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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

STRUCTURE AND PROPERTIES OF Fe-Cr-Ni BASED WEAR-RESISTANT POWER STEELS

Specialty: 3315.01– Metallurgical technology

Field of science: Technical sciences

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic. In the modern era, with the rapid technological development of mechanical engineering, construction and tool materials are required to possess high static and dynamic strength, resistance to brittle fracture, and superior wear and corrosion resistance. These properties ensure the reliability of components, machines, mechanisms, and technological equipment during operation.

In the modern era, with the rapid technological development of mechanical engineering, construction and tool materials are required to possess high static and dynamic strength, resistance to brittle fracture, and superior wear and corrosion resistance. These properties ensure the reliability of components, machines, mechanisms, and technological equipment during operation.

In this context, the main objective of metallurgical technologies is the development of new structural materials with favorable microstructure and a combination of advanced properties. One of the most efficient approaches to achieving this objective is the application of innovative metallurgical processes. Among such processes, powder metallurgy technology is of particular importance. Powder metallurgy provides the opportunity to obtain optimally alloyed, minimally machined, resource and energy-efficient, as well as economically viable composite materials.

An analysis of the structure and properties of constructional and tool steels, particularly cutting and die steels, demonstrates that one of the causes of intensive wear of machine components is an inadequate alloying process. Components manufactured from high-alloy tool steels and hard alloys are subjected to severe wear and friction; therefore, the processes occurring on the surfaces of friction pairs, especially under impact-abrasive operating conditions, must be thoroughly investigated.

The strength of the metallic matrix in hard alloys, which are primarily composed of powder-based materials such as carbides, carbide-nitrides, nitrides, and borides, significantly expands their potential applications. Among these materials, those most widely used are powder-based alloys containing tungsten, cobalt, and molybdenum.

However, since tungsten and cobalt-based raw materials are economically expensive, one of the important tasks is to explore the possibilities of obtaining more economically efficient wear-resistant powder materials through the use of readily available alloying elements.

At present, to address this complex scientific and technical problem, research is being conducted on the possibility of producing parts and components through powder metallurgy methods, where expensive alloying elements can be substituted with multicomponent alloying to achieve a synergistic effect. The analysis of scientific and technical literature indicates that, in the production of new wear-resistant materials, it is possible to obtain powder billets with superior physico-mechanical properties by implementing optimal alloying strategies. In particular, purposeful control of the residual porosity of such alloyed materials can serve as an effective approach to solving this important scientific and technical challenge.

Degree of Study of the Topic. The development of wear-resistant products is one of the priority directions of powder metallurgy. In this context, research is conducted in two main directions: improving the structural and quality characteristics of materials to meet high performance requirements, and enhancing the production technology of wear-resistant products based on cost-effective and readily available components.

Among Azerbaijani scholars, significant contributions to the theoretical and technological foundations of powder metallurgy methods including the development of alloyed and wear-resistant steels and other alloys have been made by A. T. Mammadov, Kh. M. Imanov, Z. Z. Sharifov, Z. Q. Mammadov, V. Y. Eyvazov, S. N. Namazov, V.N. Heydarov, A. I. Babayev, M. Ch. Huseynov, and other researchers.

In recent years, significant scientifically substantiated measures, proposals, and recommendations have also been developed by S. Jafarova, I. Hamdullayeva, F. Guliyev, A. Jafarova, V. Gahramanov, and others to improve the structure and properties of wear-resistant powder steels, including enhancing the tribotechnical characteristics of alloyed powder steels.

By highly appreciating the recent scientific and practical achievements in the field of powder metallurgy obtained by the aforementioned scientists and specialists, and building upon their findings, it is possible to propose the following hypothesis: by purposefully controlling the chemical and granulometric composition of powder materials, the effects of alloying elements, and the technological parameters, it is feasible to ensure favorable structure and properties of the billets, including high wear resistance under impact-abrasive conditions.

Since the research is specifically aimed at the implementation of this hypothesis, the dissertation topic is relevant and possesses significant scientific and practical importance.

Object of the Research. The object of the research is the structure and properties of alloyed powder steels with wear resistance under impact-abrasive conditions.

The subject of the research comprises technical and technological developments aimed at improving the wear resistance of powder steels alloyed with Cr and Ni.

Purpose and Objectives of the Research. The aim of the research is to improve the structure and properties of Cr and Ni alloyed powder steels with high wear resistance under impact-abrasive conditions by applying efficient powder metallurgy technologies.

In order to accomplish the stated aim of the research, the following scientific and technical objectives are to be addressed:

- ✓ Systematic analysis of the technological features of impact-abrasive wear and the production of wear-resistant powder materials;
- ✓ Justification and selection of research methods, tools, materials, equipment, and technologies;
- ✓ Experimental investigation of the composition, structure, and properties of powder steels and generalization of the obtained results;
- ✓ Evaluation of the influence of chemical composition and alloying elements on the wear resistance of powder steels;
- ✓ Study of the kinetics of diffusion processes during the heat treatment of porous materials;
- ✓ Determination of the dependence of wear resistance of powder steels on technological parameters;
- ✓ Implementation of the obtained theoretical and experimental results in the technology for manufacturing valve components of drilling pumps.

Scientific Novelty of the Research. It has been established that although chromium carbide in the composition of porous powder steels acts as a hard structural constituent, it does not ensure high wear resistance under impact-abrasive conditions. The porosity of powder steels creates stress concentration during impact-abrasive wear and increases the propagation area of cracks. Therefore, the concept that a reduction in the residual porosity of carbide-structured steels leads to a significant decrease in wear has been adopted as a fundamental approach.

It has been demonstrated that, for alloyed carbide-containing powder steels operating under impact-abrasive wear conditions, the sintering regime must ensure strong interparticle bonding and uniform distribution of alloying elements throughout the volume. It has also been established that plastic deformation of the surface of sintered powder steels by steel ball peening can significantly enhance their wear resistance under impact-abrasive conditions.

