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Efficiency of Heat Loss Reduction in the Intermediate Ladle

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Data on temperature conductivity coefficient measurement of three grades of rice husk ash and synthetic heat-insulating mixture are presented. Results of steel temperature measurement in the intermediate ladle of 6-strand continuous-casting machine when casting under rice husk ash and synthetic heat-insulating mixture are compared. Rice husk ash showed the best heat-insulating ability.

Keywords: CONTINUOUS-CASTING MACHINE, HEAT-INSULATING MIXTURE, STEEL POURING, HEAT LOSS, INTERMEDIATE LADLE

Introduction

The major functional element providing continuous casting process is an intermediate ladle as it helps to make the casting process stable. It is known that intermediate ladle (**Figure 1**) is used for molten metal teeming from a steel-teeming ladle, its homogenization on temperature at the minimum heat losses and distribution on the strands of casting machine with rather equal ferrostatic pressure during ladling. In this case, steel is protected against secondary oxidation in the intermediate ladle [1, 2].

Steel temperature averaging and protection against secondary oxidation become more important when steel teeming on multi-strand continuous-casting machines by long and ultra-long series. Maintenance of steel temperature in the intermediate ladle during pouring taking into account replacement of steel-teeming ladles is rather important in order to keep the teeming process stable. Steel level drops in the intermediate ladle in the process of steel-teeming ladles replacement which essentially changes hydrodynamics of flow motion and creates conditions for mixing cover slag.

One of the main sources of steel heat loss in the intermediate ladle is bath level with developed surface. That is why bath level is encased by special heat-insulating mixtures for heat loss reduction. Selection of heat-insulating mixture is a multipurpose problem which should consider its chemical interaction with lining of intermediate ladle (i.e. increased wear of lining in slag-line area), specific charge, heat-insulating properties, behavior of heat-insulating mixture in time (during teeming), technological properties (heat-insulating mixture should not be a source of non-metallic inclusions in steel and also should prevent secondary oxidation of steel), environmental effect.

At present, highly effective heat-insulating coating on the basis of rice husk ash is widely applied in foreign and domestic practice [3, 4]. It provides stability of steel teeming by long series at the minimum wear of intermediate ladle lining in a slag-line area. The charge of such heat-insulating mixture is 0.22-0.25 kg/t of steel which is several times lower than charge of synthetic heat-insulating mixtures on the basis of coal ash.

There are various compositions of heat-insulating mixture on the basis of rice husk ash (HIM-RHA) which differ by insignificant additions of other vegetative waste (for example, sunflower cake ash, etc.). However, pure rice husk ash provides the best results. During teeming rice husk ash is almost not consumed keeping the properties including low bulk density. Its physical

