Analysis of the Process of Electrical Steel Production

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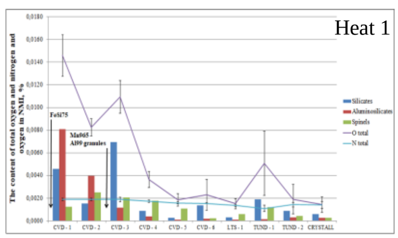
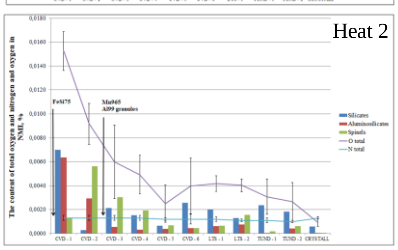
Introduction

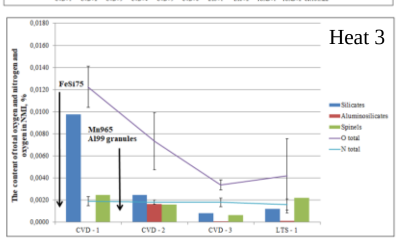
The development of soft magnetic materials characterized by low specific losses is important as a version of one of the main sources of energy saving. The class of silicon-alloyed steels used as soft magnetic materials in transformers and electrical machines consists of electrical steels (ESs). The silicon content in ESs is varied from 0.8 to 4.8%. Silicon alloying also decreases the oxygen content in steel, which increases the specific losses and exerts a strong negative effect on the magnetic properties of steel. In dynamo ESs, aluminum is used as an alloying component and a deoxidizer. The effect of aluminum is similar to that of silicon: it increases the electrical resistivity and decreases the saturation induction. The magnetic properties of ESs are affected by their chemical composition, the grain size, the metal texture, and the nonmetallic inclusion (NI) content. For example, NIs negatively affect the magnetic properties of steel: they increase internal stresses, cause lattice distortions, and suppress grain growth. A high NI content degrades the manufacturability of the metal due to the clogging of steel casting equipment and decreases the casting speed and production indicators. The most unfavorable inclusions in this respect are aluminates. Nonmetallic inclusions (oxides, nitrides, sulfides and their complex inclusions) form in the processes of refining, solidification, and cooling of a metal. The content and morphology of NIs are significantly influenced by metal deoxidation. Magnesium spinel inclusions negatively affect the properties of steel and degrade the quality of the rolled steel surface. The existence of magnesium in the NI composition is associated with the erosion of the refractory lining of a steel-teeming ladle and its presence in the composition of additional materials (dolomite, etc.) The purpose of this work is to analyze the technology of production of dynamo ES and to control the changes in oxide NI formation in a metal at the stages of secondary steel processing and casting.

Results

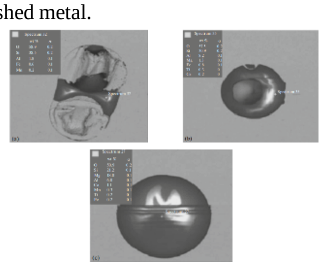
After processing the gas emission curves using the OxSeP Pro program, we determined the oxygen content contained in certain types of NIs and the total oxygen and nitrogen content in the samples. The results of determining the total oxygen and nitrogen content in the metal samples ([O]tot, [N]tot) and the oxygen contents in various types of oxide NIs. A high NI content was detected in the first sample (CVD1) on a circulating vacuum cleaner for heats 1 and 2 after deoxidation and alloying of the metal with ferrosilicon. The presence of aluminosilicates in metal samples after the introduction of the FeSi75 ferrosilicon is associated with the presence of aluminum in its composition. Silicates and spinels were found in the CVD1 sample of heat 3. The total oxygen contents in the CVD1 samples of heats I–III were 146, 153, and 122 ppm, respectively. Silicate, aluminosilicate, and spinel NIs were detected in the CVD3 samples of heats I and II and the CVD2 sample of heat III after deoxidation and alloying of the metal with manganese and aluminum. A higher silicate content (0.007%) was detected in the CVD3 sample of heat I as compared to similar samples of heats II and III, and an increase in the nitrogen content in the metal is also observed, which can indicate secondary oxidation of the metal. The increase in the number of spinels in the metal samples of all three heats is likely to be due to the introduction of deoxidizers into the metal and the intense destruction of the steel-teeming ladle lining. To confirm the FGA results, we performed EPMA of NIs on polished sections of the selected samples of the ES metal. According to analysis results, we obtained data on the main types of oxide NIs, their sizes, and chemical composition in the steel under study.







