ISSN 1027-5495. Functional Materials, 29, No.3 (2022), p. 377-380.
doi:https://doi.org/10.15407/fm29.02.377

Influence of the rhenium alloying on the wear resistance of Co–NbC, Ni–NbC eutectic alloys in high-temperature fretting-wear conditions

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Received May 25, 2022

The paper presents the results of comparative tests for wear resistance under conditions of high-temperature fretting-wear of the HTN-62 industrial alloy with a standard set of alloying elements Cr, Al, W, Fe, and experimental alloys: HTN-63 (Co–NbC system) and HTN-66 of (Ni–NbC system), alloyed with 6 mass % of rhenium. A positive effect of the Re-alloying on the wear resistance of the alloys was confirmed based on the comparative tests and microtopographical examinations of friction surfaces. Furthermore, the mechanism of the positive Re-alloying on the wear resistance has been considered.
Keywords: cobalt, nickel, rhenium, alloying, contact surfaces, wear resistance.

Вплив легування ренієм на зносостійкість евтектичних сплавів системи Co–NbC, Ni–NbC в умовах високотемпературного фретинг-зношування. *О.І.Духота, Т.С.Черепова, М.В.Кіндрачук, Г.П.Дмитрієва, А.О.Юрчук, В.О.Максимов, В.Є.Марчук, В.В.Харченко*

Представлені результати порівняльних випробувань на зношування в умовах високотемпературного фретинг-зношування промислового сплаву ХТН-62 системи Co–NbC із стандартним комплексом легуючих елементів Cr, Al, W, Fe та експериментальних сплавів ХТН-63 системи Co–NbC і ХТН-66 системи Ni–NbC, легованих ренієм в кількості 6 мас.%. На основі результатів порівняльних випробувань та результатів мікроскопічних досліджень поверхонь тертя визначено позитивний вплив легування Re на зносостійкість сплавів досліджуваних систем. Розглянуто механізм встановленого позитивного впливу Re на зносостійкість. Більш перспективною є технологія конгломерування рідких сполучних.

1. Introduction

The service life of an aircraft gas turbine engine depends on the wear resistance of the contact surfaces of the turbine blades [1, 2]. Intensive wear of these components results from mutual vibrational micro replacements of mating surfaces operated under high-temperature-fret corrosion conditions.

Welding and soldering are used to increase wear resistance and restore the shroud ends of turbine blades during engine overhaul. Welding and soldering methods were used for surfacing protective layers and plates made of special heat-resistant and wear-resistant alloys. Works [3–16] are devoted to the research and development of heat-resistant and wear-resistant alloys and coatings. Composite eutectic alloys based on iron, cobalt, and nickel with refractory carbides are most acceptable for turbine blades

Table 1. Chemical composition of studied alloys

Alloy	Concentration of component, mass %								
	Co	Ni	Nb	C	Cr	Al	W	Fe	Re
HTN-62	48.2	–	15.5	1.8	20	2	9.5	3	–
HTN-63	42.2	–	15.5	1.8	20	2	9.5	3	6
HTN-66	–	42.2	15.5	1.8	20	2	9.5	3	6

in the temperature mode of operation. Their heat and wear resistance is provided by a structural feature, when particles of high-modulus carbides and borides form a framework inside a relatively plastic matrix based on a nickel, iron, or cobalt solid solution. In addition, the alloying of the metal matrix by Cr, Al, W, Fe provides additional reinforcement and increases its heat and wear resistance.

At present, industrial eutectic alloy HTN-62 (Co, Cr, Al, Fe)–NbC [6, 7] is one of a significant number of materials that meet technological and operational requirements. Eutectic alloys of this system typically include up to 19 % (vol.) of the carbide phase. Increasing their strength and wear resistance by increasing the proportion of carbides is impossible due to excessive growth of the carbide framework and violence of the structure of eutectic alloys. To upgrade the functional properties of HTN-62 alloy, we studied the effect of additional alloying by Mo, Ta, Hf, Ce, and Re [17]. We have found that Re is the most beneficial alloying element for increasing the heat resistance and melting temperature of HTN-62 alloy. Also, in [18, 19] scientific information on the use of Re in heat resistance nickel alloys is presented. Nickel alloying with 3–6 mass% of Re increases structural stability of γ solid solution and promotes precipitation of γ' during aging. But, the effect of additional alloying on wear resistance — the basic characteristic of these alloys — was not studied. To close this gap, we aim to study the effect of additional alloying of Co–NbC and Ni–NbC alloys on their wear resistance under high-temperature fretting wear.

