Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Investigation of the Influence of Technological Parameters on the Wear Resistance of Fe-Cr-Ni Based Powder Steels

Taleh Taghiyev

taleh.taqiyev@aztu.edu.az

Azerbaijan Technical University

Islam Alyarzada

Azerbaijan Technical University

Shahin Mashayev

Azerbaijan Technical University

Article

Keywords: steel, sintering temperature, sintering duration, impact-abrasive wear

Posted Date: November 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11593957/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

INVESTIGATION OF THE INFLUENCE OF TECHNOLOGICAL PARAMETERS ON THE WEAR RESISTANCE OF Fe-Cr-Ni BASED POWDER STEELS

Taleh Taghiyev[1*], Islam Alyarzada[1] and Shahin Mashayev[2]

[1*]Azerbaijan Technical University, Baku, Azerbaijan Republic.
[2]Mingachevir State University, Mingachevir, Azerbaijan Republic.

*Corresponding author(s). E-mail(s): taleh.taqiyev@aztu.edu.az;
Contributing authors: islam.alyarzade@aztu.edu.az;
shahin.mashayev@mdu.edu.az;

Abstract

Along with the chemical composition of powder steels, several technological parameters significantly affect their wear resistance. Examples of such technological parameters include the static cold pressing pressure of the charge, sintering temperature, and sintering duration. To evaluate the influence of the mentioned technological parameters, powder steel grade ПК8Х4Н5 was used.

Keywords: powder steel, sintering temperature, sintering duration, impact-abrasive wear

1 Introduction

The use of Fe-Cr-Ni-based powder steels offers opportunities to develop wear-resistant materials with improved mechanical properties, enhanced corrosion resistance, and tailored microstructures, while also providing potential economic advantages. The service performance of these materials, particularly their wear resistance, depends significantly on their chemical composition, microstructural characteristics, and processing parameters. Understanding the mechanisms through which these factors influence material performance is of considerable scientific and practical importance

for improving the reliability and service life of machinery and mechanical components operating under frictional conditions (Iqnaibi et al 2026).

Powder metallurgy is an efficient manufacturing technology for producing components with complex geometries, reducing material consumption, and controlling microstructural development. However, the physical, mechanical, and tribological properties of powder-metallurgy steels depend strongly on processing conditions, including compaction pressure, sintering temperature, holding time, and cooling conditions. These parameters influence the density, porosity, interparticle bonding strength, and phase composition of the resulting materials, thereby affecting their mechanical integrity and wear resistance. Appropriate control of these processing variables is therefore essential for achieving the desired combination of structural and functional properties.

In Fe-Cr-Ni-based powder steels, chromium plays a key role in enhancing corrosion and oxidation resistance, primarily through the formation of a protective passive oxide layer. Nickel contributes to the stabilization of the matrix phase and can improve the strength and ductility of the steel, depending on its chemical composition and processing conditions. The effects of these alloying elements are closely associated with the microstructural evolution during sintering. In particular, the kinetics of diffusion, the development of interparticle bonds, and the extent and distribution of porosity directly influence the mechanical properties of the material and the resistance of its surface layer to damage under service conditions. Consequently, understanding the combined effects of alloy composition and sintering conditions is essential for optimizing the performance of Fe-Cr-Ni-based powder steels.

Wear in metallic materials can occur through several mechanisms, including abrasive wear, oxidative wear, and surface fatigue. The predominance of these mechanisms depends on the frictional conditions, the characteristics of the contacting surfaces, the applied load, and the hardness and microstructure of the material. In powder-metallurgy steels, porosity and the distribution of microstructural constituents may additionally affect local stress concentrations, surface damage, and material loss during sliding contact. Therefore, establishing the relationships among hardness, coefficient of friction, and wear rate is essential for evaluating tribological performance and optimizing the service properties of these materials. Such an assessment should consider the combined influence of processing conditions and microstructural characteristics rather than relying on individual material properties alone (Ceschini et al 2006).

The aim of this study is to investigate the influence of the principal processing parameters on the wear resistance of Fe-Cr-Ni-based powder steel and to establish relationships between processing conditions and the resulting structural, mechanical, and tribological properties. For this purpose, ПК8Х4Н5 powder steel was selected as the material under investigation. The study focuses on evaluating the effects of compaction and sintering conditions on material density, microstructure, hardness, and wear characteristics. The findings are expected to contribute to the optimization of the manufacturing process for Fe-Cr-Ni-based powder steels and to the identification of suitable processing conditions for improving their wear resistance and overall service performance.

