

In this case, the durability distribution function of the composite with N inclusions is determined by the formula

$$F_N(t_*) = 1 - (1 - F_1(t_*))^N. \quad (4)$$

According to expression (4), the mean value, dispersion and other probabilistic characteristics of the composite material durability can be determined.

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Shapovalov V.O.¹, Mogylatenko V.G.², Biktagirov F.K.¹, Kozin R.V.¹
(¹*E.O. Paton Electric Welding Institute of the NAS of Ukraine; ²Igor Sikorsky Kyiv Polytechnic Institute, Kyiv*)

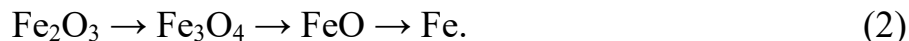
ANALYSIS OF DIRECT REDUCTION OF IRON BY HYDROGEN

Email: vmogilatenko@gmail.com

Direct reduction of iron from oxides with hydrogen has a great advantage over reduction with carbon or in a water gas atmosphere. The advantage is that the emissions of dust, sulfur gases, oxide and carbon dioxide into the atmosphere by the metallurgical enterprise are sharply reduced due to the absence of blast furnace separation and agglomeration production. In addition, there is no need for solid fuel – coke. The sponge iron obtained after recovery practically does not contain sulfur and phosphorus. The possibility of increasing the productivity of the recovery process should be taken into account, since hydrogen has a higher diffusion coefficient in metals compared to other gases and carbon. These and other advantages have led to the fact that there are more and more studies of the technology of obtaining iron by reducing it from oxides with hydrogen.

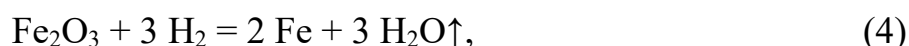
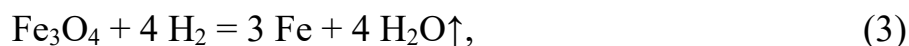
Currently, iron recovery is carried out at so-called average temperatures. At temperatures below 843 K [1, 2, 3], a two-stage reduction (1) occurs, and above

843 K – a three-stage reduction (2):



When heating scale, the formula of which is a double oxide ($\text{FeO} \cdot \text{Fe}_2\text{O}_3$), wustite (FeO) is reduced by hydrogen quite slowly. This is evidenced by the calculations, the results of which are shown in fig. 1.

At a temperature above 1273 K, the following reactions occur:



which are characterized by significantly more negative values ΔG of the system and high values of K_p , pass to the end.

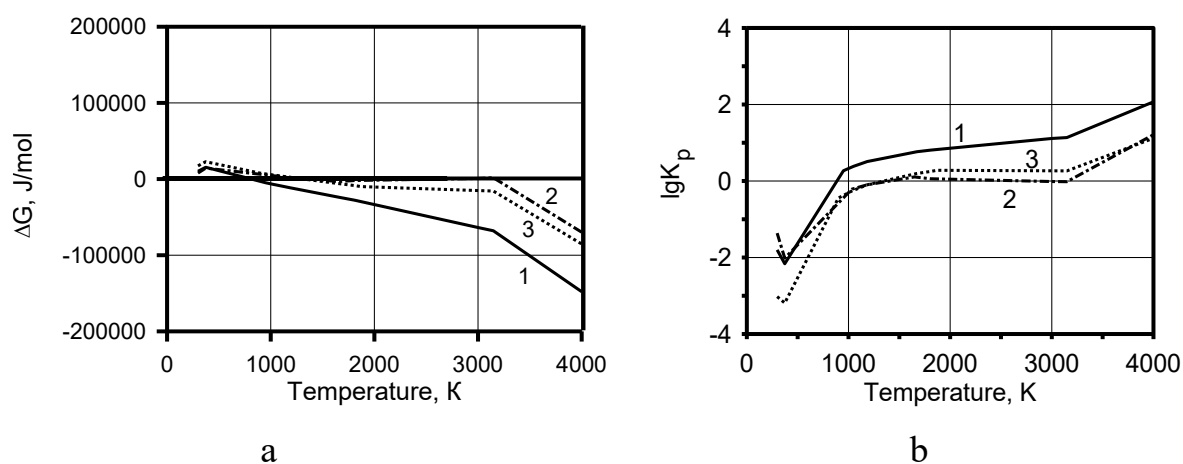


Fig. 1. Change of the Gibbs free energy (a) and equilibrium constants (b) of iron reduction reactions with hydrogen with: 1 – Fe_2O_3 , 2 – FeO , 3 – Fe_3O_4

For the reaction that limits the reduction process as a whole (5):



(see Fig. 1, curve 2) the change in free energy is negative, but small, and the equilibrium constant of the reaction ($K_p = \frac{P_{\text{H}_2\text{O}}}{P_{\text{H}_2}}$) has a small value. To accelerate the recovery, the equilibrium should be shifted in the direction of obtaining reaction products.

