MANUFACTURING TOOLS WITH A COMBINATION OF STRENGTH AND DUCTILITY USING MOLYBDENUM POWDERS

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Abstract - The article discusses the results of a study on the manufacture of tools with a combination of strength and plasticity using a powder of refractory metal, molybdenum. The results of a study on the creation of a new alloy of the Mo-TiC-Ni-W-Fe system, manufactured by powder metallurgy with improved performance characteristics, are presented, and the relevance of the development, which consists in the introduction of new materials obtained by high-tech methods, in particular materials in a highly dispersed state, is of particular importance. It is shown that one of the main tasks of the work was to develop a new composition of sintered powder alloy of the Mo-TiC-Ni-W-Fe system. To improve the technological and operational characteristics of the experimental roller, a metal-ceramic material was created for the manufacture of rollers on its basis, increasing their wear resistance when working in extreme conditions, due to a decrease in their density, an increase in hardness and bending strength.

Keywords: Metal-ceramic material, Metal powder, Molybdenum powder, Refractory metal, Charge, Mixture, Alloy, Hard alloy, Powder metallurgy, Sintering.

1. Introduction

The world's industries face the challenge of producing carbide tools with special mechanical, technological, and physical properties based on refractory metal powders. In solving a range of problems related to increasing productivity, reliability, and durability of tools, and improving product quality, it is important to create new materials or improve the physical and mechanical properties of existing ones.

With the independence of our country, the market economy has given preference to the creation of new technologies for producing highly dispersed refractory metal powders from local raw materials and creating new carbide tools based on them.

Today, to solve these problems, there is a need to set up the production of carbide tools made of new alloys, made of highly dispersed powder materials, intended, among other things, for export and the production of many new types of finished products by processing the mineral resources of the Republic of Uzbekistan. In this regard, the relevance of the development and implementation of carbide tools from new alloys and powder materials obtained by high-tech methods, in particular, from materials in a highly dispersed state, is of particular importance. The above indicates the relevance of this topic.

Scientific research aimed at obtaining carbide tools from new alloys based on highly dispersed powders of refractory metals with special technological, chemical, and physical properties is a very urgent task. In this direction, research work is carried out in the leading scientific centers and higher educational institutions of the world, including the Institute of Metallurgy and Mechanical Engineering named after A.A. Baikov (Russia), the Institute of Chemistry, Ural Branch of the Russian Academy of Sciences (Russia), the Japan Institute of Metallurgy (Japan), the American University of Science and Technology (USA), Nagoya University (Japan), the English University of Technology (England), the Belarusian National Technical University (Belarus), the Frantsevich Institute for Problems of Materials Science I.N. (Ukraine), and the Tashkent State Technical University (Uzbekistan).

In the scientific works of foreign scientists X. Shreter, R. Kiffer, T. Shtraux, P. Rautal, Dj. Norton, P. Shvarskop, Dj. Gerlend, Suzuki, Kubota, S. Takeda, K. Gerber, H. Kroto, Dj. Gyorlend and others, research work were carried out on the creation of carbide tools, as well as the creation of tungsten-free carbide tools with an optimal combination of strength and plasticity from most refractory metals by sintering based on highly dispersed powders was not given due attention. The German scientist X. Shreter made a decisive step in the development of sintered hard alloys (Germany).

The development of the scientific school in the field of sintered hard alloys in metallurgy and materials processing belongs to scientists of the Commonwealth of Independent States under the leadership of G.A. Meerson and L.P. Malkov: the first samples of hard alloy were obtained at the Electrolamp Plant (Russia).

This study relates to the field of metallurgy, namely to the production of molybdenum-based alloys used for the manufacture of high-temperature pressing molding tools.

A molybdenum-based alloy is known, containing, by weight %: B-0.01-0.03; Ti-0.4-0.5; Ni-3-4; Co-3-4; Fe-0.1-0.3; Mo-the rest, which is used to improve the weldability of alloys and cannot be used to produce high-temperature pressing shaping products [1-2]. There is a molybdenum-based alloy containing titanium carbide and technological additives with tungsten. The alloy composition includes, by weight %: Mo - 85%, TiC-10.5%, W-1.0%, and Zr-0.6%.

The disadvantages of the above alloy include the instability of the technological properties of the alloy and its high cost, due to the introduction of a large amount of expensive molybdenum [2-3].