Purpose of the study. The study investigated the wear resistance of Fe-Cr-Ni-based powder steel by optimally selecting the cold pressing pressure, sintering temperature, and sintering duration.

2 Methodology

To evaluate the effect of cold pressing pressure, the methodology of the experiments was as follows. The powder charge of wear-resistant ПК8Х4Н5 steel was pressed in a cylindrical die under a pressure range of 200 MPa to 700 MPa in an impact-abrasive wear environment. The pressed briquettes were subjected to sintering at 1000-1250°C for 30 to 300 minutes (Table 1.). During sintering, quartz sand and aluminum oxide were used, and dissociated ammonia was selected as the sintering atmosphere. After sintering, the samples were quenched in water at 950°C and then tempered at 180-200°C for 1 hour (Elguezabal et al 2020; Namazov et al 2022).

Table 1 Technological Parameters and Variation Intervals

Factors	Codes	Variation Intervals of the Parameters				
		+1,414	+1	0	-1	-1,414
Sintering temperature, ^{0}C	X_1	1000	1036	1125	1213	1250
Sintering duration, min	X_2	30	70	165	260	300

Comparative analysis of the experimental results has shown that the sintering temperature and sintering duration exert a very significant influence on the impact-abrasive wear resistance of the samples. It was determined that during sintering, a certain shrinkage occurs in the samples, which intensifies the densification process and ultimately increases the impact-abrasive wear resistance of the product.

The wear resistance of samples produced from powder steel should be evaluated depending on their residual porosity. It is necessary to thoroughly investigate whether shrinkage occurs during the sintering of samples pressed under the corresponding pressures. This phenomenon determines the extent to which shrinkage affects the impact-abrasive wear resistance, as well as the shape and dimensions of powder steel products.

Additionally, regression equations should be developed to determine the relationship between sintering temperature and duration with impact-abrasive wear and volumetric shrinkage.

When the pressing pressure was 300, 400, 500, 600, and 700 MPa, the residual porosity and hardness of the samples were examined. Within the scope of the study, various graphs were plotted, appropriate mathematical equations and regression coefficients were determined in Excel based on experimental and theoretical indicators, and the obtained results were analyzed (Namazov et al 2023).

To determine the rational values of the technological parameters of the sintering process, the method of mathematical planning of experiments was applied. The

experimental results were processed using the "STATISTIKA-6.1" software. Using micro X-ray structural analysis, the mechanism of the influence of chromium (Cr) and nickel (Ni) present in the charge on the sintering process was investigated (Hryha and Nyborg 2014).

3 Discussion of the results

The wear resistance of the test samples produced from powder steel was evaluated based on their residual porosity (Figure 1.). In the samples pressed at 200 MPa, a slight shrinkage occurred during the sintering process. Although this phenomenon increased the impact-abrasive wear resistance of the samples to some extent, it also caused a loss in the accuracy of their shape and dimensions.

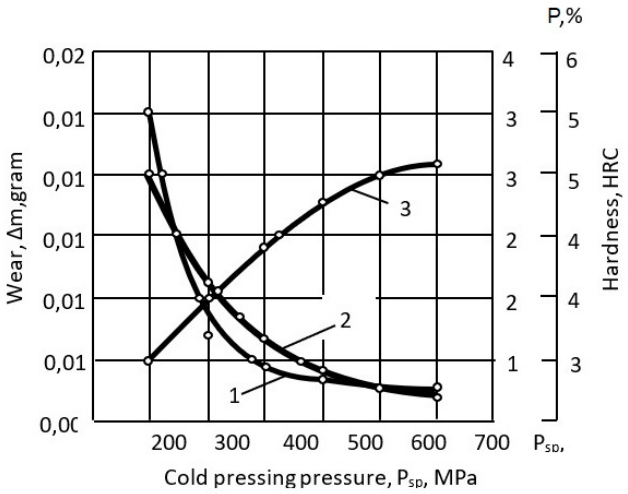

Figure 1 Dependence of impact-abrasive wear (1), residual porosity after sintering (2), and hardness after thermomechanical treatment (3) on the pressing pressure for powder steel grade ПК8Х4Н5

When the pressing pressure was 300 MPa, a partial increase in hardness of the samples was observed (38-39 HRC); however, high residual porosity was recorded in the samples (Figure 1, curves 2 and 3). Increasing the pressing pressure from 400 MPa to 700 MPa led to an increase in hardness from 43 HRC to 51 HRC, while the wear process was intensively reduced to 0.09-0.098 g (Figure 1, curves 1 and 2) (Salunkhe et al 2024).

