

## Conference Paper

# Manufacturing and Application of Complex Ferroalloys

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## Abstract

The tightening of requirements for the quality of steel, a change in the composition of raw materials requires the release of more efficient ferroalloys of the new generation, suitable for progressive steel production processes. Such products include complex ferroalloys containing, in addition to iron, two or more functional elements. Complex ferroalloys should be created in the most favorable combination of components, contributing to the necessary effective impact on the quality of the metal being processed, with a high degree of assimilation of useful elements in it. Changes in the characteristics of complex ferroalloy, affecting the assimilation of target (basic) elements, should be carried out by regulating the composition and ratio of elements that can be included in almost any ferroalloy, since they are part of all steels and cast irons or they're required by the conditions of their smelting. Firstly, these elements should include silicon and manganese. Silicon can reduce the melting temperature, density, and melting time of ferroalloy in the liquid metal. For example, the addition of 1% silicon to low-carbon ferrochrome can reduce the melting point of the alloy by 8–9 degrees. Compositions of new complex ferroalloys of systems Fe-Si-Ca-Ba, Fe-Si-B, Fe-Si-Al-Nb, Fe-Si-Mn-V have been successfully tested and introduced into production.

**Keywords:** metallurgy, ferroalloy, melting, density, physical and chemical properties, steel

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## 1. Introduction

Ferroalloy production is closely related to consumers of products - steel smelting [1, 2], cast iron [3] and non-ferrous metals. The volume of steel production determines the scale of production of ferroalloys.

In 2000, the world produced 800 million tons of steel and 18 million tons of various ferroalloys, and in 2017, 1670 and ~ 40 million tons, respectively.

Improving the quality of the metal has always been the most important task for world metallurgy. Quality improvement issues have become even more important recently. For the next 4-8 years around the world, including Russia, the tasks are set to increase the strength and ductility properties of steel by 50-60%, some new, previously not existing

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requirements (for example, corrosion resistance of steel) have appeared, and besides, generally not by one property requirement, but on a complex of properties of metal.

Since one of the main methods of influencing properties of steel and cast iron traditionally remains the treatment of liquid metal with ferroalloys, the toughening of steel quality requirements leads to an increase in the output of alloyed grades and, consequently, to an increase in specific consumption of ferroalloys. The average global consumption of all ferroalloys per unit of steel in 2001 was 22.5 kg/t, and in 2015 already ~ 30 kg/t.

Main products of ferroalloy plants are standard ferroalloys, which often don't have all the necessary service characteristics and are unsuitable for processing metal in the ladle, and the developing advanced technology of steelmaking has to adapt to the existing range of ferroalloys, standards that were not updated for 50 or more years. This leads to the technology complication, reduces productivity of steel production and product quality.

In addition, recently, the sources and markets of ferroalloy raw materials have changed, its quality and the content of leading elements have decreased, which makes it difficult or impossible to get ferroalloys by existing standards.

In this connection, there is the need to release more efficient ferroalloys of the new generation, suitable for new processes in the developing fields of ferrous and non-ferrous metallurgy, smelted from new types of domestic ore raw materials.

First of all, these include the so-called complex or multicomponent ferroalloys containing, in addition to iron, two or more functional elements.

Complex ferroalloys (CF) should be created in the most favorable combination of components, contributing to the necessary effective impact on the quality of the metal being processed, with a high degree of assimilation of useful elements in it [4].

All elements included in the CF, can be divided into the following groups:

1. Target (basic) elements, whose content in the alloy is determined by the tasks of steel processing, its composition (these are Cr, Mn, Nb, V, etc.).
2. Elements that can be part of almost any ferroalloys, as they are in the composition of all steels and cast irons or these elements are required by conditions of their smelting (Fe, Mn, Si).
3. Elements that have a positive effect on steel and cast iron (modification, etc.) remaining in small quantities in the processed metal due to their low solubility or transition to slag (Ca, Ba, Mg).

