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NITROGEN ABSORPTION IN STEEL FE-0,04 C-18 CR- 10 NI DURING PLASMA-SLAG REMELTING

Chromium-nickel steels are among the most widely used structural austenitic steels in industry. Nitrogen, known as an alloying element in chromium-nickel and chromium-manganese steels, is a strong austenizer agent that was initially used as an additive to chromium-nickel steels to enhance the stability of austenite, and later as a replacement for a portion of nickel in chromium-nickel-manganese steels. Considering the cost of nickel, replacing part of it with nitrogen significantly increases the economic viability of producing stainless steels.

Steels with supersaturated nitrogen content are advisable to produce under a sub-atmospheric nitrogen pressure or by plasma-arc remelting (PAR) with nitrogen alloying of the metal directly from the gas phase. From the perspective of achieving supersaturated nitrogen content in the metal, the use of nitrogen plasma is more effective. A promising approach is to combine plasma, which activates nitrogen molecules as a heat source, with slag treatment, thereby providing opportunities to cleanse the melt from unwanted impurities and non-metallic inclusions.

The absorption of nitrogen by liquid steel in the gas-slag-metal system during plasma-slag melting (PSM) depends on both the gas absorption by the metal and

the transfer capacity of the slag. Therefore, the issue of studying the kinetics of such a complex process arises. The nitrogen absorption by the slag and through the slag by the metal during plasma-slag melting was performed using steel Fe-0,04 C-18 Cr-10 Ni under a slag of 50 % CaO + 50 % Al₂O₃.

The determining factors for alloying the metal with an excess equilibrium amount of nitrogen during PSM are the partial pressure of nitrogen in the plasma-forming gas and the process temperature.

During the plasma heating of the metal, the law of the square root for nitrogen absorption is fulfilled, but the proportionality coefficient significantly exceeds the Sieverts' constant.

Regarding the sorption capacity of the slag with respect to impurities, it depends on both the gas pressure and the oxidizing-reducing potential of the environment, which can be determined by the equilibrium partial pressure of oxygen. Unlike the Sieverts' law for metals, in the case of slag, the partial pressure of nitrogen is also taken into account, considering the oxidation state or valence of the gas in the slag. The solubility of nitrogen in basic slags is two to three times greater than in iron. In acidic slags, with increasing temperature, nitrogen dissolves faster than in iron. The interaction in the nitrogen-slag-metal system is a multi-stage process, and depending on the rate of the elementary stages of the process, one or another stage may determine the overall rate of nitrogen absorption.

Initial experiments conducted with steel Fe-0,04 C-18 Cr-10 Ni showed that the nitrogen content in steel, depending on the partial pressure of nitrogen above the metal, follows Sieverts' law. The Sieverts' constant for the experimental conditions is 0,277674 and is described by the equation:

$$[\%N] = 0,277674 \cdot \sqrt{P_{N_2}}. \quad (1)$$

Theoretical calculations of nitrogen solubility in the studied steel were performed using the Chipman-Corrigan equation. The nitrogen solubility was determined by the formula:

$$[\%N]_{04X18H10} = \sqrt{p_{N_2}} \cdot 10^{\left(\frac{1328}{T} - 1,4029\right)}.$$

This made it possible to estimate the melting temperature in the conditions of the experiments when the molten metal sample was covered by a plasma torch:

$$[\%N] = [\%N]_{04X18H10},$$

$$0,277674 \cdot \sqrt{P_{N_2}} = \sqrt{p_{N_2}} \cdot 10^{\left(\frac{1328}{T} - 1,4029\right)},$$

from which the melting temperature of the steel is approximately 2385 K.

The summarized relationships of the variation of nitrogen content in the molten plasma-slag melting (PSM) steel with the square root of the partial pressure of nitrogen are shown in Fig. 1.

In the conditions of plasma-slag melting, the nitrogen content in steel and slag follows the Sieverts' law. The linear dependence of the nitrogen content in the slag is described by the equation:

$$(\%N) = 0,360025 \cdot \sqrt{p_{N_2}} + 0,00336233,$$

with the coefficient of determination $R^2 = 0,995207$ and the mean square deviation $6,31644 \cdot 10^{-5}$, indicating high model significance. The free term of the last equation indicates the initial (residual) nitrogen content in the slag.

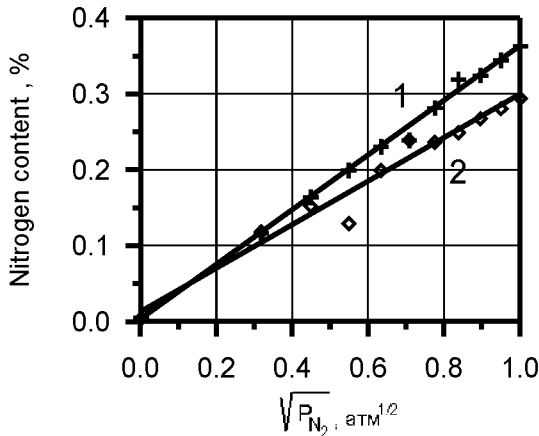


Figure 1 – The effect of nitrogen pressure ($\sqrt{p_{N_2}}$) on its content in slag and steel Fe-0,04 C-18 Cr-10 Ni at PSM: 1 – slag, 2 – metal

The same can be said about the dependence of nitrogen content in steel under slag. The linear dependence takes the following form:

$$[\%N] = 0,286549 \cdot \sqrt{p_{N_2}} + 0,0129405, \quad (9)$$

The coefficient of determination is 0,964987, and the standard deviation is equal to $3,01468 \cdot 10^{-4}$. A comparison of the Sieverts' constant for steel under plasma-slag melting (1) with the constant under plasma-arc melting (9) shows the closeness of their values. The difference is 0,008875, corresponding to a 3,2 % error. The distribution coefficient of nitrogen between the slag and the metal is equal to 1.1-1.2.