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PROPERTIES OF NICKEL POWDER ALLOYS HARDENED WITH TITANIUM CARBIDE

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We determine the melting point, hardness, and porosity of nickel powder alloys obtained by the method of hot pressing. A titanium content of 30–60 vol.% guarantees the wear resistance of alloys under the conditions of fretting corrosion. The heat resistance of these alloys was determined at a temperature of 1100°C and their wear resistance was found at temperatures of 20, 850, 950, and 1050°C. It is shown that, as the porosity increases, the heat resistance of the alloys decreases, and the characteristics of mean linear wear increase with temperature. We managed to obtain an alloy of the optimal composition with a melting point higher than 1300°C, which can be used in the aircraft industry.

Keywords: nickel powder alloys, titanium carbide, heat resistance, wear resistance, melting point.

The service life of the aircraft engines is determined by the durability of various components of its hot gas pass, including working blades whose serviceability depends on the wear and corrosion-erosion resistance of their contacting surfaces, i.e., of the shroud platforms. The faces of shroud platforms can be protected by applying coatings formed by materials whose wear resistance is higher than the wear resistance of the blade material. This increases their service life and simplifies repairs, which is reduced, in this case, to the replacement of the coatings but not of the blades themselves. At present, the KhTN-61 and KhTN-62 cast eutectic-type alloys created at the Institute for Metal Physics of the Ukrainian National Academy of Sciences are successfully used for this purpose [1, 2].

As a result of the development of gas-turbine engines of new generation and upgrading of the existing engines in the case where, parallel with the prolongation in the life, it is necessary to increase the power per unit mass of the engine, which inevitably leads to the increase in working temperatures and acting loads, it is necessary to develop new wear-resistant materials capable to meet the elevated requirements [3]. The commercial KhTN-type cast alloys contain insufficient amounts of the carbide phase determined by the composition of the eutectic and, hence, cannot provide the required high level of wear resistance. To increase the carbide content of alloys, the development of new materials was based on the application of the methods of powder metallurgy and taking into account the following design-basis requirements: the specific contact loads > 20 MPa, the range of working temperatures 20–1100°C, the heat resistance on the level of the heat resistance of alloys used for these purposes within the entire range of working temperatures, the wear resistance must be higher than for the KhTN-type alloys, and the melting point of the alloy must satisfy the technological conditions of manufacturing of the blades (degassing and soldering at 1270°C), i.e., must be higher than 1300°C.

To solve this problem, it was proposed to use a hot-pressed wear-resistant powder alloy based on cobalt with a content of titanium carbide of up to 50 vol. % [4].

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The replacement of cobalt with nickel in these alloys gives certain advantages, namely, better adhesion to the blades made of nickel alloys (ZhS32 and ZhS6U), thermal expansion coefficients close to the corresponding coefficients of the blade material, the absence of polymorphic transformations in alloys based on nickel, and a cost reduction caused by the lower cost of nickel.

Among other carbides of refractory metals, titanium carbide exhibits the highest oxidation resistance [5]. Nickel alloys with titanium carbide prepared by the method of powder metallurgy should be more wear-resistant than the cast eutectic alloys because the application of this method makes it possible to introduce much larger amounts of the carbide phase into the composite.

The presented work is a step in the process of development of wear-resistant and refractory alloys based on cermet composites, investigation of their physicomechanical properties, and determination of the conditions of manufacturing with an aim of their application for the purposes of hardening of the contact surfaces of blades in the aircraft gas-turbine engines.

The aim of the present work is to establish the dependences of the properties of pressed powder alloys based on nickel, namely, their melting point, heat resistance at maximum working temperatures, hardness of the alloys, and wear resistance under the conditions of fretting corrosion on the content of the carbide phase.

Materials and Methods of Investigation

The investigated specimens were prepared by the method of hot pressing in an SPD-120 installation from a mixture of powders of pure metals (a 5–20 μm fraction): PNE-1 nickel, PAKh-99N5 chromium, PZhV1 iron, PA-0 aluminum, and titanium carbide according to the TU 06173-74 standard. The alloying additives for powder composites based on nickel were chosen by analogy with the case of alloying of a powder refractory alloy based on cobalt with an aim to get compositions with high heat and wear resistances. The composition of the metallic fraction of powder alloys contains 20 wt.% of chromium and 3 wt.% of iron and aluminum. To compensate free carbon present in any carbide powder (in the composition of titanium carbide, its amount is ~ 1.5%) and prevent the formation of low-melting eutectics of nickel and chromium carbide Cr_3C, we additionally introduced titanium hydride TiH in some alloys. In the course of pressing the alloys, this hydride decomposes as temperature increases and prevents the oxidation of titanium, whereas the released titanium binds the excess of carbon into carbide.

