The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2026

Volume 40, Pages 122-128

ICBAST 2026: International Conference on Basic Sciences and Technology

Influence of Alloying Elements on the Kinetics of Austenite Transformation in Powder Steels

Maxim Egorov
Don State Technical University

Rimma Egorova
Don State Technical University

Michail Chaava
Don State Technical University

Filipp Pastuhov
Don State Technical University

Abstract: Structural materials obtained by powder metallurgy methods are the most common type of such products, widely used in mechanical engineering and instrument making. This paper investigates the features of the formation of the structure and properties of alloyed powder steels. The study analyzes the influence of the method of introducing alloying components (carbide-forming elements Cr, Mo, W), their dispersity, as well as sintering parameters on the homogenization of the material. It is shown that complete dissolution of alloying elements, especially large particles, requires high temperatures (up to 1300°C) and long isothermal holdings. Particular attention is paid to the effect of porosity on the kinetics of austenite transformation. It has been established that an increase in porosity reduces the incubation period and increases the temperature of the onset of the martensitic transformation (Mn point). The influence of chromium and molybdenum on the critical points Ac_1 and Ac_3, as well as on the hardness after quenching, is analyzed. It is shown that in complex-alloyed powder steels, due to chemical heterogeneity, insoluble carbides may form, reducing the hardness of the material.

Keywords: Powder metallurgy, Alloying elements, Sintering, Porosity, Austenite transformation

Introduction

Powder Metallurgy (PM) encompasses the production of metal powders, as well as articles made from them or their mixtures with non-metallic powders. A distinguishing feature of PM from other methods is that within a single technological process, both the formation of the powder material (charge) and the shaping of the finished product from this material occur, followed by subsequent processing. Powder metallurgy, at first glance, represents a symbiosis of multidirectional processes in which a monolithic material is first dispersed into a powder, and then this powder is reconsolidated into a solid body. However, this technology remains viable due to its advantages compared to other methods. In, the author presents the following advantages of powder metallurgy and its benefits over other technological processes, which make it attractive and cost-effective for manufacturing various materials and products with unique properties and high precision.

Powder metallurgy has a number of disadvantages and limitations, such as increased costs for materials and equipment, the need for specific operations and requirements, and the fact that it is only justified in large-scale production. These disadvantages and limitations should be considered when choosing this technology for a

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

specific production application. (Agureev et al.,2020, Baek, et al.,2020, Dorofeyev 2019). Despite certain drawbacks, powder metallurgy technology is actively used in industries requiring large-series or mass production of articles, as its advantages outweigh the disadvantages under these conditions. Authors in works note the significant development of powder metallurgy in the field of creating special steels and alloys (heat-resistant, tool steels, those possessing high strength and superplasticity). A great contribution to the development of powder metallurgy was made by such outstanding scientists as: Balshin, Kiparisov, Antsiferov, Fedorchenko, Andrievsky, Skorokhod, Kovalchenko, and Dorofeev. In their works, they address issues of the theory of sintering powder alloys, the theory of pressing, problems of powder materials science, the theoretical foundations of hot working of porous materials by pressure, dynamic hot pressing of powder products, and much more (Egorov et al.,2024, Eremeeva et al.,2016, Soffritti et al.,2020, Stern et al.,2016). Of course, the noted features are not isolated; they are closely related and intertwined, reflecting to a certain extent the general characteristics of the development of science and technology. They are also guided by the well-known advantages of PM, namely, obtaining products with a high material utilization rate, minimizing machining, as well as the possibility of automating the production of these products and obtaining articles with unique properties.

Heat treatment is understood as a set of operations involving heating, holding at high temperatures, and cooling with the aim of changing the structure and workability of the material, improving the combination of its mechanical and physical properties without altering the shape and dimensions of the products. Heat treatment is an effective method for enhancing the physical-mechanical properties and wear resistance of steel. The specific features of sintered steels (porosity, structural heterogeneity, high oxidizability, etc.) make it difficult to use the heat treatment processing regimes developed for cast steels, although the basic regularities of the processes occurring during heating and cooling of compact steel can be transferred to sintered materials as well. Heat treatment of powder steels has a number of features, primarily due to residual porosity, as well as chemical and structural heterogeneity (Egorov et al.,2024, Beskopylny et al.,2020, Geroldinger 2023, Li et al.,2025).

