Mathematical modelling of the process of melting alloys of the Si-Cr-Ni-Fe system in the iron-carbon melt

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Mathematical modelling of the process of melting alloys of the Si-Cr-Ni-Fe system in the iron-carbon melt

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Abstract. The process of melting of the Si-Cr-Ni-Fe ferroalloys in the iron-carbon melt under static conditions was studied using the method of mathematical modelling. It was found that the melting process takes place in three stages. The effect of silicon concentration and the initial size of a piece of alloy on the duration of each stage of alloy melting is revealed. It was shown that an increase in the silicon content from 6 to 40 % in the complex ferroalloy of the 50 mm fraction containing ~ 27 % Cr and ~ 12 % Ni leads to a decrease in the total melting time of the alloys from 67 to 30 seconds at the iron-carbon melt temperature of 1600 ºC.

1. Introduction

In recent years the production of corrosion-resistant chromium-nickel steels has significantly increased in the world [1, 2]. In Russia electrolytic nickel is mainly used for smelting of such steels, the high price of which doesn't promote the development of steelmaking [3]. At the same time there is a shortage of relatively cheap complex nickel ferroalloys in Russia [4, 5]. The development and application of this type of ferroalloys requires awareness of their physicochemical properties [6–8]. One of the most important properties of the alloy intended for alloying steel is the melting time and dissolution in the iron-carbon melt that determines both the recovery and distribution of the principal alloying elements of the ferroalloy in the metal volume [9]. The melting mechanism of alloys is a fundamental factor determining the time of its melting in an iron-carbon melt. Extensive research has been carried out in this area by both domestic [10, 11] and foreign [12–14] metallurgists.

2. Materials and methods

In this work to study the melting process of complex nickel-containing alloys in an iron-carbon melt a mathematical model for calculating the melting time developed by scientists of the Ural Federal University and the IMET Ural Branch of the Russian Academy of Sciences was used. The model includes hydrodynamic and thermal parts. The thermal part of the model is based on the classification of ferroalloys depending on the ratio of their liquidus temperatures (T_l), bath temperatures (T_b) and crystallization temperatures of the iron-carbon melt (T_{cm}). Thus the ferroalloys are divided into low melting ($T_l \le T_{cm}$), high melting ($T_{cm} < T_l < T_b$) and ultra-high melting ($T_l \ge T_b$).

The samples of complex alloys of the Si-Cr-Ni-Fe system, corresponding in composition to ferroalloys that may be smelt from domestic mineral raw materials, were selected for the study [15, 16] (table 1).

Table 1. Chemical composition of ferroalloys.

	Content[a] (%)		
No.	Si	Ni	Cr
1	5.8	12.2	27.4
2	13.0	11.9	28.8
3	20.4	12.1	26.3
4	40.1	11.7	25.5

[a] ~ 0.2 % C, Fe – the rest.

3. Results and discussion

The simulation results are presented in figures 1, 2.