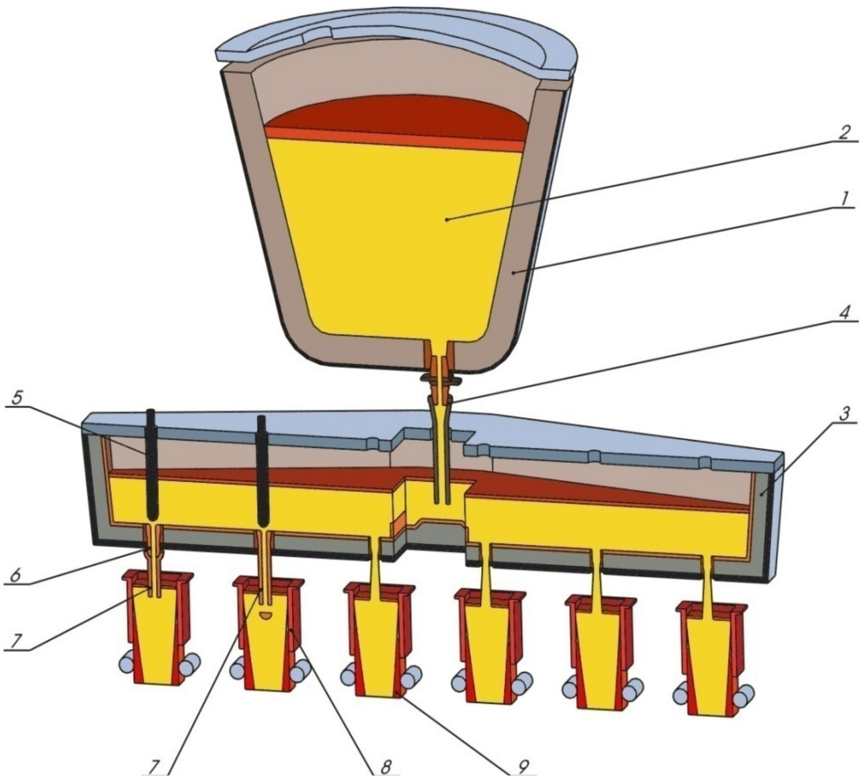

Figure 1. The general view of six-strand continuous-casting machine intermediate ladle when closed jet (left) and open jet (right) pouring: *1* - steel-teeming ladle; *2* - molten metal; *3* - intermediate ladle; *4* - protective pipe; *5* – locking monoblock device; *6* - metering nozzle; *7* - submerged nozzle; *8* - crystallizer; *9* - billet

characteristics almost do not vary as a result of assimilation of non-metallic inclusions, enter of slag from steel-teeming ladle and lining fracture. At the contact with molten steel HIM-RHA forms a liquid film 5-7 mm thick which sharply reduces oxygen and nitrogen absorption by steel. At the same time, this cover absorbs non-metallic inclusions (aluminum oxides) in the molten steel. And not molten part of HIM-RHA is on the surface in the form of friable substance, which provides the maximum thermal insulation effect. It is determined in practice that when using rice husk ash, heat losses are reduced in 1.5-2 times in the intermediate ladle as compared to application of synthetic slag-forming mixes [4].

Meanwhile, the research has shown that technological and operational properties of HIM-RHA could vary significantly depending on supplier. Probably, it should be considered as a result of using rice husk from all over the world [5] and application of various high-heat treatments. Now consumption of rice husk ash in steelmaking is approximately 220-250 thousand tons per year. Primarily, rice husk is exported from USA, countries of South East Asia and India.

Usually, HIM-RHA suppliers do not provide the consumer with information about thermal-physical properties of product but only basic operational characteristics are available which significantly complicates identification of applied material. Accordingly, the purpose of present work is comparison of thermal diffusivity of HIM-RHA used by various suppliers.

Results and Discussion

Metal temperature was changed in the intermediate ladle when using HIM-RHA and synthetic heat-insulating mixture produced in Ukraine for six-strand continuous-casting machine. Teeming was carried out by open jet without application of protective pipe which should be considered as the most uncomfortable conditions for heat-insulating mixture owing to its mixing by dropping jet. Obtained data introduced in **Table 1** testify that HIM-RHA provides more effective operation of intermediate ladle in view of thermal loss minimization. The average temperature drop of steel per melting is 2.5 °C when HIM-RHA pouring and 5 °C when synthetic heat-insulating mix pouring. It is necessary to note that HIM-RHA keeps its heat-insulating properties during all series of pouring (in our case 10 smelting operations). As judged by noninstrumental observation, this can be explained by the fact that upper layer of rice husk ash almost completely keeps the primary properties (low density and flowability) during pouring. At the same time, synthetic heat-insulating mixture gradually mixes with slag losing the operational properties.

Three various products used at metallurgical plants of Ukraine and one synthetic heat-insulating mixture were selected for estimation of HIM-RHA properties (**Table 2**). Thermal diffusivity parameter was accepted as a main criterion of thermal work of HIM-RHA. To determine thermal diffusivity of investigated materials we used the laboratory method [6] based on the solution of differential heat equation for cylinder of infinite length at symmetric heating in relation to its axis:

$$\frac{\partial t}{\partial \tau} = a\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r}\right) \qquad \text{(Eq. 1)}$$

where t – temperature, °C; τ - heating time, s; a – thermal diffusivity, m^2/s; r – distance from cylinder axis, m.

