

Conference Paper

Simulation of the Melting Process for Complex Nickel-containing Ferroalloys in Steel

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Abstract

In this study, the melting process simulation for the complex nickel-, silicon-containing ferroalloys in a steel melt was performed. For the study, complex ferroalloys samples (~ 10% Ni, 5–56% Si) were selected, by composition corresponding to the alloys, which can be smelted from poor Russian oxidized nickel ores. It is shown that all the alloys under consideration belong to the group of low-melting ferroalloys, in which the liquidus temperature (T_l) does not exceed the crystallization of the iron–carbon melt (T_{cm}). The process of their melting in an iron–carbon melt takes place in three periods. During the first period, the ferroalloy warms up and when the surface temperature reaches T_l , it begins to melt. In this case, ferroalloy pieces are in the shell of solid steel, the thickness of which increases at the beginning of the period and decreases toward the end. It was revealed that an increase in the fraction of all the alloys under consideration from 1 to 50 mm leads to a stable increase in the melting time (τ). It is shown that increasing the silicon concentration from 5 to 18% reduces τ , a further growth of the Si content up to 31%, on the contrary, is accompanied by an increase of τ in the alloys, and a subsequent increase in Si to 53% leads to a gradual reduction of τ . In general, complex nickel-, silicon-containing ferroalloys are characterized by a much faster melting process course in steel compared to ferronickel.

Keywords: metallurgy, ferroalloys, steel, melting time, thermophysical properties

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1. Introduction

One of the nickel industry problems in our country is a sharp decrease in the extraction and processing of oxidized nickel ores (ONO). In 2010 ores of four deposits were developed and the nickel share from the ONO in Russian production reached 10% but in recent years mining operations have been carried out on only one deposit, and production does not exceed 5% [1]. The current situation is mainly due to the lack of profitable technologies for the extraction and processing of oxidized nickel ores. At the same time,

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in recent years, the production of nickel-containing alloys and steels has significantly increased in the world. In Russia, electrolytic nickel (~ 99% Ni) is mainly used for their smelting, the high price of which does not contribute to the development of the production of nickel-containing steels [2]. At the same time, in our country, there is a shortage of relatively cheap nickel and complex ferroalloys containing 10–30% Ni [3, 4], which can be produced from domestic ONO [5, 6]. At present, a number of methods have been developed [7], which make it possible to efficiently process poor oxidized nickel ores with the production of new types of ferroalloys [8, 9], however, such alloys are still in low demand in steelmaking. To use new ferroalloys in the processing of steel, it is necessary to know their physicochemical characteristics. One of the most important characteristics of the alloy intended for steel alloying is the time of its melting and dissolution in the iron–carbon melt [10], on which depend both the absorption and the distribution of the leading elements of the ferroalloy in the metal volume [11, 12]. The mechanism of alloys melting is a fundamental factor determining the time of its melting in an iron–carbon melt [13]. Extensive research was conducted in this area by both domestic [11, 14, 15] and foreign [12, 16–21] metallurgists.

In this work, to study the melting process of complex nickel-containing alloys in an iron–carbon melt, we used a mathematical model for calculating the melting time developed by scientists of UrFU and IMET UB RAS. The model includes hydrodynamic and thermal parts. The hydrodynamic part of the model determines the speed of ferroalloys movement in relation to the melt of the processed metal, considering the forces acting on the alloys at each time point. The thermal part of the model is based on the classification of ferroalloys depending on the ratio of their liquidus temperature (T_l), bath temperature (T_b) and crystallization of the iron–carbon melt (T_{cm}) into low-melting ($T_l \leq T_{cm}$); refractory ($T_{cm} < T_l < T_b$) and ultra-refractory ($T_l \geq T_b$). The course of the melting process is mainly determined by the temperatures ratio of T_l , T_{cm} , T_b .

For the study, there were selected samples of complex nickel-containing ferroalloys with a composition corresponding to the alloys that can be smelted from domestic oxidized nickel ores [22, 23]. The chemical composition of the samples and their thermo-physical properties are presented in the table.

The simulation results are presented in Figures 1–3¹. In the calculations, it was assumed that $T_{cm} = 1530^\circ\text{C}$, the initial temperature of the ferroalloy $T_0 = 25^\circ\text{C}$, the temperature of the iron–carbon melt bath is 1600°C ; crystallization heat $L = 1,79 \cdot 10^9 \text{ J/m}^3$, thermal conductivity coefficient of steel in the liquid state $\lambda = 30 \text{ W/m K}$ [24]. In real conditions, the initial temperature of a ferroalloy piece is always lower than the temperature of steel crystallization, and therefore a crust of solid steel [25] is formed

TABLE 1: Chemical composition and thermophysical properties of ferroalloys at a temperature of 25°C.

