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MANUFACTURE OF FERROUS AND NONFERROUS METALS

# Effect of a Lining on the Degree of Oxidation of a Metallic Melt

A. V. Dub, A. N. Romashkin, T. V. Morozova, and I. A. Shchepkin
*OAO NPO TsNIITMASh*

**Abstract**—The interaction of periclase and alundum refractories with iron-based melts of various degrees of oxidation is studied under laboratory conditions. It is shown that a lining can accumulate iron oxide inclusions as a result of its interaction with an oxide metal, significantly increasing its oxidizing potential. The contact of such a lining with a metal with a low degree of oxidation (metal deoxidized by aluminum) is accompanied by the opposite transition of FeO from the lining to the metal, which causes its secondary oxidation. This secondary oxidation mechanism can be critical for the production of a high-quality high-reliability structural steel, especially at a large specific lining surface area.

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## INTRODUCTION

The approaches to high-reliability structural materials have recently changed to a great extent. It was revealed that, among the factors that most significantly decrease the lifetime of metallic products, oxide inclusions become more and more important. Their content in metallic products is controlled by the limitation of the oxygen content in a metal and is characterized by an inclusion number and the maximum allowable inclusion size. The modern requirements imposed on steels of various grades according to these criteria are given in Table 1.

These values of the characteristics were obtained from an experimental database for the effect of an inclusion number on the mechanical, technological, and service properties of materials and from the relation between the inclusion number and the oxygen content in the metal. Figures 1 and 2 show examples of such relations obtained by us in studying low-alloy 10G2FB and 06GFBAA manganese steels. As follows from these curves, the contamination of a metal by oxides at the level of number one or two (GOST (State Standard) 1778) corresponds to a total oxygen concentration of about 0.002%.

To make a metal with an oxygen content and a maximum nonmetallic inclusion size satisfying the requirements given in Table 1, one has to use a proper technology of deep deoxidation and to maintain the reached degree of oxidation of the metal until its solidification. The latter is achieved by weakening the interaction between a metallic melt and oxidizing phases, which are mainly represented by a slag and atmosphere. Moreover, the interaction of oxygen with a lining can substantially affect the oxygen content in steel. The purpose of this work is to study this interaction.

The effect of a lining on the degree of oxidation of a metallic melt was revealed in [8], where the deoxidation of a low-alloy steel was investigated in a laboratory vacuum induction furnace. The authors of [8] found that, as the aluminum content in a metal increases, its degree of oxidation (oxygen activity in the metal) decreases with the following specific feature: at low aluminum activity, experimental data are scattered as much as possible and the measured oxygen activity differs from the equilibrium activity most substantially; as the aluminum content in the metal increases, the degree of oxidation of the metal decreases and the oxygen activity becomes more stable. Since the experiments were performed in an inert atmosphere in the absence

**Table 1.** Maximum allowable oxygen content and nonmetallic inclusion size in steels of various purposes

| Type of steel | Maximum oxygen content in the metal, % | Maximum allowable inclusion size, μm |
|---|---|---|
| Autobody sheet steel | 0.004 [1] | 100 [1, 2, 3] |
| For deep drawing | 0.002 [2] | 20 [2] |
| For gas and oil pipelines | 0.003 [1, 4] | 100 [1, 2] |
| Ball-bearing steel | 0.001 [1, 5, 6] | 15 [4, 7] |
| Cord steel | 0.0015 [1, 4] | 10 [1, 4] |
| | 0.005* | 20 [3] |
| For shipbuilding, drilling platforms, bridges | 0.002 [1, 4] | 200 [2] |
| Wire steel | 0.003 [1, 4] | 20 [1, 4] |
| Rail steel | 0.002** | 500** |
| For nuclear reactor casing | 0.0025 | Undetected |
| Rotor steel | 0.002*** | Undetected |

Notes: * Wire rod sorbitized from high-purity steel for a metal cord 5.5–6.5 mm in diameter. Specifications TU 14-1-4752–89. GUP BMZ.
** GOST R 51685–2000. Railroad rails. General specifications.
*** Specifications for St. 152 (10% Cr, 10% Ni).