Boundary and initial conditions:

$$t\big|_{r=R} = \varphi(\tau) = t_0 + c\tau; \quad t\big|_{r=0} = F(\tau) = t_0;$$

$$t\big|_{\tau=0} = t_0, \qquad \text{(Eq. 2)}$$

where R – cylinder radius, m; t_0 – cylinder temperature in the initial moment of time, °C; c – rate of temperature change on the cylinder surface, °C/s; τ - heating time, s.

Analytical solution of equation 1 is as follows:

Table 1. Comparison of results of metal temperature measurement in the intermediate ladle of six-strand continuous-casting machine when HIM-RHA and synthetic heat-insulating mixture teeming

Mix grade	No. of ladle	Metal temperature in the ladle, °C	Metal temperature in the intermediate ladle, °C			Metal temperature drop in the intermediate ladle, °C	
			start melting	middle melting	end melting	middle melting	end melting
Feuromat S 35	1	1577	1555	1555	1553	0	2
	2	1570	1548	1546	1543	2	5
	3	1570	1545	1542	1541	3	4
	4	1570	1540	1538	1542	2	2
	5	1570	1538	1539	1538	-1	0
	6	1570	1541	1540	1540	1	1
	7	1570	1541	1542	1540	-1	1
	8	1570	1540	1537	1537	3	3
	9	1571	1540	1537	1537	3	3
	10	1570	1539	1537	1537	2	2
Synthetic heat-insulating mixture	1	1573	1546	1545	1543	1	3
	2	1572	1545	1545	1547	0	-2
	3	1568	1545	1545	1541	0	4
	4	1568	1545	1540	1541	5	4
	5	1570	1543	1540	1538	3	5
	6	1570	1541	1543	1535	-2	6
	7	1570	1539	1541	1535	-2	4
	8	1573	1541	1538	1535	3	6
	9	1572	1538	1538	1536	0	2
	10	1570	1547	1539	1542	8	5
	11	1570	1547	1537	1542	10	5
	12	1572	1545	1537	1529	8	16

Table 2. Chemical composition and specific physical properties of HIM-RHA under investigation

Material grade	Feuromat S 20	Feuromat S 35	Nermat AF	Heat-insulating mixture
Chemical composition:				
SiO_2	89.4	81.6	91.2	38.1
CaO	3.4	3.4	n/a	23.4
MgO	1.8	1.6	1.8	8.9
Fe_2O_3	0.89	0.82	0.5	2.6
Al_2O_3	0.56	0.50	1.5	0.3
MnO	4.1	9.0	2.0	4.2
C	2.2	6.2	4.6	24.2
Na_2O+K_2O	Rest	Rest	Rest	5.2
Sintering temperature, °C	1490-1500	1500	1500	n/a
Melting temperature, °C	1590-1600	1600	1600	n/a
Bulk weight, g/cm^3	0.26-0.30	0.30-0.33	0.20-0.23	0.4-0.5
Granulometric composition, mm	0-2	0-2	< 3	< 1
Country	India	USA	South-East Asia	Ukraine

$$t = t_0 + c\tau + \frac{cR^2}{4a}\left(\frac{r^2}{R^2} - 1\right) + \frac{cR^2}{a}\sum_{n=1}^{\infty}\frac{2}{\mu_n^3 I_1(\mu_n)} I_0\left(\mu_n \frac{r}{R}\right) e^{-\mu_n^2 a\tau / R^2} \qquad \text{(Eq. 3)}$$

where I_0 and I_1 – zero- and first-order Bessel functions; μ_n - roots defining equation $I_0(\mu_n) = 0$.