The closest analog in technical essence is a metal-ceramic material based on molybdenum, containing titanium carbide and tungsten, and, additionally, nickel, iron and lanthanum hexaboride, with the following ratio of components, mass %: titanium carbide - 45-48%, nickel 1.5-2.5%, tungsten 1.0-1.5%, iron 4.0-5.0%, lanthanum hexaboride - 0.15-0.25%, molybdenum - the rest [4-6].

The disadvantage of this metal-ceramic material is the presence of a rare and expensive element - lanthanum hexaboride, as well as its fairly high density and reduced degree of hardness and bending strength of the forming tools, which reduces the wear resistance and reliability of the tool operating in extreme conditions.

2. Research Methodology

The object of the study is molybdenum powder and compact products based on it, rollers of the input box of stand No. 23 and No. 25 of mill-300 SPC-2 at JSC “Uzmetkombinat”, the technological process for producing alloys with operationally important characteristics, a molybdenum alloy of the Mo-TiC-Ni-W-Fe system manufactured by the powder metallurgy method and the hydrogen-plasma reduction unit PUV-300.

Creation of a metal-ceramic material for the manufacture of rollers based on it, increasing their wear resistance when working in extreme conditions, by reducing their density, increasing hardness and bending strength.

The set task is solved by the fact that in the metal-ceramic material based on molybdenum, containing titanium carbide, tungsten, nickel, and iron, the new sintered powder alloy of the Mo-TiC-Ni-W-Fe system, the components are in the following ratio, wt. %: titanium carbide 39-42%, nickel 11-12%, tungsten 3-4%, iron 3-4%, molybdenum - the rest.

The research work uses macro- and microstructural, X-ray phase, X-ray structural, spectral, and electron microscopic methods of analysis.

Determination of technological and operational characteristics of alloys and blanks during analysis using the existing standard measuring equipment.

3. Research Results

X-ray structural studies of highly dispersed molybdenum powders were carried out. To identify specific mineral phases, the nanopowders submitted for study were subjected to X-ray structural analysis on the Dron-3 installation. Fig. 1 shows the diffraction pattern of the micro powder. As can be seen from Figure 1, the diffraction patterns have a low intensity of most angular values of interplanar distances of the crystalline phase, which sometimes appears X-ray amorphous [12]. It is impossible to establish the phase nature of the analyzed powder using this diffraction pattern. Presumably, the powder is a mixture of several metal compounds, among which it is not possible to determine the presence of titanium carbide.

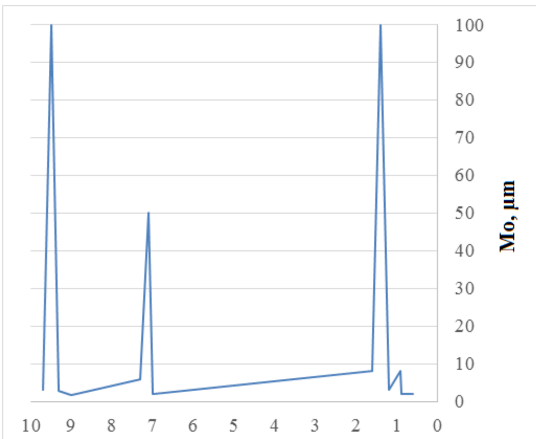

Figure 1: Molybdenum powder diffraction pattern

Figure 2 shows the diffractogram of the 2nd powder. Although there are separate lines of interplanar distances of the atoms of the compound being studied, it is impossible to determine their belonging to a certain phase, except for the analyst's conclusion about the absence of the compound.

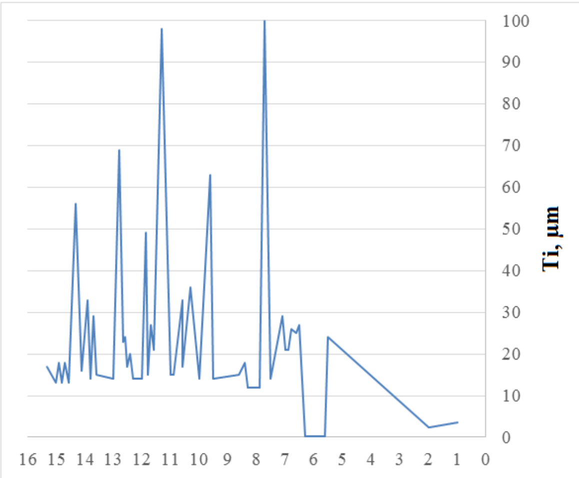

Figure 2: TiC powder diffraction pattern

The values of interplanar distances of the atoms of the compound obtained here indicate, following the American catalog ASTM 4-0806, that this powder belongs to pure metallic molybdenum.

