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# Structure, Phases and Alloying Elements Distribution of Nikorim (High-Temperature Strength Ni-Cr Alloy) in Its Cast Form.

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Structure, phase's content, hardness, microhardness of structure components in high-temperature strong nickel-chromium alloy are studied. $Cr_7C_3$, TiC carbides and $Ni_3Al$ intermetallic compound are exposure with the help of X-ray structure analysis. It was shown that research alloy is characterized of structure homogeneity in a broad temperature interval. This alloy has structure and properties stability of details for metallurgical equipment working at the high temperatures.

Keywords: STRUCTURE, PHASE'S CONTENT, HIGH-TEMPERATURE STRONG, NICKEL-CHROMIUM ALLOY, CARBIDE, INTERMETALLIC COMPOUND

## Introduction

High-chromium steels and alloys are expanding their applications in modern technology due to the rapid development of machine building technologies for chemical industry, power plant engineering, and others. The demand for higher working temperatures and stresses and aggressive working media exclude many items from the steel range in the above mentioned applications and make high-chromium alloys the only possible metal to be used there [1].

High-chromium high-temperature strength alloy may contain several alloying elements; these alloying elements sometimes act in different ways to modify the structure and properties of the alloy. Therefore, one can obtain the required structure and properties of an alloy only by means of carefully chosen combinations and percentages of the alloying elements. High-temperature strength alloys of Ni-Cr group are known to possess better high-temperature strength than that of high-chromium cast irons and steels [2].

From the standpoint of their chemical compositions and phases, Ni-Cr high-temperature strength steels vary greatly due to the ability of nickel to dissolve partially the alloying elements, which respectively influence its high-temperature strength. Therefore, one cannot help noting that nickel alloys are promising alloys to enhance their high-temperature strength. The increase in aluminum and titanium contents in a Ni-Cr alloy develops better long term strength of the alloy because these elements form the redundant phases to strengthen the alloy: η ($Ni_3Ti$), γ ($Ni_3Al$), and $Ni_3$, (Al, Ti). Introduction of alloying heat-resistant elements into the chemistry of a nickel solid solution along with formation of several phases to strengthen the alloy ensures its better high-temperature strength [3].

More importantly to point out, that the majority of alloying elements to be dissolved in nickel have positive influence on its high-temperature strength and therefore they may be defined as possible candidates for alloying; but only three of them (Fe, V, Be) have no bearings on strength of Ni-Cr alloys at the temperature of 700°-800°C while W, Co, Nb, Mo, Ti, Al, Mn, Cr may be considered as effecting elements to strength the alloy [4].

## Results and Discussion

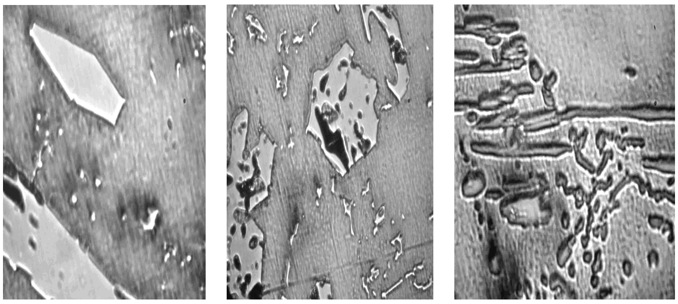
The present paper investigation studies the Ni-Cr high-temperature strength samples of Nikorim alloy. These samples are to become the initial material for large diameter pipe mandrels that are the tools for rolling. The chemical compositions of the experimental samples are represented in table 1. The alloying elements distribution in phases and structural constituents are studied by means of electron microscope JSM-840 and microanalysis Link-850/500 (Link Analytical production). The investigations are carried out by means of the modes of secondary electrons (SEI) and back scattering electrons (BEI). The beam current of $I=10^{-7}\ldots10^{-10}$A, the beam diameter of 1 … 1.5 mkm, and the voltage of U=20 kV are used to analyze the above-mentioned items. The analysis is carried out with ZAF4/FLS program during 100 seconds. The standard pure samples (99.99% purity) of Link Analytical production are used to compare them with the material under investigation. 10 % nitric acid is used to reveal the samples' microstructure, which is investigated with optical microscope Neophot-21. Microhardness of phases and structural components is defined by using microhardness measuring instrument PMT-3 according a standard procedure. Phase composition of samples is studied on the diffractometer DRON-3M in $FeK_{\alpha}$ - radiation.