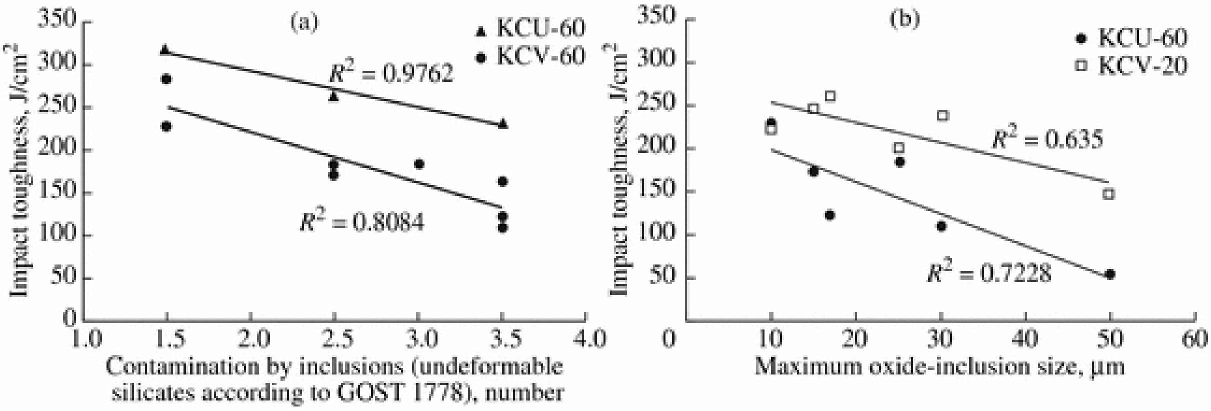


**Fig. 1.** Effect of the nonmetallic-inclusion (a) number and (b) size on the impact toughness of tube steel. (The inclusion-number studies were performed by the Sh method according to GOST (State Standard) 1778, and the main fraction of inclusions with the maximum size belongs to undeformable silicates (according to GOST 1778).

of slag, the oxygen supersaturation of the metal was obviously caused by the lining.

The effect of this factor is also supported by a comparison of the data in [8] with the data in [9–14] on the degree of oxidation of a low-alloy steel and iron during their deoxidation by aluminum (Fig. 3). This comparison demonstrates that the measured degree of oxidation of the metal maximally deviates from the equilibrium degree of oxidation for furnaces with a high specific lining surface area (Fig. 3, curves *1–3*) provided that the metal is not oxidized by an atmosphere and slag (i.e., at a low aluminum content in the metal). As the aluminum content increases, the measured values of $a_O$ approach equilibrium values.

Let us assume that this high degree of oxidation of a metallic melt is caused by oxygen diffusion from the lining as a result of the decomposition of FeO molecules that entered into it when the lining interacted with an oxidized metal, i.e., before deoxidation.

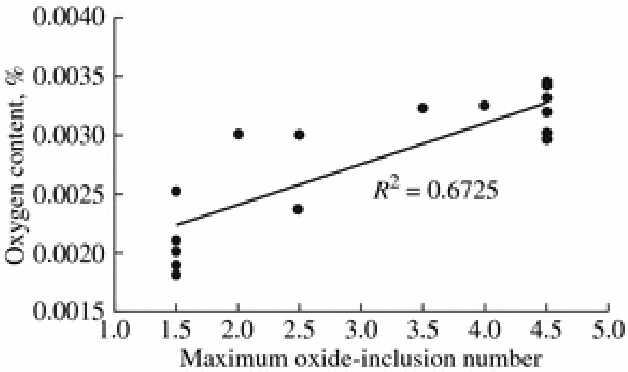


**Fig. 2.** Effect of the contamination of tube (06GFBAA type) steel by nonmetallic inclusions on the oxygen content in it. The maximum number was characteristic of inclusions that belong to undeformable silicates (according to GOST 1778).

## EXPERIMENTAL

To support this assumption, we performed a series of experiments to study a change in the composition of the near-surface layer in refractories in contact with a deoxidized or deeply deoxidized iron melt. We studied samples 17 × 17 mm in cross section and 100–150 mm in height cut from a P-91 periclase brick. The average contact area between a sample and a metal was 3700 mm$^2$ (74 cm$^2$/kg metal).

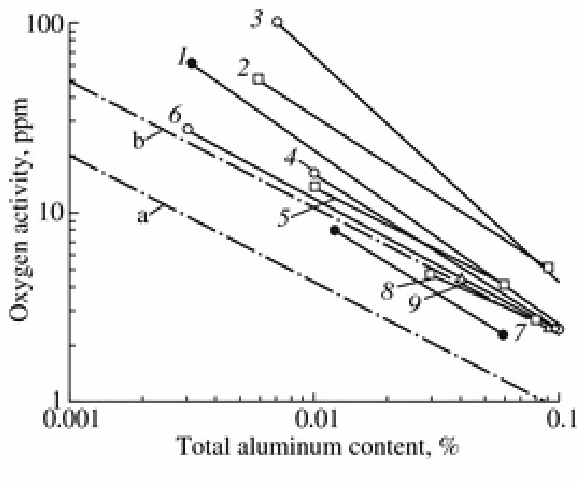


**Fig. 3.** Oxygen activity vs. the total aluminum content according to (*1–7*) [8, 9–14], respectively, and (*8*, *9*) OAO Severstal' and OAO NLMK, respectively. (a, b) Maximum and minimum equilibrium values of $a_O$ at $K_{Al}^{1873}$ = $9.54 \times 10^{-15}$ [16] and $1.19 \times 10^{-13}$ [15], respectively.