4. Harmful elements whose content in steel and ferroalloys is limited (S, P, non-ferrous metals).

By picking up target and related elements of the alloy its rational composition can be determined, that ensures high and stable assimilation of useful elements, rapid dissolution and their uniform distribution in the whole volume of the melt.

To determine the characteristics and rational composition of CF the scientific team of IMET UB RAS has developed a complex scheme which includes the following stages: - preliminary selection of elements in the alloy in accordance with the structure and specified properties of metals; - determination of the efficient ratio of elements based on the study of the physicochemical properties of alloys and characteristics of their interaction with the processed melt.

The physicochemical characteristics of the alloys that are responsible for the assimilation of elements in the liquid metal and its quality [5, 6] are studied: the temperature of the beginning and ending of melting; ferroalloy density; the kinetics of its oxidation; the number and shape of resulting non-metallic inclusions in the processed melt; thermal effect of CF interaction with iron-carbon melt; the duration of the ferroalloy melting and its thermal characteristics.

When creating a CF, it was taken into account that in its composition there should be, in addition to the target elements (group 1), also elements of group 2, which favorably influence performance characteristics of ferroalloys, contributing to an increase in the absorption of its components by steel.

These elements include silicon, the most widely used in CF. Suffice it to say that silicon is part of the world's most mass ferroalloy - ferrosilicon manganese [7, 8]. It currently produces about 1/3 of the total assortment of ferroalloys (Figure 1) [9].

Silicon has a beneficial effect on such important characteristics of a ferroalloy as melting point, density, and time of swimming in the liquid metal.

We have conducted experiments on the effect of silicon on the characteristics of low carbon ferrochrome (Table 1) [10, 11].

Figure 2 shows the dependence of the density, temperature and melting time of ferrochrome on the content of silicon in it. These figures show that silicon has a significant impact on all of the alloys characteristics. Silicon exposure is especially significant in the range up to 10% (melting point can drop to 200°C).

The effect of silicon on ferroalloys properties can be observed by other types of alloys. Table 2 shows the effect of silicon on the liquidus temperature and density of the Fe-Si-B complex alloy

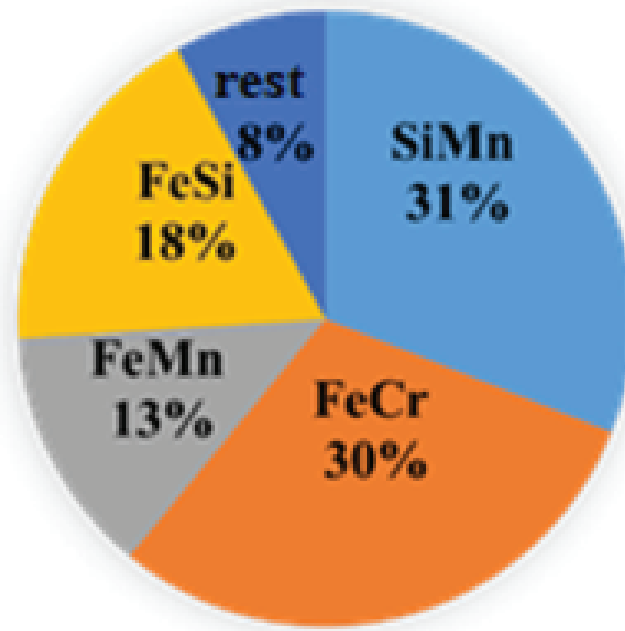


Figure 1: The world structure of ferroalloys production.

TABLE 1: Chemical composition of ferrochrome \*, %.

Alloy N <sup>o</sup> .	Cr	Fe	Si
1	64,6	34,8	0,5
2	64,8	32,8	5,3
3	57,8	32,1	10,0
4	51,4	29,8	18,7
5	46,2	27,2	26,5
6	41,9	25,7	32,3
7	35,6	22,3	42,0
8	29,2	17,1	53,6