Method

The work investigated powders of metals such as iron, chromium, copper, molybdenum, and nickel. Carbon was added to the charge in the form of GK-1 pencil graphite. For the preparation of the powder mixture, special high-efficiency equipment was used — a RT-NM05S double-cone mixer manufactured in Taiwan (Figure 1), which ensures high-quality mixing of components with energy and time savings.

Figure 1. RT-NM05S double-cone mixer

Table 1. Mixer technical specifications

Model	Power, kW	Voltage, V	Load Capacity, kg	Working Volume, L	Total Volume, L	Rotation Speed, rpm	Weight, kg	Overall Dimensions, L×W×H, mm
RT-NM05S	0,18	220	5	8	16	15-30	38	808×400×602

The sintering process was performed in the heat treatment laboratory of the Department of Materials Science and Metal Technology at DSTU using a PKZ-1.0-7 chamber electric furnace with a protective atmosphere (Russia) (Figure 2, Table 2). The sintering was conducted within a temperature range of 900–1150°C in a dissociated ammonia protective gas atmosphere, with sintering times varying from 15 to 180 minutes. The influence of alloying elements on the transformation of austenite must be associated with the work expended on the rearrangement of the crystal lattice.

Figure 2. PKZ-1.0-7 laboratory chamber electric furnace with protective atmosphere

Table 2. Electric furnace technical specifications

Type	Tmax, °C	Gas flow rate, L/min	Working space W×H×D, mm	Overall dimensions W×H×D, mm	Power/Voltage, kW/V
PKZ -1,0-7	1300	4,1	150×180×290	795×585×605	2,5/220

The effect of nickel on the transformation kinetics of austenite in powder steels is similar to its effect in cast steels. By altering the mobility of iron atoms and the diffusion rate of carbon in α- and γ-Fe, nickel increases the stability of austenite, shifting the isothermal austenite decomposition curves downward and to the right. In high-carbon steel, the effect of nickel on the position of the isothermal decomposition curves is less pronounced than in low- and medium-carbon steel. Nickel increases the ability of austenite to undercool. Under the influence of nickel, the temperature at which the martensitic transformation begins (the Mn point) decreases; therefore, the transition of austenite to martensite occurs at a lower temperature. It increases the hardness of the austenite decomposition products, and by lowering the Mn point, it increases the amount of retained austenite (Romero-Resendiz et al.,2025, Buathong et al.,2025, Gabriel et al.,2025, Xu et al.,2025).

Copper, like nickel, increases the stability of austenite, but to a lesser extent than nickel. With an increase in porosity and a decrease in the carbon content in copper-containing steels, the duration of the incubation period decreases, the temperatures of minimum austenite stability and the start of the martensitic transformation increase, and the transformation time of austenite and the hardness of the transformation products decrease.

Results and Discussion

The most significant influence on the kinetics of austenite transformation is exerted by carbide-forming elements (Cr, Mo, W, etc.). In their presence, the duration of the incubation period and the time for complete decomposition of austenite increase. With an increase in porosity, the total transformation time of austenite decreases, and the transformation diagram shifts to the region of higher temperatures. Thus, chromium, by increasing the stability of austenite, enhances its tendency to undercooling, significantly lowers the critical quenching rate, and improves the hardenability of steel.

Table 3. Ac_1 and Ac_3 point values of powder steels

№	Steel grade	Critical point values, °C	
		Ac_1	Ac_3
1	Fe+1%C	715	755
2	Fe+1%C+2%Cr	752	786
3	Fe+1%C+2%Cu	730	762
4	Fe+1%C+2%Cr+2%Cu	760	795
5	Fe+1%C+5%Cr+5%Cu	787	880
6	Fe+1%C+5%Cr+10% Mo	800	880
7	Fe+1%C+12%Cr+2% Mo	807	883

