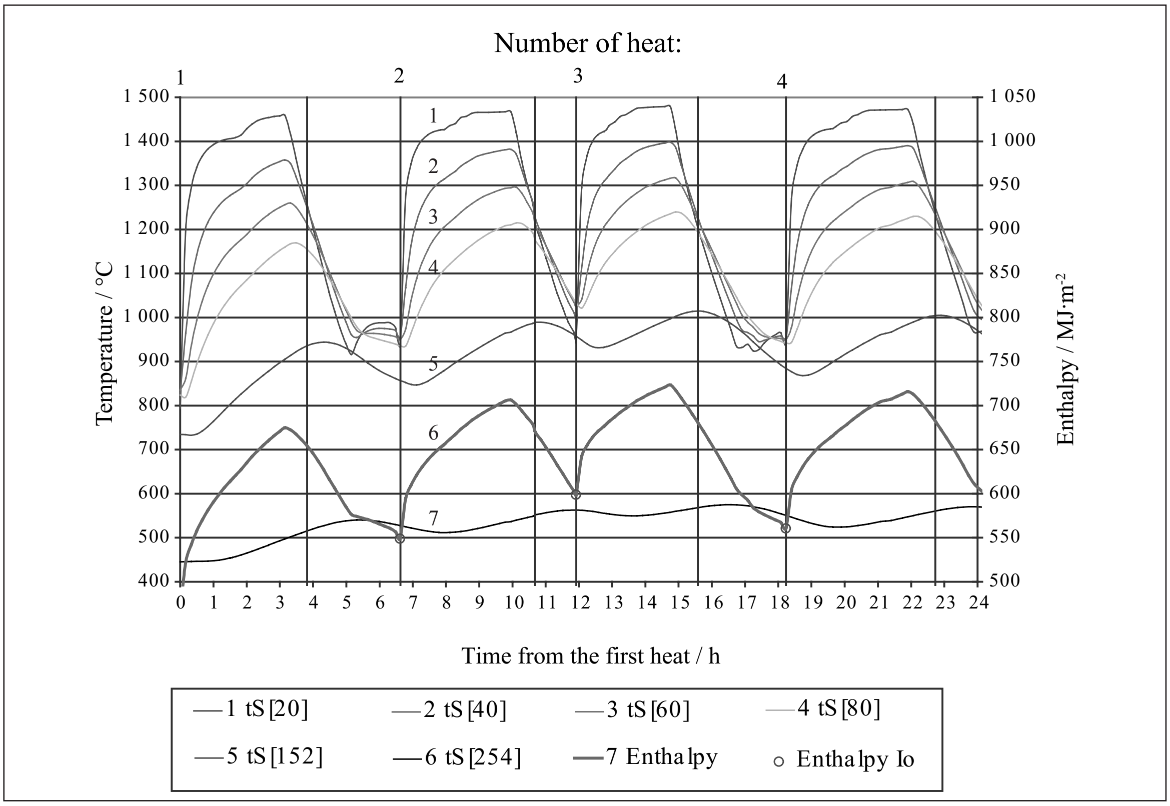

Figure 2 The course of lining temperatures and enthalpy in ladle wall – time section: from the first to the fourth heat

$$\Delta t_{\text{lin}} = \frac{Q_{\text{lin}}}{m_{\text{st}} \cdot c_{\text{st}}} \quad (3)$$

where:

Q_{lin} is heat loss through lining in a specific time period / J,

m_{st} - steel weight in a ladle / kg,

c_{st} - specific heat capacity of steel / J·kg^{-1}·K^{-1}.

The basic parameter is speed of temperature change in steel caused by heat loss through lining Δt_{lin}. From this parameter is determined the decrease of temperature of steel in model:

$$v_{\text{lo}}^{n} = \frac{\Delta t_{\text{lin}}^{n}}{\Delta \tau^{n}} \quad (4)$$

where:

n is a serial number of a section / 1,

Δt^{n}_{lin} - temperature chase of steel caused by heat loss through lining in the n-th sub-segment / °C,

$\Delta\tau^{n}$ - time of the n-th sub-segment / min.

Dates about speed of temperature change of steel caused by heat loss through lining in partial sub-segments were treated by a regression analyses as a linear dependence on enthalpy of a ladle lining at the tapping. There was used following dependence:

$$v^{n}_{lo} = a_0 + a_1 \cdot I_0 + a_2 \cdot I^2_2 \quad (5)$$

where:

I_0 is the enthalpy of a ladle lining wall at tapping / MJ·m^{-2},

a_0, a_1, a_2 constants for model of temperature changes in steel at the ladle, resp. constants for model of heat loss through a ladle lining at assigned sub-segment n.

The total temperature change in steel caused by heat loss through lining can be calculated according to relation:

$$\Delta t_{\text{lin}} = \sum_{1}^{n} (v_{\text{lo}}^{n} \cdot \Delta \tau^{n}) \quad (6)$$

By the successive summation in equal (6) for a sequence of a time periods one can obtains dependence Δt_{lin} on time. The partial model for determination of thermal losses through the ladle lining is part of model for temperature change of steel in ladle.This one solves thermal losses through the lining in partial sections. Time interval between the tap and the end of casting was selected into 6 partial sections:

1. filling of ladle after the tap
2. time between the end of steel flow and the 10th minute after the tap
3. time between the 10^{h} minute after the tap and start of processing at ladle furnace
4. processing at ladle furnace
5. transport of ladle from ladle furnace to DCC
6. casting from the ladle at DCC

RESULTS AND DISCUSSION

The model for evaluation of the ladle thermal state (model of the ladle enthalpy change) needs new setting of the constants for determination of the enthalpy at the end of the technological sections. It has to be pointed out that the constants have individual character and is necessary to be set individually for each type of the ladle lining. Under the indication of lining type can be understand the construction of lining as well as type of the used refractory and insulation materials for bottom lining and ladle walls including the slag zone.

Ladle can during it' s cycle in steelworks occur in following operational states: high – temperature heating, tap, transport of the ladle filled with steel, out – of – furnace processing in ladle furnace, casting, open – air cooling (before tap, after steel casting), cooling under lid.

CONCLUSIONS

Aim of the optimization of ladle lining thermal work under new operation and technological condition of steelworks was to utilize the accumulated heat in ladle lining in the period from the tap till the end of casting heat as much as possible. When steel stays long time in ladle reaches accumulated heat high values. The obtained results and following solution can be summarized into these points:

- After finishing the casting determinate the enthalpy of ladle lining with aid of algorithms obtained from operation measurements.
- Out of this enthalpy decide when to begin high-temperature heating.
- Ladle is to be in every possible moment covered with lid not to come to heat removal.
- Let the ladle cycle without VTO as many times as possible if the present operation situation of steelworks makes it possible and the ladle lining fit the expectations of min. enthalpy after tap.

The mean for optimization of the ladle lining thermal work is evaluation model of ladle thermal state whose constants were for the new operation conditions of steelworks derived from the operation experiment results.

The results can be summarized into the following points:

- appreciable savings of heating mediums with a direct impact on decrease the CO_2 emissions;
- at fair abidance by covering the ladles by a lid immediately after steel casting along with implementation of insulating layer into the ladle lining it will lead to minimize of a thermal losses of steel through the lining;
- this will signify partly more even temperature gradient at ladle-tundish and partly the possibility of permanent reduction of tapping temperature with subsequent increase of life not only the furnace lining, but also the ladle lining (less thermal "shocks" during the tapping).

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Note: The responsible for English language are M. Klarova and P. Tvardek, Ostrava, Czech Republic