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Physical Chemistry

Research of the Alloy VZh 98 with the System Co-Mo-Cr-Si-B Interaction Processes

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ABSTRACT. The purpose of the work is the research of the processes of the interaction of the system Co-Mo-Cr-Si-B with the heat-resistant nickel alloy VZh 98 concerning the development of the technology of strengthening of the contact surfaces of the working blades of the ship gas turbine engines. During this work the methods of the microroentgen spectral analysis, the electron microscopy were used. The adhesive activity of the researched alloys was researched by the method of horizontal drop. It showed that the experimental compositions have high adhesive activity relating to the heat-resistant nickel alloys at the temperatures 1190…1210°C, which creates the favourable conditions for their use in the ship gas-turbine building. *© 2019 Bull. Georg. Natl. Acad. Sci.*

Key words: heat-resistant nickel alloys, wear-resistant materials, microstructure, separation of chemical elements, adhesive activity

The important problem of the ship gas-turbine building is the need of the increase of efficiency, reliability and the resource of the gas-turbine engines operation. First of all, these parameters are identified by the intensity of the work blades contact surfaces wear, which are in the most difficult conditions of operation. That is why the materials and the technologies of strengthening of the contact surfaces require development of new progressive solutions.

Today, there is a wide range of the wear-resistant materials, which can be applied on the contact surfaces with melting or without melting of the base material [1]. In this case, the most important criteria of the workability is their melting temperature and the possible for use methods of application. In the conditions of the concrete production, the specified criteria can give the mutually exclusive action, which complicates the choice of the optimal material and technologies [2].

In shipbuilding, gas-turbine building heat-resistant nickel alloys of types ChS88U-VI, ChS70U-VI and others are used for the production of the working blades. The specified alloys are strengthened by the use of disperse separations of γ′-phase $Ni_3(Al, Ti)$, which has the tendency for coagulation during the interaction of high temperatures. It creates good conditions for the increase of wear intensity, including the intensification of the processes of the surface ball oxidation, which is the de-enrichment by the alloying elements.

These alloys are not melted practically because the temperature of their heating during the application of the wear-resistant material is no more than 1210…1220ºC. In other case, there is the transient decrease of the basic material strength, which leads to the degradation of γ'-phase and the appearance of the fractures in the point of melting [1]. That is why the alloy, which strengthens the contact surface, must have the temperature of melting no more than 1210…1220ºC during the application in liquid condition. At high melting temperature, its joint with basis can be executed, for example, by the use of high-temperature soldering. But the construction of the turbine blades does not always allow to use this efficient method.

The wear-resistant materials for the ship-turbine should be classified in two groups in accordance with the melting temperature: it is below or over 1210…1220ºC. The difficult problem is the development of the materials, which are of the first group. They have the necessary level of wear-resistance at working temperatures (up to 900ºC) and can pass the short-time thermal loadings at the temperature up to 1150ºC, which is the closest to the conditions of the dissolution of γ' - phase in the base metal.

The well-known alloys of the first group are of the composition KBNKhL-2, for example, with the melting temperature at the level of 1070…1090ºC, which does not give the possibility to pass the short-time heating up to 1150ºC [3] for the alloy.

All known alloys on nickel and cobalt base can be in the second group, for example, the alloys VZhL-2, VKNA-2M [4], V3K-r [5], Stellite 12 [6], Kh30N50YU5T2 [7], Kh25N10B8 [4], KhTN-61 [8], KhTN-62 [9], Tribaloy T-800, T 400, T 401 [10] etc. The listed alloys have the melting temperature more than 1220ºC, which makes their use difficult during applying on the contact surfaces of the working blades of the ship gas-turbine engines by the method of melting.

That is why, in the Admiral Makarov National University of Shipbuilding, with the Zorya-Mashproekt Gas Turbine Research and Development Complex, the perspective wear-resistant materials KMKh and KMKhS were developed. They have the necessary level of the wear-resistance at working temperatures up to 900ºC and the melting temperature less than 1220ºC [2]. The chemical composition and the alloys melting temperature are shown in Table 1.