The components were mixed in alcohol in a SAND planetary mill for 2 h and dried in air. The obtained mixture was placed in a pressing tool with repressing of ~ 20 kN. The pressing tool was placed in an inductor and heated to 1000°C in order to remove oxygen and perform pressing in an atmosphere of CO (carbon monoxide). The rate of increase in temperature was 50°C/min. The working temperature was measured with the help of a “Promin'” optical pyrometer with an error of ± 20°C. The optimal hot pressing was realized in the following mode: $T = 1350$°C, $P = 10$ MPa with holding till the end of shrinkage, which was monitored by an indicating clock-type gauge with a scale factor of 0.01 mm. After grinding, the size of the pressed compact blanks was ~ 48 × 35 × 6 mm. The porosity of the specimens was measured by the method of hydrostatic weighing.

The temperature of hot pressing was higher than the melting point of the eutectic in the Ni–TiC system [6]. Among other consequences, this promoted the formation of a certain amount of the eutectic liquid and, hence, a decrease in the porosity of specimens because the main requirement imposed on pressing is to attain its minimum possible values.

The temperatures of phase transformations, i.e., the onset and termination of melting, the onset and termination of crystallization, the solid-state transformations were measured in a VDTA-8M installation with the help of differential thermal analysis on specimens cut out from pressed compacts by the method of spark machining. The specimens were heated at a rate of 80°C/min in a helium atmosphere.

The heat resistance of alloys was found in air at a temperature of 1100°C by heating the specimens in an electric resistance furnace after the measuring their surface areas and weighing in alumina crucibles. Each specimen cut out from a pressed blank by spark machining was placed in an individual crucible. The procedure of heating in the furnace was monitored by a thermocouple; the total duration of holding was 50 h. The specimens were cooled down with the furnace. The heat resistance of the alloy was found according to the weight gain of the specimens after every 10 h of annealing relative to its surface area.

The wear-resistance tests of pressed powder alloys based on cobalt and hardened with titanium carbide were carried out at the Kyiv National Aviation University in an MFK-1 machine for the investigation of materials under the conditions of fretting [7]. To attain the required temperature conditions, this machine was equipped with an annular furnace, thermocouple, and milliammeter. The tested specimens were cut out from the pressed alloys by spark machining in the form of rings with an outer diameter of 9 mm and a thickness of the wall of 1.25–1.3 mm and a pellet 11 mm in diameter and then soldered to steel holders by VPr11N and VPr24 high-temperature solders in a vacuum. These specimens formed an annular friction path with a total area $S = 35\ \text{mm}^2$ and a width of 1.5 mm. The proposed equipment enables one to investigate fretting corrosion within the frequency range 10–30 Hz under a normal pressure to 60 MPa for amplitudes of 0.001–2.5 mm.

Prior to testing, the working surfaces of the specimens were ground on a machine to an identical roughness $\sim R_a = 0.32\ \mu\text{m}$. The tribological couple is formed by a pellet and a ring made of the same material; the pellet is immobile and the ring is moving. The process of wear runs on the surface of two contacting specimens. After testing, we measured the mean linear wear of the specimens according to GOST 23.211-80. For this purpose, we used an MOD-201 profilometer. We partitioned the circular surface of the specimen (pellet) into eight sectors, performed five measurements on the friction path within each sector, determined the mean line of the working surface, and found, in a similar way, the mean line of the base surface. The mean linear wear was found as the difference between the levels of the mean lines of the base and working surfaces on the pellet.

Results of Investigation

To study the properties of alloys, we prepared pressed compact blanks whose compositions are presented in Table 1. The specimens for thermal analysis ~ 5 × 5 mm in size were cut out from these blanks by the method of spark machining. The specimens for the determination of the heat resistance of alloys had almost identical sizes ~ 10 × 8 × 5 mm. The sizes of the specimens tested for wear resistance have already been indicated.

The results of determination of the melting point, hardness, and mass gain of the alloys after holding for 50 h at a temperature of 1100°C in air are presented in Table 2.

The comparison of the melting points of alloys with different contents of titanium carbide reveals their identity; namely, a melting point of 1320 ± 10°C is typical of all specimens with contents of titanium carbide within the range 30–50 vol.%. This is an expected result because all these pressed materials have the same binder, i.e., the eutectic formed by alloyed nickel and carbide. The only exception is a composition with 60 vol.% TiC, a melting point of ~ 1300°C, and an additional transformation near this temperature, which may be a result of the insufficient amount of the metallic binder in the blank due to which the eutectic of alloyed nickel and carbide is not formed and the reactions run between different components of the charge mixture. The procedure of heating of the alloys to a temperature higher than the solidus by 50–80°C does not lead to the loss of their shape.