The iron recovery process can be intensified by transferring hydrogen from molecular to atomic or ionized state. Works on reduction in "low-temperature" hydrogen plasma [4] are known, the results of which showed the effectiveness of using a high-frequency hydrogen capacitive discharge to reduce iron to metal.

The use of plasma using methane or hydrocarbon destruction products as plasma-forming gas [5–7] also gives positive results. However, the process generally depends on the presence of carbon.

There is a possibility of realizing the process of recovery of iron from the oxide melt at temperatures above 1870 K.

As can be seen from fig. 1 reduction of iron from the melt of oxides to FeO occurs quite easily, and the last stage of reduction to Fe proceeds very sluggishly. This may be related to the form of existence of hydrogen as a reducing agent: up to a temperature of ~3000 K, hydrogen exists in molecular form, in the temperature range of 3000–15000 K hydrogen dissociates into atoms to varying degrees depending on the temperature and at a temperature >15000 K it is ionized [8, 9]. However, even in low-temperature plasma hydrogen particles have increased internal energy of vibrational motion and rotational motion [10].

Analysis of studies of deoxidation of iron by argon-hydrogen high-temperature plasma, carried out at the E.O. Paton Electric Welding Institute of the NAS of Ukraine [11-14] about 50 years ago, showed that hydrogen deoxidation did not develop properly mainly due to the low speed of the process. So far, there are isolated scientific publications that deal with the removal of oxygen or the recovery of iron from an oxide

melt with hydrogen.

Calculations show (Fig. 2) that the high values of free energy and the positive thermal effect of the reaction of the reduction of liquid iron oxide (wustite in composition) with hydrogen indicate that the reaction is best carried out at the lowest possible temperatures.

Deoxidation is essentially a refinement of both dissolved oxygen and non-metallic inclusions. As for dissolved oxygen, the following dependence is given in [14] as the most reliable data for the equilibrium constant of the reaction of hydrogen deoxidation of liquid iron:

$$\lg K_p = \frac{6817}{T} - 3,13.$$

It follows from this that at least up to a temperature of 2178 K, the constant of the deoxidation reaction has a very small value and the process itself proceeds very slowly. The author comes to the conclusion that in order to deoxidize liquid iron, nickel and alloy FeNi50, it is necessary to lower the temperature of the process.

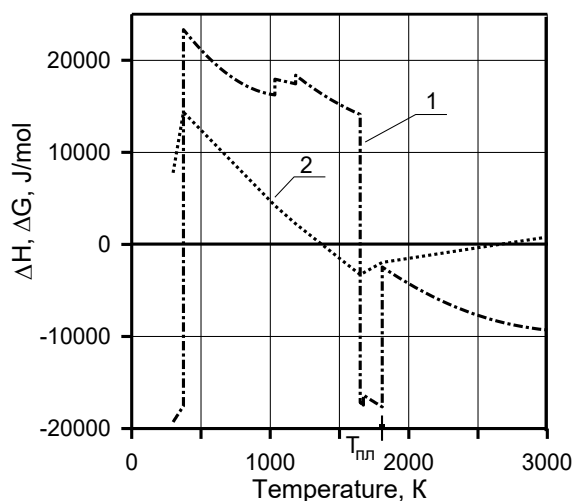


Fig. 2. Enthalpy change (1) and Gibbs free energy change (2) of the reaction $\text{FeO} + \text{H}_2 = \text{Fe} + \text{H}_2\text{O}$

statistical analysis, and the conclusion about the influence of the method of introducing hydrogen on deoxidation should be considered, if not incorrect, then as one that requires

The same author, after studying the influence of technological parameters of smelting on plasma-hydrogen deoxidation, came to the conclusion that the method of introducing hydrogen directly into the plasma-hydrogen lance or furnace chamber does not affect the deoxidation of iron. This conclusion was made on the basis of only 12 experiments, of which 4 belonged to iron, and 8 – to iron-nickel alloy FeNi50. For this reason, due to the small volume of data, it is impossible to subject the results to

additional verification [14].

The equilibrium content of oxygen in the metal during deoxidation with hydrogen is proportional to the value of the oxidizing potential of the gaseous atmosphere. In our case, this is the amount of hydrogen mixed with water vapor, i.e. $\frac{P_{H_2O}}{P_{H_2}}$. At the same voltage on the arc [14], when introducing hydrogen into the plasma-hydrogen lance, its maximum possible content was 13-15%, and in the furnace chamber – 25-30% at a voltage of 2-60 V.