It was determined that the fragmentation of samples occurs at residual porosity values of P = 30-32%, and in this case, the strength of the samples is low and their cohesion is not high. When porosity decreases from 16-17% (P_{sp} = 300 MPa) to 12-13% (P_{sp} = 700 MPa), the mass loss of the samples occurs only during impact-abrasive wear (Balabanov et al 2025).

At a pressing pressure of 300 MPa, the microstructure of the surface layer of the samples (Figure 2, a) shows certain fissures around crack networks. In this case, wear occurs due to the propagation of these fissures.

When samples pressed at 500 MPa with a residual porosity of 15% were subjected to wear, some roughness and deformation occurred. In this case, due to frictional forces, certain deformations in the structure, crack propagation, and deepening of surface roughness were observed (Figure 2, b).

At pressing pressures of 600-700 MPa and a reduction in residual porosity to 13-14%, the wear of the sample surface primarily occurs due to the detachment of alloying element particles from the surface layer. Despite surface fragmentation, a decrease in cracks around the pores was observed (Figure 2, c) (Yusubov et al 2025).



a) b) c)

Figure 2 Microstructures of ПК8Х4Н5 powder steel after impact-abrasive wear depending on pressing pressure (×640): a - 300 MPa, b - 500 MPa, c - 700 MPa

Figure 3 shows the dependence of the impact-abrasive wear of ПК8Х4Н5 powder steel on residual porosity. As can be seen, when the residual porosity ranges from 12% to 30%, the impact-abrasive wear of the samples varies from 0.009 g to 0.018 g.

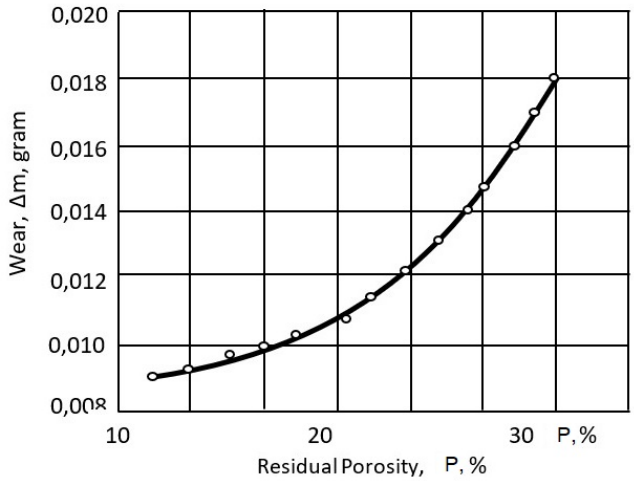

Figure 3 Dependence of impact-abrasive wear of samples made from ПК8Х4Н5 steel on residual porosity

The following regression equations were developed to determine the relationship between sintering temperature and duration, impact-abrasive wear, and volumetric shrinkage:

$$\Delta m = 0{,}25 - 0{,}286 \cdot 10^{-3} \cdot T_{sin} + 0{,}159 \cdot 10^{-6} \cdot T_{sin}^2 + 0{,}164 \cdot 10^{-3} \cdot t_{sin} + 0{,}38 \cdot 10^{-6} \cdot t_{sin}^2 + 0{,}61 \cdot 10^{-7} \cdot t_{sin} \cdot T_{sin} \quad (1)$$

$$\frac{\Delta V}{V} = -49{,}48 - 0{,}84 \cdot t_{sin} - 0{,}345 \cdot 10^{-4} \cdot t_{sin}^2 + 0{,}025 \cdot T_{sin} - 0{,}2 \cdot 10^{-4} \cdot T_{sin}^2 - 0{,}121 \cdot 10^{-4} \cdot T_{sin}^2 - 0{,}121 \cdot 10^{-4} \cdot T_{sin}^2 \quad (2)$$

Using expressions (1) and (2), the dependency shown in Figure 4, was constructed. As seen from Figure 4, the change in wear resistance and volumetric shrinkage depending on the firing process is a characteristic phenomenon.

