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INVESTIGATION OF HEAT-RESISTANT PROPERTIES AND MICROSTRUCTURE OF EXPERIMENTAL STEEL BASED ON THE Cr-Ni-Ti-Nb SYSTEM OBTAINED UNDER INDUSTRIAL CONDITIONS

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Preliminary Note – Prethodno priopćenje

The Nb effect on long-term strength of Cr18Ni10Ti steel is considered. There is substantiated selecting this steel for obtaining cast parts for metallurgical furnaces. It is shown that introduction of Nb in the amount of 1 % into steel of a given composition increases tensile strength and long-term strength by 15 %. Improving the properties is associated with the formation of NbC carbides.

Keywords: Cr-Ni-Ti-Nb steel, heat-resistant, long-term strength, carbides, microstructure.

INTRODUCTION

Cr18Ni10Ti heat-resistant steel is used in many parts of equipment in the metallurgical and oil and gas industries. Examples include parts of furnace fittings, manifolds, furnace rollers, pickling basket boxes and covers, mine retort spouts, etc. [1-2]. Cr18Ni10Ti steel has sufficiently good mechanical properties, shows satisfactory heat resistance and heat resistance properties at a relatively low cost compared with Nimonic alloys, which has led to its wide distribution. However, the service life of parts made of this steel grade is not long enough: on average, parts are replaced every 2 - 3 months, which leads to equipment downtime and reduced productivity.

One of the current trends in improving the properties of heat-resistant steels is the alloying with refractory elements such as Mo, W, Hf, and Nb [3-9]. Alloying with these elements, as strong carbide-stabilizing, leads to the formation of small refractory carbides, evenly distributed throughout the matrix and having a more rounded shape compared to the classic primary carbides.

In works [10,11] it was noted that in the process of operation NbC carbide is transformed into the G-phase composition of $Ni_{16}Nb_7Si_6$ or Nb_3Ni_2Si, which negatively affects the heat- resistant. It was shown that the presence of Ti (from 0,2 %) in the alloy composition prevents the formation of unwanted G-phase [10].

In an earlier study [12] it was shown that the niobium alloying 1 % of steel containing Cr, Ni and Ti leads to an increase in the ultimate strength of about 17 % compared to the original steel without additional alloying. The increase in the long-term strength limit is associated with the formation of NbC carbides. According to earlier studies [12] in the experimental laboratory alloy G-phase was not detected, which can be explained by the presence of titanium in the initial composition of the alloy in the amount of 0,9 % wt.

The purpose of this study is to verify previously obtained laboratory results at the industrial site, since melting and casting production can lead to levelling the results of niobium alloying for various reasons: reduction of the metallurgical quality of steel, difficulties in introducing the ligature, carbon pickup, etc.

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EXPERIMENTAL STUDIES

Equipment and tools

Industrial experiments were conducted at the production site of KMZ named after Parkhomenko LLP (Karaganda, Kazakhstan). Smelting was carried out in an arc furnace, which makes it possible to smelt this steel grade containing a large number of refractory alloying elements, the ability to regulate the content of injurious impurities and temperature control throughout the volume without local overheating. Ferroniobium FNb65 was introduced into the melt 30 minutes before the end of melting in order to make the final composition of the alloy with niobium content of about 1 %. For better assimilation, ferroalloy of size class 3 was used (GOST 16773-2003). In order to improve the metallurgical quality of steel (reducing the number of non-metallic inclusions, increasing structural homogeneity, and reducing gas content in the metal) ultrasonic treatment of the melt was carried out on the manufacturing plant.

The chemical composition of the experimental alloy was monitored using a Poly Spec-F spectrometer Table 1.

Table 1 **The material chemical compositions**

Element	Sample		
	Cr18Ni10Ti steel (reference sample)	Experimental steel (laboratory)	Experimental steel (industrial)
Cr	17,6	17,9	17,7
Ni	9,7	9,4	9,0
Ti	0,78	0,8	0,9
Al	-	0,04	0,05
Mn	1,85	1,80	1,85
Si	0,60	0,71	0,92
Ta	-	-	-
Nb	-	0,95	1,15
C	0,85	0,15	0,21
Fe	rem	rem	rem

At the end of melting, the grates were cast from the experimental alloy (sample 3) by lost foam casting (LFC). This casting method was chosen because this technology is widely used at this company. The finished castings were subjected to heat treatment consisting of hardening at 1 150 ^{0}C followed by tempering at 500 ^{0}C.

Samples were cut from the finished castings to determine hardness, tensile strength, and long-term strength.

Hardness measurements were made on a DuraScan-70 Vickers microhardness tester (EMCO-TEST, Prüfmaschinen GmbH).

Tensile strength tests on INSTRON-100 machine and long-term strength tests on TRMP-50 machine at 600 ^{0}C for 100 hours.

The structure of the experimental alloy was studied by EDA (energy-dispersive analysis) and COMPO (backscattered electrons) methods on a JEOL JSM-7600F scanning electron microscope (Japan).

Figure 1 shows the elemental composition of the melted alloy (sample 3).

Elemental composition data obtained by MRSA correlate well with chemical analysis data, which indicates the correct smelting and correctness of the developed process flowchart.