The essence is that the metal-ceramic material based on molybdenum contains titanium carbide 39-42%, nickel 11-12%, tungsten 3-4%, iron 3-4%, and molybdenum - the rest. A significant difference and novelty are the changed quantitative ratios of the components, allowing to obtain a new quality of products from the proposed composition of the metal-ceramic material, with improved properties. In the proposed composition, unlike the analog, the amount of titanium carbide was reduced and the amount of binding metals was increased. It was experimentally established that a decrease in the amount of titanium carbide to 39-42%, when obtaining a metal-ceramic material, helps to reduce the sintering temperature of the alloy and energy costs for the sintering operation, while nickel, titanium, and iron, being alloying elements, in the proposed ratio help to maintain the deformability and homogeneity of the structure of the material with a uniform distribution of elements, also enhancing their synergistic interaction with titanium carbide, which is a modifier, which leads to an improvement in structure formation. This allows obtaining from the metal-ceramic material hard alloys of higher quality in terms of technological indicators with a density of 5.5-6.1 g/cm^3, hardness of 82-84 HRC and bending strength of 1080-1150 MPa, exceeding the indicators of the analog by 1.2-1.3 times in terms of the above technological indicators, due to a change in the composition of the metal-ceramic material, which indicates the achievement of the technical task set in the invention, and the presence of a cause-and-effect relationship between the invention and the technical task set.

The metals contained in the proposed metal-ceramic material based on molybdenum, a new sintered powder alloy of the Mo-TiC-Ni-W-Fe system, behave as follows during high-temperature sintering:

Nickel, introduced into the composition within 11-12%, activates hot sintering and, at the temperature of the technological process selected by us and the specified amount of the component, the maximum coating of the surface of the particles of tungsten flowing around with nickel occurs and, due to the significant solubility of tungsten in nickel, recrystallization of tungsten particles occurs, contributing to an increase in plasticity, and therefore, the pressability of the metal-ceramic material and the compaction of hard alloys, which leads to an improvement in operational indicators, such as wear resistance and reliability, of the products obtained from it [11].

Increasing the tungsten content in the composition to 3-4% helps to strengthen the molybdenum base and obtain a higher alloy hardness compared to the analog. In addition, as a result of processing titanium carbide with iron of 3-4% concentration, on the surface of titanium carbide particles there is a reduction of oxides and complete assimilation of molybdenum by titanium and, as a consequence, - strengthening of the material and increase in plasticity, because molybdenum is well amenable to pressure processing.

The content of titanium carbide, which is a modifier, in the metal-ceramic composition in the amount of 39-42% when interacting with the other above alloying components in an increased amount, allows for optimal physical and chemical interaction of the components at a lower sintering temperature, which ensures the achievement of higher technological indicators for density and hardness, as well as plasticity of the metal-ceramic material, due to which the material lends itself well to processing in hard alloys [9].

We describe the elements that make up the metal-ceramic material:

- Titanium carbide has a fine-grained structure, high stability, refractoriness, and low plasticity. It is used in metallurgy to modify alloys. Increases wear resistance.
- Nickel is a silvery-white metal, malleable and ductile. It is stable in air and water. It is used as a powder in the manufacture of hard and superhard materials as a binder.
- Tungsten is a grey to black, heavy, refractory metal. Chemically active, used in the metallurgical and chemical industries. It is a reducing agent.

- Molybdenum is a refractory metal, light gray, characterized by high plasticity, malleability, and a low coefficient of expansion at high temperatures, T_m = 2625 °C. It is used in metallurgy in heat-resistant alloys. It is a reducing agent.

- Iron is a shiny, silvery-white metal, T_m=1539 °C. It is plastic, easily forged, rolled, and drawn. The ability to dissolve carbon and other elements serves as the basis for obtaining various alloys that can withstand high and low temperatures, high pressures, etc.