2. Experimental

Taking into account results of previous studies [13, 17], for the understanding of the Re-alloying effect on the wear resistance of gas turbine engine working blades shrouds contact surfaces, the alloys HTN-63 based on cobalt Co (Cr, Al, W, Fe, Re) and HTN-66 based on nickel Ni (Cr, Al, W, Fe, Re) have been chosen. The results were compared with those for the HTN-62 eutectic alloy. The chemical compositions are presented in Table 1.

The samples are made by electric-arc melting with a non-consumable tungsten electrode on the Cu-made water-cooled ladle in an argon atmosphere.

Wear tests were carried out on an MFK-1 friction machine with a tubular electric furnace according to the method [20]. Samples were fixed in the heating zone by special extended holders; they were soldered to the holders with high-temperature solder VPr-24 in a vacuum furnace. It is this material that is used for gluing and repairing the blades of D18 aircraft engines [1]. The samples are in the shape of a cylinder: movable — a cylindrical sleeve or pipe, stationary — a solid cylinder with a diameter 2 mm larger than the outer diameter of the sleeve. The wear track has a circular plane shape that ensures uniform contact and unchanged friction conditions throughout the test, which is identical to the interaction between engine blades. Both the sample and a pair of analogues were made of identical materials (see Table 1). Other test conditions: contact pressure is $P = 20$ MPa, displacement $A = 120$ µm, fretting frequency $f = 30$ Hz, test duration $N = 5{\cdot}10^5$ cycles, test temperature $t = 800$°C. The wear of the samples was measured by a linear method with an accuracy of $1{\cdot}10^{-3}$ mm. The average linear wear was converted into volume wear per unit area (specific volume wear V_s, mm^3/mm^2). Topographical examinations of wear tracks were carried out using a MIM-7 optical light microscope with a digital camera. To study the microstructure of the cross sections of the alloys, a Neofhot-32 microscope was used.

3. Results and discussion

Structural studies of the additionally alloyed HTN-62 confirm that the most optimal is moderately hypereutectic structure, since this alloy contains the maximum allowable amount of the carbide phase (Fig. 1, a). Induction melting of these materials in heat-resistant crucibles is complicated due

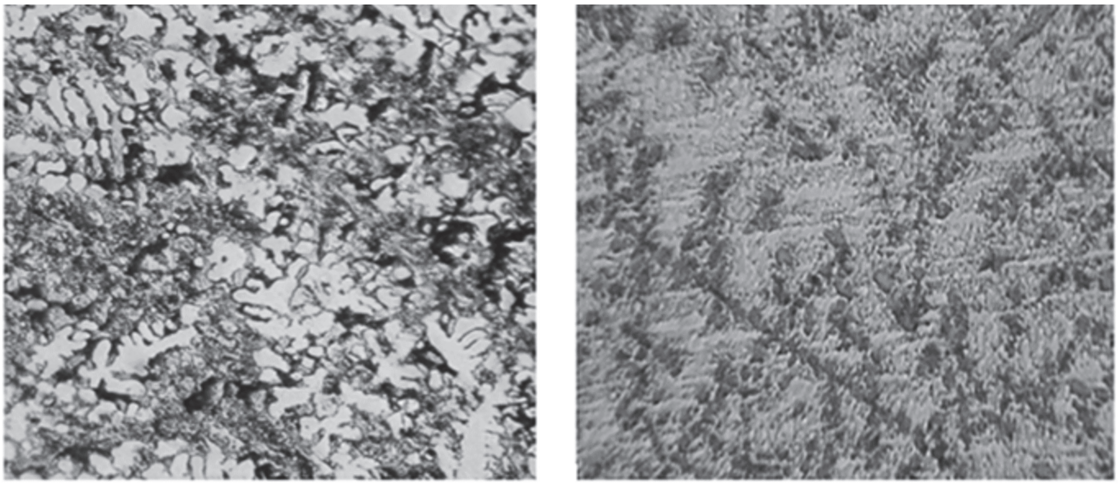


Fig. 1. The microstructure of HTN-62 alloy.

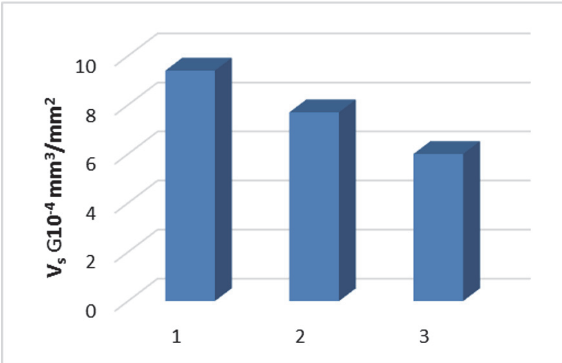


Fig. 2. Diagram of specific volumetric wear of HTN-62 (*1*), HTN-63 (*2*) and HTN-66 (*3*) alloys during high-temperature fretting-wear tests.