In present report, the structure, phase composition, hardness, microhardness of structural components and distribution of alloying elements within phases and structural constituents of high-chromium alloys of Nikorim which are to be used for large pipe production are studied. The samples under investigation are both Nikorim's varieties but in this paper they are referred as Nikorim 1 and Nikorim 2.

**Figure 1** and **Figure 2** represent the microstructural analyses of alloy 1 and alloy 2 (both are Ni-Cr high-temperature strength alloys of Nikorim); they show that from the standpoint of the casting fractures the both alloys possess the structures, which are very close to the homogeneous types. The alloys differ from each other more with the carbon and iron contents (table 1). There are carbides of $Cr_7C_3$ and carbides of TiC in the microstructures of the alloys under investigation. $Cr_7C_3$ is present both in the longitudinal fracture and the lateral fractures. The flaking of $Cr_7C_3$ occurs due to the high carbon content in the alloy. Thus, more carbon content in alloy 2 produces respectively more noticeable $Cr_7C_3$ flaking effect in it, than that in alloy 1. A high carbon content makes carbide $Cr_7C_3$ more brittle during the alloy mechanical operation (or graphic specimen arrangement) and the $Cr_7C_3$ flakes inhomogeneous in its crystal. Therefore, higher carbon content in the alloy makes carbide less stable. These carbides have the regular cubic shape and are distributed inhomogeneously both in carbides of $Cr_7C_3$ and in the casting matrix.

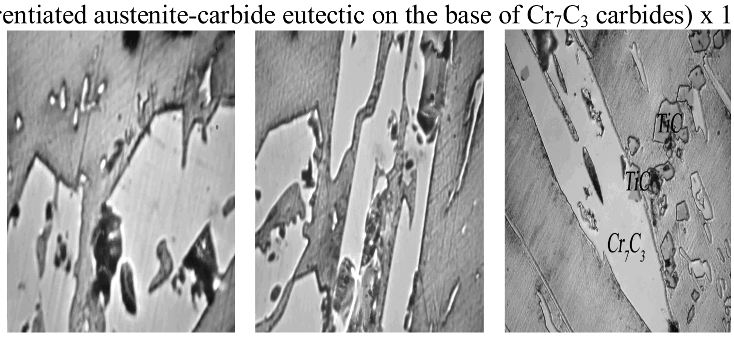
**Table 1.** Chemical composition of Nikorim alloys under research

| №n/s | Chemical composition % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Al | Si | Ti | Cr | Mn | Fe | Ni | C |
| 1 | 1.88 | 0.63 | 0.66 | 36.00 | 0.25 | 1.68 | 57.21 | 1.52 |
| 2 | 1.96 | 0.78 | 0.66 | 35.74 | 0.25 | 2.16 | 55.80 | 2.62 |



a b c

**Figure 1.** Microstructure of Nikorim 1 (a – the longitudinal fracture of $Cr_7C_3$ carbides; b – the lateral fracture of $Cr_7C_3$; c – roughly differentiated austenite-carbide eutectic on the base of $Cr_7C_3$ carbides) x 1000




a b c

**Figure 2.** Microstructure of Nikorim 2 (a – the longitudinal fracture of $Cr_7C_3$ carbides; b – the lateral fracture of $Cr_7C_3$; c – carbide TiC growing together with $Cr_7C_3$) x 1000.

The phases of Nikorim 1 and Nikorim 2 are studied by means of diffraction analysis (**Figure 3, Figure 4**).

**Figure 3** and **Figure 4** represent Nikorim 1 and Nikorim 2. The diffraction analysis reveals their eutectic redundant carbides $Cr_7C_3$ and their high-nickel austenite structures. This is proved by high intensity of the lines (111). The figures of diffraction analysis show that alloy 1 and alloy 2 possess carbides TiC and intermetallic compounds $Ni_3Al$ each.

The distributions of alloying elements within the phases (**Figure 5** and **Figure 6**) and the structural constituents (**Table 2** and **Table 3**) evidence that the structures of alloys are homogeneous. The Cr content and other alloying elements in Nikorim's carbides $Cr_7C_3$, Nikorim's matrix and Nikorim's carbides TiC are also determined. So, carbides $Cr_7C_3$ in sample 1 contains 96.34% of Cr, while carbides $Cr_7C_3$ in sample 2 – 95.35% of Cr. The other alloying elements are present in these carbides in small amounts. Matrix of Nikorim1 contains 72.14% Ni and 25.56% Cr and those of Nikorim 2 – 79.13% and 21.9 % Cr. Nikorim's matrix is a solid solution on the nickel base with FCC lattice. Titanium carbides TiC has respectively titanium percentages of 91.5% and 90.55% in Nikorim 1 and Nikorim 2.