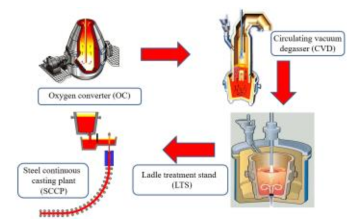
EPMA of NI's confirmed the FGA results for the main groups of oxide NI's located in the finished metal.



Main groups of oxide NIs:
(a) silicates, (b) aluminosilicates,
(c) spinel.

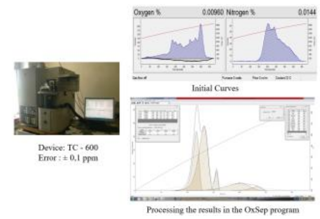
Experimental

We studied the samples taken at the stages of secondary steel processing and casting of ES. The logs of commercial heats I–III were analyzed, and thermodynamic calculations of the melt refining in casting and secondary steel processing were carried out. Technological scheme for the production of dynamo electrical steel:



FGA is a modification of reducing melting in a graphite crucible in a carrier gas current at a given linear heating rate of a sample. This method is based on the difference in the thermodynamic strengths of oxides, which mainly contain oxygen bound in a metal. When the melt temperature increases, the oxides are reduced by carbon from the graphite crucible and oxygen is extracted from the melt in the form of carbon monoxide. In this case, the gas analyzer records the gas release curve from the sample depending on the change in the melt temperature.

The contents of different types of oxide NI's in the metal are calculated using the OxSeP Pro software based on the chemical composition of the sample.



The main advantage of FGA is the ability to quickly obtain information about the total oxygen and nitrogen content in a metal and the oxygen content distributed in various types of oxide NI's. The types of NI's contained in metal samples were estimated by optical metallography on an Olympus PME 3 microscope integrated into the Thixomet image analysis system.The chemical compositions of the inclusions in the samples were analyzed using a Tescan Vega 3SB electron microscope equipped with an Oxford Instruments attachment for electron-probe microanalysis (EPMA).

Conclusions

(1) The technology of melting and secondary steel processing of ES was analyzed to determine the factors affecting the metal quality and oxide NI formation.
(2) FGA and scanning electron microscopy with EPMA were used to analyze the NIs in metal samples taken at the stages of ladle treatment of ES. The total oxygen and nitrogen content in the metal samples and the oxygen distribution over the types of NI's were determined.
(3) The NIs in the metal samples are divided into silicates, aluminosilicates, and spinels. Their formation is related to the introduction of alloying and deoxidizing elements.
(4) The increase in the amount of magnesium spinel NIs in the metal samples is associated with the influence of deoxidizers on the destruction of the ladle lining, and the increase in the oxygen and nitrogen content in the samples of heat I from CVD and a tundish points to secondary oxidation at these stages of treatment.
(5) When analyzing the heat logs, we detected an increase in the phosphorus and carbon content in the samples at the stage of metal processing in a circulating vacuum cleaner. The increase in the phosphorus content after deoxidation and metal alloying was 20 ppm, and the increase in the carbon content after deoxidation and alloying was 10–16 ppm. The increases in the contents of phosphorus and carbon after deoxidation in a circulating vacuum cleaner are assumed to be associated with their presence in the composition of the alloying deoxidizing agents.
(6) We recommend using additive materials with low phosphorus and carbon contents in their compositions, which would help one to decrease the phosphorus and carbon content in the finished metal and to improve the quality of the finished product.
(7) Based on the assumption that the steel-teeming ladle is intensely destroyed under the action of deoxidizers, we performed a thermodynamic calculation to determine the deoxidizer that exerts the maximum effect on the lining destruction and found that intense destruction of the lining begins after aluminum deoxidation of the metal.