The features of oxidation of steel 15N8G6M3FTB deposited by a flux-cored wire

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Abstract. The scale resistance of the deposited steel 15N8G6M3FTB subjected to surface oxidation at a temperature of 900 °C was studied. It was established that the main increase in the mass of scale for this steel occurs in the first hours, and later this dependence is almost straightforward. The average weight gain of the metal scale of such a coating at 900 °C is 0.0128 kg/(m²·h). It has been shown that the basis of metal oxide of composition 15N8G6M3FTB is hematite Fe₂O₃ and magnetite Fe₃O₄, as well as MnO, which have weak protective properties. The number of other phase compounds with high protective properties is extremely small. The coating of steel 15N8G6M3FTB can be used for applying to the surface of parts operating at low temperatures.

1. Introduction
The increase in operating temperatures of parts and assemblies of petrochemical production plants necessitates the development of effective protection of their surface from high-temperature oxidation [1, 2]. When heated, the metal surface interacts with oxygen to form scale [3]. As a result of changes in the chemical composition of the surface layer of the metal, its mechanical and operational properties are reduced [4]. Therefore, the problem of failure of parts operating in conditions of not only wear but also high temperatures is extremely important.

It is possible to increase the service life of such parts by surfacing the working surfaces with new types of wear-resistant steels [5]. From this point of view, the processes of applying wear-resistant coatings on economically alloyed martensitic steels deposited by flux-cored wire to the working surfaces are widely used [6, 7].

Previous studies of steel 15N8G6M3FTB found that such steel as a result of aging has a significant hardening effect and can be used for wear-resistant surfacing [8]. However, the features of the oxidation of such steel at high temperatures have not been studied.

In this regard, the aim of the work is to study the scale formation and changes in the structure and phase composition of 15N8G6M3FTB steel as a result of exposure to high temperatures in the air.

2. Objects and methods of research
The object of research was cast steel coating deposited by a flux-cored wire based on steel 15N8G6M3FTB, the composition of which is given in Table 1.

Table 1. The calculated composition of the experimental flux-cored wire, %

| Ni | Mn | Mo | FeV | FeTi | FeNB | Na₂SiF₆ | Fe |
|----|----|----|-----|------|------|---------|----|
| 8.5| 6  | 3.5| 3   | 5.2  | 3.3  | 0.3     | 17.6|

Tests of the experimental composition of the coating metal for scale resistance (heat resistance) were carried out in a calm air atmosphere according to standard methods (GOST 6130-71). An increase in the mass of samples at a temperature of 900 °C during a test period of 25 hours was chosen as a characteristic of scale resistance.
Metallographic studies of oxidized samples were carried out using a JEOL JCM-5700 scanning electron microscope with a JED-2300 energy dispersive spectrometer.

X-ray phase analysis of oxidation products was carried out on a Shimadzu XRD-7000 multifunctional X-ray diffractometer. To do this, the obtained scale of the experimental composition of the metal coatings was crushed in an agate mortar under a layer of ethyl alcohol, in order to obtain a fine powder. After drying, the powder was pressed under pressure of 50±5 MPa on a hydraulic press into tablets with a diameter of 10 and a thickness of 5 mm. Filming was carried out in filtered copper $K_\alpha$–radiation with an operating mode of an X-ray tube of 40 kV and 40 mA. The average value of the radiation wavelength fixed by the detector is $\lambda=1.5406$ Å. To process and analyze diffraction spectra, the Match! Software package version 3.8.1.151 was used.

3. Results of the experiments and discussion

The results of measuring the mass gain of metal deposited by a flux-cored wire of composition PP15N8G6M3FTB depending on the exposure time in an oxidizing atmosphere are presented in Figure 1.

As you can see, the main increase in the mass of scale occurs in the first hours, and later this dependence is almost straightforward. If in 1 hour of testing the increase in the mass of scale was about 0.0432 kg/m², then in 5 hours it was 0.0785 kg/m², and after 25 hours it was only 0.3209 kg/m². The thickness of the scale after 1 hour of testing at 900 °C is 76.79...99.83 microns, and after 5 hours - 104.31...133.37 microns. On the surface of the sample after 25 hours of testing, a thick layer of dark gray, friable bubble dross formed, upon cooling of which there was a partial detachment of the dross from the surface due to the occurrence of internal stresses. The thickness of the remaining part of the scale is 300.18...344.49 microns.

The microstructure of the thin section of the lateral surface of the metal 15N8G6M3FTB with scale obtained after holding for 25 hours with the location of the scan points is shown in Fig. 2. The chemical composition of the scanned areas is presented in Table 2.

Figure 2 shows that the scale is layered, with many outgoing cavities of various shapes and sizes. In the outer layer of scale, the amount and dispersion of residues of non-oxidized metal is much less than in the layer adjacent to the metal.

Scan points 1, 2, 3 correspond to the base metal; point 4 – transition zone; 5, 6 – scale.