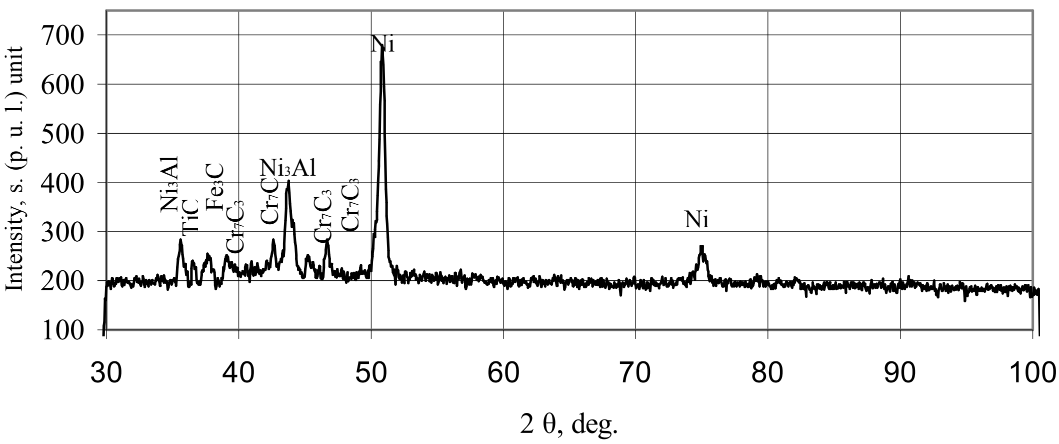



**Figure 3.** Scheme of diffraction analysis of Nikorim 1

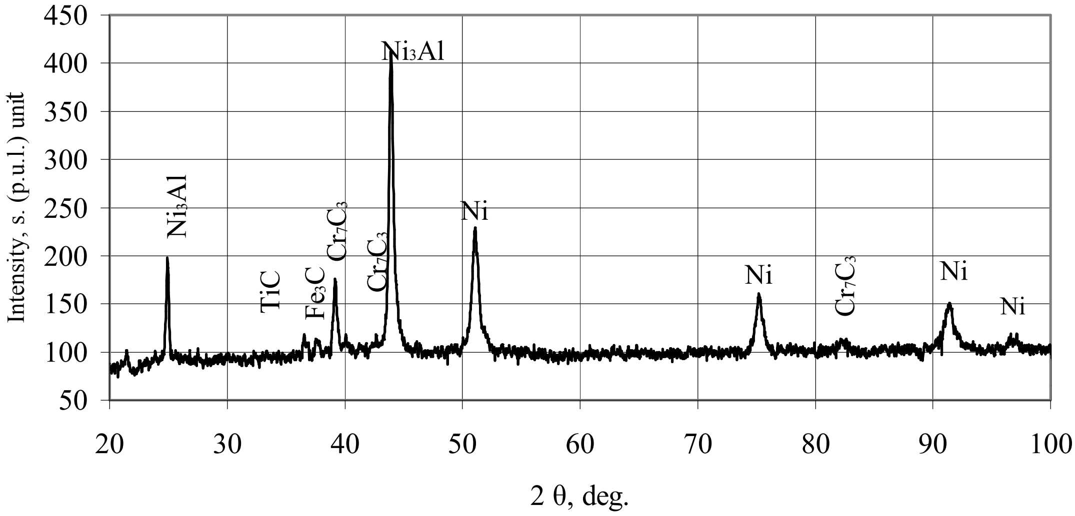



**Figure 4.** Scheme of diffraction analysis of Nikorim 2

The data obtained through the investigation tell us that Nikorim 1 matrix has Cr by 3% higher than that in Nikorim 2 matrix. In Nikorim 1, carbides $Cr_7C_3$ and carbides TiC have higher contents of Fe, Si and Mn than those in Nikorim 2.