The thermal curves of the powder alloys containing 30–50 vol.% of titanium carbide reveal the possibility of formation of a composite material based on nickel in which any transformations are absent in the course of

Table 1. Composition and Porosity of Pressed Compacts

No. of the specimen	TiC		TiH	Ni	Cr	Al	Fe	Porosity, %
	vol.%	wt.%	wt.%					
1	30	17.84	1.16	55.5	19.6	2.95	2.95	7.1
2	40	25.36	1.64	50.0	17.7	2.65	2.65	4.4
3	40	25.36	1.64	50.0	17.7	2.65	2.65	10.0
4	50	33.8	2.2	43.83	15.51	2.33	2.33	4.32
5	50	33.8	2.2	43.83	15.51	2.33	2.33	3.6
6	60	42.73	2.77	3.33	13.21	1.98	1.98	9.8

Table 2. Melting Point, Hardness, and Heat resistance of Alloys at 1100°C

No. of the specimen	Melting point, °C	Hardness, HRC	Mass gain $\Delta m \cdot 10^{-5}$ (g/mm^2)				
			duration of holding (h)				
			10	20	30	40	50
1	1330	52	5.79	10.78	14.77	16.17	19.16
2	1320	58	6.5	9.193	10.99	10.99	13.0
3	1310	58	11.15	16.92	19.23	23.46	25.77
4	1320	61	8.92	13.04	15.79	16.25	19.22
5	1310	62	6.62	11.15	12.89	15.68	18.81
6	1300	64	10.44	17.4	22.01	23.34	28.08

heating to the melting point. The absence of additional thermal effects confirms the stability of the phase and structural compositions of the obtained composite materials. At temperatures higher than the solidus temperature, the alloy loses the stability of its phase composition, as shown by the appearance of additional thermal effects in the process of cooling. The solidus temperature of the composite materials based on nickel and titanium carbide is 13200 ± 10°C and does not depend on the content of titanium carbide within the range 30–50 vol.%.

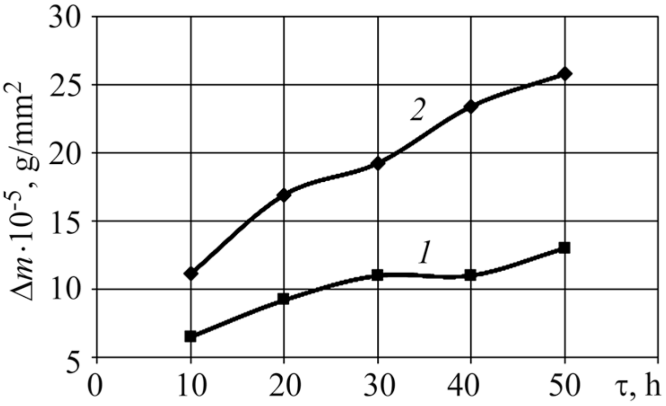

Fig. 1. Heat resistances of the powder alloys No. 2 (1) and No. 3 (2) with porosities of 4.4 and 10%, respectively.

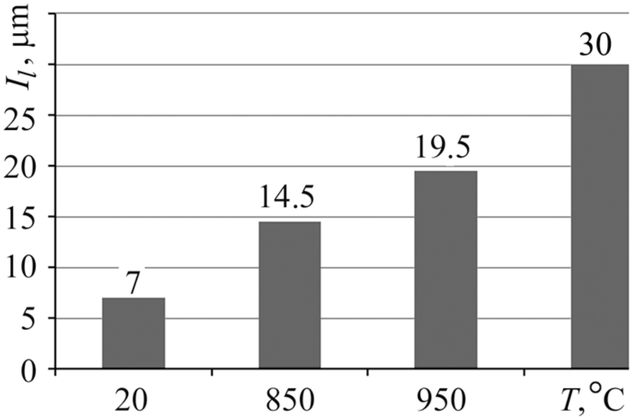

Fig. 2. The mean linear wear of alloy No. 4 at different temperatures (the amplitude is equal to 120 μm and the load is equal to 30 MPa on the test base of 10^6 cycles).

The elevation of the Rockwell hardness of the investigated specimens observed as the content of titanium carbide increases from 52 HRC for 30 vol.% TiC to 64 HRC for 60 vol.% TiC also seems to be quite natural.

