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UDC 669.245.018.044:620.193.53

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PREDICTING THE PROPERTIES OF CAST NICKEL-BASED SUPERALLOYS

Details of modern thermally stressed gas turbine engines are made from multicomponent heat-resistant alloys based on nickel, cobalt and iron using equiaxial, directional or single-crystal casting methods. The most critical parts of gas turbine engines are the gas turbine blades, which determine the maximum temperature of the working gas at the turbine inlet. One of the ways to solve the problem of increasing the working temperature of the gas before the turbine is to increase the ratio of the parameters of the crystal lattice of the matrix and γ'-phase [1-7].

For experimental and theoretical studies of temperature performance, a working sample of industrial superalloys was formed. The selection of alloys was made from the standpoint of a variety of chemical compositions (alloying systems). According to the content of chemical elements, they have a wide doping range. The value of the properties of alloys were taken from open sources in articles, books and Internet resources. On their basis, correlation dependences of the "parameter-property" type were established in the form of mathematical models. The resulting equations have sufficiently high coefficients of the correlation criterion $R^2>0.85$ and can be used for predictive calculations of these characteristics with a relative error of about 4%.

The phase composition was determined by XRD method using Bragg-Brentano focusing on a RIGAKU MINIFLEX 600 diffractometer (CoKα-radiation). The samples were examined in the range of angles 20...120 according to the modes: U=30 kV, I=15 mA, scanning step 0.1°

Dimensional discrepancy δ or γ/γ'-misfit was calculated using the formula from expression 1:

$$\delta = 2\frac{a_{\gamma'} - a_{\gamma}}{a_{\gamma'} + a_{\gamma}} \times 100\% \qquad (1)$$

where aγ and aγ' are the lattice periods of the γ- and γ'-phases, respectively.

As a result of the analysis and processing of experimental data, the ratio of alloying elements:

$$K_{\gamma'} = 5\frac{\sum_{\gamma'} (Al+Ti+Nb+Ta+Hf)}{\sum_{\gamma} (Cr+W+Mo+Re+Co+Ru)} \qquad (2)$$

which is used to assess the mechanical properties, and takes into account the complex effect of the main components of the alloy. The calibration factor (which is used) has been specially selected to provide the best ratio of elements according to the following considerations. γ′-forming elements make a much larger contribution (about 5 times greater) to the strengthening of the alloy, due to an increase in the amount of the hardening phase and an increase in the lattice mismatch γ/γ′ (δ) in comparison with γ-hardening elements. The dimensional discrepancy between the lattice parameters is associated with the degree of concentration solid solution strengthening of the γ- and γ'-phases, the efficiency of the dispersion strengthening of the alloy, the creep rate and other properties of the alloys. This makes it possible to relate the Kγ′ ratio with the properties of multicomponent systems.

It has been established that the size discrepancy δ (for single-crystal alloys) has an exponential dependence. An increase in the Kγ′ ratio leads to an increase in δ. It's connected with a decrease in the number of γ-solution hardeners and an increase in γ′-forming elements that affect the parameters of the crystal lattices of the phases and maximize their mismatch.

Experimental verification of the obtained dependences was carried out on industrial nickel-based superalloys ZMI-3U, Udimed-500 and ZMI-M8 (different production technologies) for which the properties obtained by calculation and empirical were compared. The results of calculations of the parameters of crystal lattices obtained from the diffraction pattern, Table 1 shows the data obtained by calculation (according to the obtained dependencies) and experimental data (obtained by the methods described in the second section).

Table 1 - The measured and calculated values of lattice parameters, misfit, and mechanical properties of ZMI-3U, Udimed-500 and ZMI-M8 alloys.

Method of obtaining results	aγ, Å FCC Fm3m	aγ', Å FCC ordered L12	δ^{20}, %	σ_B, MPa	σ_{100}^{1000}, MPa
ZMI-3U					
Calculated	3.578	3.585	0.207	920	155
Experimental	3.580	3.588	0.220	980	175
Udimed-500					
Calculated	3.569	3.580	0.322	810	100
Experimental	3.569	3.581	0.330	850	130
ZMI-M8					
Calculated	3.575	3.599	0.676	700	-
Experimental	3.575	3.600	0.697	670	-

Table 1 shows that the calculated and experimental data are in good agreement with each other in almost all parameters. There is a slight discrepancy due to possible measurement and calculation errors. Thus, the dependences obtained can be used to predict the properties of nickel-based superalloys when developing new compositions or improving existing ones.

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UDK 669.1+662.6

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REGARDING THE ANALYSIS OF THE EFFECTIVENESS OF COKE SUBSTITUTES IN THE BLAST FURNACE PROCESS

Coke was and remains irreplaceable and one of the most expensive components of blast furnace charge, the cost of which only increases over the years. One of the reasons is the reduction of the coal raw material base for the production of coke, which is accelerating. These circumstances constantly prompted scientists and practitioners of metallurgy to search for alternative solutions and technologies, which can be bring to two directions:

- replacement of coke as a reducing agent and heat source in the blast furnace process;
- replacing the blast furnace process with another one, in which the reducing agent can be gas with appropriate properties and/or solid or liquid fuel containing carbon, hydrogen and their compounds.

It is well known that the first direction has certain limitations regarding the maximum possible replacement of coke due to the need to ensure the gas permeability of the charge column. The practice of the blast furnace process with the pulverized coal injection (PCI) into the blast furnace as a substitute for coke showed that achieving high rates of specific coal consumption (200 kg/t of cast iron and more) requires a set of measures that ensure stability (sustainability) of the main process indicators and the use of high-quality coke qualities (strength in a solid and especially hot state). Even under ideal conditions and state-of-the-art PCI blowing equipment and process control, it will still require about 300 kg of coke