The results of chemical analysis show that the concentration of Nb and Mo in the metal increases as it approaches the transition layer (points 1, 2, 3), and the concentration of Ti, V, Mn, Ni decreases. Nitrogen and oxygen appear in the transition layer (point 4); the concentration of all the main alloying elements except Ni is high. In the subsequent scale layer (point 5), mainly Fe, Mn, and Ni are present. Only Fe and Mn are present directly in the surface layer (point 6).
The results obtained indicate the formation of significant chemical microinhomogeneity in the deposited coating. As you approach the scale, metal depletion of the main alloying elements is observed. On the surface of the scale there is a complete absence of alloying. A rapid decrease in the concentration of the main alloying elements is associated with their active participation in diffusion processes due to high temperatures [9].

![Figure 2](image2.png)

**Figure 2.** The lateral surface of a thin section of a metal of composition 15N8G6M3FTB with an oxide layer after a scale test at 900 °C – 25 hours with the location of the scan areas at points

| Point № | N   | O   | Ti  | V   | Mn  | Fe  | Ni  | Nb  | Mo  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1       | 0   | 0   | 1.15| 1.99| 5.6 | 70.05| 13.29| 3.57| 4.35|
| 2       | 0   | 0   | 0.58| 1.42| 4.43| 76.29| 10.62| 2.03| 4.63|
| 3       | 0   | 0   | 0.94| 1.28| 4.77| 70.87| 7.9  | 4.17| 10.07|
| 4       | 3.29| 13.86| 2.31| 2.31| 2.95| 63.42| 1.9  | 5.13| 4.83|
| 5       | 1.28| 16.37| 0.05| 0   | 3.26| 75.14| 3.6  | 0.23| 0.07|
| 6       | 0   | 4.04| 0   | 0   | 12.46| 82.36| 0.45 | 0   | 0.69|

**Table 2.** The chemical composition of the scanned metal regions of composition 15N8G6M3FTB after a scale test at 900 °C – 25 hours

The characteristic structure of the surface part of the scale with the location of the scanning points is shown in Fig. 3. The chemical composition of scanned objects is given in Table 3.

![Figure 3](image3.png)

**Figure 3.** The surface of the metal oxide layer of composition 15N8G6M3FTB after the scale test at 900 °C – 25 hours with the location of the scan areas at points
It is seen that the surface layer of the scale is a mixture of mostly large round particles up to 30 microns in size and a small amount of small particles also round in sizes up to 5 microns. Large particles contain mainly Fe and a little Mn (points 1, 2, 7, 12-21). Small particles contain Fe and a large amount of Mn (points 3-6, 22-28, 31-33). The content of all the main alloying elements in the particles is negligible, or they are completely absent. Almost all objects contain nitrogen and oxygen.

The results of X-ray diffraction analysis of the metal scale composition 15N8G6M3FTB after exposure for 25 hours at a temperature of 900 °C are shown in Table 4.
Table 4. Phase composition of the metal scale of composition 15N8G6M3FTB after holding at a temperature of 900 °C

| №  | Phase designation and card number | Intensity | Type of grid  | Grid parameters |
|----|----------------------------------|----------|---------------|----------------|
| 1  | Fe₂O₃ (96-154-6384)              | 920      | trigonal (hexagonal axis) | a = 5.0300 Å  |
| 2  | Fe₃O₄ (96-900-2320)             | 870      | cubic         | c = 13.7500 Å  |
| 3  | MnO (96-900-6666)                | 210      | cubic         | a = 4.4042 Å  |
| 4  | TiN (96-110-0039)               | 210      | cubic         | a = 4.4000 Å  |
| 5  | Fe₃C₀.₁₁₆N.₁₁₆ (96-152-5727)    | 120      | trigonal (hexagonal axis) | a = 4.7644 Å  |
| 6  | Ni₀.₉₀₆Ti₀.₀₉₄ (96-152-2996)    | 80       | cubic         | c = 4.3906 Å  |
| 7  | Fe₆Ni₃ (96-152-4834)            | 80       | cubic         | a = 3.5556 Å  |
| 8  | Fe (96-900-6602)                | 60       | cubic         | a = 3.1590 Å  |
| 9  | Ni₃C (96-152-8751)              | 40       | trigonal (hexagonal axis) | c = 12.9200 Å |
| 10 | TiC (96-153-9506)               | 27       | cubic         | a = 4.3500 Å  |
| 11 | TiV (96-152-7472)               | 27       | cubic         | a = 3.1590 Å  |

The results obtained show that the basis of metal scale of the composition 15N8G6M3FTB is hematite Fe₂O₃ and magnetite Fe₃O₄, as well as MnO, which have weak protective properties. The number of other phase compounds with high protective properties is extremely small.

Thus, selective intercrystalline oxidation takes place, the products of which are simple iron oxides.

4. Conclusion
1. The investigated coating of steel 15N8G6M3FTB is subject to significant surface oxidation. The average weight gain of the metal scale of such a coating at 900 °C is 0.0128 kg/(м²•h).
2. The coating of steel 15N8G6M3FTB can be used for applying to the surface of parts operating at low temperatures.

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