It has been determined that wear resistance increases significantly as a result of a sharp reduction in the porosity of the surface layer of the specimens. Under these conditions, the chromium and iron carbides present in the steel structure become more finely dispersed and occupy energetically favorable positions, achieving uniform distribution and strong bonding within the martensitic matrix. As a result, the formation of such a structure enhances the load-bearing role of these carbides in the martensitic matrix under impact-abrasive friction conditions, preventing their pull-out from the matrix during friction.

The kinetics of diffusion processes occurring in iron-based powder composites has been determined, and the variation coefficients of alloying element concentrations as well as the quantitative characteristics of diffusion layers in pressed billets have been evaluated.

Theoretical and Practical Significance of the Research. The conducted research made it possible to determine the kinetics of diffusion processes occurring in iron-based powder composites and to quantitatively evaluate the diffusion layers in pressed billets. Technological regimes for producing bi-component coatings in powder composites were developed, and the optimal structures and properties of non-conductive, semiconductive, and conductive powder coatings were established.

Through sequential saturation with several elements, coatings with favorable structures and properties were obtained, and the necessary rational technological parameters were determined. The specific features of saturating sintered powder composites with carbon and carbide-forming elements were identified, and the corresponding technological regimes were developed.

The technological foundations for producing pressed billets from wear-resistant powder steels alloyed with chromium and nickel have been developed. By selecting a rational charge composition and using readily available alloying elements, the optimal limits of technological parameters for manufacturing powder components have been determined.

Approval and Implementation of the Results. The scientific and practical results, as well as the technical and technological developments obtained in the dissertation, are aimed at increasing the efficiency of powder metallurgy production.

A scientifically substantiated new technology has been developed for the production of valve components for the high-pressure pump NP-720×105. The proposed technology made it possible to manufacture valve components, including the seat and the disc, with high wear resistance under impact-abrasive conditions. As a result of the implementation of modern technologies, material consumption and labor intensity have been significantly reduced, and the service life of the valve components has been increased.

The technology for manufacturing drilling pump valve components from wear-resistant powder steels has been developed, tested at “Oil and gas equipment” JSC, and recommended for implementation. Certain results of the dissertation can also be applied at industrial enterprises such as Oil and Mining, and Oil and gas repair.

The materials presented in the dissertation can be used in the educational process at the Azerbaijan Technical University, including lectures, practical classes, course projects, graduation theses, and master's dissertations at both the undergraduate and graduate levels.

Reliability of the Research Results. The objectives set in the dissertation were solved on the basis of analytical and experimental studies conducted under laboratory and production conditions. The reliability of the obtained results was confirmed through experimental investigations carried out using modern instruments and measurement tools.

Organization Where the Dissertation Was Carried Out. The dissertation was carried out at the Department of Metallurgy and Materials Technology of the “Azerbaijan Technical University” PLE

Personal Contribution of the Author. The relevance of the topic was substantiated by the author, a systematic review of modern scientific and technical literature was carried out, and the objectives and tasks of the research were defined. The preparation of articles for scientific and technical journals, as well as the preparation and delivery of conference presentations, was personally performed by the author.

Discussion of the Work. The main provisions of the dissertation were discussed and approved at the following scientific and technical conferences and seminars:

1. 7th Moscow International Conference "Theory and Practice of Manufacturing Technology for Composite Materials and New Metallic Alloys," Moscow, October 6–8, 2015.
2. 5th International Scientific and Practical Conference on "Modern Problems of Metal Physics," Baku, AzIMU, June 10–11, 2016.
3. International Scientific and Technical Conference on "Intellectual Technologies in Mechanical Engineering," Baku, AzTU, September 28–30, 2016.
4. Scientific seminars of the Department of Metallurgy and Metal Science of AzTU, Baku, 2017–2020.
5. International Scientific and Technical Conference on "Measurement and Quality: Problems and Perspectives," Baku, AzTU, November 21–23, 2018.
6. Scientific Seminars of the Department of Metallurgy and Materials Technology, AzTU, 2021–2024.

Publication of the Dissertation Results. The main content of the dissertation has been reflected in 18 scientific publications.

The volume of the structural sections of dissertation separately and the general volume with the sign. The structure of the dissertation consists of the title page (669 characters), table of contents (4177 characters), introduction (13380 characters), Chapter I (57350 characters), Chapter II (27903 characters), Chapter III (40997 characters), Chapter IV (26556 characters), Chapter V (23791 characters), conclusion (5035 characters), list of references, and appendices. The total volume of the dissertation comprises 26 figures, 25 graphs, 18 tables, and a list of 120 references. The main text, excluding figures, tables, graphs, and references, amounts to 199858 characters and occupies 152 computer-typed pages.

MAIN CONTENT OF THE STUDY

In the Introduction, the relevance and the degree of development of the research topic are substantiated, and the objectives and tasks of the study, as well as its object and subject, are identified. The research idea and hypothesis are formulated, and the scientific novelty together with the principal scientific and practical results submitted for defense are characterized. The theoretical and practical significance of the work is explained, while the research methods, approbation of the study, practical implementation of the results, and information on the publication of the research findings are presented.

Chapter 1 is devoted to the technological features of the production of wear-resistant powder metallurgy materials and products. Based on a review of the literature and industrial practice, the types of wear and the characteristic features of abrasive wear are systematically analyzed. A classification scheme of the main types of wear is presented, along with characteristic images of ductile and brittle fracture occurring under impact–abrasive wear conditions [13][1].

