CHEMICAL TECHNOLOGIES, MATERIALS SCIENCES, METALLURGY

Original article
UDC 621. 762. 1
https://doi.org/10.23947/2541-9129-2022-2-76-83

Determination of mechanical properties of sintered dispersion-strengthened iron-based alloys depending on sintering conditions

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Introduction. The problem of creating new sintered materials is now in the center of attention of the entire domestic community in the field of powder metallurgy. Today, when creating a new class of structural materials, first of all, it is worth paying attention to their strength properties. The article considers technological features in the formation of high-quality interparticle splicing of dispersion-strengthened materials. High-quality splicing is primarily determined by the mechanical properties of the alloys, which show the degree of its completeness during sintering. Depending on the density of the materials, the sintering temperature and the percentage of carbon that is introduced into the charge, the mechanical properties of the material also change. The determination of these properties is the main task of the research.

Problem Statement. To determine the strength and plastic characteristics of the materials under consideration, it is necessary to analyze how these characteristics are affected by free carbon introduced into the charge. Determination of mechanical properties will allow us to recommend an alloy with the best characteristics for further research.

Theoretical Part. As a theoretical description, the processes of sintering of dispersion-strengthened alloys, carbon homogenization, and the effect of compaction density and pressure on the mechanical properties of alloys are given.

Conclusions. The obtained mechanical properties show that the addition of 0.8% carbon is sufficient to achieve high strength characteristics. However, the addition of carbon by 20-30% reduces the plastic characteristics of the alloys. The results obtained in this work will help to recommend the material for the manufacture of products with high performance properties.

***Keywords*:** sintering, carbon, alloys, strength limits, yield strength, elongation, surface microstructure, fracture surface factography.

***For citation*:** Egorov M. S., Egorova R. V. Determination of mechanical properties of sintered dispersion-strengthened iron-based alloys depending on sintering conditions. Safety of Technogenic and Natural Systems. 2022;2:76–83. https://doi.org/10.23947/2541-9129-2022-2-76-83

Introduction. Among the list of powder materials, iron-based and steel-based alloys have the greatest use. When creating new structural materials, along with the requirements of improving quality, reliability and operational durability, the task of saving and replacing expensive and scarce alloying elements with less scarce and low-cost ones is put forward. This fact has served as an incentive for a new round of development of domestic metallurgy in the field of obtaining materials with specified properties, the development of methods for assessing their properties. Currently,

there are a large number of nanoscale additives having different properties, and the same additive can be obtained by different methods and have different properties, shape and dimensions. Also of particular interest is the search for an answer to the question of how the introduction of nanoscale particles will affect the structure formation of alloys during various types of molding or deformation. The fundamental processes of the formation of hot-deformed alloys are the structure formation of the material and the creation of qualitative bonds between the powder particles.

The aim of the work is to determine the dependence of the pre-sintering parameters on the formation of the structure and properties of high-density dispersion-strengthened hydra metals. It is necessary to do this for the possibility of further effective use of heat treatment in order to improve the mechanical and operational properties of such alloys.

Problem Statement. To determine the strength and plastic characteristics of sintered materials, it is necessary to analyze how the free carbon introduced into the charge affects them. Knowledge of these mechanical properties will allow the authors to recommend an alloy with the best characteristics for further research.

Theoretical Part. Sintering plays a major role in the formation of a complex of physical and mechanical properties of complex alloyed powder steels. In dispersion-strengthened alloys, during their sintering, a structure is formed that differs significantly from the structure of cast and forged materials. Sintered compacts are primarily porous products in which the number of pores can vary from 0.5–2 to 80-90%. Thus, for powder materials and alloys, porosity acts as a structural component. The shape of the pores, their size, morphology and volume content are determined by the physicochemical, mechanical and other properties of the products, as well as the scope of their application. When sintering, a special role is played by carbon, which is added to the composition of the charge in various ways. The percentage of carbon is selected based on what properties the products will have to have after the sintering. In our case, the amount of carbon was taken as a percentage of the total volume of the material and was 0.5 and 0.8%, respectively [1-3].

Sintering is quite an important operation in powder metallurgy, and the quality of the products obtained depends on the choice of its technological modes. It is advisable to consider two consecutive stages of the sintering process at once: the formation and growth of interparticle contacts (the initial, early stage of the process), as well as an increase in the density of the sintered body due to a decrease in the number and volume of pores (intermediate and late stages). In real conditions, both of these processes cannot be completely separated; they are intertwined and proceed mostly in parallel [2-6].

