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Modifying and Micro-Alloying Effect on Carbon Steels Microstructure

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Abstract. Small additives of elements exhibiting high chemical activity with respect to iron and impurities, included in its composition, have a complex effect on the structure and properties of steel. Moreover, as a result of the modifying and refining effect of micro-additives, the amount, dispersion and morphology of nonmetallic inclusions change, and when alloying the matrix, hardenability, uniformity of structure and resistance to brittle fracture of steels change, too. The article presents a metallographic analysis of carbon steel deoxidized by a complex *Ca – Ba* alloy. Deoxidation of steel using the complex Ca – Ba alloy allows significant reducing the content of nonmetallic inclusions, modifying residual nonmetallic inclusions into favorable complexes with their uniform distribution in the volume of steel, and significant increasing the mechanical properties of steel. The high surface activity of barium makes it possible to consider barium as a rather effective modifier. The use of barium in alloys leads to grinding of non-metallic inclusions, homogenization of liquid metal, lowering the liquidus temperature, grinding of primary grains of cast steel, and increasing technological ductility.

Introduction

A promising trend that allows saving expensive metals, significant increasing the physical-and-mechanical and technological properties of steels, is microalloying, which has a significant effect on the purity of steel, changes the crystallization conditions, the structure of boundary grains, and helps to obtain a homogeneous structure. Improving the composition of steels in order to increase reliability and durability of machine parts requires a comprehensive study of the refining, modifying and alloying effects of microadditives [1].

Small additives of elements exhibiting high chemical activity with respect to iron and impurities included in its composition have a complex effect on the structure and properties of steel. Moreover, as a result of the modifying and refining effect of microadditives, the amount, dispersion and morphology of nonmetallic inclusions change, and when alloying the matrix, hardenability, uniformity of structure and resistance to brittle fracture of steels change, too [2, 3].

The needed technological and consumer properties of structural steels and alloys are mainly provided by a rational choice of the chemical composition, improvement of metallurgical quality, appropriate heat treatment and surface hardening [4].

It is known that increasing the residual calcium content in steel to several hundredths of a percent contributes to an effective increase in its impact strength at low temperatures. The positive effect of calcium microadditives is caused by the effective removal of sulfur from the solid solution and its binding to globular sulfides [5].

Complex ferroalloys with alkaline earth elements of calcium and barium have a great prospect in metallurgy of cast iron and steel as modifiers, deoxidizers and desulfurizers [6, 7]. They have a relatively low melting point and high density, which contributes to the complete assimilation of them by metal during deoxidation. Barium complex alloys are also active dephosphorators. In contrast to metal deoxidation by standard ferroalloys, complex alloys with alkaline earth elements globularize and evenly distribute non-metallic inclusions, which contributes to the hardening of cast iron, and steel ductility increases [8, 9].

Experimental Studies

Studies on the subject were carried out by methods of the microscopic analysis and determination of mechanical properties. To change the phase composition, structure, and properties of alloys, complex alloying and heat treatment of metals were used [10].

The microstructure of steel samples was revealed by etching the surface of the sections with Rzheshotarsky reagent (solution of 4 % nitric acid in alcohol). The phase composition and structure of the alloys were studied using a Leica optical microscope with 100 and 500 magnification.

Smelting steel deoxidized with calcium and barium alkaline earth elements was carried out in a Tamman furnace; it was preheated to 1600 °C and then slowly cooled. The microstructure of steel obtained during such cooling is presented in the Figures below.

The microstructure of steels is studied in equilibrium, i.e., in the state when the phase transition processes have completely occurred, which is achieved only with very slow cooling. There was studied steel, the chemical composition of which is presented in Table 1.

Table 1. Chemical composition of St3sp steel

Steel grade	Chemical composition, %									
	C	Si	Mn	P	S	Cr	Cu	Ca	Ba	Al
St3sp	0.2	0.4	0.6	0.025	0.025	0.7	0.25	0.06	0.02	0.004

Figure 1 shows the ferrite - perlite structure of the resulting steel. Ferrite forms a grid at the grain boundaries. Separate ferrite needles stand out in austenite along twin boundaries [11]. There is thin plate perlite. Inside one grain surrounded by a grid of ferrite, several colonies of perlite are visible. In the event that the grains of free ferrite have the same orientation as perlite ferrite, the boundary between them is not formed, as shown in the upper right corner of the microphotograph. Larger sections of perlite consist of several colonies of perlite, which differ in contrast due to the unequal orientation of the carbide plates.