When the holding time of the samples at the given firing temperature was increased from 30 minutes to 100 minutes, their wear decreased from 0.02-0.018 grams to 0.01-0.012 grams.

When the firing temperature was increased within the range of 1000-1200 °C and the firing duration was extended up to 120 minutes, the intensity of the wear process decreased. At a firing temperature of 1150 °C and a firing duration of 90-130 minutes, the wear of the samples was 0.01-0.013 grams. As the firing temperature and duration increase, the wear of the samples decreases significantly (Dubrovin et al 2025).

Thus, at temperatures of 1180-1200 °C, the best results were obtained in samples fired for 90-100 minutes. In this case, the volumetric shrinkage of the samples is 4%. Even when the firing duration is 250 minutes at a firing temperature of 1200 °C, the volumetric shrinkage of the obtained samples does not exceed 4% (Figure 4).

Using micro-X-ray structural analysis, the mechanism of the influence of chromium (Cr) and nickel (Ni) present in the charge on the firing process was studied. Samples containing different amounts of chromium and nickel were subjected to firing at 1125 °C for 30, 165, and 300 minutes (Figure 5). With a 0.45-0.5% increase in the chromium and nickel content, the hardness of the samples reached 47-48 HRC, while wear did not exceed 0.012-0.013 grams (Figure 5). The microstructures of the steels after firing are shown in Figure 5. At high concentrations of chromium and nickel in the composition (Figure 5), bright spots appear on the surface. In the central part of these bright spots, the amount of nickel is higher than that of chromium. However, despite this, the diffusion of chromium varies at significantly higher values compared to that of nickel.

Using micro-X-ray structural analysis, the mechanism of the influence of chromium (Cr) and nickel (Ni) present in the charge on the firing process was studied. Samples containing different amounts of chromium and nickel were subjected to firing at 1125 °C for 30, 165, and 300 minutes (Figure 5). With a 0.45-0.5% increase in the chromium and nickel content, the hardness of the samples reached 47-48 HRC, while wear did not exceed 0.012-0.013 grams (Figure 5). The microstructures of the steels after firing are shown in Figure 6. At high concentrations of chromium and nickel in the composition (Figure 6), bright spots appear on the surface. In the central part of these bright spots, the amount of nickel is higher than that of chromium. However, despite this, the diffusion of chromium varies at significantly higher values compared to that of nickel.

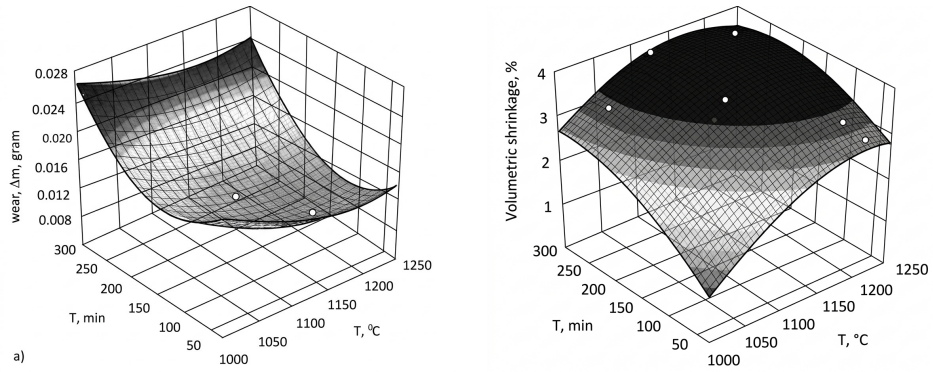

Figure 4 Influence of firing temperature and firing duration on the impact-abrasive wear (a) and volumetric shrinkage (b) of ПК8Х4Н5 grade steel shavings.