The purpose of the work was the research of the processes of the interaction of the wear-resistant materials with the heat-resistant nickel alloy VZh 98, concerning the development of the technology of strengthening of the contact surfaces of the working blades of the ship gas-turbine engines. The specified alloy has the classical level of the alloying, which allows to establish the

Table 1. Properties of the alloys KMKh and KMKhS

Alloy brand	Chemical composition, % mass							Melting temperature, ºC*
	Co	Cr	Mo	Si	B	Ni	Cr_3C_2	
KMKh	Base	17-18	27-28	2.8-3.2	0.8-1.2	–	–	1185^{+5}
KMKhS	Base	17-18	27-28	2.8-3.2	0.8-1.2	2.8-3.2	1.9-2.1	1165^{+5}

* Melting temperature has been identified by the method of high-temperature differential thermic analysis.

Table 2. Chemical composition of the alloy VZh 98

Alloy brand	Chemical composition, % mass.							
	Ni	C	Mn	Si	Ti	Cr	Fe	W
VZh 98	Base	≤ 0.1	≤ 0.5	≤0.8	0.3 - 0.7	23.5 - 26	≤ 0.4	13 – 18

general regularities of the influence of the quantity of the alloying elements of the base metal into the adhesive characteristics of the alloys, which are melted and the chemical composition of the melted ball in accordance with the melting temperature. The chemical composition of alloy VZh 98 is shown in Table 2.

The activity of the alloys KMKh and KMKhS were researched by the method of drop in the calm state during the meltdown in the vacuum of 10-2 Па on the backing made from alloy VZh 98. The duration of ageing at the temperature from 1175 up to 1210ºC is 3 minutes. The analysis of the received results showed that both alloys have high adhesive activity concerning the alloy VZh 98. At heating temperature 1175…1185ºC the edge angle of wetting for the alloy KMKhS exceeds 12 degrees, and for the alloy KMKh – 20 degrees, which is not enough from the point of view of workability. In the fusing temperature interval 1190…1210ºC, the edge angles of wetting are less than 12 degrees for the alloy KMKh and less than 5 degrees for the alloy KMKhS. Later the areas of spreading are more than 0.5 mm^2/mg for both alloys, which is more than enough from the point of view of the workability and it creates favourable conditions for their production use.

The separation of the chemical elements in the area of the interaction of the alloys KMKh and KMKhS with the heat-resistant alloy VZh 98 at the range of temperature 1175…1210ºC is shown in Figs. 1-2. The analysis of the interaction of the alloy KMKh with the alloy VZh 98 at the temperature 1175ºC shows (Fig.1, a-c) that nickel from the base metal passes into the melted ball. At the distance of 125 microns from the line of the joint, its concentration is 1% mass, and at the distance of 390 microns – 0% mass. The mass particle of Cr in the base metal at the distance of 270 microns from the joint can be 30% mass, at the standard concentration for the alloy VZh 98 24…26% mass. The decrease of the Cr concentration in some points of the melted metal is connected with the ingress into “light” phase, which is blocked by Cr (9…11% mass), and near the joint has the concentration of Cr – 18…16% mass. Co is in the base metal at the distance of 10 microns from the line fusing (up to 5% mass) and at the distance of 120 microns from the line of the fusion of alloy KMKh, its particle is in accordance with the base composition (in the “light” phase, it can be decreased up to 35% mass).

The duration of the transfer zone of Mo from the melted into the base metal is very small. There is the small increase of Mo concentration in the base metal (up to 1.5% mass) at the distance of 10 microns from the line of the fusion. The concentration of the Wo concerning the base metal up to the line of the joint is at the down limit of the alloy VZh 98 (up to 13% mass). There is the increase of the melted metal concentration in the interval from 1.5 up to 2.0% mass at the distance of 120 microns from the fusion line in the melted metal. Si in the base metal is not found.In the zone of the joint the concentration of Si is 0.5% mass., at the distance of 120…140 microns from the fusion line, in the melted ball, its concentration is 3% mass (in the “light “phase is up to 4.5…5.0% mass). The mass concentration of Ti in the base metal is 0.4…0.6%, in the joint – 0.08%, and at the distance of 100 microns in the melted metal it is not found. The concentration of Fe in the base and melted metal is at the level of the hum values.