Fig. 1. Ferrite and perlite, *100

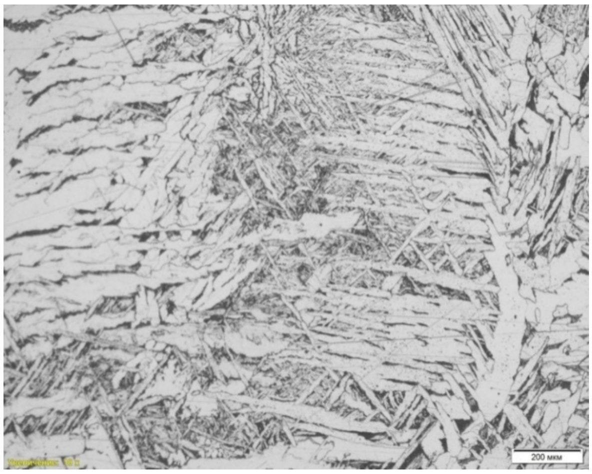
Fig. 2. Needle structure,*100

The presence of calcium in the composition of steel also gives a favorable result, since it is known that the positive effect of calcium microadditives is caused by the effective removal of sulfur from the solid solution and its binding to globular sulfides [12].

Figure 2 clearly shows the needle structure. In ferrite, precipitation is observed, especially along the grain boundaries. Perlite containing cementite plates equally oriented in rather long sections. They are interspersed with granular cementite. In the upper right corner of the microphotograph, there is no clear boundary between the grains of hypereutectoid ferrite and perlite; it appears in the lower part of the microphotograph. Sometimes groups of plates of cementite fall into the plane of the oblique section [13, 14].

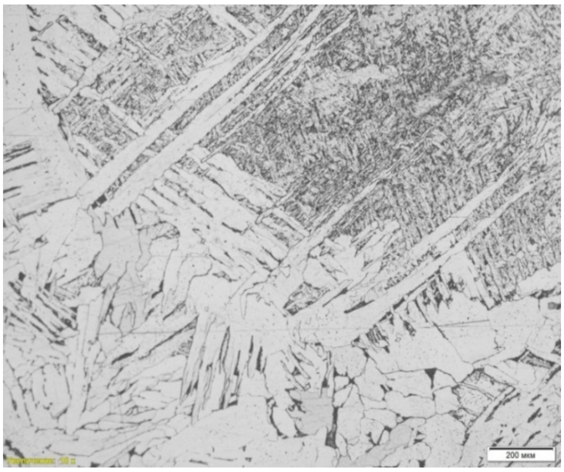

Fig. 3. Signs of uneven cooling, *100

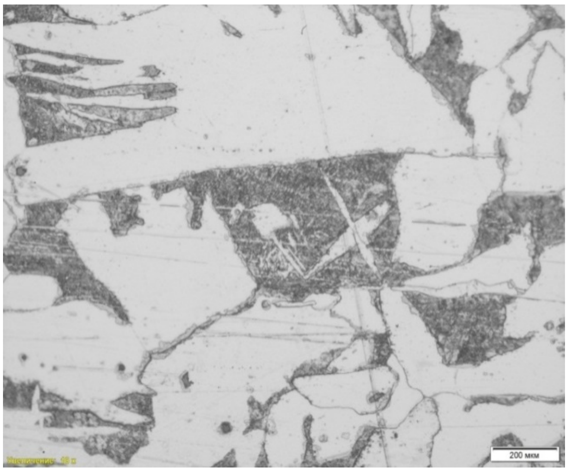

Fig. 4. Perlite structure, *500

It should also be noted that there are signs of uneven cooling (Figure 3), which indicates that there were deviations from the crystallization technology of the alloys, or cooling modes (temperature, time and cooling rate) were violated [15].

In some areas (Figure 5), the ferrite structure (over 90 %) is very clearly observed. There are ferrite grains with uneven boundaries and precipitations along the boundaries. Perlite areas are heterogeneous in size and shape [16].

On the surface of individual ferrite grains, there is formed a relief in the form of wrinkles; thin plate perlite is also present.