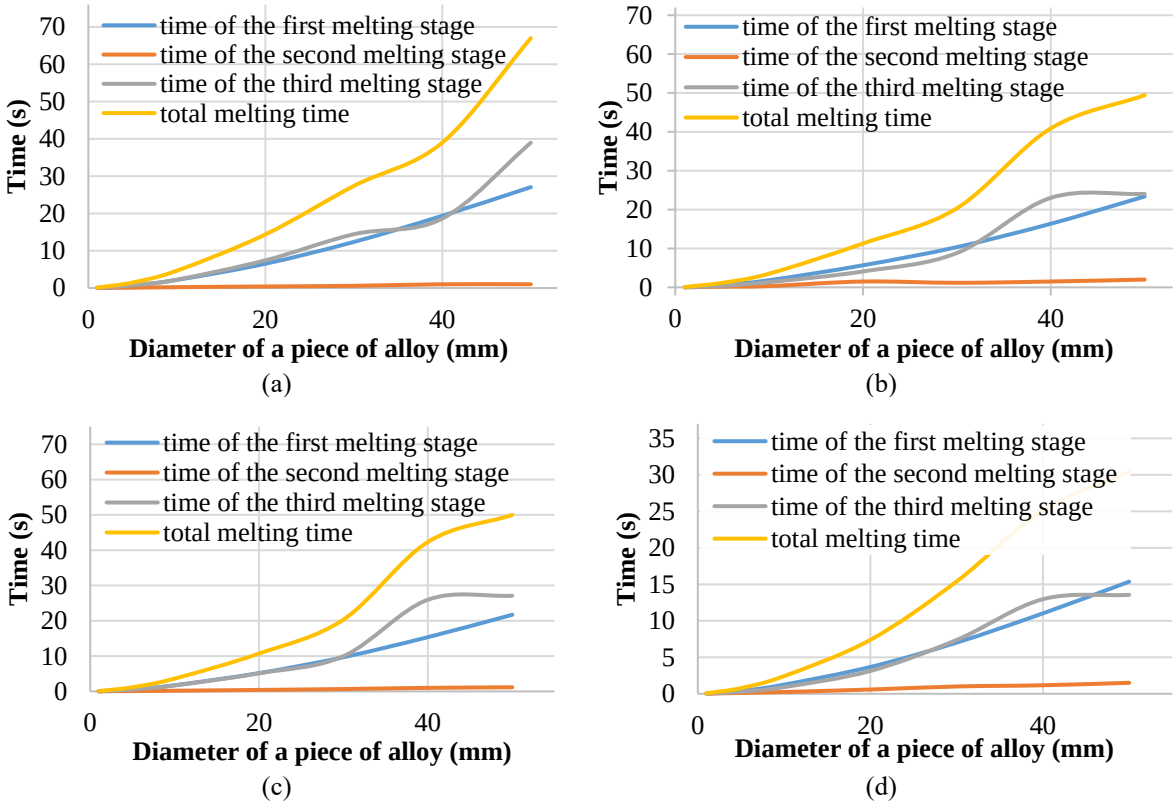

Figure 1. Dependence of the melting time of nickel-containing ferroalloys on the fractional composition at T_b = 1600 °C by melting stage: (a) – alloy 1; (b) – alloy 2; (c) – alloy 3; (d) – alloy 4.

In the calculations it was assumed that $T_{cm} = 1530\,°C$, the initial temperature of the ferroalloy $T_0 = 25\,°C$ and the temperature of the bath of the iron-carbon melt is 1600 °C. The physicochemical properties of the ferroalloys were taken from the calculated [17] and previously obtained experimental data [18]. Under real conditions the initial temperature of a piece of ferroalloy is always lower than the

crystallization temperature of steel, therefore at first a crust of solid steel is formed on its surface. The thermal part of the model includes Fourier differential heat condition equation for each of the phases (crust, solid core, liquid layer of the ferroalloy) and boundary conditions determined by convective heat transfer and the melting process.

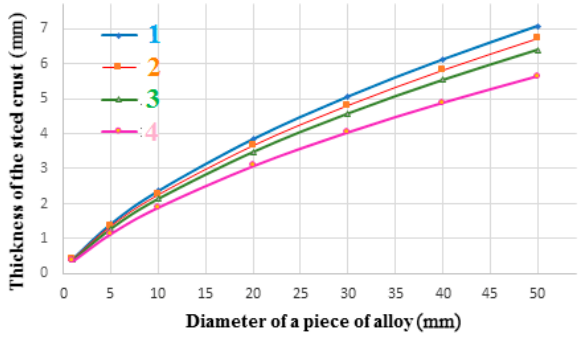

Figure 2. Dependence of the thickness of the solidified steel crust on the fractional composition of the ferroalloy at T_b = 1600 °C (the numbers of the curves correspond to the numbers of alloys in the table 1).

All considered alloys belong to the group of low melting ferroalloys in which $T_l \leq T_{cm}$. The process of their melting in the iron-carbon melt takes place in three stages. During the first stage the ferroalloy warms up, and when the surface temperature reaches T it begins to melt. Pieces of ferroalloy in this case are in the shell of solid steel, the thickness of which increases at the beginning of the stage and decreases towards the end. In the second stage the ferroalloy melts under the crust of solid steel due to the heat coming from the iron-carbon melt. It ends with the complete melting of the solid shell and the contact of the not melted but rather heated part of the piece of ferroalloy with liquid steel. The longer the first stage lasts the more intensely the crust of the solidified steel warms up and the bigger part of it melts thereby reducing the duration of the second stage. For all studied alloys the second stage is the shortest (no more than 5 % of the total melting time for a fraction of 50 mm). In the third stage a solid piece of ferroalloy melts directly contacting with liquid steel.

The influence of the initial size of the piece is unambiguous. With diameter decreasing, the total melting time is reducing (figure 1). With a decrease in ferroalloy fineness by a factor of 50, the total melting time decreases by a factor of 500–600.

An increase in the Si content from 6 to 40 % in the considered alloys leads to a decrease in the total melting time from 67 to 30 s (figure 1) and to a reduction in the thickness of the solidified steel crust from 7.1 to 5.6 mm (figure 2) with an initial ferroalloy diameter of 50 mm. This is due to the dependence of the thermophysical characteristics of the ferroalloys under study on the silicon concentration. In general, alloys of the Si-Cr-Ni-Fe system are characterized by a much faster melting process in steel compared to standard ferrochrome and ferronickel [9].

4. Conclusions

The process of melting ferroalloys of the Si-Cr-Ni-Fe system in an iron-carbon melt under static conditions was studied by mathematical modelling. It was revealed that the melting process proceeds in three stages. It was shown that an increase in the silicon content from 6 to 40 % in the complex ferroalloy of the 50 mm fraction containing ~ 27 % Cr and ~ 12 % Ni leads to a decrease in the total melting time of alloys from 67 to 30 sec at the temperature of iron-carbon melt of 1600 ºC. In general, alloys of the Si-Cr-Ni-Fe system are characterized by a much faster melting process in steel compared to standard ferrochrome and ferronickel.

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