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New Slag-Forming Mixture for Ladle Treatment of Steel

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Abstract—The components of a slag-forming mixture for the ladle treatment of steel are considered. The ratio of the mixture components is calculated, and the main characteristics and thermophysical properties of the mixture at high temperatures are determined.

Keywords: slag-forming mixture, melting point, viscosity

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Ladle treatment of steel by slag-forming mixture calls for optimal proportions of the components and optimal physicochemical and thermochemical properties of the mixture. Essentially, the slag-forming mixture is a multicomponent fine-grain system with the following functions:

—protection of the steel from secondary oxidation;

—heat insulation of the metal meniscus in the ladle;

—assimilation of the nonmetallic inclusions from the steel;

—prevention of the formation of a slag crust in casting.

The specified properties of the slag-forming mixture include the viscosity, softening temperature, melting point, thermal conductivity, and density. These properties may be regulated by selecting the chemical and phase composition of the mixture. The composition of the slag-forming mixture for the ladle treatment of steel with the necessary properties is selected on the basis of the oxide system Al_2O_3–MnO–SiO_2, taking account of the nonmetallic inclusions formed in the steel on reduction. We know that, for most nonmetallic inclusions, the reaction products are associated with reduction and alloying of the steel; they are mainly oxides of aluminum, silicon, and manganese [1]. Correspondingly, the density of the nonmetallic inclusions is about two or three times less than that of the steel. That facilitates the free circulation of the nonmetallic inclusions with convective fluxes in the metal and their unobstructed entrainment to the metal–slag boundary, where they are partially assimilated by the slag [2]. The effectiveness with which the slag coating assimilates nonmetallic inclusions largely depends on the affinity of the corresponding phases.

On the basis of the composition of the predominant nonmetallic inclusions—oxides of the Al_2O_3–MnO–SiO_2 system—the optimal proportions of the components in the mixture may be calculated. That entails taking the function of each component into account. We propose the following composition: 50% ash from thermoelectric plants (which has heat-insulating and assimilative properties); 45% slag from ferrosilicomanganese production (which improves fusibility and impurity assimilation); and 5% lime (as a binder). The overall composition must ensure that the melting point of the refining component in the mixture, in contact with the steel, is 1300–1450°C (Fig. 1).

The proposed mixture is prepared by mechanical mixing of powder components produced by grinding. Table 1 presents the chemical composition of the initial materials. The fractional composition, mass, and pack-

Table 1. Composition of initial materials (wt %)

Material	SiO_2	Al_2O_3	CaO	MgO	MnO	Fe_2O_3	C	P	P_2O_5	S	CL
Lime*	1.92	0.70	88.8	0.59	–	0.25	1.19	–	–	0.08	7.63
Ash	44.99	24.86	5.88	1.54	2.93	18.03	3.53	–	1.32	0.09	–
Slag	46.06	8.93	21.94	–	22.06	1.43	–	0.027	–	0.26	–

The slag is taken from the lime-roasting shop; the ash is from thermoelectric plants; and the slag derives from ferrosilicomanganese production. Notation: CL, calcination losses.

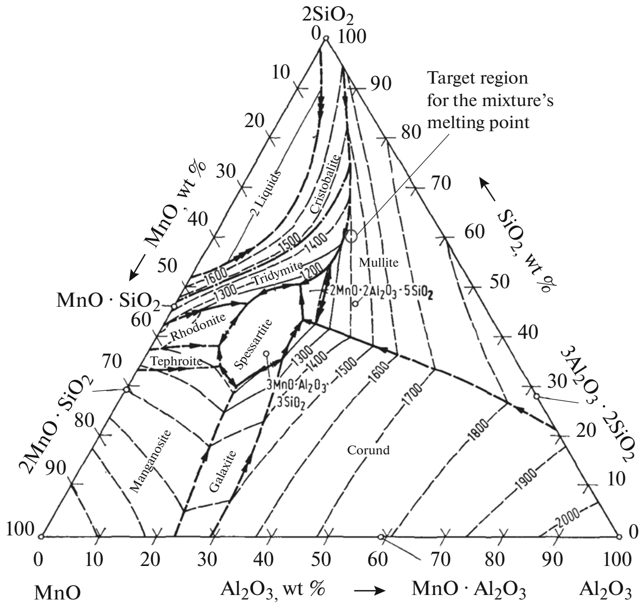

Fig. 1. Target region for the melting point of the proposed slag-forming mixture in an Al_2O_3–MnO–SiO_2 triangle.