The interaction of the alloy KMKhS with the alloy VZh 98 at the temperature 1175ºC executes in accordance with the analog scheme (Fig. 1, d-f). The part of Cr is increasing slowly from the base metal (close to 30% mass) up to the melted metal (20…25% mass). In the “light” phase its concentration decrease can be 15% mass. Co concentration in the base metal, at the distance of 120…130 microns from the fusion line is about 0.4% mass, and from the joint line it is increasing and at the distance of 430 microns in the melting is 48% mass. Ni transfers into melted metal and the depth of the penetration is up to 550 microns. At the

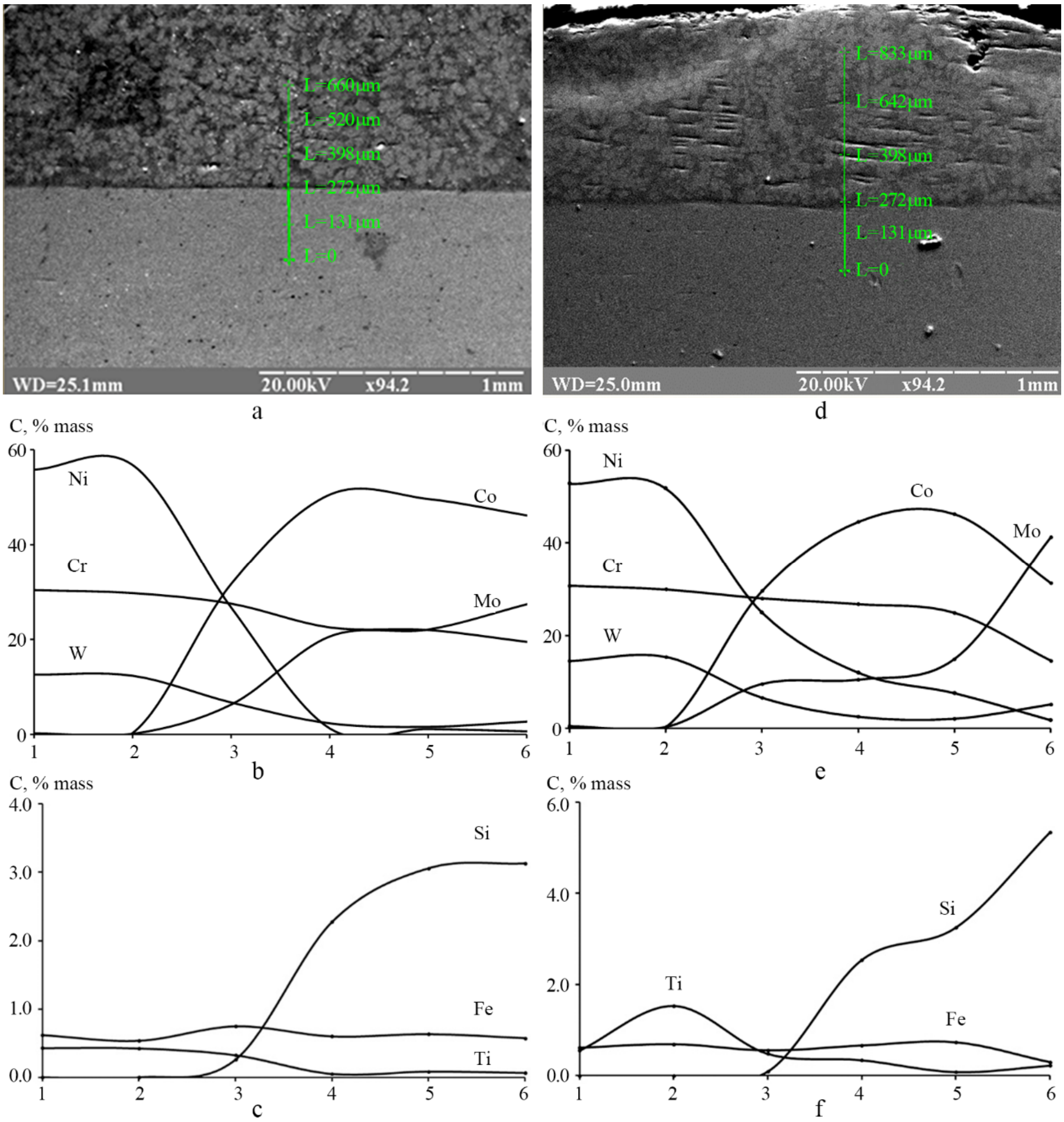

Fig. 1. Microstructure and separation of the chemical elements in the area of the interaction of the alloys KMKh (a, b, c) and KMKhS (d, e, f) with the heat-resistant alloy VZh 98 at temperature 1175°C.