It has been demonstrated that, in order to prevent impact-abrasive wear of materials, it is possible to improve the structure and properties of powder steels through the use of efficient methods and techniques of powder metallurgy. The main technological directions of research aimed at increasing the impact-abrasive wear resistance of powder steels have been identified as follows:

- It is possible to enhance the impact-abrasive wear resistance of porous powder steels by increasing their strength, toughness, and matrix plasticity through the use of alloying elements;
- Ensuring the homogeneity of alloying elements in the structure, applying optimal sintering, thermal, and pressure treatment regimes, reducing the porosity of the pressed blanks, and increasing their structural strength make it possible to enhance wear resistance under impact-abrasive conditions.

Thus, based on the review of theoretical and experimental studies

[1] Investigation of wear-resistant materials working under shockabrasive wear conditions and test conditions. Subhan Namazov, Taleh Taghıyev, Shahin Mashayev.

on the structure and properties of Fe-Cr-Ni based powder steels, including the improvement of their wear resistance under impact-abrasive conditions, the following conclusions have been drawn [14][2]:

1. A systematic analysis of the wear processes of machines and mechanisms has shown that the impact-abrasive wear process is a complex physico-mechanical phenomenon with a wide spectrum, in which abrasive wear and surface destruction occur through different mechanisms under the influence of external impact forces.

2. Steels and alloys with high surface hardness exhibit greater resistance to wear under constant loading. However, such steels are not necessarily resistant to impact-abrasive wear.

3. It has been established that the chemical composition, structure, density of powder steels, as well as the characteristics of the principal element serving as the matrix, are the main factors that significantly influence the impact-abrasive wear process.

4. To improve the resistance of powder materials to impact-abrasive wear, it is necessary to develop a favorable structure and properties and to enhance the material's resistance to external forces.

5. During the sintering of powder steels, diffusion processes and homogenization occurring within the pressed compacts lead to an increase in the surface resistance to impact-abrasive wear. However, to ensure diffusion proceeds to the required extent during sintering, the amount and granulometric composition of the alloying elements in the mixture play a crucial role.

Chapter 2 substantiates, develops, and selects the research methods, the materials under investigation, the necessary equipment, devices, and accessories for testing, as well as the technologies for specimen preparation used in the study.

In the tests, iron powders of grade ПЖВ 3.160.26 (GOST 9849-86) and graphite powders of grade ГК-3 (GOST 4404-78) were used. As alloying agents, corrosion-resistant steel powder of grade ПВ-Х18Н15-056 (GOST 13084-88), atomized steel powder of grade ПР-65Х25П3Н3, nickel powders of grades ПНК-1Л5 and ПНЭ-1 (GOST 9722-97), as well

[2] Development of Production Technology for the Valve of Steel Drilling Pump Brand of PK08X4H5. Namazov S.N., Taghıyev T.A, Mashayev Sh.M.

as low-carbon ferrochrome FeCr70C30 and high-carbon ferrochrome powder ФХ-800А (GOST 5448-81) were employed. Zinc stearate powder (TU 6.09-3567-75) with a density of 1.0 g/cm³ in the amount of 0.6% was added to the charge as a plasticizer.

The cold static pressing (CSP) of the samples was carried out on a ПСГ-50 hydraulic press [2][3].

The powder mixture was compacted under a pressure of 300–700 MPa**.** The residual porosity of the pressed specimens ranged between 15% and 35%**.** Cylindrical samples with a height of 20 mm were densified by means of uniaxial pressing.

To determine the mechanical properties of porous materials, the specimens were sintered in a chamber furnace. The furnace interior was lined with a refractory material consisting of 25% asbestos, 50% quartz sand, and 25% aluminum oxide. The specimens were placed in ceramic boats inside a container made of heat-resistant steel.

In the furnace, the specimens were heated at 600–800°C for 1 hour**.** The temperature inside the furnace was regulated with an accuracy of ±10 °C using a thermocouple. For tempering the sintered specimens, electric furnaces were used, with dissociated ammonia serving as the protective atmosphere. The specimens were heated at 950–960°C for 20 minutes inside the furnace. The tempered specimens were subsequently cooled in a mixture of quartz sand and aluminum oxide under an ammonia atmosphere [3][4].

The process of dynamic hot pressing was carried out using hammers with an impact force of 50 kg. The compacts were heated to a temperature of 1100°C in an electric furnace under a dissociated ammonia atmosphere for 20 minutes. After heating, the compacts were removed from the furnace and subjected to the dynamic hot pressing operation. The velocity of the applied dynamic impacts ranged from 0.5 m/s to 5 m/s.

The plastic deformation of the surface of the sintered compacts was carried out on a lathe using a specially designed device. The machining speed ranged from 6 to 10 m/min, with a cross-sectional feed rate of 0.5

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[3] Основные способы компактирования порошковых материалов и применение их при изготовлении деталей машиностроения. С.Н.Намазов, Т.А.Тагийев, И.А.Майылов.

[4] Технология получения наноструктурных порошков, применяемых в технике. С.Н.Намазов, Т.А.Тагийев, Р.Р.Зейналов.

mm/rev. The applied force on the sample surface during processing varied between 50 N and 650 N.

A test rig was designed and fabricated to determine the impact-abrasive wear of the powder metallurgy compacts. The proposed design features a simple structure and compact dimensions. The experimental setup makes it possible to assess the wear of the samples under impact-abrasive conditions that are adequate to real operating conditions. The tests were carried out in accordance with GOST 23.207-79, with the impact energy ranging from $F_e = 2.94$ to 29.4 J and the impact velocity varying between $V_e = 0.5$ and 5 m/s [5][5].

To determine the surface wear and microstructure of the samples, metallographic sections were prepared. For etching the samples, a 4% solution of ethyl alcohol was used, while "Marble" and "Murakami" reagents were applied to reveal the structure and phases. The microstructures were examined using a Viem MET optical microscope, and porosity was determined by the hydrostatic method.

