A. Z. ISSAGULOV, SV. S. KVON, V. Y. KULIKOV, N. B. AITBAYEV

ISSN 0543-5846
METABK 55(3) 388-390 (2016)
UDC – UDK 669.14.018.620.17:669.15.782.893:620.18.17=111

STUDYING MICROSTRUCTURE OF HEAT RESISTANT STEEL DEOXIDIZED BY BARIUM FERROSILICON

Received – Primljeno: 2015-08-14
Accepted – Prihvaćeno: 2016-01-10
Preliminary Note – Prethodno priopćenje

The paper examined the nature and distribution of non-metallic inclusions in the heat-resistant steel 12H1MF (0,12 % C, 1 % Cr, 0,5 - 0,6 Mo, 0,5 % V), ferrosilicobarim. As a reference, used by steel, deoxidized silicon. Melting was carried out in a laboratory, research-metallic inclusions, their shape and distribution, pollution index were studied according to conventional methods. Studies have shown that ferrosilicobarim deoxidation in an amount of 0,1 - 0,2 %, reduce the overall pollution index of non-metallic inclusions and change the nature of their distribution.

Key words: heat-resistant steels, ferrosilicobarim, microstructure, mechanical, properties

INTRODUCTION

In recent years, modification and alloying of steel by calcium-containing and barium-containing alloys have been very popular both abroad and in Kazakhstan [1]. Calcium alloys are used extensively and for a long time whereas an effect of barium alloy on the properties and microstructure of steel is insufficiently studied.

Kazakhstan possesses sufficient reserves of barite ores that by properties, chemical composition and amount can serve as a reliable base for commercial manufacture of barite alloys.

Comparison of physicochemical properties of calcium and barium suggests that the effect of barium on liquid metal should be more efficient and, hence, its effect on formation of microstructure and alloy properties after crystallization should be stronger [1,2].

Analysis of the causes of failure of parts made of heat-resistant steels shows that one of the major factors affecting the properties is the concentration of detrimental impurities, both dissolved in the steel and those in the form of non-metallic inclusions.

Alkaline earth metals and rare earth metals are widely used as components of high refining properties that help to control the nature, shape and distribution of non-metallic inclusions.

Nonmetallic inclusions result from a number of physicochemical phenomena occurring in molten and solidifying metal during the production process. To a greater or lesser extent, inclusions exist in any steel according to its composition and production conditions. The amount of non-metallic inclusions in steel typically is not more than 0,1 %. However, due to its small size the number of inclusions in general is very large.

A.Z. Issagulov, Sv.S. Kvon, V.Y. Kulikov, N.B. Aitbayev Karaganda State Technical University, Karaganda, Kazakhstan

Non-metallic inclusions in steel are foreign bodies disturbing homogeneity of its structure, so its impact on mechanical and other properties can be significant. Obviously, these are heat-resistant properties that are the main indicator of quality of heat-resistant steel, yet, however, we should bear in mind other mechanical properties, especially such an important indicator of plasticity as toughness. Meanwhile, it is size, shape, nature, and the location of non-metallic inclusions that exert a decisive influence on this parameter.

EXPERIMENTAL PART

The main objective of the work is studying the impact of introduction of barium ferrosilicon on metallurgical quality of the steel, in particular on the number and distribution of non-metallic inclusions.

Barium ferrosilicon is a ferroalloy containing 57 - 60 % Si, 15 - 22 % Ba, and the rest is Fe. In this paper, for metallographic study we used samples made of steel 12H1MF. The alloy was produced by the technology developed in Abishev Chemical and Metallurgical Institute (Karaganda, Kazakhstan) [3,4].

Heat-resistant 12H1MF steel is used for producing steam pipes, superheat pipes and some parts of engines operating at a temperature of 600^0 C. During the operation, it must have a certain limit of long-term strength and good toughness to withstand alternating loads associated with changes in pressure.

The melting of prototypes was carried out in Tamman furnace, with barium ferrosilicon being introduced a few minutes before the end of the melting. Additional steel deoxidation was carried out by silicon. After cooling, standard metallographic specimens were made of the resulting samples. As a reference sample we used 12H1MF steel deoxidized by silicon only. Non-metallic inclusions, their shape and distribution were studied according to conventional methods, and impurity index was determined by the formula:

$$I_{general} = \frac{b\sum a_i \cdot m_i}{l} \qquad (1)$$

where b is ocular scale graduation value at a given increase in microns;

a_i is the average value of the size of the inclusions in the ocular scale divisions;

m_i is a number of inclusions of the given group;

l is the length of calculation in microns.

The nature of non-metallic inclusions was determined by X-ray diffraction. The results of these studies are shown in Table 1.

As seen from the Table the minimum nonmetallic impurity rating and the toughness maximum rating are present in samples modified by 0,1 – 0,2 % of barium ferrosilicon (samples 3, 4).

In steels deoxidized by conventional methods the most of the inclusions (more than 60 %) is located on the boundary of the grains.