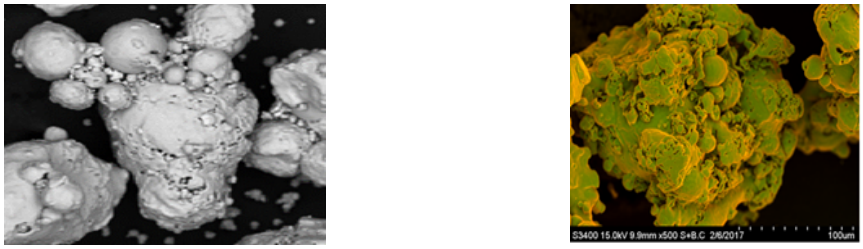
Since the homogenization process does not have time to fully occur during the sintering of steels obtained from the charge of components, this should entail the formation of an inhomogeneous structure. The presence of such a structure, along with porosity, makes the system non-equilibrium, which should have a specific effect on the nature of the processes occurring during heating and cooling of powder steels. The determining technological parameters of sintering of compacts are the temperature regime, the duration of sintering, the parameters of pretreatment of material particles by pressure, etc. In addition, it is necessary to take into account certain features inherent in the sintering processes of single-component and multicomponent materials. When sintering single-component materials, diffusion processes contribute to the compaction of bodies in most cases, and in multicomponent systems, a deceleration of the compaction process and even expansion of the sintered volume may occur due to uneven diffusion. A decrease in the free energy of a multicomponent system during sintering can occur not only as a result of a decrease in the surface and the number of pores, recrystallization and a reduction in the density of defects in the crystal structure, but also due to the formation of alloys. At the same time, the use of low-oxidized and finely dispersed alloy particles, the high sintering temperature before pressing and the maximum possible compaction of the compacts by pressure contribute to the process of alloy formation [7-10].

Analyzing the factors affecting the sintering process and, accordingly, the quality of the materials and products obtained from them, it is impossible not to take into account such an important parameter as the time factor.

The structure of powder steels affects not only the temperature, but also the kinetics of austenization. In conditions of high-speed heating, not only the temperature of the beginning of transformation decreases, but also the incubation period decreases, the temperature and time intervals of transformation increase. With an increase in porosity, the content of non-metallic inclusions, and an increase in the defectiveness of powder particles, these features of the austenization process are enhanced.

In order to obtain high-quality interparticle splicing, which characterizes high mechanical properties, it is necessary to achieve complete dissolution of carbon in the alloy charge.

In this work, modern powder mixtures of grades PL-N4D2M and PZHRV 2.200.26 produced by Severstal AO (Cherepovets) were used (Fig. 1).



a) *b*)

Fig. 1. X-ray diffraction analysis of alloy particles: a) PL-N4D2M alloy; b) PZHRV 2.200.26 alloy

Table 1 provides data on their chemical composition.

Table 1

Chemical composition of alloys

Alloy grade	Mass content of components, %									
	Mo	Ni	C	O	H	Cu	Si	Mn	P	S
PZHRV 2.200.26	–	–	0.09	0.14	–	–	0.014	0.087	0.012	0.005
PL-N4D2M	0.45–0.55	3.5–4.5	0.02	0.2	–	1.3–1.7	–	–	0.02	0.02

Chemical composition of the alloys was chosen based on the composition of alloying elements and the assessment of the influence of these elements on mechanical properties [11–14].

Results and Discussion. Let us consider the dependences of the mechanical properties of the PL-N4D2M alloy on the density of the manufactured samples and the amount of carbon introduced into the charge (Fig. 2). Sintering was carried out at a temperature of 1200°C for 30 minutes 0.5 and 0.8% carbon were added to the charge, respectively [15-18].