The percentages of Ni, Fe, Ti in Nikorim 2

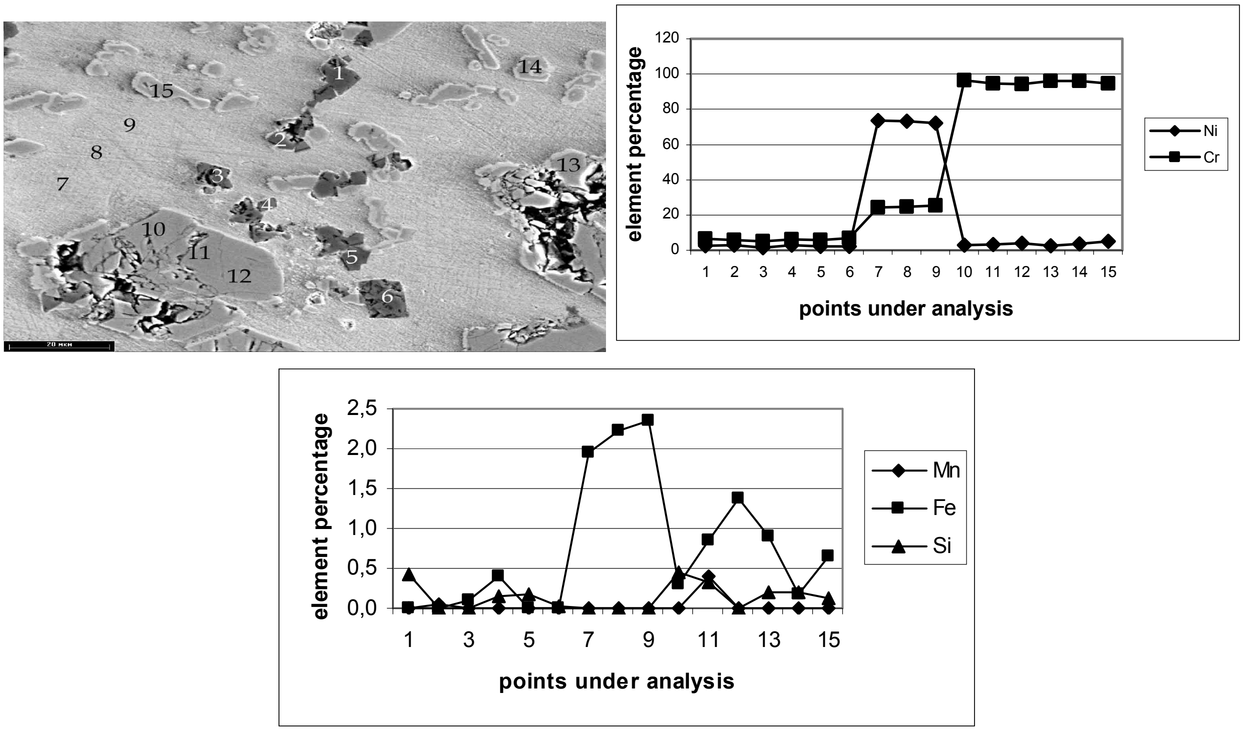



**Figure 5.** Distributions of alloying elements within the phases and structural constituents in Nikorim 1

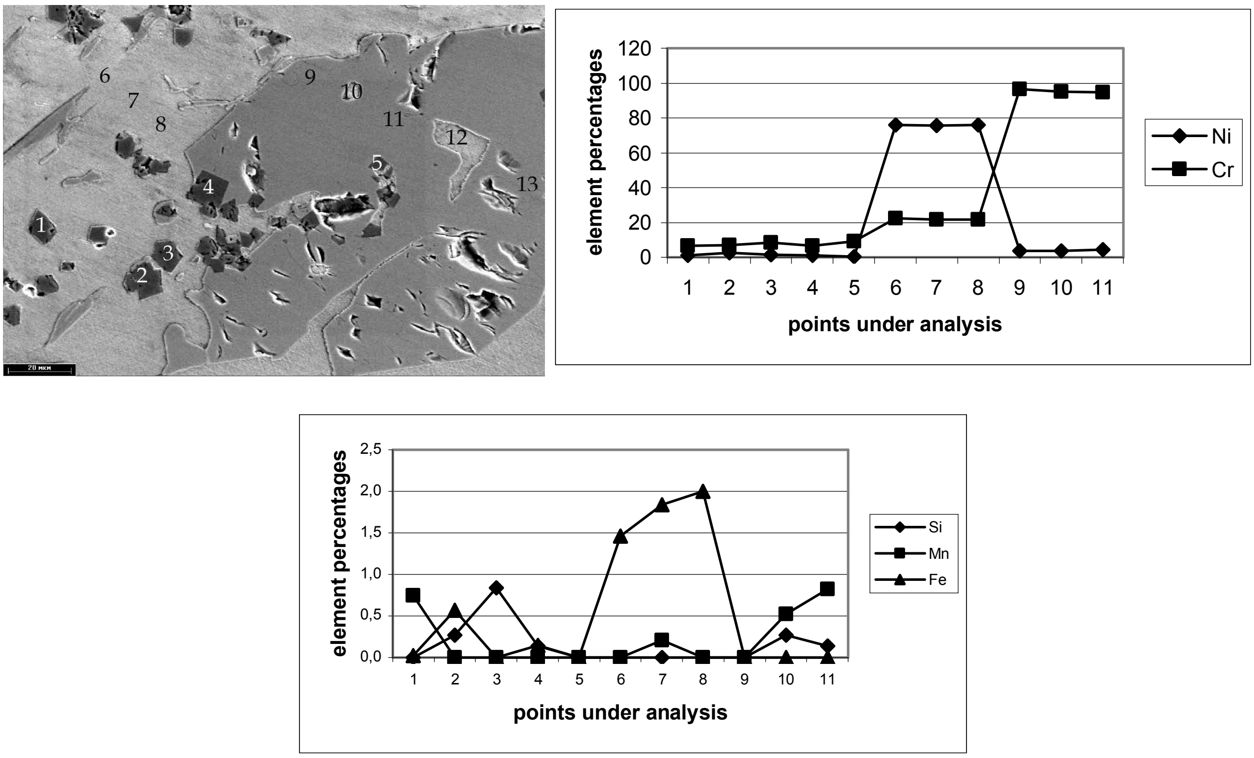



**Figure 6.** Distributions of alloying elements within the phases and structural constituents in Nikorim 2.

matrix are by 7% higher in comparison against to Nikorim 1 matrix. Fe and Ti in Nikorim 2 are inconsiderable higher than those in Nikorim 1. It should be notices that the samples under investigation differ from each other with the percentages of alloying elements in their matrixes, but the amounts of alloying elements in carbide $Cr_7C_3$ and carbide TiC are equal in these samples. Nikorim 1 and Nikorim 2 are identical in hardness, which is 33 HRC. They are also identical in microhardness, which is 2438 MPa. The microhardness of Nikorim 2 carbide $Cr_7C_3$ is higher because it contains more Ni and Mn.

**Table 2.** Distributions of alloying elements within the phases and structural constituents in Nikorim 1.

| Structural components | Alloying elements in structural constituents, % | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cr | Ni | Fe | Ti | Si | Mn | Σ of alloying elements, % |
| Matrix | 24.80 | 72.90 | 2.18 | 0.09 | - | - | 27.07 |