This leads to the fact that the grain boundaries are defective component since these areas cumulate an increased number of dislocations and they are becoming stress raisers due to increased content of non-metallic inclusions. Modifying by barium ferrosilicon leads to a redistribution of nonmetallic inclusions between the arms of dendrite and the grain. This phenomenon can lead to ambiguous results. On the one hand, purification of the grain boundaries should lead to lower levels of stress and, consequently, to an increase in toughness. On the other hand, for heat-resistant materials, any limitation of grain growth results in an increase of heat resistance, and this is what the heat-resistant steel alloying theory is based on. Under optimum ligature additives, about 35 % of the inclusions remain on the borders of the cast grains with barium.

Studies of the nature of non-metallic inclusions indicate that the steel in all variants of modification demonstrates presence of MeC and Me3S - type carbides, sulfides, and oxysulfide-type complex phases. With the increasing number of barium ferrosilicon additive, a greater number of inclusions acquired a rounded shape (Figure 2).

Table 1 **Effect of modification on the distribution of non-metallic inclusions**

N	Addition agent / %	Impurity index I_{gen}*10^{-3}		
		boundary	arms of dendrite	common
1	Reference sample	1,85/62	1,27/40,7	3,12/100
	FS65Ba/15 %	boundary	arms of dendrite	common
2	0,05	1, 02/ 52,8	0,91 /47,2	1,93 /100
3	0,10	0, 68/38,4	0,65 /61,6	1,33/100
4	0,20	0, 68 /50,0	0,68/50,0	1,36 /100
5	0,30	1,12 /47,25	1,25/52,7	2,37/100
6	0,40	0,95/35,3	1,74/64,7	2,47 /100

Note: numerator is an absolute value, denominator is a relative percentage.

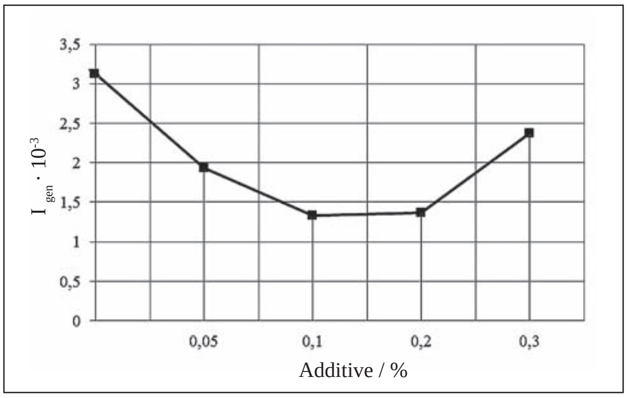
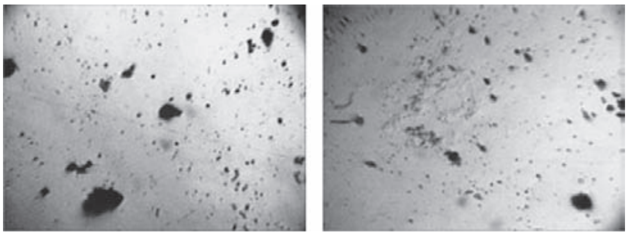


Figure 1 Effect of modification by barium ferrosilicon on the distribution of non-metallic inclusions



a) b)

Figure 2 Distribution and shape of nonmetallic inclusions in original; a) and experimental steel, b) 12H1F x 200

X-ray microanalysis of globular nonmetallic inclusions of non-carbide phase showed the presence of barium, aluminum and sulfur in their composition. Lack of silicon in globular inclusions with barium confirmed endogenous nature of forming. Such inclusions precipitate at an initial stage of crystallization and are located in the middle of the grain which results in purification of the cast grain boundaries.

RESULTS AND DISCUSSION

It is logical to assume that a change in the character of distribution of non-metallic inclusions will lead to some changes in the mechanical properties. For this purpose, long-time strength and toughness of the steel had been measured. Alloys used as the samples are shown in Table 1. The samples were subjected to a hardening heat treatment consisting of quenching (860^0, oil) and high-temperature tempering (660^0 C, air). Long-time strength test and toughness test were carried out according to conventional techniques. The results are given in Table 2 and Figure 3.

As can be seen from Table 2 and Figure 3, the limit of long-term strength of reference sample steel and of steel deoxidized by barium ferrosilicon differ insignificantly. Modification effect is in the change in toughness: in all samples, toughness is higherthan those of the reference samples, yet in samples with minimal impurity index (samples 3 and 4) the toughness increases by 19 % and 36 % respectively. This is quite easily explained if we consider that the effect of non-metallic inclusions is particularly high on toughness [2].