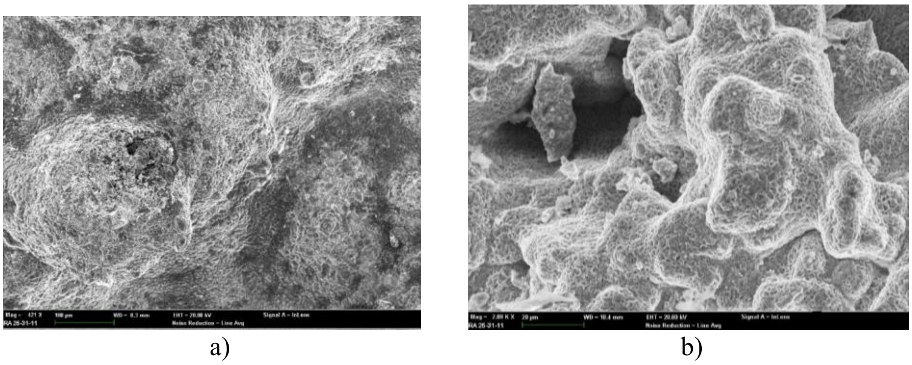
While in cast steels the position of the martensitic point is independent of the molybdenum content, in powder steels molybdenum reduces the critical cooling rate, even more significantly than chromium. Molybdenum steels exhibit high hardenability and have little tendency to overheat. The values of the critical points Ac_1 and Ac_3 for chromium-molybdenum powder steels are given in Table 3.

From the data presented in Table 3, it follows that as the chromium and molybdenum content increases, the critical points shift to the region of higher temperatures, i.e., chromium and molybdenum raise the critical points Ac_1 and Ac_3. The hardness of these steels after quenching in water from a temperature of Ac1 + (30–150) °C is given in Table 4.

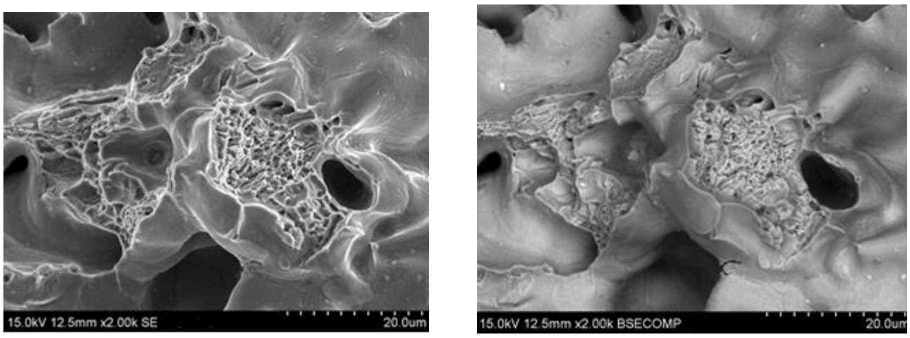
Table 4. Hardness of powder steels after quenching

№	Steel grade	Optimal quenching temperature, °C	Optimal holding time during heating for quenching, min	Hardness, HRC
1	Fe+1%C	840	10-15	56-60
2	Fe+1%C+2%Cr	860	15-20	55-58
3	Fe+1%C+2%Cu	860	15-20	52-55
4	Fe+1%C+2%Cr+2%Cu	860	20-25	48-52
5	Fe+1%C+5%Cr+5%Cu	910	20-25	41-45
6	Fe+1%C+5%Cr+10% Mo	920	25-30	38-45
7	Fe+1%C+12%Cr+2% Mo	970	25-30	34-40

From Table 4, it follows that as the content of alloying elements increases, the optimal quenching temperature rises, as does the holding time. It can also be observed that the hardness of the quenched samples decreases with an increase in the content of alloying elements. This is explained by the following. During the sintering of chromium-molybdenum steels, numerous primary, difficult-to-dissolve special carbides are formed, which do not have enough time to dissolve during heating for quenching. Since the carbide phase binds part of the carbon, its amount in the solid solution decreases, leading to the formation of low-carbon martensite and troostite, which reduce the hardness of the steel. Additionally, the inhomogeneity of the solid solution lowers the stability of supercooled austenite and shifts the Mn point to a region of higher temperatures (Kim et al.,2023, Hojati et al.,2022, Egorova et al.,2018).



a) b)



c) d)

Figure 3. Fractographs of the fracture surface of Fe+1%C+12%Cr+2%Mo alloy samples fabricated under the following conditions: quenching temperature 970 °C, density 7.4 g/cm³: (a, c) carbon content 0.5%; (b, d) carbon content 0.8%

Fractographic studies of the samples quenched at 970°C showed that the fractures are characterized by a ductile-brittle fracture mechanism, which occurs along grain boundaries with ductile tear areas. The pores have a rounded shape, with a size of 5–10 μm. The ductile fracture surface indicates significant plastic deformation during failure.