Experiments [14] on studying the content of oxygen in ingots depending on the temperature (and reaction equilibrium constant) and the oxidation potential of the atmosphere of the plasma-arc furnace showed a decrease in the content of oxygen in iron with an increase in the partial pressure of hydrogen or a decrease in the content of H₂O vapor (Fig. 3).

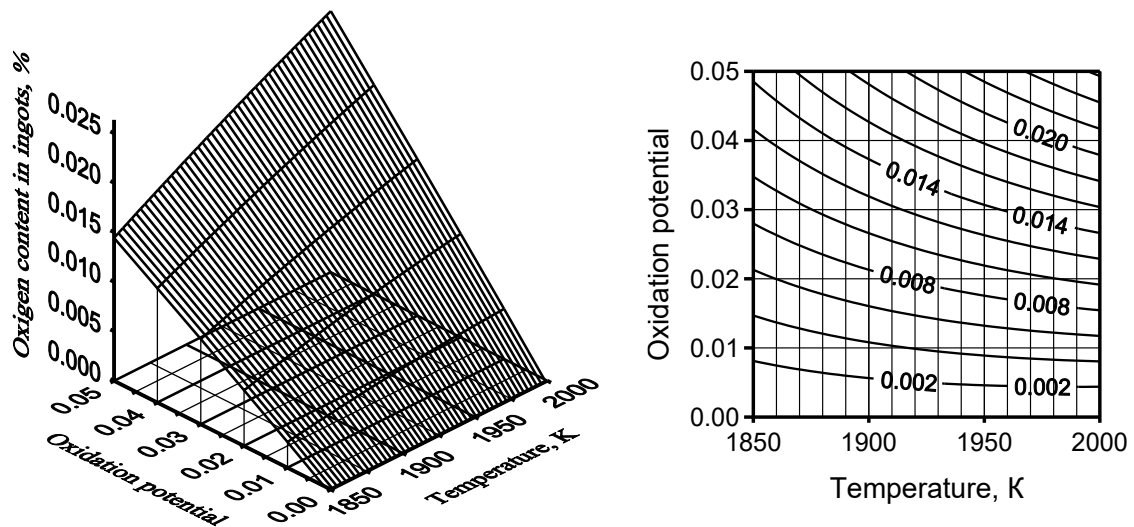


Fig. 3. The effect of oxidation potential and temperature on the oxygen content in iron during hydrogen deoxidation of the melt (constructed according to the results of [14])

Wustite is characterized by a wide area of homogeneity, and the composition of wustite should influence its reduction by hydrogen. The authors of the paper [15]

established that for the recovery of wustite in the temperature range of 900–1600 K, it is necessary that the mole fraction of hydrogen in the gas phase was higher than 0.55, which corresponds to 55% by volume or 12% by mass.

However, with plasma-arc melting, the mass transfer in the melt and the activity of hydrogen, both in the plasma torch and outside its boundaries, increase greatly. And from this point of view, the reducing ability of hydrogen should increase strongly.

Thus, differences in the kinetics and mechanism of the process of reduction of solid and liquid oxides can accelerate reduction reactions. It is possible to intensify the process, increase the degree of recovery and the degree of hydrogen utilization during melting using highly concentrated energy sources that allow hydrogen to be activated. Among the known sources of energy, the ability to use controlled gas environments belongs to plasma.

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Smirnov O.M, Semenko A.Yu., Skorobagatko Yu.P., Goryuk M.S.
(PTIMA NAS of Ukraine, Kyiv)
**STUDYING OF THE MAGNETIC FIELD DISTRIBUTION IN THE
SUBMERGED ENTRY NOZZLE FOR CONTINUOUS CASTING**
E-mail: semenko.au@gmail.com

The steel casting process in continuous casting machines (CCM) is accompanied by some mandatory process transfers, with a few critical physical and chemical processes performed. They largely determine the efficiency and stability of the steel casting process in general, as well as billet quality. Meanwhile, the steel jet moving from the ladle through the tundish to a mold is the main factor of dynamic and stable monitoring of the quasi-continuous steel casting process under the conditions of discrete replacement of ladle and tundish, as well as submerged entry nozzles (SEN) and metering nozzles.

In practical continuous casting, ceramic SEN is the functional part, which is highly exposed to wear and tear in the steel pouring and metering process. There are two types of wear and tear: clogging of the SEN cavity and reduction in thickness of the SEN walls, in the lower section, because of chemical interaction between the SEN wall material and aggressive slag formed immediately in the casting process. Here the configuration of the SEN cavity changes, and the jet configuration is transformed, thus causing jet fluctuations, and splashing. In practice, the worn SEN is periodically replaced (for example, each 2-6 hours on an average) with a new one, which is pre-heated to 1000-1100 °C. The procedure for replacing the SEN provides for a mandatory stoppage of steel supply through the metering nozzle to the mold for the period of SEN