Table 2 **Properties of steel modified by barium ferrosilicon after thermal treatment**

N	Mechanical properties,	
	σ^{560}_{100} / MPa	*KCU* / MJ/m^2
Reference sample	140	0, 77
1	140	0,76
2	138	0,71
3	137	0,95
4	137	1,02
5	142	0,63
6	140	0,65

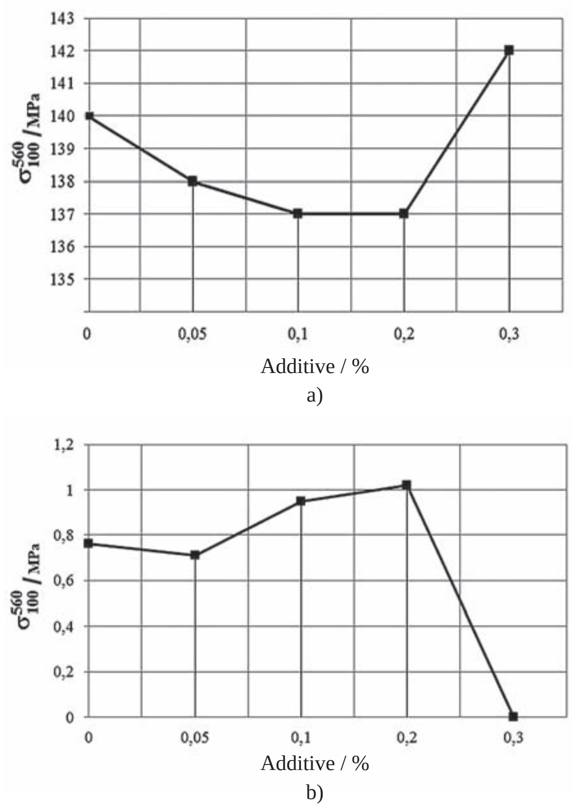


Figure 3 Effect modification ferrosilikobariem steel (a) to limit long-term strength and toughness (b)

The mechanism of effect of barium ferrosilicon under steel modification on the distribution of non-metallic inclusions and, hence, on the properties is as follows [1,5,6]. When introduced into the steel, barium ferrosilicon alloy particles after melting actively interact with the base metal. It must be borne in mind that iron and silicon are dissolved in the steel, and the remaining particles of insoluble barium are highly reactive and interact with oxygen and other elements. At this, interfacial tension is significantly reduced, which may lead to Ba particles self-dispersion to very small sizes, even up to nanoparticles.

As a result of these processes, for a very short period of time equal to the time of Ba presence therein, the steel witnesses the formation of fine-grained self-organizing system of Ba particles the behavior of which determines the nature of modification process. It is the emergence of an enormous number of Ba micro- and nanoparticles in the metal melt at local introduction of modifiers that allows to explain and understand the possibility of changes in the microstructure and properties of all liquid steel which will later affect the change in the properties of finished products.

Atoms or nanoparticles of barium in metal and at coming out to the metal-slag boundary are connected with adsorbed surface-active metalloids (O, S and P) and in the form of compounds BaO, BaS, Ba3, and P2 transfer into slag. Due to small size, they are readily absorbed by the slag thereby contributing to a reduction of oxygen, sulfur and phosphorus content in the steel [1].

Thus, changes in the structure of the molten steel due to modification by barium ferrosilicon under crystallization lead to a change in the microstructure and properties of the metal that can remain after thermal hardening operations.

The proposed hypothesis fairly well explains the obtained experimental data on the nature of the nonmetallic inclusions and changes in some mechanical properties of steel modified by barium ferrosilicon.

CONCLUSIONS

The studies found that the use of barium ferrosilicon as a deoxidizer reduces nonmetallic impurity rating and improves toughness, yet long-term strength changes insignificantly.

Introduction of barium ferrosilicon increases plastic properties of a metal matrix and contribute to a more favorable form of nonmetallic inclusions thereby enhancing overall operational stability of steel.

REFERENCES

[1] Deryabin A.A., Mogilny V.V., Hodyk L.A. Efficiency and mechanism of modifying steel with barium // Journal OAS «Chermetynformatsyya». Bulletin «Chernaya Metallurgy», (2007) 6,59.

[2] Golubtsov V.A. Theory and practice of steel doping. – Chelyabinsk, 2006. pp 422.

[3] Privalov O.E., Baysanov S.O. Ductility and electrical resistance of oxide melts in Fe–Si–Ba–Al–O systems, modeled for smelting ferrosilicium-barium and ferrosilicium with barium // Journal Industries Kazakhstan, (2001) 4,110.

[4] Privalov O.E., Dubrovin A.S., Baysanov S.O., Takenov T.D. Producion test of technology for smelting ferrosilicium-barium and ferrosilicium with barium // Proceedings Evrazyyskoho University. – 2000. pp 82 – 86.

[5] Mizin V.G., Ageev Y.A. Formation conditions, compound and properties of non-metallic impurities in calcium-containing steels.//Pro. SA USSR. Metals, (1981), 5,15.

[6] Zaslavsky A.Y., Gusev Z.F. Barium in calcium steels.// Pro. SA USSR. Metals, (1985), 5,74.

Note: The responsible translator for English language is N.M. Drag, Karaganda, Kazakhstan