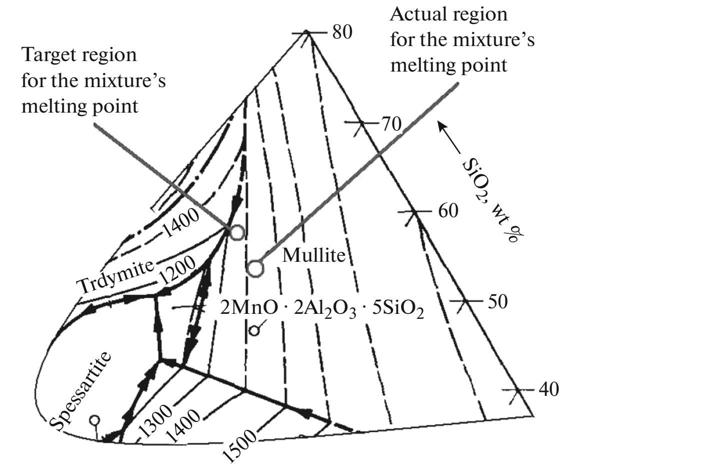

Fig. 2. Actual and target regions for the melting point of the proposed slag-forming mixture. Fragment of an Al_2O_3–MnO–SiO_2 triangle.

ing density are determined by familiar methods. The chemical composition of the proposed slag-forming mixture is as follows: 43.32 wt % SiO_2; 17.25 wt % CaO; 16.48 wt % Al_2O_3; 10.70 wt % MnO; 7.91 wt % Fe_2O_3; 1.49 wt % MgO; 1.82 wt % C; 0.17 wt % S; 0.69 wt % P_2O_5; 0.38 wt % TiO_2. The packing density is 1.178 g/cm^3. The content of the 0.003–0.3 mm fraction is 7.5–10%; the content of the 0.3–1.0 mm fraction is 85–90%.

The density of the slag-forming mixture is determined pycnometrically. A sample is weighed and ground and then placed in a 50-mL pycnometer that has been preliminarily dried and weighed. Alcohol at 20–22°C is added to the specified level marker, the lid is closed, and the pycnometer is again weighed. Measures are taken to prevent air bubbles in the pycnometer. The experiments show that the density of the mixture is 2.2 g/cm^3.

To determine the thermophysical properties of the mixture, we estimate the softening temperature and melting point of the mixture, its thermal conductivity, and its viscosity. The thermal conductivity of the proposed slag-forming mixture is determined by means of a heating element, a tube, and a metallic cylinder. The heating element is placed in the tube and the tube is placed in the cylinder. Slag-forming mixture is introduced in the gap between the tube and cylinder. A Cr–Re thermocouple is used to measure the temperature difference. The thermal conductivity is found to be 2.5–3.0 W/m K.

The melting point is determined by high-temperature experiments in a Tamman furnace. The proposed slag-forming mixture is placed in a crucible, which is then introduced in the furnace. The mixture is melted and cooled in the furnace. The composition of the remelted sample of slag-forming mixture is as follows: 15.52 wt % CaO; 46.95 wt % SiO_2; 25.59 wt % Al_2O_3; 8.20 wt % MnO; 2.42 wt % MgO; 1.67 wt % Fe_{tot}; 0.050 wt %n P_2O_3; 0.70 wt % K_2O; 9.39 wt % Na_2O; 0.22 wt % S; 0.122 wt % C. According to X-ray phase analysis, the sample consists of a complex glass, without crystalline structure.

The considerable decrease in Fe, Mn, and C content in the remelted sample is due to the reduction of Fe and Mn from their oxides as a result of reaction with carbon. Metals beads are formed at the bottom of the crucible, with the following composition: 1.18 wt % Mn; 81.19% Fe; 1.41 wt % Si.

In the high-temperature experiments, we find that the softening temperature of the proposed slag-forming mixture is 1160°C. The temperature of total melting is 1480°C. As we see in Fig. 2, the actual temperature of total melting is 40–100°C higher than the calculated value. That may be explained by the changes in the phase composition on melting. However, these changes do not interfere with the basic functions of the mixture.

We determine the viscosity of the molten slag-forming mixture by vibrational viscosimetry: specifically, the changes in the forced vibrations of a spindle immersed in the liquid are determined [3]. The viscosity is measured at intervals of 30–40°C from the instant of complete melting of the mixture to its complete cooling. We conclude from the experimental results (Fig. 3) that, in the temperature range corresponding to the ladle treatment of steel and subsequent casting (1530–1580°C), the proposed slag-forming mixture is sufficiently liquid for effective assimilation of the ascending nonmetallic inclusions.

The results confirm that the proposed slag-forming mixture may be used in the ladle treatment of steel.

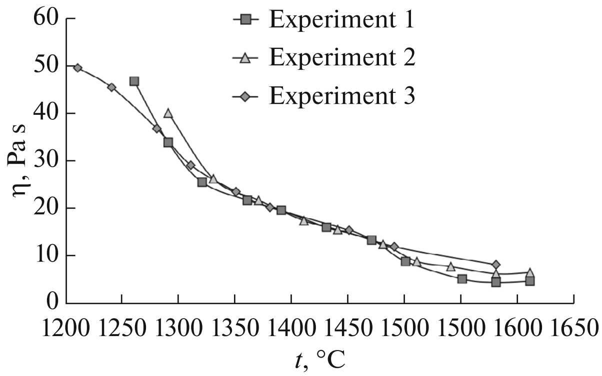

Fig. 3. Temperature dependence of the viscosity for the proposed slag-forming mixture.

With a melting point close to the temperature of the liquid steel and strong affinity for the nonmetallic inclusions formed on treatment of the steel, the slag-forming mixture will melt at contact with the liquid metal and absorb the inclusions.

In addition, the layer of molten mixture protects against secondary oxidation of the steel by atmospheric oxygen. The upper layer of mixture does not melt and forms a highly porous covering that effectively decreases heat losses from the steel surface.

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