For complex-alloyed steels with varying porosity, the thermokinetic diagrams are close to the austenite transformation diagrams of corresponding cast steels and are independent of porosity. The influence of porosity on the transformation kinetics is similar to its effect on the austenite transformation in carbon and singly-alloyed powder steels: an increase in porosity reduces the incubation period, increases the decomposition rate, and raises the temperature of minimum austenite stability and the temperature of the start of the martensitic transformation – the Mn point.

At the same time, the influence of porosity on the stability of austenite in complex-alloyed steels is more pronounced than in carbon steels. Thus, increasing porosity from 5% to 15% in carbon steels with 0.8% C reduces the period of minimum austenite stability by 0.3 s, while in steel 80%Fe+2%Ni+2%Cu+0.8%C, it decreases by 1.5 s.

The sintering temperature also has a significant effect on the stability of austenite in complex-alloyed steels: for example, it has been shown that increasing the sintering temperature from 1180°C to 1280°C enhances the homogeneity of austenite, increases the incubation period, widens the temperature range of maximum stability, and increases the amount of decomposed austenite.

Conclusion

In alloyed steel, complete decomposition of austenite does not occur. Retained austenite is always observed in the decomposition products. With an increase in porosity in complex-alloyed steel, the amount of retained austenite decreases. An increase in the Mn temperature leads to self-tempering of alloyed martensite, a reduction in its tetragonality, and a decrease in hardness. Significant chemical heterogeneity of steels made from complex-alloyed powder mixtures leads to the formation of carbides of the Me_3C_2, Me_7C_3, $Me_{23}C_6$ type that are insoluble up to the melting point. This sharply reduces (in comparison with cast steels) the incubation period and increases the critical quenching rate. As a result, even at high cooling rates in complex-alloyed steels, areas of troostite may appear alongside martensite. The presence of insoluble carbides depletes the solid solution in terms of carbon content, thereby reducing hardness.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

Funding

* This research received no external funding.

Acknowledgements or Notes

* This article was presented as a poster presentation at the International Conference on Basic Sciences and Technology (www.icbast.net) held in Konya/Türkiye on April 02-05, 2026.

References

Alikhani, A. A., Ghasemi, A., & Pirjamadi, A. (2025). Understanding microstructural evolution and metallurgical challenges in wire-arc directed energy deposition of 430 ferritic stainless steel. *Materials Characterization, 219*, 114645.

Baek, G., Shin, G., Lee, K., & Shim, D. (2020). Effect of post-heat treatment on the AISI M4 layer deposited by directed energy deposition. *Metals, 10*(6), 703.

Beskopylny, A., Fominov, E., Shuchev, C., & Egorov, M. (2020). The influence of thermodynamical characteristics of high speed steels on temperature and forces values when turning construction steel. *IOP Conference Series: Materials Science and Engineering, 13*, 012003.

Buathong, S., Harnchana, V., Pimsawat, A., et al. (2025). Electrodeposition of Ag-doped diamond-like carbon films on stainless steel for supercapacitor applications. *Journal of Alloys and Compounds, 1010*, 177942.

Dekhtyar, A., Bondarchuk, V., Karasevskaya, O., & Oryshich, D. (2019). Changes in the microstructure during hot deformation of zirconium alloys synthesized by powder metallurgy. *Materials Characterization, 158*, 109949.

Despres, A., Mithieux, J. D., & Sinclair, C. W. (2021). Modelling the relationship between deformed microstructures and static recrystallization textures: Application to ferritic stainless steels. *Acta Materialia, 219*, 117226.

Dorofeyev, V. (2019). Revisiting some prospects for the further development of ideas by academician V. N. Anrsiferov in the field of structural powder materials. *Russian Journal of Non-Ferrous Metals, 60*(6), 682–686.

Egorov, M. S., Egorova, R. V., & Eremeeva, Z. V. (2024). Diffusion processes in the formation of the structure of alloyed powder steels. *Safety of Technogenic and Natural Systems, 8*(2), 78–89.