The results of investigation of the heat resistance of composite powder materials based on nickel show that the dependence of this property on the content of the carbide component is much weaker than its dependence on the porosity of the specimens. Specimens No. 4 and No. 5 with a TiC content of 50 vol.% and porosities of 4.32 and 3.6% are characterized by almost identical heat resistances. At the same time, for specimens No. 2 and No. 3 containing 40 vol.% of titanium carbide, the mass gains in the course of annealing for 50 h differ almost by a factor of two. The porosities of specimens No. 3 and No. 2 are equal to 10% and 4.4%, respectively (Fig. 1). The comparative analysis enables us to conclude that the heat resistance of a more compact material is higher.

The wear-resistance tests of pressed powder alloys based on nickel and hardened with titanium carbide were performed under the conditions of vibrocyclic interaction (fretting process without opening of the joint). As a unit of measurements, we took 10^6 loading cycles. It is quite clear that, as the testing time increases, the wear rate also increases. The mean linear wear of the alloys was evaluated for an amplitude of vibrations equal to 120 μm under a load of 30 MPa.

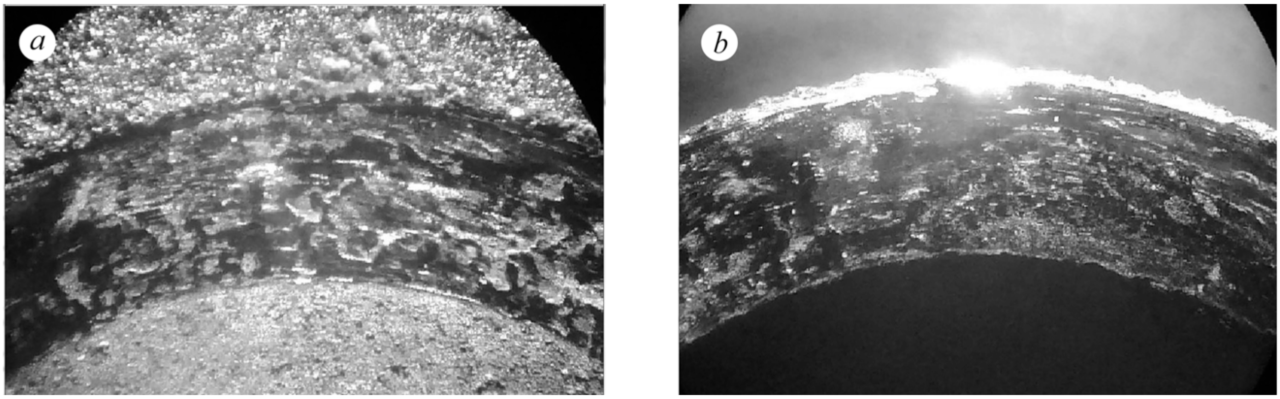

Fig. 3. Friction surfaces of a pellet (a) and a ring (b) of alloy No. 4 at 950°C and an amplitude of 120 μm under a load of 30 MPa; × 10.

The mean linear wear of all tested alloys at room temperature was of the same order and varied within the range 7–10 μm. The alloy with maximum acceptable content of titanium carbide (50 vol.%) and satisfactory characteristics of hardness, melting point, and heat resistance (promising from the viewpoint of wear resistance) was tested at elevated temperatures of 850, 950, and 1050°C (Fig. 2). Its degree of wear gradually increases with temperature.

In analyzing specimens after tests, it was established that, at elevated temperature, they oxidized to dark gray color without noticeable traces of peeling and exfoliation of oxides. The specific features of fretting wear, such as the absence of indications of mutual displacements of the material and the formation of a smooth lustrous (vitrified) surface in the contact zone, are typical of all specimens to a greater or lesser degree (Fig. 3).

The vitrifying of the surface observed for all specimens is a positive phenomenon because this surface is very dense and characterized by a high hardness and a high wear resistance. The results of metallographic analyses demonstrate that dense amorphous oxides are formed in the zone of vitrification and prevent the phenomenon of seizure (detrimental in the process of friction) and the transfer of the material in the contact zone.

CONCLUSIONS

Summarizing the accumulated results, we can make the following main conclusion: The properties of pressed powder alloys based on alloyed nickel with titanium carbide enable us to use them as a composite material aimed at hardening the shroud platforms of gas-turbine engines. These alloys are more wear-resistant than cast alloys due to a larger content of carbides; they can be used at the temperatures of up to 1100°C because their melting point exceeds 1300°C, and they have a high heat resistance. The alloy based on alloyed nickel with a content of titanium carbide ~ 50 vol.% exhibits the optimal properties. The obtained results can be used as basic for the subsequent industrial testing of the developed friction materials aimed at application in the aircraft industry.

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