As seen from Figure 5, when the amount of chromium and nickel in the composition decreases to 0.42-0.46, the impact-abrasive wear of the samples decreases significantly (Figure 5, curves 1 and 2), while the hardness increases (Figure 5, curves 3 and 4) (Taghiyev 2023).

In the studies,a gradual increase in the amount of alloying elements resulted in an increase in the impact-abrasive wear resistance of the samples. This effect can be explained by the fact that alloying elements promote the formation of a favorable microstructure, which in turn leads to improved impact-abrasive wear resistance.

When the firing duration is 300 minutes and the chromium and nickel content in the charge is 0.35-0.42%, the wear resistance and hardness of the samples decrease. This effect is often associated with decarburization of the sample surface.

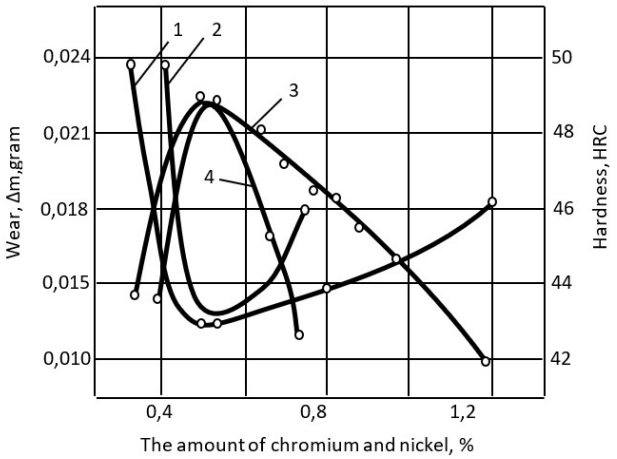

Figure 5 Dependence of the impact-abrasive wear (1, 2) and hardness (3, 4) of ПК8Х4Н5 grade steel shavings on the amount of chromium (1, 3) and nickel (2, 4).

At a firing temperature of 1125 °C and a firing duration of 30 minutes, numerous pores are observed in ПВ-Х18Н15-56 grade steel shavings (Figure 6, a). After wear testing, deep depressions form on the surface of the samples (Figure 6, b). When the firing duration is increased to 165 minutes, strengthening of the samples occurs due to the alloying elements chromium and nickel. This effect can be explained by the diffusion of alloying element particles into the pores, leading to the filling, reduction, and closure of the pores, which in turn results in strengthening (Figure 6, c).

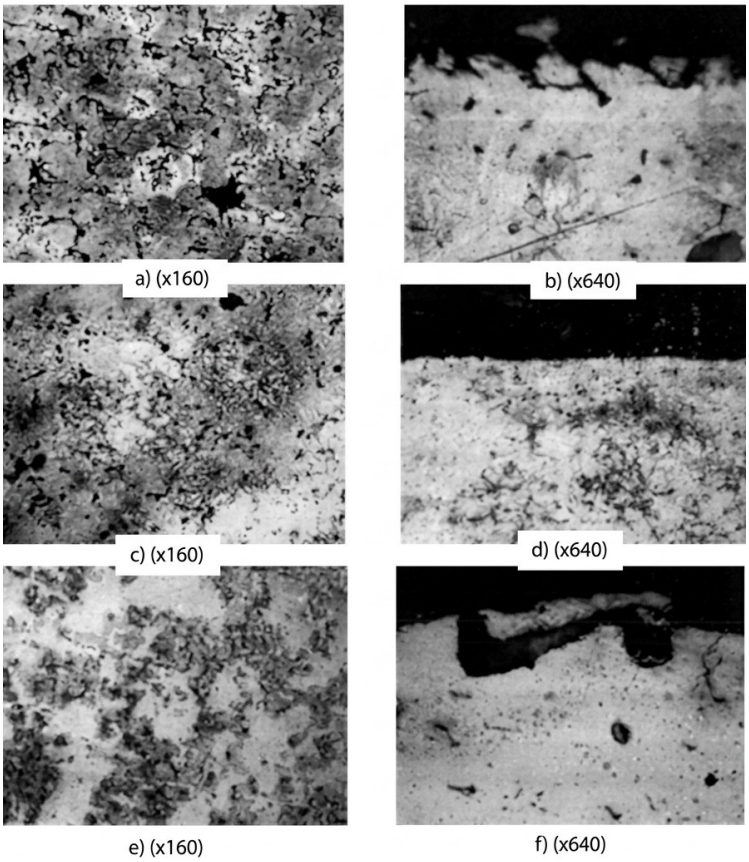

Figure 6 Microstructures of the core region (b, d, e) and surface layer (a, c, f) of steels fired at 1125 °C after wear: a and b-30 minutes, c and d-165 minutes, e and f-300 minutes