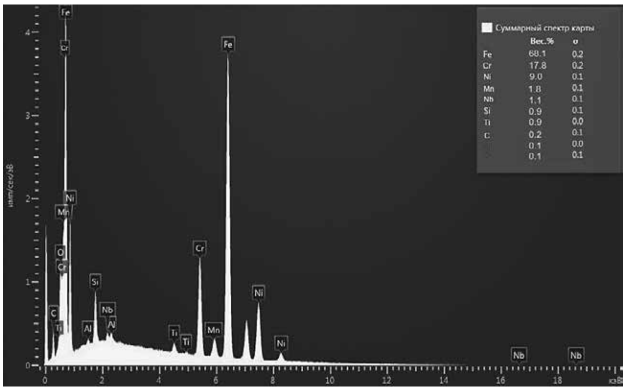
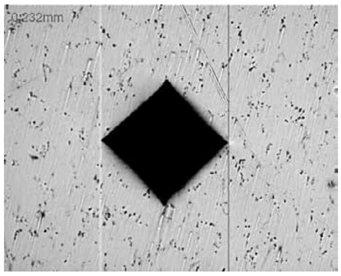


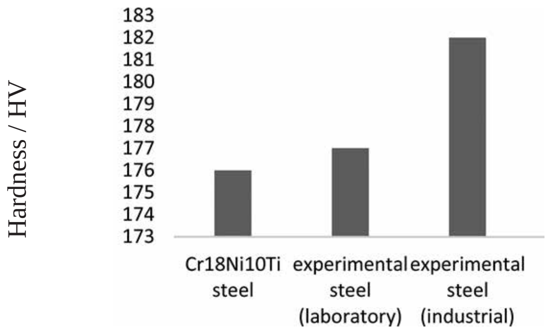
Figure 1 Elemental composition of the experimental alloy

Figure 2 shows the results of hardness measurements on the studied samples.

It should be noted that a slight increase in the hardness of sample 3 compared to sample 2 (3-4 %) is associated with the development of carburizing, which takes place during casting on gasified models. Indirectly this fact is confirmed by some increase in carbon content (Table 1).

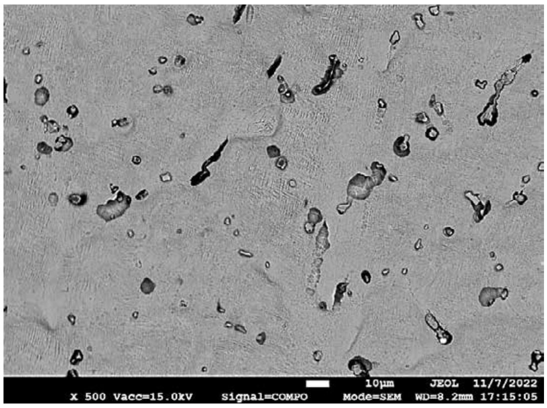


a)

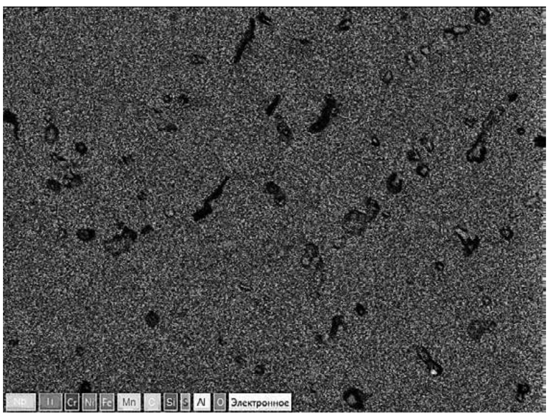


b)

Figure 2 Determination of hardness of samples: a - example of hardness determination; b - obtained hardness results.



a)



b)

Figure 3 Microstructure of an experimental industrial alloy (sample 3): a - microstructure after pickling; b - map of element distribution;

As noted above, studies conducted in work [6] indicate the transformation of the carbide phase during heating and stress, which leads to the formation of an unwanted G-phase and a decrease in the heat resistance. Consequently, it is necessary to control the presence in the structure of the appearance of this phase during any change in the composition, especially with the introduction of strong carbide-stabilizing, which include niobium.

In order to control the structure for the presence of G-phase, the structure of the industrial alloy was analyzed (sample 3). Figure 3 shows the alloy microstructure and element distribution map.

As expected, the microstructure of the alloy is represented by the austenitic matrix, in which Cr, Ti, Nb are partially miscible, as well as inclusions of various shapes and nature. The presence of oxygen and carbon in the composition suggests the presence of nonmetallic inclusions and a carbide phase in the structure.

The analysis of individual objects made it possible to identify these inclusions as TiC, NbC carbides, and a number of nonmetallic inclusions. The analysis of the inclusions did not reveal the presence of G-phase, so we should expect the values of the ultimate strength comparable to the same parameters in the laboratory samples (sample 2).

Tests of strength and durability of the samples were carried out in accordance with the relevant GOST. Table 2 shows the test results. For comparison, the data on the same parameters for the reference sample and the laboratory alloy are given [5]. As a comparison sample we used samples cut from Cr18Ni10Ti steel.

Table 2 **Heat-resistance characteristics of the experimental alloy**

Sample number	Samples	σ_{100}^{600} / MPa	R_m / MPa
1	Sample comparison (Cr18Ni10Ti)	245	510
2	Experimental alloy (laboratory)	313	606
3	Experimental alloy (production)	295	590

Analysis of the results shows that the parameters of long-term strength and durability of laboratory and industrial samples are almost the same, the difference does not exceed 5 %, and the strength values in both samples are higher than in the reference sample. A slight difference in the strength values of laboratory and industrial samples can be explained by a decrease in the metallurgical quality of steel, which, in any case, takes place when melting in an industrial furnace.

CONCLUSIONS

The results of studies of the structure and properties of samples melted under production conditions indicate a positive effect of niobium alloying. The presence of about 1 % niobium in Cr18Ni10Ti steel results in the formation of niobium carbide, which is an additional strengthening phase at high temperatures. The presence of titanium in the alloy composition avoids the undesirable G-phase, which can form when alloyed with niobium. The tests showed a good correlation between the laboratory data and the data obtained at the production site.

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Note: Responsible for the English language is Natalya Drak, Karaganda, Kazakhstan