| Carbide $Cr_7C_3$ | 95.32 | 3.55 | 0.71 | 0.18 | 0.22 | 0.07 | 4.73 |
| Carbide TiC | 6.08 | 2.34 | 0.09 | 91.36 | 0.13 | 0.07 | 8.71 |

**Table 3.** Distributions of alloying elements within the phases and structural constituents in Nikorim 2.

| Structural components | Alloying elements in structural constituents, % | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cr | Ni | Fe | Ti | Si | Mn | Σ of alloying elements, % |
| Matrix | 21.90 | 79.13 | 1.77 | 0.31 | - | 0.07 | 24.04 |
| Carbide $Cr_7C_3$ | 95.35 | 3.90 | - | 0.14 | 0.13 | 0.45 | 4.62 |
| Carbide TiC | 7.56 | 1.33 | 0.15 | 90.55 | 0.25 | 0.15 | 9.44 |

**Conclusions**

The structure and phases of the Ni-Cr high-temperature strength alloy called Nikorim are investigated and the carbide analyses are carried out. The investigations show:

1. There is high-nickel austenite, high-chromium carbides $Cr_7C_3$, titanium carbides TiC, and intermetallic compounds $Ni_3Al$ in the structure and phases of Ni-Cr high-temperature strength alloy.

2. The presence of high-chromium carbides in the alloys under investigation ensures their high strength.

3. The casting fractures show that the Nikorim has a homogeneous structure and homogeneous distribution of the alloying elements.

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