distance of 430 microns from the fusion line, its concentration is about 7% mass. Mo, at the distance of 300 microns, in the base metal is on the hum level (0.3…0.5% mass), which shows its low diffuse mobility in these conditions. In the melted metal its division in the phases is in accordance with the source state of the alloy KMKhS (Table 1). Wo in the base metal at the distance of 270…300 microns is at the level of 14.5% mass, in the joint – 6.5% mass, and in the melted metal at the distance of 600 microns from the fusion line, its part in the "light" phase is about 5 % mass, and in the "dark" – close to 2.5% mass. Si in the base metal is not found, and during transfer through the fusion line it is in the quantity, which is in accordance with the initial composition of the alloy KMKhS (Table 1). Ti in the base metal is at the level of 0.5…0.8% mass, in the melted metal – up to 0.2-0.3% mass at the distance of 120…130 microns from the fusion line. Fe is in the base and melted metal at the hum level.

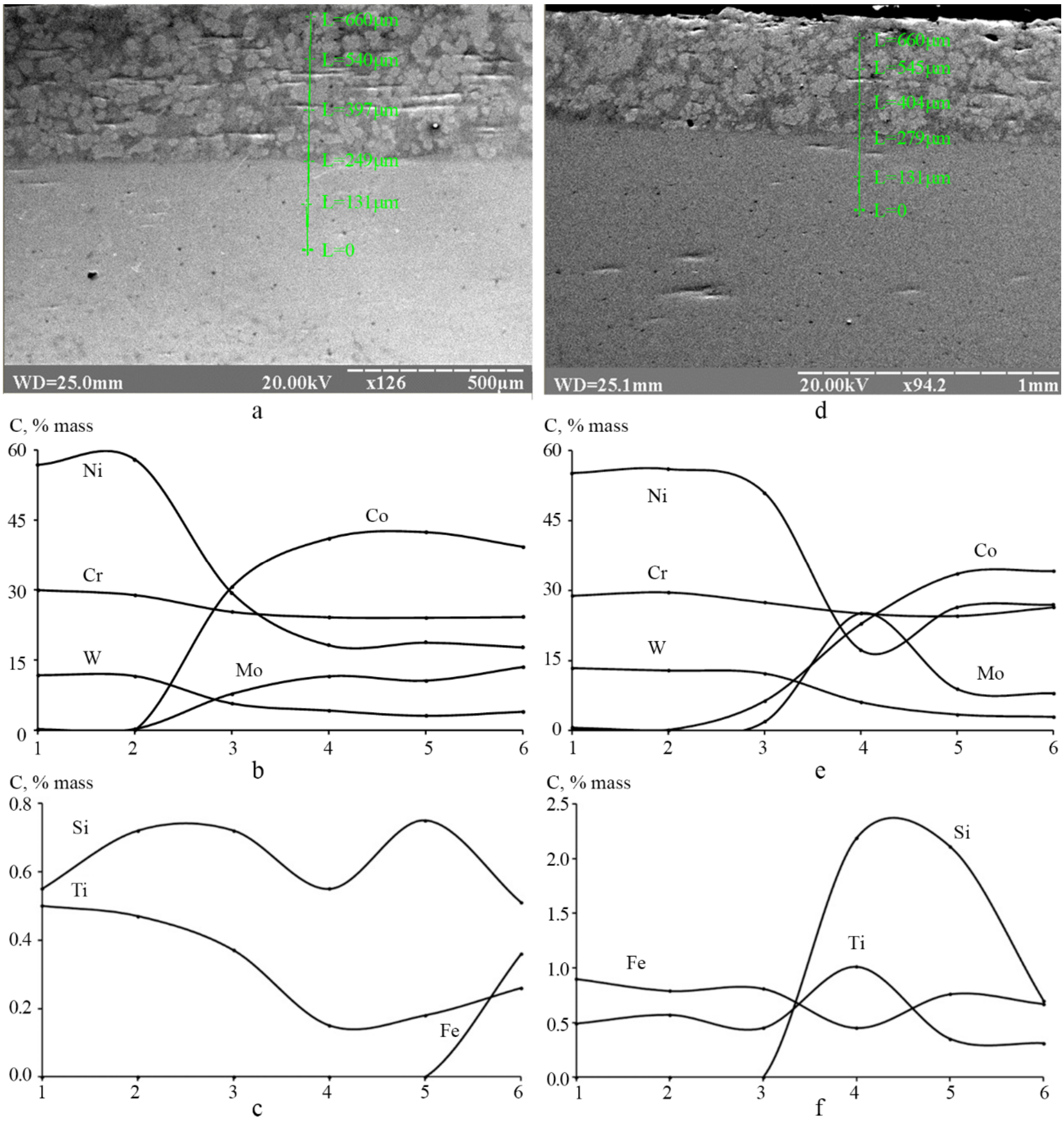

Fig. 2. Microstructure and separation of chemical elements in the area of the interaction of the alloys KMKh (a, b, c) and KMKhS (d, e, f) with the heat-resistant alloy VZh 98 at temperature 1210°C.

At temperature 1210°C the zone of the interaction of the alloy KMKh with the heat-resistant alloy VZh 98 is the following (Fig. 2, a-c). Ni penetrates through the joint (17…30% mass) into the melted ball (up to 11…18% mass) at the distance of 400 microns from the fusion line when its part in the base metal is 56…58% mass , at its reduced part in the “light” phase (up to 5% mass). Cr has the stable index (close to 28% mass) in the base metal, reduces up to 24% mass in melting, 15% mass – in the “light” phase. Co transfers into base metal weakly like earlier: 0.2% mass at the distance of 250 microns from the fusion line. After the fusion line transfer its concentration in the melting is 39…42% mass, with a small reduction (up to 32% mass) in the “light” phase. Mo is in the base metal at the level of 