The wear of the surface of this type of sample is fairly smooth, and the wear process occurs due to plastic deformation (Figure 6, d). When considering the microstructure of samples made from ПК8Х4Н5 steel with a firing duration of 300 minutes, bright areas can be observed (Figure 6, e). These microstructures were obtained after the samples underwent abrasion for more than 30 seconds (Namazov et al 2024).

After wear, deep depressions appear on the surface of the samples due to abrasive particles (Figure 6, f). In this case, the impact-abrasive wear largely depends on the density of the samples and the homogeneity of their microstructure.

4 Conclusion

1. Thus, the conducted tests have shown that the wear process of steel shavings in an impact-abrasive environment largely depends on the residual porosity. It has been established that steel shavings with high density exhibit significantly higher impact-abrasive wear resistance compared to porous materials.
2. The decrease in the wear resistance of steel shavings can also be attributed to decarburization of the sample surface.

References

Balabanov I, Movlazade V, Yusubov N, et al (2025) Development of a parametric model for calculating cutting forces in external cylindrical turning of 20CrMn steel (1.7147) using an SNMG 15 06 16-PR 4425 insert. Reliab Theory Appl 20(SI 7(83)):335–342. https://doi.org/10.24412/1932-2321-2025-783-335-342

Ceschini L, Palombarini G, Sambogna G, et al (2006) Friction and wear behaviour of sintered steels submitted to sliding and abrasion tests. Tribol Int 39(8):748–755. https://doi.org/10.1016/j.triboint.2005.07.003

Dubrovin V, Kulakov B, Karpinsky A, et al (2025) Modeling and simulation of ductile-iron blank casting processes for an electrohydraulic power amplifier body. Reliab Theory Appl 20(SI 7(83)):274–280. https://doi.org/10.24412/1932-2321-2025-783-274-280

Elguezabal B, Alkorta J, Martínez-Esnaola JM (2020) Study of Astroloy powder compaction at high temperature under hydrostatic load using finite elements. Powder Technol 364:92–100. https://doi.org/10.1016/j.powtec.2020.12.001

Hryha E, Nyborg L (2014) Microstructure development in powder metallurgy steels: effect of alloying elements and process variables. Mater Sci Forum 782:174–180. https://doi.org/10.4028/www.scientific.net/MSF.782.467

Iqnaibi MR, Sarhan AAD, Mohammed AS (2026) A comprehensive review on the impact of porosity fraction, size, and morphology on the tribological characteristics of porous steel alloys produced by powder metallurgy (PM) and related techniques. Arab J Sci Eng 51(1):775–799. https://doi.org/10.1007/s13369-025-10926-z

Namazov SN, Taghiyev TA, Mashayev ShM (2022) Influence of thermal temperature on impact-abrasive wear resistance of powder steel PK08KH4N5. International Federation for the Promotion of Georgian Mechanics Science 4(89):21–35

Namazov S, Taghiyev T, Mashayev S (2023) Investigation of wear-resistant materials working under shock-abrasive wear conditions and test conditions. Machine Science (1):28–35. https://doi.org/10.61413/haxg9390

Namazov S, Taghiyev T, Mashayev S (2024) Development of production technology for the valve of steel drilling pump brand of PK08X4H5. Adv Sci Technol 148:87–93. https://doi.org/10.4028/p-PhqQk6

Salunkhe S, Prasad M, Davim J (2024) Powder Metallurgy: Characterization, Processing, and Optimization Techniques. CRC Press, Boca Raton

Taghiyev T (2023) Evaluation of the economic efficiency of the manufacture of the high-pressure pump valve from powder steel. Ecoenergetics (1):81–86

Yusubov N, Abbasova H, Dadashov R (2025) Matrix model of accuracy in machining conical surfaces on CNC lathes. Reliab Theory Appl 20(SI 7(83)):393–400