Chapter 3 is devoted to the experimental investigation of the structure and properties of Fe-Cr-Ni based wear-resistant powder steels. The key factors that have a decisive influence on the impact-abrasive wear resistance of powder steels were identified. These include: the chemical and granulometric composition of the powders, the technology of charge preparation, the method of compact formation, the sintering temperature and duration, as well as the thermal and thermomechanical treatment regi-mes of the products.

It was established that cementite accelerates the impact-abrasive wear process**,** as its brittle nature causes it to easily fracture into particles, which subsequently act as additional abrasive elements. As a result, the wear of the product surface intensifies. X-ray structural analysis revealed that, under these conditions, the structure consists of 100% alloyed cementite phase [12][6].

It was determined that an increase in the amount of graphite in the

[5] Ovuntu poladlarının zərblə-abraziv yeyilməyədözümlülüyünə təsir edən amillər və onların öyrənilməsi üsulları. S.N.Namazov, T.Ə.Tağıyev, Ş.M.Maşayev.
[6] Ovuntu poladlarından hazırlanan hissələrin yeyilməyədözümlülülüyünə kimyəvi tərkibinin təsirinin araşdırılması. V.F.Qəhrəmanov, T.Ə.Tağıyev.

composition accelerates the wear process, which, in turn, leads to the formation of new pores. Since graphite is considered a void within the structure, its presence results in an increase in the overall porosity of the material. In general, carbon exhibits a high solubility in austenite during the sintering process.

The effect of the chemical composition, particularly carbon (graphite), chromium, and nickel, on the impact-abrasive wear resistance of powder steels was evaluated. Based on numerous experimental studies, it was established that the most wear-resistant powder steels should preferably contain 0.7–0.8% carbon, 3.5–4% chromium, and 4–5% nickel (Figure 1) [16][7].

In most cases, the particles of the alloying elements, whose hardness is higher than that of the matrix, lead to the formation of surface roughness in the wear zone and completely change the surface topography (Figure 1). It was determined that when the graphite content in powder steels exceeds 1.5%, the wear resistance decreases, while the amount of secondary cementite increases. This increase predominantly occurs along the grain boundaries, and in such cases, the hardness of the samples rises from 700 HV to 1000 HV.

Thus, it has been confirmed that the wear process in porous materials proceeds more intensively compared to compact materials. During friction, the detached dispersed particles from the surface accelerate the wear of the material.

Experimental studies have shown that the elements that enhance the resistance of the specimens to impact-abrasive wear are chromium and nickel. The specimens exhibiting the minimum wear typically contained 2-4% chromium and 1-5% nickel. However, increasing the nickel content above 5% does not lead to any significant improvement in wear resistance [9][8].

When steel shavings of grades ПВ-Х181115-56 and ПР-65Х25Г13Н3 were added to the powder mixture, a significant increase in the impact-

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[7] Kimyəvi tərkibin ovuntu poladlarinin zərblə-abraziv yeyilməyədözümlülüynə təsiri. T. Tagiyev.

[8] Ovuntu poladlarının yeyilməyədözümlülüyünə xromun təsiri. S.N.Namazov, Tağıyev T.Ə., Ş.M.Maşayev, V.F.Qəhrəmanov.

abrasive wear resistance of the specimens was observed. The best results in terms of wear resistance were recorded in specimens produced from regenerated shavings of grade ПР-65Х25Г13Н3.

To determine the optimal composition of the charge mixture, the method of statistical experimental design was employed. In the mathematical planning process, variable factors, their levels of variation, and several parameters were taken into account (Table 1). The charge mixture included graphite of grade ГК-3, chromium alloying additive of grade ПР-65Х25Г13Н3, and carbonyl-nickel powder of grade ПНК-1Л5.

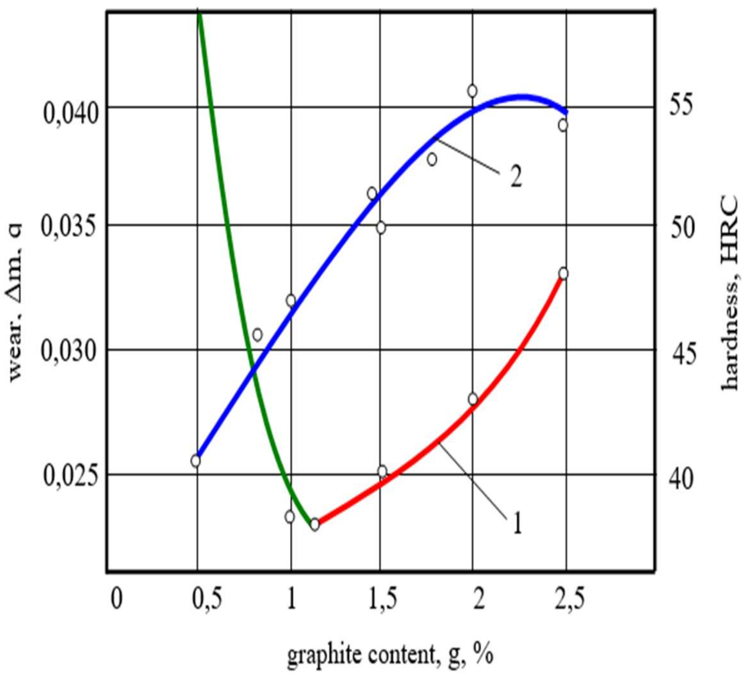

Figure 1. Dependence of wear (1) and hardness (2) on the graphite content in the composition.