0.25…0.70% mass at the distance of 250 microns from the fusion line, 7…11% mass in the joint and 11…15% mass in melting at the distance of 400 microns from the joint, at stable 38% mass in the “light” phase. Si in the base metal, like earlier, is not found. During melting it is 3% mass, taking into account its position in the “light” phase. Ti and Fe are the same at temperature 1190 °C.

The alloy KMKhS at temperature 1210°C increases its activity concerning the alloy VZh 98 (Fig. 2, d-f). Ni distributes irregularly from 26 up to 28% mass at the distance of 380…390 microns with the single “spikes” in points (2 and 14% mass) in the close to the base metal the volumes of the fusion. Cr shows stably 27…28% mass in the base metal, 24…26% mass is in the joint, it is reducing in the “light” phases of the fusion up to 12% mass. Co is fixed weakly as early, in the base metal (0.2…0.4% mass, at the distance of 280…310 microns from the fusion line, 6-8% mass is in the joint and 35% mass is at the distance of 390 microns from the fusion line (the nominal value is not reached). Mo is inert: 0.45…0.60% mass is in the base metal at the distance of 280…310 microns from the fusion line, 2…8% mass is in the joint, about 8% mass is in the “dark” phase and 42% mass, its concentration in the joint is at the level 5…6% mass, 3…4% mass is the duration of 380 microns in accordance with the fusion line, 10% mass is in the “light” phase. Si in the fusion is at the level of 1.7…2.2% mass, reducing in the “dark” phase up to 0.7% mass and the hopping increase in the “light” phase up to 5.5% mass Ti mass part in the base metal is at the level of 0.5…0.7%, and it is reducing gradually in the fusion up to 0.30…0.35% at the distance of 380 microns from the fusion line, with the sharp reduction practically up to 0% in the “light” phase. Fe concentration in the fusion is at the level of 0.6…0.7% mass with the duration of 380 microns in accordance with the fusion line (in the base metal it is 0.7…0.9% mass), with the reduction up to 0.4% mass in the “light” phase.