Egorov, M. S., Egorova, R. V., & Lopatin, V. Yu. (2024). Phase transformations in powder sintered steels during cooling. *Safety of Technogenic and Natural Systems, 8*(3), 67–77.

Egorova, R., Egorov, M., & Pustovoit, V. (2018). Strengthening of powder material with hot hardness measurement. *Uprochnenie Tekhnologii i Pokrytiya, 4*(160), 157–160.

Eremeeva, Z., Nikitin, N., Korobov, N., & Ter-Vaganyants, Y. (2016). Investigation of the processes of thermal treatment of powder steels alloyed with nano-sized additives. *Nanotechnology: Science and Production, 1*(38), 63–74.

Gabriel, A. H. G., Fonseca, E. B., Valim, D. B., et al. (2025). Tailoring PBF-LB of austenitic stainless steel for potential antifouling applications. *Journal of Manufacturing Processes, 144*, 278–293.

Geroldinger, S. (2023). *Rohstoffeffiziente Sinterstähle durch Hybrid-Masteralloylegierungstechnik [Resource-efficient sintered steels through hybrid master alloy alloying technique]*. In *Pulvermetallurgie in Wissenschaft und Praxis* (Vol. 38, pp. 329–357).

Hojati, M., Danninger, H., & Gierl-Mayer, C. (2022). Mechanical and physical properties of differently alloyed sintered steels as a function of the sintering temperature. *Metals, 12*, 13.

Kim, B. K., Ko, Y. S., Jung, I. H., et al. (2023). Role of the alloy grain boundaries in the high-temperature oxidation and Cr volatilization of 22 wt% Cr ferritic stainless steel for SOFC applications. *Corrosion Science, 213*, 110940.

Li, N., Wu, C., Wu, Z., Jiang, M., Hou, J., & Dong, F. (2025). Effect of sintering temperature and time on microstructure and mechanical properties of CoCrFeNiMn high-entropy alloys. *Metals, 15*, 591.

Romero-Resendiz, L., Huang, Y., Knowles, A. J., et al. (2025). Exceptional strength-ductility combination of hetero-structured stainless steel for cryogenic applications. *Scripta Materialia, 258*, 116527.

Savushkina, L., Laptev, S., Ivanov, I., Ivanov, B., Kostikov, A. V., & Eremeeva, Z. (2020). Study of sintered aluminum materials with nanoparticles microadditions. *IOP Conference Series: Materials Science and Engineering, 848*, 012078.

Soffritti, C., Fortini, A., Sola, R., Fabbri, E., Merlin, M., & Garagnani, G. L. (2020). Influence of vacuum heat treatments on microstructure and mechanical properties of M35 high speed steel. *Metals, 10*(5), 643.

Stern, M., & Kartuzov, E. (2016). Features of the origin and propagation of shock waves in highly porous materials. *Powder Metallurgy, 3*, 13–22.

Xu, Y., Wang, R. Z., & Sato, Y. S. (2025). Interfacial characteristics and microstructural evolution of austenitic to ferritic stainless steels bimetallic structure fabricated by wire-arc directed energy deposition. *Additive Manufacturing, 98*, 104629.

Author(s) Information

Maxim Egorov
Don State Technical University, Rostov-on-Don, Russia
Gagarin Square, Rostov-on-Don, 344003, Russia
ORCID iD: https://orcid.org/0000-0002-4289-1601
*Contact e-mail: *aquavdonsk@mail.ru*

Rimma Egorova
Don State Technical University, Rostov-on-Don, Russia
Gagarin Square, Rostov-on-Don, 344003, Russia
ORCID iD: https://orcid.org/0009-0006-5871-9079

Michail Chaava
Don State Technical University, Rostov-on-Don, Russia
Gagarin Square, Rostov-on-Don, 344003, Russia
ORCID iD: https://orcid.org/0000-0003-3726-4950

Filipp Pastuhov
Don State Technical University, Rostov-on-Don, Russia
Gagarin Square, Rostov-on-Don, 344003, Russia
ORCID iD: https://orcid.org/0000-0002-0668-5739

*Corresponding author(s) contact email

To cite this article:

Egorov, M., Egorova, R. Chaava, M., & Pastuhov, F. (2026). Influence of alloying elements on the kinetics of austenite transformation in powder steels. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 40,* 122-128.