Table 1

Factors and Levels of Variation

Factors	Codes	Natural Equivalents of the Corresponding Coded Factors				
		+1,682	+1	0	-1	-1,682
Chromium content, %	X1	5,5	4	2,7	1,2	0
Nickel content, %	X2	5	3,7	2,5	1,3	0
Graphite content, %	X3	2,4	1,8	1,2	0,6	0

The sample preparation technology involved mixing the powder charge for 2 hours, pressing it under a pressure of 600 MPa, sintering at 1150 °C for 2 hours, followed by heat treatment consisting of quenching in oil at 940 °C and tempering at 200 °C. The impact energy was 4.9 J/cm, and the impact velocity was 1.6 m/s. The obtained experimental results were statistically processed, and the following regression equation was derived to evaluate wear, expressed as weight loss:

$$\Delta m = 0{,}068 + 0{,}0029\,Cr - 0{,}0172\,Ni + 0{,}017\,Ni^2$$

As can be seen from the expression, the value of absolute wear is primarily dependent on the chromium (Cr) and nickel (Ni) content (Figure 2). The wear resistance of Cr and Ni alloyed powder steels is strongly correlated with the diffusion processes occurring during sintering. During the sintering process, the mutual adhesion forces between chromium, nickel, and iron particles increase, which significantly delays the formation of microcracks under impact-abrasive wear conditions, thereby enhancing wear resistance.

The influence of the granulometric composition of powders on the homogenizing sintering regime was investigated. It was determined that the variation in the amounts of chromium and nickel depends on the granulometric composition of the powder charge. The refinement of the powders accelerates the formation of a homogeneous structure.

It has been established that pores in powder steels lead to the formation of stress concentrations under impact–abrasive wear conditions and promote the propagation of cracks. Experimental results demonstrated that a reduction in residual porosity in the specimens leads to a significant decrease in wear.

It has been shown that the sintering regimes of alloyed powder steels operating under impact-abrasive wear conditions must ensure strong bonding between dispersed particles and a uniform distribution of alloying elements throughout the volume of the pressed compacts.

It has been established that, in ПК08Х4Н5-grade powder steels, the optimization of the granulometric composition reduces the homogenization process from 12 hours to 4–6 hours. Experimental results have confirmed that, when the coefficient of variation of alloying elements in ПК08Х4Н5 powder steels reaches 0.3, the wear resistance under impact-abrasive testing conditions decreases significantly[14][9].

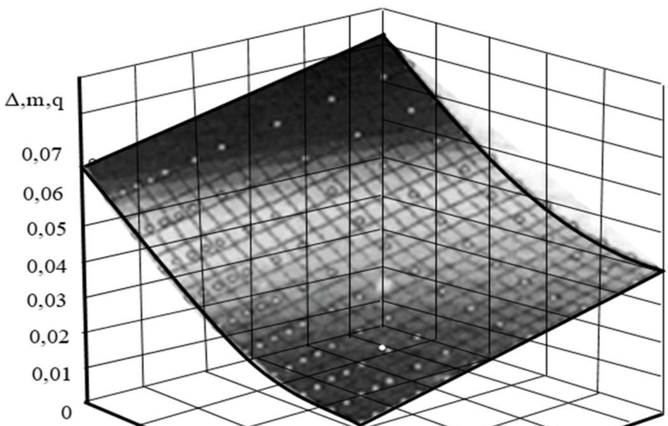

Figure 2. Dependence of the absolute wear of sintered Fe-Cr-Ni-C (graphite) based steels on the chromium and nickel content

[9] İnfluence of thermal temperature on impact-abrasive wear resistance of powder steel PK08KH4N5 Namazov S.N., Taghıyev T.A, Mashayev Sh.M.

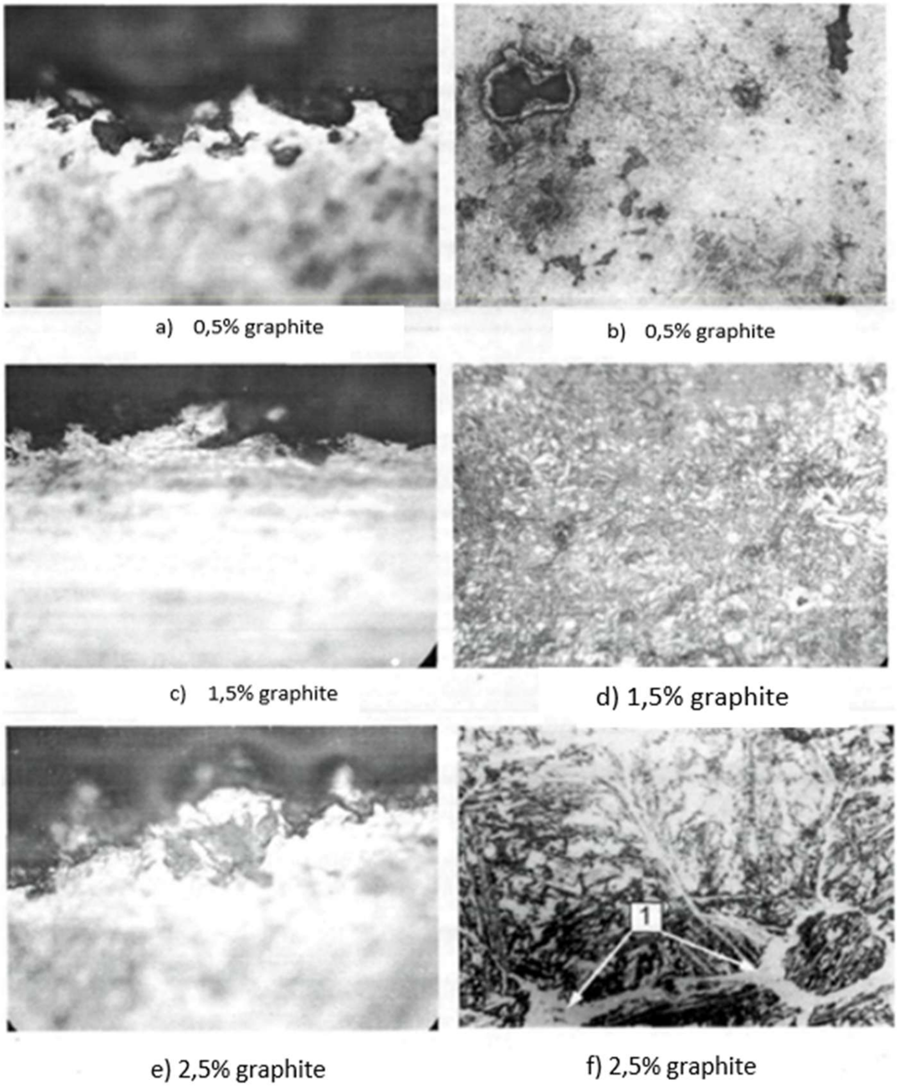

Figure 1. Microstructure of the surface layer (a, c, e) and the core region (b, d, f) of specimens containing graphite:
a, b – 0,5% graphite; c, d – 1,5% graphite; d, e – 2,5% graphite