№.	Composition*, %		Liquidus temperature, °C	Thermal conductivity, W/(m.K)	Specific heat capacity, J/(kg.K)	Density, kg/m ³
	Si	Ni				
1	5.1	10.3	1420	84	463	7420
2	17.5	10.6	1220	93	496	6810
3	31.4	10.0	1340	102	532	6190
4	55.8	11.7	1210	119	596	4870

Note: * Fe – the rest.

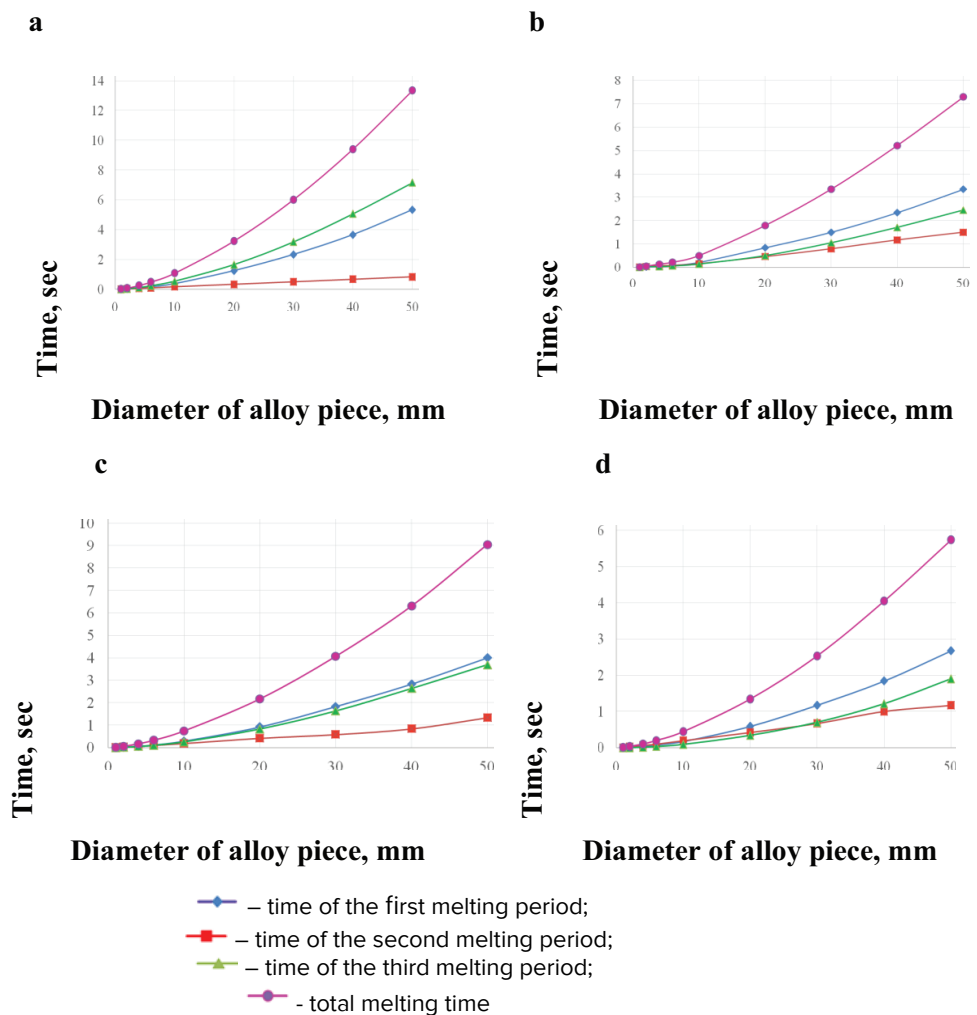


Figure 1: Dependence of the melting time for the periods of melting for nickel-containing ferroalloys on their fractional composition at $T_b = 1600^\circ\text{C}$: a – alloy 1; b – alloy 2; c – alloy 3; d – alloy 4 (table).

on its surface. The following notation for the melting time is taken: τ_1, τ_2, τ_3 are the duration of individual periods, τ is the total melting time. The thermal part of the model includes the differential Fourier thermal conductivity equation for each of the phases (crust, solid core, liquid ferroalloy layer), the number of which depends on the process

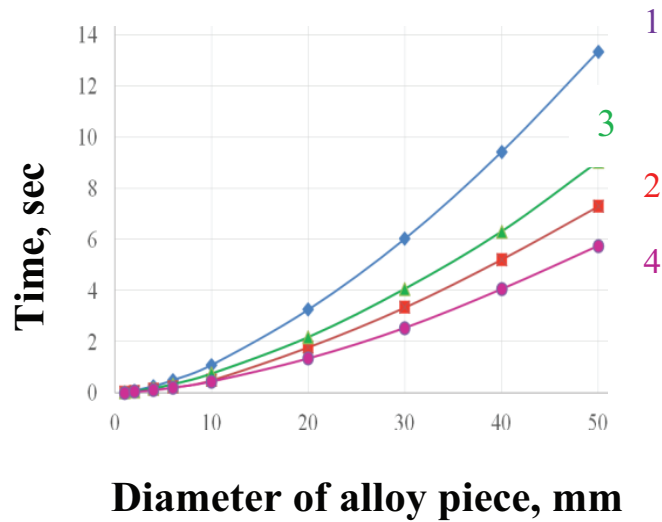


Figure 2: Dependence of the melting time for ferroalloys on the fractional compositions at $T_b = 1600^\circ\text{C}$; Curves numbers according to the alloys compositions in the Table.