So, the increase of the heating temperature from 1175°C up to 1210°C leads to the intensification of the processes of the interaction of the base metal with the fusion, and first of all the processes of the separation of the base metal by the alloy, which is fusing. At the same time the activity of KMKhS alloy is higher than KMKh alloy, which is concerning its additional alloying by chromium carbide. The metal of fusion is becoming full by the chemical elements of the base metal, and first of all, by Ni and Wo. Ti and Fe show high diffuse mobility in these conditions, but their small concentration in the base metal does not make a big influence on the change of the properties of the melted metal. The zone of the diffuse interaction in the melted metal at the close area to the fusion line is increasing from 390 microns (for KMKh alloy) and 550 microns (for KMKhS alloy) at temperature 1175°C, up to 830 microns (for all height of the fusion) for both alloys at the temperature 1210°C. The chemical elements of the melted alloys, such as Co, Mo, Si and Cr, are penetrated weakly in the base metal, which is solid during the process of the fusion. The zone of the diffuse penetration of the specified elements into the base metal, for this temperature interval, is at the level of 10 microns for KMKh alloy at temperature 1175°C, up to 280…310 microns, for KMKhS alloy at temperature 1210°C. In the researched diffuse zones the concentration of the chemical elements are fixed at the level of the tenth particles of the mass %, which cannot have a big influence on the properties of the base metal.

Bo concentration at the researched samples was not identified due to the absence of the technical possibility.

The specified particulars are necessary to be calculated for selection of the temperature of application of the compositions of KMKh and KMKhS alloys on the real details. The excessive increase of the temperature of the base metal heating will have the negative influence on the working characteristics of the melted compositions. The analysis of the received results during the researches shows that the temperature of the heating of the base metal at melting should not exceed the temperature of the melting of the compositions which are applied. So, for KMKh alloy, the optimal temperature of the base metal heating at the melting does not exceed 1185+5°C, and for KMKhS alloy it is 1165+5°C. At the same time, the duration of the stay at this temperature should be minimal. That is why during the development of the real technology we should exactly control the temperature of the heating of the details, which are strengthening and reduce it to the adequate minimum of the adhesive activity of the materials which are melted.

Conclusions. KMKh and KMKhS alloys show high adhesive activity concerning VZh 98 alloy at the specified operational temperature interval of melting (1190…1210ºC). The edge angles of wetting are less than 12 degrees for KMKh alloy and less than 5 degrees for KMKhS alloy. Later the areas of the spreading are more than 0.5 mm2/mg for both alloys, which is adequate from the point of view of the workability and gives specified conditions for their production use. The excessive increase of the temperature of the base metal heating at melting effects badly on the working characteristics of KMKh and KMKhS compositions due to their initial enrichment by the chemical elements of the base. The temperature of the heating of the base metal at melting is necessary to be restricted. It must not exede the temperature of melting of the applied compositions. The optimal temperature of the heating of the base metal for KMKh alloy does not exede the temperature 1185+5°C, and for KMKhS alloy it is 1165+5°C. At the same time, it is necessary to minimize the duration of staying at this temperature.

ფიზიკური ქიმია

VZh-98 შენადნობისა და Co-Mo-Cr-Si-B სისტემის ურთიერთქმედების პროცესების შესწავლა

ა. კოსტინი*, ვ. მარტინენკო*, ა. ლაბარტყავა**

** ადმირალ მაკაროვის სახ. გემთმშენებლობის ეროვნული უნივერსიტეტი, საშემდუღებლო წარმოების კათედრა, ნიკოლაევი, უკრაინა*
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(წარმოდგენილია აკადემიის წევრის გ. თავაძის მიერ)

წინამდებარე ნაშრომის მიზანია Co-Mo-Cr-Si-B სისტემისა და ნიკელის მხურვალმედეგ შენადნობ VZh-98-ის ურთიერთქმედების პროცესების შესწავლა, რაც ასევე მოიცავს გემის აირტურბინული დანადგარების მომუშავე ფრთების საკონტაქტო ზედაპირების გამაგრების ტექნოლოგიის განვითარებას. კვლევის განმავლობაში გამოყენებულ იქნა მიკრორენტგენულ-

სპექტრული ანალიზისა და ელექტრონული მიკროსკოპიის მეთოდები. საკვლევი შენადნობების შემაკავშირებელი მოქმედების შესწავლისას გამოყენებულ იქნა ჰორიზონტალური ვარდნის მეთოდი. ნაჩვენებია, რომ ექსპერიმენტულ შედგენილობებს 1190-1210°C ტემპერატურაზე გააჩნია მაღალადჰეზიური აქტივობა ნიკელის მხურვალმედეგ შენადნობებთან, რაც ხელსაყრელ პირობებს ქმნის გემის აირტურბინების მშენებლობისას მათ გამოსაყენებლად.

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