Chapter 4 is devoted to the study of the influence of technological parameters on the wear resistance of powder steels. It has been demonstrated that the main technological parameters significantly affecting the wear resistance of powder steels are: cold compaction pressure of the powder mixture, residual porosity, sintering temperature, sintering duration, as well as the method and regime of thermomechanical treatment. Using ПК08Х4Н5 grade powder steel, the effects of these technological parameters were evaluated (Figure 3).

The influence of residual porosity of the compacted billets on the impact-abrasive wear resistance of powder steels was investigated. It was found that, in chromium-nickel powder steels with high wear resistance, the residual porosity was 5–6%, a result that was achieved through the application of dynamic hot pressing.

Samples made from ПК08Х4Н5 powder steel, sintered at 1200°C, quenched at 950°C, and tempered at 200°C demonstrated high resistance to impact-abrasive wear

In order to determine the correlation between sintering temperature, sintering duration, and impact-abrasive wear, a regression equation was derived:

$$\mathbf{\Delta m = 0,25 - 0,286 \cdot 10^{-3} T_{sin} + 0,159 \cdot 10^{-6} T_{sin}^{2} + 0,164 \cdot 10^{-3} t_{sin} + 0,38 \cdot 10^{-6} t_{sin}^{2} \cdot T_{sin}}$$

Chapter 5 is devoted to the implementation of the results of theoretical and experimental studies and the validation of the proposed hypothesis. For this purpose, the seat and disc components of a high-pressure drilling pump valve widely used in the oil and gas industry were selected as objects of study.

The operating conditions of the drilling pump valve were analyzed, and it was decided to manufacture the seat and disc from alloyed powder steel. The investigations demonstrated that by purposefully controlling the chemical composition, microstructure, and technological parameters, it is possible to ensure high wear resistance of ПК08Х4Н5 powder steel [17][10].

At "Baku Oilfield Equipment" JSC, a manufacturing technology for producing the valve seat and disc from ПК08Х4Н5 powder steel was

[10] Development of Production Technology for the Valve of Steel Drilling Pump Brand of PK08X4H5. Subhan Namazov, Taleh Taghıyev, Shahin Mashayev.

developed and proposed (Figure 2).

The technological process comprises the following operations: 1. Selection of the powder mixture composition. 2. Mixing of the powder mixture. 3. Cold pressing of the powder mixture at a pressure of 400 MPa for producing the base part, and 250-300 MPa for the powder mixture of the working surface. 4. Sintering of bimetallic specimens in a chamber furnace at 1200°C for 4 hours in an ammonia atmosphere. 5. Hot pressing and surface plastic deformation of the specimens. 6. Mechanical machining of the pressed blanks. 7. Quenching and tempering of the pressed blanks in a protective atmosphere.

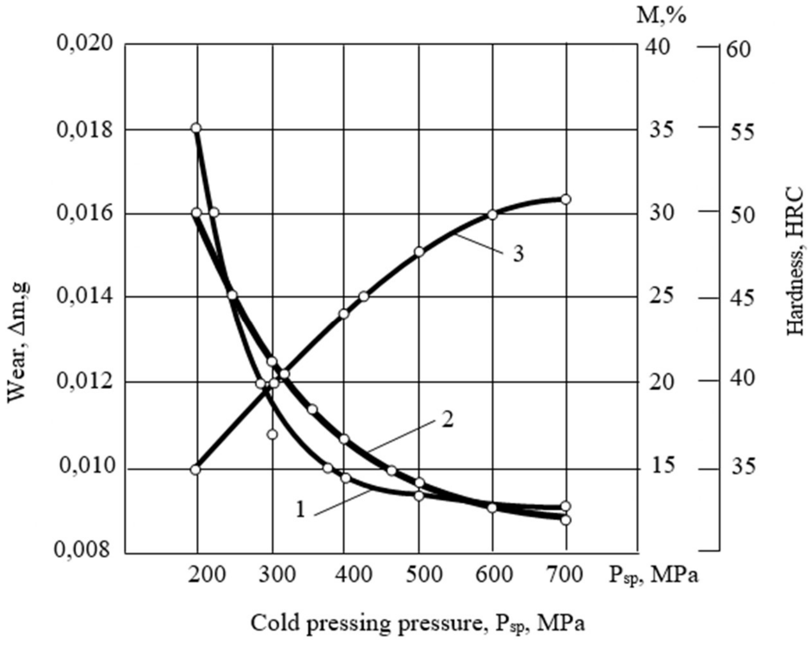

Figure 3. Dependence of impact–abrasive wear (1), residual porosity after sintering (2), and hardness after thermomechanical treatment (3) on the compaction