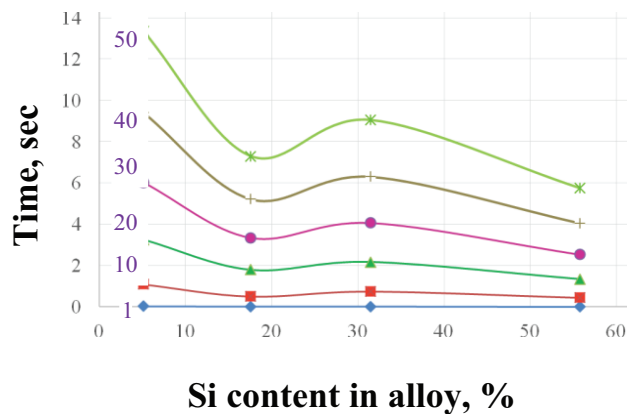


Figure 3: Dependence of the melting time for ferroalloys on the Si composition for different fractions at $T_b = 1600^\circ\text{C}$; Numbers of curves equal to alloy fractions, mm.

period and the type of ferroalloy, and the boundary conditions determined by convective heat transfer and melting process.

All the alloys under consideration belong to the group of low-melting ferroalloys (see table), in which $T_l \leq T_{cm}$. The process of their melting in an iron-carbon melt takes place in three periods. During the first period (Figure 1, τ_1), the ferroalloy warms up and when the surface temperature reaches T_l , it begins to melt. In this case, pieces of ferroalloy are in the shell of solid steel, the thickness of which increases at the beginning of the period and decreases towards the end. The mass of the alloy piece at the beginning of the first melting period increases relatively quickly due to a significant temperature gradient at the boundary of the frozen crust with the alloy, then this process gradually slows down as it approaches the point T_{cm} where crystallization begins and completely stops when reaching this point.

In the second period (Figure 1, τ_2), the ferroalloy melts under a 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 with the contacting of the not melted, but sufficiently heated part of the ferroalloy piece with the liquid steel. The longer the first period, the more the crust of the freeze steel is heated and partially melted, which leads to the reduction of the second period share in the total melting time. For the studied alloys of all fractions, the second period is the least long, it takes no more than 20% of the total melting time.

In the third period (Figure 1, τ_3), the solid piece of ferrosilicon nickel is melted, directly contacting with liquid steel. Theoretically, in periods 1, 2 there is no direct contact of the ferroalloy with liquid steel. Therefore, the interaction between the ferroalloy and the liquid metal (deoxidation reactions, mass transfer, etc.) is absent. The process of ferroalloy melting accelerates its movement in the iron–carbon melt.

The influence of the initial piece size is unambiguous: with increasing diameter, the total melting time increases (Figure 2). With an increase in the ferroalloy size up to 50 times (from 1 to 50 mm), the total melting time increases up to 450–1800 times.

An increase in the Si content from 5 to 18% in the considered alloys leads to a decrease in the melting time (Figure 3), a further increase in the Si concentration to 31%, on the contrary, is accompanied by an increase in the melting time of the alloys, and a subsequent increase in Si to 53% leads to a smooth decrease of τ . This is related to the liquidus temperatures values of the corresponding alloys (Table) and the possible formation in the region for silicon concentration of 17–23% for low–melting Fe_3Si and Fe_5Si_3 phases, characterized by a low liquidus temperature of 1261°C [26, 27]. It should be noted that the effect of the silicon concentration in the alloy on the total melting time increases significantly with increasing of ferroalloys fractional composition.

2. Conclusion

Thus, the work studied the melting kinetics of complex nickel–, silicon–containing ferroalloys in a steel melt. It is shown that an increase in the fraction of all the alloys under consideration from 1 to 50 mm leads to a stable increase in the melting time, and an increase in the silicon concentration from 5 to 18% reduces τ , a further increase in the Si content to 31%, on the contrary, is accompanied by an increase in τ of alloys, a following increase of Si content to 53% leads to a gradual reduction of τ . In general, complex nickel–, silicon–containing ferroalloys are characterized by a much faster course of the melting process in steel compared to ferronickel.

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