Solution of equation (1) is as follows for temperature differential between surface and axis of cylinder:

$$\Delta t = \frac{cR^2}{4a} - \frac{cR^2}{a}\sum_{n=1}^{\infty}\frac{2}{\mu_n^3 I_1(\mu_n)} e^{-\mu_n^2 a\tau / R^2} \qquad \text{(Eq. 4)}$$

Thermogram obtained by experimental method presented below was divided into m sections with interval 10 °C in order to determine thermal diffusivity. Heating rate on each section was considered as a constant. In this case, equation (4) is as follows:

$$\Delta t_k = \frac{c_k R^2}{a_k}\left[\frac{1}{4} - \sum_{n=1}^{\infty}\frac{2}{\mu_n^3 I_1(\mu_n)} \exp(-\varepsilon_n^2 a_k \sum_{i=1}^{k}\Delta\tau_i)\right] \qquad \text{(Eq. 5)}$$

where k – number of i-section for which thermal diffusivity is calculated; $\varepsilon_n = \mu_n / R$ - parameter depending on body shape.

Heating rate on k-section was determined by the following method:

$$c_k = \frac{1}{2}\left(\frac{t_k - t_{k-1}}{\Delta\tau_k} + \frac{t_{k+1} - t_k}{\Delta\tau_{k+1}}\right) \qquad \text{(Eq. 6)}$$

where t_k – sample surface temperature in the end of k-section, °C; $\Delta\tau_k$ - heating time of k-section, s.

Data about rate of temperature change on the axis and surface of cylinder are necessary for calculation of thermal diffusivity depending on temperature. A number of laboratory experiments were carried out. Thin-walled alundum crucible with diameter 40 mm and height 150 mm was filled with investigated material. Then two thermocouples VR 5/20 were put in the crucible: in the centre on cylinder axis and on periphery (**Figure 2**). Further the crucible was put in the Tamman furnace heated to 1500 °C. Thermocouple readings were recorded until there was leveling of temperatures on the axis and surface of crucible. Obtained experimental data were used in equations (5) and (6) and processed on the computer in the programming environment Delphi.

Results of calculations are shown in **Figure 3**.

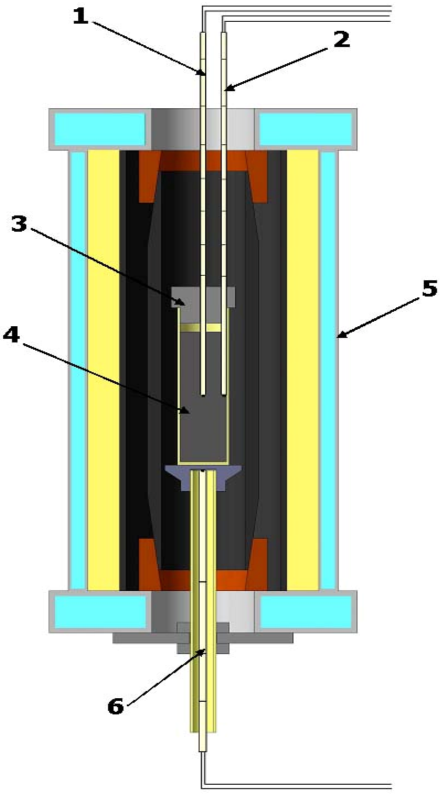

Figure 2. Investigation of thermal diffusivity of heat-insulating material: *1* - thermocouple on cylinder axis; *2* - thermocouple on cylinder surface; *3* - graphitic stopper; *4* - alundum crucible with investigated material; *5* – Tamman furnace; *6* - thermocouple controlling temperature in the furnace