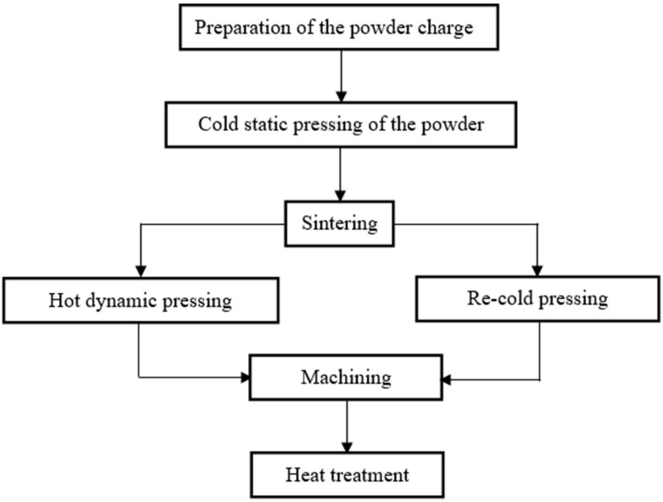

Figure 2. Technology for manufacturing the valve seat and disc of the high-pressure pump model НП-720×105 from powder materials

An optimal design of the pressing die for compacting the powder mixture was developed, and an algorithm of the technological processes was elaborated. The proposed technological process and its implementation algorithm ensure a low residual porosity throughout the entire volume of the specimens. As a result, the energy consumption for pressing is reduced, and it becomes possible to obtain powder products with the required physical and mechanical properties.

GENERAL CONCLUSIONS

1. A systematic analysis of the wear processes of machines and mechanisms has shown that the impact–abrasive wear process is a complex physico-mechanical phenomenon characterized by a wide spectrum of interactions, where abrasive wear and surface fracture occur through various mechanisms under the action of external impact forces. It has been established that the chemical composition, structure, density, and properties of the main matrix-forming elements of powder steels are the key factors

that significantly influence the impact–abrasive wear process.

In order to improve the resistance of powder materials to impact–abrasive wear, it is necessary to obtain an optimal structure and properties that enhance the material's ability to withstand external forces. During the sintering of powder steels, diffusion processes and homogenization in the compacted preforms lead to an increase in surface resistance to impact–abrasive wear. However, for diffusion to proceed effectively during sintering, the content of alloying elements and the granulometric composition of the powders play a crucial role.

2. The methodology and equipment for determining the impact–abrasive wear of powder steels were substantiated and selected. The chosen equipment is characterized by its compact dimensions and allows variation of the impact energy within the range of 3–30 J and the impact velocity within the range of 0.5–5 m/s. In the experimental apparatus designed and fabricated for the determination of impact–abrasive wear, a special fixture for securing the specimens was installed, and elastic springs were incorporated to prevent the fracture of brittle components.

3. The influence of carbon content and alloying elements on the impact–abrasive wear resistance of powder steels has been investigated. It was found that the optimal composition for achieving the highest wear resistance contains 0.7–0.8% carbon, 3.5–4% chromium, and 4–5% nickel.

4. The experimental results revealed that one of the key factors affecting the impact-abrasive wear resistance of powder steels is the residual porosity of the pressed compacts. For chromium-nickel powder steels with high wear resistance, the residual porosity was found to be in the range of 5-6%, which was achieved through dynamic hot pressing (DHP) and cold static pressing (CSP) under an applied load of 300-350 N. It was determined that the impact-abrasive wear resistance of samples obtained after cold static and dynamic hot pressing was significantly higher than that of compacts produced by conventional methods. To further enhance the impact-abrasive wear resistance, surface strengthening by plastic deformation (using shot peening) was proposed.

5. Based on theoretical and experimental studies, a multicomponent alloying approach was proposed to minimize energy losses during the sintering of powder products while ensuring high impact-abrasive wear resistance. It was established that the chemical and granulometric

composition of the powder mixture allows the heterodiffusion sintering process in ПК08Х4Н5 powder steels to be shortened from 12 hours to 4-6 hours, resulting in improved physical and mechanical properties.

6. The influence of the concentration of elements on the partial values of heterodiffusion coefficients in the Fe-Cr-C (graphite), Fe-Ni-C (graphite), and Cr-Ni-C (graphite) systems was investigated. It was found that in Fe-Cr systems, graphite slows down the diffusion process, leading to the formation of chromium particles around the carbide structures. In contrast, in Cr-Ni and Fe-Ni systems, graphite intensifies the mass-transfer exchange during the diffusion process.

7. To ensure impact-abrasion wear resistance, samples made of ПК08Х4Н5 grade powder steel were sintered at 1200°C, quenched at 950°C, and subjected to low-temperature tempering at 200°C. After the heat treatment, the coefficient of variation of chromium and nickel content in the composition decreased to 0.3.

8. Using specialized software, the optimal dimensions and configuration of the specimens were determined to ensure a uniform distribution of residual porosity. In axisymmetric compacts, the inner and outer conical walls were subjected to a forming operation through dynamic hot pressing.

9. A new technology has been developed for the production of valve components seat and disc of the high-pressure pump model NP-720×105 from powder metallurgy steels. The proposed technology enables the manufacture of seats and discs with enhanced resistance to impact-abrasive wear. Based on scientifically substantiated technological processes, the material, energy, and labor intensity of powder product manufacturing have been significantly reduced, while the service life of the components has been increased.

10. The proposed scientifically substantiated technical and technological solutions were successfully tested on a test bench at the Baku Oilfield Equipment Plant and have been recommended for industrial implementation. The expected techno-economic effect of producing high-pressure pump components of model NP-720×105 from wear-resistant powder metallurgy steels amounts to 34,866 AZN per year [17][11].