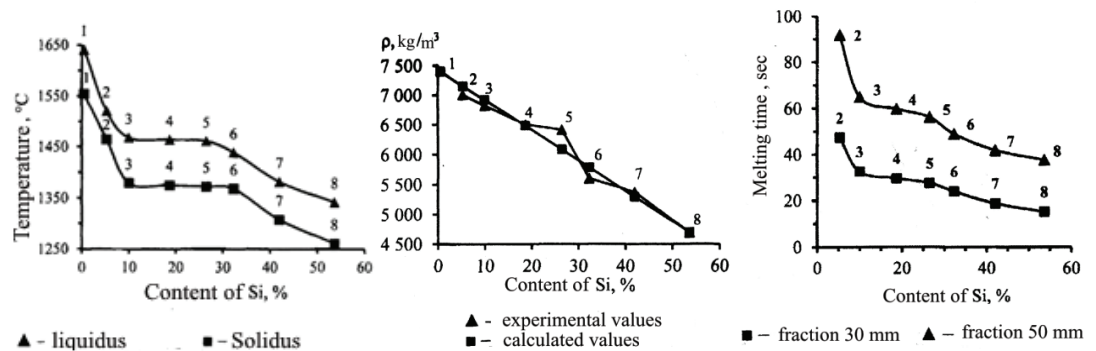
Note: \*Carbon content, 0,1 %.

TABLE 2: Composition and physico-chemical properties of ferrosilicoboron.

B	Content,%*		T liquidus, °C	Density, kg/m <sup>3</sup>	B	Content,%*		T liquidus, °C	Density, kg/m <sup>3</sup>
	Si					Si			
1	-		1460	7800	5	-		1430	7550
1	24,7		1395	6200	5	23,7		1418	6000
1	44,5		1275	5520	5	42,7		1350	5340
1	74,2		1258	3820	5	71,2		1273	3530

Not: \*other is Fe.

The effect of silicon on the reduction of the melting temperature of refractory ferroalloys is quite significant. So, for ferrotungsten containing 70-80% W, the melting start



**Figure 2:** Dependence of characteristics of ferrochrome on the content of silicon in it. The numbers in the figure correspond to the numbers in Table 1. a - dependence of the melting point; b - dependence of the density value; c - dependence of the melting time of ferroalloy in steel.

temperature is  $\sim 2000^{\circ}\text{C}$ , the density is  $15500 \text{ kg/m}^3$ ; when it contains 5% Si, the characteristics are improved to  $1920^{\circ}\text{C}$  and  $13000 \text{ kg/m}^3$ , and at 12% Si to  $1720^{\circ}\text{C}$  and  $11000 \text{ kg/m}^3$ , respectively [12].

Manganese affects the melting point to a lesser extent than silicon. So for low-carbon ferrochrome (0.1% C; 34-44% Cr) an increase in the manganese content from 12 to 31% reduced the liquidus temperature by only 48 degrees (from  $1359$  to  $1311^{\circ}\text{C}$ ).

It should be noted that lower quality ore raw materials can be used to produce complex ferroalloys than for smelting standard alloys, for example, substandard materials, production waste, poor and complex ores and concentrates. This is due to the fact that in the composition of the CF there are small concentrations of the leading elements in comparison to the composition of standard grades of ferroalloys (10-40, not 60-90%). Due to the low price of unconventional raw materials, the possibility of its use and disposal, the cost of CF will be lower, and there appears a new raw material base of ferroalloy production.

The practice of CF production has shown that due to more flexible regulation of the technological parameters of smelting process, for example, the composition and melting point of the slag, softening and electrical resistance of the charge, it is possible to produce alloys in melting units with higher technical and economic indicators.

The negative side of complex ferroalloys is the loss of their universalism due to the increase in the number of components. At the same time, the use of CF allows to reduce the number of different types of ferroalloys used in the steel melt.

Practicing the developed method of designing the composition of CF using non-traditional raw materials, melting technologies were developed and various complex

ferroalloys of several systems (Fe-Si-Ba-Ca, Fe-Si-B, Fe-Si-Al-Nb, Fe-Si -Ca-Mg, Fe-Si-V-Ca-Mn, Fe-Si-Al) were obtained on an industrial scale. Patents for inventions were obtained for compositions and technology for producing several alloys [13, 14].

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