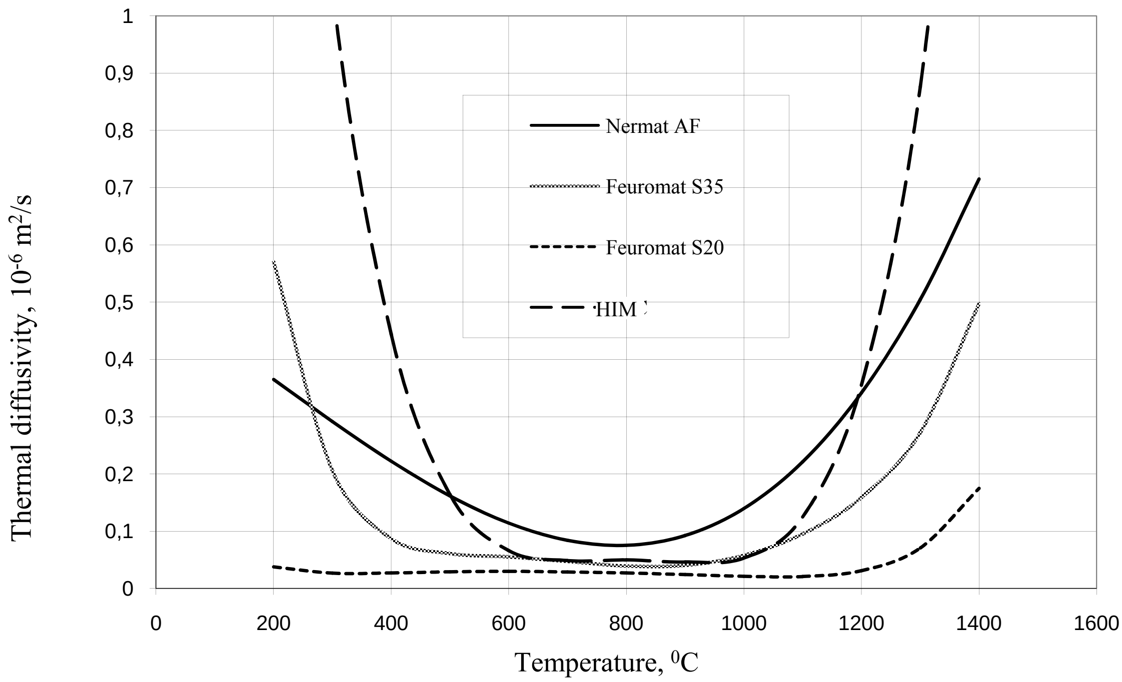

Figure 3. Dependence of thermal diffusivity of rice husk ash and heat-insulating mixture on temperature

It is determined that all tested heat-insulating mixtures have low values of thermal diffusivity that are provided in various temperature ranges. So, the lower temperature range in which thermal diffusivity value is less than $0.1 \cdot 10^{-6}$ m^2/s is observed for Nermat AF (650-920 °C) and synthetic heat-insulating mixture (550-1100 °C). At the same time, HIM Feuromat S35 and Feuromat S20 are featured by the smallest values of thermal diffusivity in the range of temperatures 400-1200 °C which allows considering that these heat-insulating mixtures have the highest operational properties.

Conclusions

Checking the temperature of metal in the intermediate ladle of 6-strand continuous-casting machine when casting with the use of synthetic heat-insulating mixture and rice husk ash, Feuromat S 35 showed the best heat-insulating ability of the latter: the average temperature drop of metal in the intermediate ladle when pouring under Feuromat S 35 is 2.5 °C, and when HIM pouring - 5 °C. Results of thermal diffusivity measurements for three various compositions of rice husk ash and one synthetic heat-insulating mixture show that certain HIM-RHA grades can provide better operational properties than synthetic analogues.

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Эффективность снижения тепловых потерь в промковше

Смирнов А.Н., Подкорытов А.Л., Епишев М.В.

Приведены данные по измерению коэффициента температуропроводности трех марок золы рисовой шелухи и синтетической теплоизолирующей смеси. Сопоставлены результаты замеров температуры стали в промковше 6-ручьевой сортовой МНЛЗ при разливке под золой рисовой шелухи и синтетической ТИС, которые показали лучшую теплоизолирующую способность золы рисовой шелухи.