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[11]S.N.Namazov, T.Ə.Tağıyev. Kimyəvi tərkibin ovuntu poladlarının zərblə-abraziv yeyilməyədözümlülüyünə təsiri

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1. С.Н.Намазов, Т.А.Тагийев, И.А.Майылов. Исследование по определению механических свойств пластических масс и композиционных материалов // 7-я Московская Международная конференция "Теория и практика технологии производства изделий из композиционных материалов и новых металлическых сплавов" Москва, Россия, 6-8 октября 2015, с. 77-81
2. С.Н.Намазов, Т.А.Тагийев, И.А.Майылов. Основные способы компактирования порошковых материалов и применение их при изготовлении деталей машиностроения // 7-я Московская Международная конференция "Теория и практика технологии производства изделий из композиционных материалов и новых маталлическых сплавов". Москва, Россия, 6-8 октября 2015, с. 384-390
3. С.Н.Намазов, Т.А.Тагийев, Р.Р.Зейналов. Технология получения наноструктурных порошков, применяемых в технике // Научно-технический журнал «Оборудование и технологии для нефтегазового комплекса» Москва, Россия, 17.02.2015, с. 38-43
4. A.M.Quliyeva, Ş.M.Maşayev, T.Ə.Tağıyev. Molibdenli ovuntu poladlarında bişirmə zamanı yaranan fazaların poladın struktur və xassələrinə təsiri // "Maşınqayırmada intellektual texnologiyalar" Beynəlxalq Elmi-Texniki Konfransı. 28-30 sentyabr 2016-cı il, Bakı, Azərbaycan Texniki Universiteti, səh. 275-278
5. S.N.Namazov, T.Ə.Tağıyev, Ş.M.Maşayev. Ovuntu poladlarının zərblə-abraziv yeyilməyədözümlülüyünə təsir edən amillər və onların öyrənilməsi üsulları // "Maşınşünaslıq" Beynəlxalq elmi jurnalı, 5-ci cild, N2, Bakı, 2016, səh. 90-93
6. Namazov S.N., Tağıyev T.Ə. Dəmir əsasli ovuntu kompozisiya materiallarının səth qatında xromsilisiumlaşdirma ilə örtüklərin alinması // Metallar fizikasının müasir problemləri" mövzusunda V Beynəlxalq elmi-praktiki konfrans. Bakı, 2016, s. 354-356
7. S.N.Namazov, Tağıyev T.Ə, Ş.M.Maşayev, İ.A.Mayılov. Ovuntu poladlarının kimyəvi tərkibinin zərblə-abraziv yeyilməyədözümlülüyə təsiri // AzTU, "Elmi əsərlər", Texnika elmləri, Bakı, 2017, N2, səh. 88-94

8. Namazov S.N., Tağıyev T.Ə. Dəmir əsasli ovuntu kompozisiya materiallarinin sementitləmədən və borlamadan sonra mexaniki xassələrinin yaxşılaşdırılması // Elmi əsərlər, AzTU, Bakı, 2017, №1, s. 11-16

9. S.N.Namazov, Tağıyev T.Ə., Ş.M.Maşayev, V.F.Qəhrəmanov. Ovuntu poladlarının yeyilməyədözümlülüyünə xromun təsiri // "Ölçmə və keyfiyyət: problemlər və perspektivlər" mövzusunda Beynəlxalq Elmi-texniki konfrans, Bakı, AzTU, 21-23 noyabr 2018, səh 356-357

10. S.N.Namazov, T.Ə.Tağıyev. Molibdenli ovuntu poladlarında formalaşan karbid fazalarının poladın struktur və xassələrinə təsiri // Azərbaycan xalqının Ümummilli lideri Heydər Əliyevin anadan olmasının 96-cı ildönümünə həsr olunmuş tələbə və gənc tədqiqatçıların "Gənclər və elmi innovasiyalar" mövzusunda Respublika Elmi-texniki konfransı, 2-4 may 2019-cu il, səh. 463-465

11. S.N.Namazov, T.Ə.Tağıyev. Kimyəvi tərkibin ovuntu poladlarının zərblə-abraziv yeyilməyədözümlülüyünə təsiri // Azərbaycan xalqının Ümummilli lideri Heydər Əliyevin anadan olmasının 96-cı ildönümünə həsr olunmuş tələbə və gənc tədqiqatçıların "Gənclər və elmi innovasiyalar" mövzusunda Respublika Elmi-texniki konfransı, 2-4 may 2019-cu il, səh. 469-471

12. V.F.Qəhrəmanov, T.Ə.Tağıyev. Ovuntu poladlarından hazırla-nan hissələrin yeyilməyədözümlülülüyünə kimyəvi tərkibinin təsirinin araşdırılması // Mühəndis mexanikası jurnalı, 2020. səh. 42-47

13. T. Tagiyev. Kimyəvi tərkibin ovuntu poladlarinin zərblə-abraziv yeyilməyədözümlülüynə təsiri // Avadanliqlar, texnologiyalar, materiallar. ADNSU, Cild 1, buraxiliş ,01/2020, s. 93-99

14. Ramiz Hasanli, Ilham Aliyev, Nizami Poladov, Lala Azimova, Taleh Tagiyev. Izothermal Transformations in High-Strength Cast Iron // Scientific herald of Uzhhorod University Series "Physcs", Uzhhorod, 2022, cild 51, s. 48-58

15. Namazov S.N., Taghıyev T.A, Mashayev Sh.M. İnfluence of thermal temperature on impact-abrasive wear resistance of powder steel PK08KH4N5 // İnternational federation for the promotion of Georgian mechanic science, 22.12.2022 p 21-35

16. Subhan Namazov, Taleh Taghıyev, Shahin Mashayev. Investigation of wear-resistant materials working under shockabrasive wear conditions and test conditions // Machine science, AZTU, number 1/2023 p 45-52

17. T.Tagiyev. Evaluation of the economic efficiency of the manu-facture of the high-pressure pump valve from powder steel // Ecoenergetics, Number 1, Bakı, 2023, p. 81-86

18. Subhan Namazov, Taleh Taghıyev, Shahin Mashayev. Development of Production Technology for the Valve of Steel Drilling Pump Brand of PK08X4H5 // Advances in Science and Technology, 2024-04-12, p. 87-93

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