The invention is implemented as follows.

According to a well-known method, a batch of powders is prepared to obtain a metal-ceramic material by separately grinding in different small-sized ball mills one part of the mixture, which includes a sample of specified quantities of nickel, tungsten, iron, and molybdenum, and the second part of the mixture, which is titanium carbide.

Then the compositions are combined, and the final mixing also continues in the mill for another 6-8 hours. After that, the mixture is dried in a distiller at a temperature of 100-120 °C for 8-12 hours and mixed with a plasticizer of 8% rubber solution in gasoline, then dried again for 20-30 minutes at the same temperature. The finished mixture is pressed in molds under a pressure of 100 kgf/mm^2 on a P4626 press unit.

After pressing, the products are dried in a steam oven for 18-24 hours at a temperature of 100-120 °C, then subjected to preliminary high-temperature sintering (1000-1100 °C), in a hydrogen atmosphere with an exposure of 1 hour. The final sintering mode is selected depending on the purpose of the product. Upon completion of the process, measurements of density, hardness, and bending strength are taken on standard samples according to the methods established by the State Standard of the Republic of Uzbekistan for hard alloys, on the following devices:

- density (specific gravity), ρ, g/cm^3 - by hydrostatic weighing method - apparatus 33 № 67761.

- hardness, HRC - on the Vickers-ZIP device model TK-2M, GOST, 13407-67 № 1793;

- bending strength, $\sigma_{из}$ - on the tensile testing machine UMM-5.

Example 1. Preparation of metal-ceramic material, a new sintered powder alloy of the Mo-TiC-Ni-W-Fe system in the form of a powder mixture, for the manufacture of a roller for the input box of cage No. 25, was carried out in small-sized ball mills with a ratio of the volume of the mixture to the volume of balls made of VK6 hard alloy, 30 mm in diameter, equal to 1:4.

To achieve the above, the sample of the components included in the composition was divided into two groups: the first group included a sample of Ni- 11% (1100 g), W-3% (300 g), Fe-3% (300 g), Mo-41% (4100 g), and the second group included TiC- 42% (4200 g).

A 5800 g sample of nickel, tungsten, iron, and molybdenum powder was loaded into a ball mill, where preliminary mixing was carried out in an ethyl alcohol medium, at a consumption rate of 1.2 l of ethyl alcohol per 1 kg of powder, for 11 hours. A 4200 g sample of titanium carbide was loaded into another mill and also mixed in an ethyl alcohol medium. Then the compositions were combined in one mill and mixed for another 7 hours.

The resulting mixture was dried in a distiller at a temperature of 110 °C for 10 hours, then mixed with a plasticizer - in an 8% solution of rubber in gasoline and dried again in a dryer at a temperature of 110 °C for 30 minutes. The finished mixture was pressed in specified forms, on a P4626 press unit, under a pressure of 100 kgf/mm^2.

After pressing, the products were dried in a steam oven at a temperature of 110 °C for 20 hours with a holding time of 1 hour, then the molding products were subjected to preliminary sintering in a hydrogen atmosphere at a temperature of 1100 °C, with a holding time of 1 hour.

Next, the final high-temperature sintering operation was carried out, which was carried out in the environment-vacuum mode of 10-3 mm Hg for 2.5 hours, while the sintering temperature was 1400 °C with a holding time of 1 hour.

The final sintering mode of the products is selected depending on the purpose of the manufactured product.

After completion of the sintering process, to determine the technological parameters of the obtained hard-sintered material, standard samples were taken - sintered rods, measuring 5x5x34 mm, on which measurements were taken according to the methods established by the State Standard of the Republic of Uzbekistan for hard sintered alloys.

Example 2. Using the technology of example 1, to compare the physical and mechanical properties of the invention with an analog, from the metal-ceramic material of the analog, composition, wt.%: TiC - 45-48; Ni-1.5-2.5; W-1.0-1.5; Fe- 4.0-5.0; LaB6 - 0.15-0.25 Mo-rest, and at a sintering temperature of 1450 °C, an experiment was conducted using the technology of the analog to obtain a hard alloy, from which a sample for testing was also made in the form of a bar.

The following results of technological parameter measurements were obtained for the analog sample: density - 6.5 g/cm^3, hardness - 80 HRC, bending strength - 800 MPa (Table 1).