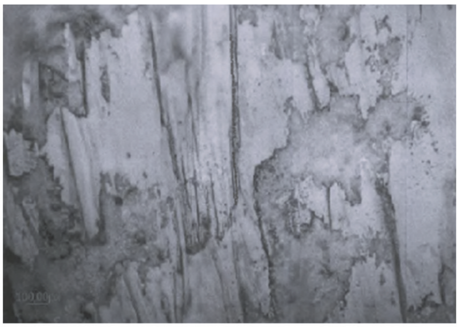
to the increase in the melting temperature (liquidus) of the alloy (Fig. 1, b). Also, the alloy toughness decreases due to the growth of primary carbides. If the amount of the carbide phase is less (for instance, in the eutectic alloy), the high-temperature wear resistance is significantly lower. The most optimal alloy structure of the final alloy should consist of primary crystals of niobium carbides and a bimodal eutectic (consisting of two phases — cobalt-based solid and alloyed niobium carbides).

The results of wear tests of the alloys are presented in Fig. 2. According to the presented results, HTN-63 and HTN-66 alloys alloyed with rhenium have increased wear resistance by a factor of 1.2 and 1.6, respectively, compared to the HTM-62 alloy. Nickel-based HTN-66 alloy has the highest wear resistance, followed by cobalt-based HTN-63 alloy.

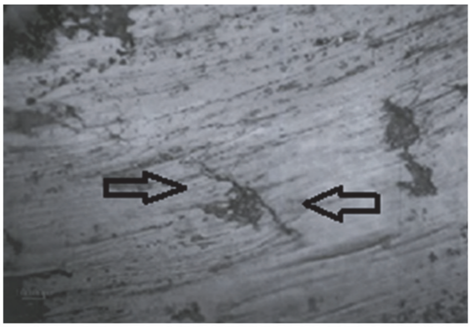
Microanalysis of wear traces indicates that their surface is 80–90 % covered with an oxide film (Fig. 3). In addition, the tribofilms of HTN-63 and HTN-66 alloys show signs of plastic deformation, but are not broken (Fig. 3b, c, arrows).

The results presented in [21, 22] prove that the formation of a stable secondary oxide friction film is necessary to ensure high wear resistance during operation under high-temperature fretting conditions. These secondary ultrafine thin-film structures, created as a result of high-temperature tribooxidation, play the role of protective screening layers. They prevent sticking at the point of metal-to-metal contact. The stain in the tribocontact zone is also redistributed and reduced.

With regard to the stability of oxide films, the substrate material must maintain proper strength until their destruction in the operating temperature range [22]. On the other hand, slight plastic deformation of the oxide film is useful. This requirement could be called limited deformation under given fretting conditions for the metal-oxide system. The start temperature of this deformation will be higher if the heat resistance of the base material and the elasticity of the oxide film are larger, but the thickness of the oxide film is smaller. This requirement is met by non-crystalline amorphous glass-like oxide films. These films can maintain their integrity at ambient temperatures and even recover when damaged [23, 24]. The improved wear resistance of HTN-63 and HTN-66 alloys compared to HTN-62 industrial alloy could be explained by increasing the melting temperature and heat resistance as a result of a decrease in the crystallization of secondary oxide tribofilms. Also, their flexibility and stability are increased.



a



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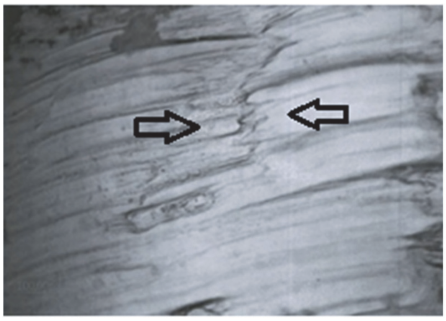

c

Fig. 3. Topography of friction surfaces for HTN-62 (a), HTN-63 (b) and HTN-66 (c) alloys.

4. Conclusions

The data of tests of wear resistance are presented for industrial eutectic alloy HTN-62 based on the Co–NbC system with a standard set of alloying elements (Cr, Al, W, Fe) and experimental alloys HTN-63 (Co–6Re–NbC) and HTN-66 (Ni–6Re–NbC). The wear resistance of HTN-63 and HTN-66 alloys is, respectively, 1.2 and 1.6 times higher than that of HTH-62. The increase in the wear resistance of HTN-63 and HTN-66 is the result of the positive effect of 6 wt. % Re and additional alloying properties of the friction-induced oxide film.

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