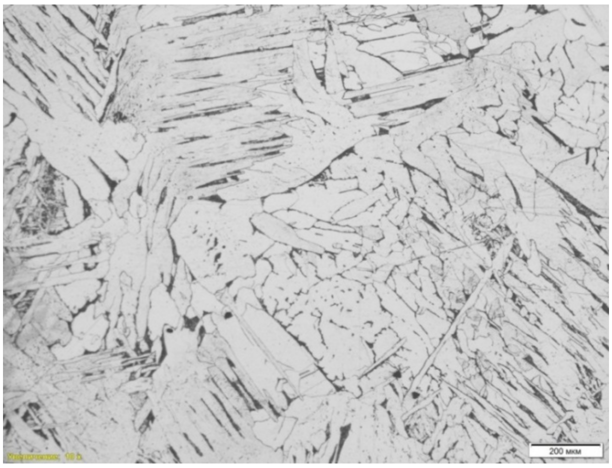

Fig. 5. Ferrite structure, *100

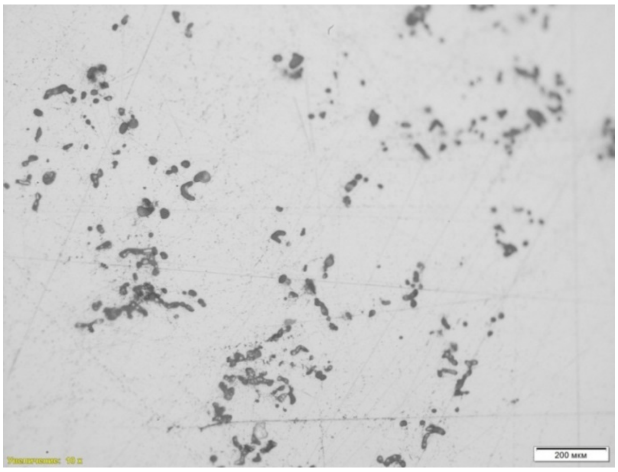

Fig. 6. Cluster of inclusions, *100

Figure 4 shows a thin section with a perlite structure. There is ferrite and thin plate perlite. Inside ferrite grains and especially along their boundaries, there are found thin precipitates. The interphase boundaries of perlite and ferrite are clear, straight. If there is no boundary between perlite and hypereutectoid ferrite, the contour of perlite grains is not continuous and consists of the contours of individual cementite plates of various lengths [17].

As it was noted above, due to the uneven cooling of the alloy, in some parts of the thin section, one can also observe a cluster of non-metallic inclusions (Figure 6) and the presence of pores along the metal cross section (Figure 8).

Most likely, the cluster of inclusions is a consequence of the low content of calcium, which in this case is a modifier element, which does not allow more complete removing non-metallic inclusions and reducing their number to the required values that determine the most favorable mechanical characteristics of steel.

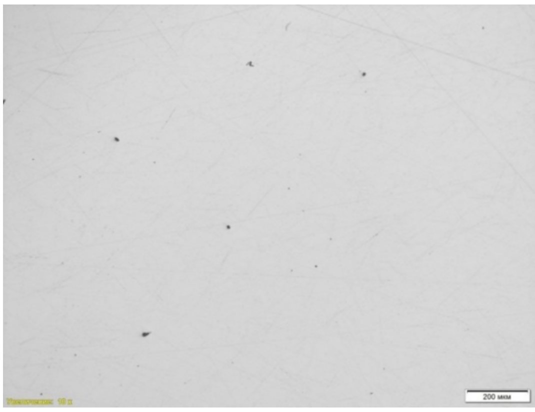

Fig. 7. Single non-metallic inclusions, *100

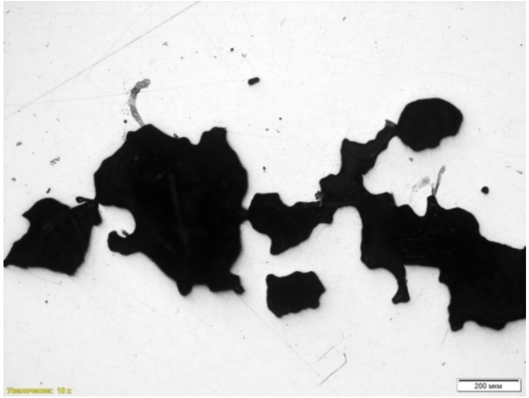

Fig. 8. Pores, *500

Non-metallic inclusions (Figure 7) during deoxidation of the obtained steel were smaller and globular in shape with no line-like inclusions of alumina and accumulation of oxides. This is ensured by calcium and barium in the alloy, which in addition to desulfurizing and dephosphorizing properties also exhibit modifying properties similar to surfactants, which is manifested in the coagulation of oxides into fusible complexes that are easily removed from the bulk of steel [18].

Indeed, a modifying effect of barium is observed in the industrial metal. Typically, the modifying effect is evaluated by the effect on the size of non-metallic inclusions, on the size of the primary grain in the cast metal, technological ductility and on the operational properties of the metal. In the production of structural and transport metal, after introducing complex alloys with barium, grinding of non-metallic inclusions is noted (but barium is not determined in them), decreasing the primary grain, decreasing the anisotropy of the mechanical properties, and increasing the cast metal ductility [19].

The analysis of the properties of effective modifiers shows that they are usually characterized by low solubility in steel, high chemical activity (high affinity for oxygen, sulfur, nitrogen, carbon) and short-term action, accompanied by a long-term increasing of the steel properties. In this regard, barium is suitable for all requirements and can be an effective modifier. So, the absence of large inclusions after introducing barium into steel can be due to a high surface activity of barium [20]. Barium that is present in the metal lowers the interfacial tension between the nascent inclusion and the liquid metal and thereby reduces the critical radius of the nucleus and supersaturation of the metal components. The result is a large number of small inclusions that do not significantly affect the mechanical properties of steel.

Conclusion

1. Deoxidation of steel using the complex *Ca – Ba* alloy allows significant reducing the content of non-metallic inclusions, modifying residual non-metallic inclusions into favorable complexes with their uniform distribution in the volume of steel, and significant improving the mechanical properties of steel.
2. Due to the low solubility in liquid metal and high surface activity, barium cannot be an effective deoxidizing agent for steel.
3. A high surface activity of barium makes it possible to consider barium as a rather effective modifier. The use of barium in alloys leads to grinding of non-metallic inclusions, homogenization of liquid metal, lowering the liquidus temperature, grinding of primary grains of cast steel, and increasing technological ductility.

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