In addition to the products given in the examples, other samples were also manufactured and tested using similar technology from a metal-ceramic material, a new sintered powder alloy of the Mo-TiC-Ni-W-Fe system: a forming tool, Form 8 - GOST9457-75, forms 07.67 - GOST25426-86, forms 110114-110 408 - GOST190 65-80, forms 02, 114-100608 - GOST19048-8.

The results of measurements of the technological parameters of these products were within the results of the samples of example 1. The results of the experiments are given in Table 1.

As can be seen from Table 3.8, the best indicators for the level of hardness, density, and bending strength of the manufactured samples of parts were obtained by the dissertation author using components of the metal-ceramic material, a new sintered powder alloy of the Mo-TiC-Ni-W-Fe system in the amount, wt.%: TiC-39-42, Ni-11-12, W-3-4, Fe-3-4, Mo-39-42.

The optimal composition of the composition includes TiC-42%; Ni-12.0%; W-4.0%; Fe-3.0%, Mo-39.0%.

When changing the amount of components of the metal-ceramic material towards a decrease or increase from the specified amounts, no improvement in the physical and mechanical properties was observed.

The test results showed that the hardness limit of the test samples was 82-84, HRC; density - 5.5-6.5 (specific gravity), g/cm^{3,} and bending strength σ_{ben} - 1000-1050 MPa.

Table 1. Physical and mechanical properties of samples made of metal-ceramic material, a new sintered powder alloy of the Mo-TiC-Ni-W-Fe system depending on its composition, sintering temperature 1400 °C

№	Alloy components, mass. %						Properties		
	TiC	Mo	Ni	W	Fe	LaB_6	Density, ρ, g/cm^3	Hardness, HRC	Strength, σ_{ben}, MPa
Analog									
	46	47,0	1,5	1,0	4,5	0,2	6,5	80	800
The proposed metal-ceramic material									
1	39	44	11	3	3	-	5, 6	82,0	970
2	41	41	10	4	4	-	5,5	82,5	980
3	40	42	11	3	4	-	5,5	83,5	1000
4	40	41	11	4	4	-	5,5	83,8	1030
5	42	41	11	3	3	-	5,5	84,0	1045
6	42	39	12	4	3	-	5,5	84,0	1050
7	45	38	11	3	3	-	5,6	82,0	980
8	45	35	12	4	4	-	5,6	82,0	970

As follows from Table 1, the indicators for density, hardness, and bending strength exceed the indicators of the analog by 1.2-1.3 times, which confirms the achievement of the set technical task.

All the above-mentioned samples from the proposed new sintered powder alloy of the Mo-TiC-Ni-W-Fe system were manufactured under business agreements with "UzKTJM" JSC and underwent pilot tests for density, hardness, and bending strength at the pilot plant of "TURON ABRAZIVE" LLC and under the conditions of "SPZ-BEARINGS" JV in the period of 2015-2016.

As a result of the pilot industrial tests of samples of molding products made of the proposed metal-ceramic material, it was found that due to the increase in plasticity, characterized by an increase in bending strength and hardness, the wear resistance of the tools increased by 1.5 times compared to the analog, and due to a decrease in density, the specific gravity of the products decreased, which contributed to a 1.2-fold reduction in the weight of the mechanisms and improved working conditions, compared to the analog. In addition, due to a decrease in the sintering temperature by 100 °C, energy costs for the sintering process decreased [8,9].

4. Conclusions

A new Mo-TiC-Ni-W-Fe alloy has been created, and manufactured using powder metallurgy with improved performance characteristics, and the relevance of the development, which consists in the introduction of new materials obtained by high-tech methods, is of particular importance.

The technological process of processing large powders was replaced with highly dispersed ones, which allows reducing the sintering temperature of the blanks and makes it possible to obtain a more homogeneous and fine-grained structure of the sintered products.

The composition and properties of a new sintered alloy of the Mo-TiC-Ni-W-Fe system, produced by powder metallurgy, have been investigated and established.

The most optimal option for obtaining high-quality molybdenum powder is its production by hydrogen reduction.

Analysis of the obtained data shows that the most advantageous combination of plasticity and wear resistance is possessed by alloys with a ratio of large and small fractions of carbide of 60:40.

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