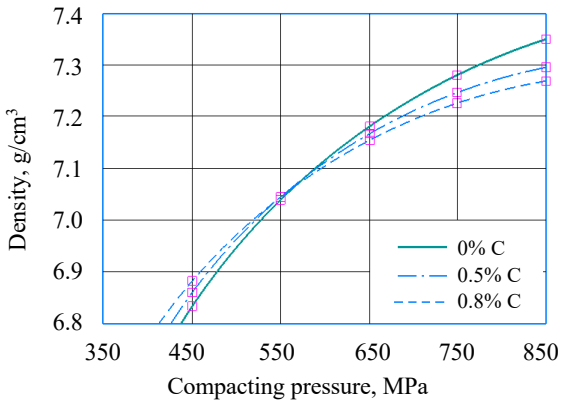


Fig. 2. Compaction of the PL-N4D2M alloy charge depending on the compacting pressure and the amount of introduced carbon

The stretching samples were made with different densities (from 6.7 to 7.6 g/cm^3), with different carbon content and sintered in a dissociated ammonia medium for 30 minutes at a temperature of T = 1200°C. Figures 3-6 present the results of the experiments

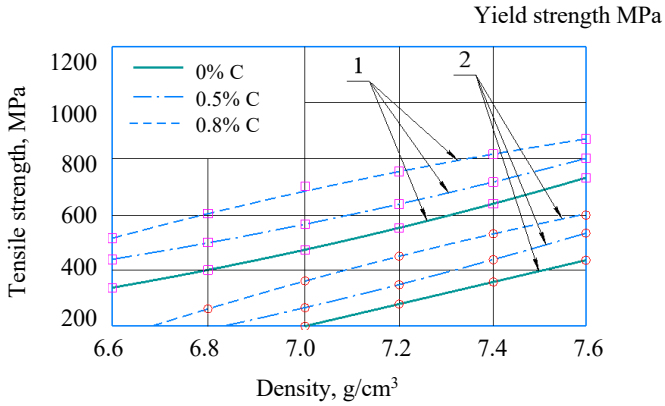


Fig. 3. Dependence of the tensile strength (straight lines 1) and yield strength (straight lines 2) on the density of samples during sintering at T = 1200°C for 30 minutes PL-N4D2M alloy (carbon content in the charge 0% C, 0.5% C, 0.6% C)

The results of the experiment: the tensile strength of the pure PL-N4D2M alloy shows a value of 750 MPa at a density of 7.6 g/cm^3, and with the addition of carbon in an amount of 0.8%, the value increases to 900 MPa.

Next, we will determine the dependence of the hardness of the PL-H4D2M alloy on the density of the samples and the carbon content.

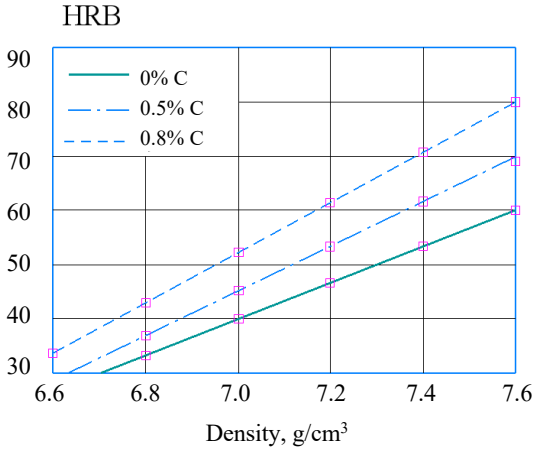


Fig. 4. Dependence of HRB hardness on sample density during sintering at T = 1200°C for 30 minutes of PL-H4D2M alloy (0% C, 0.5% C, 0.8% C)

Let us note the changes in the relative elongation of the samples at break depending on their density and the amount of carbon in the charge.

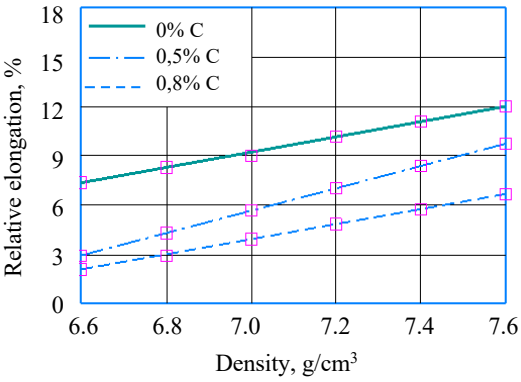


Fig. 5. Dependence of elongation in tension on the density of samples during sintering at T = 1200°C for 30 minutes of the PL-N4D2M alloy (0% C, 0.5% C, 0.8% C)

The data presented in Fig. 5 show that this alloy has better plastic tensile characteristics than the alloys of the Swedish company Höganäs.

The next step is to determine the dependence of the shrinkage of the samples on the density and the amount of carbon introduced into the charge.

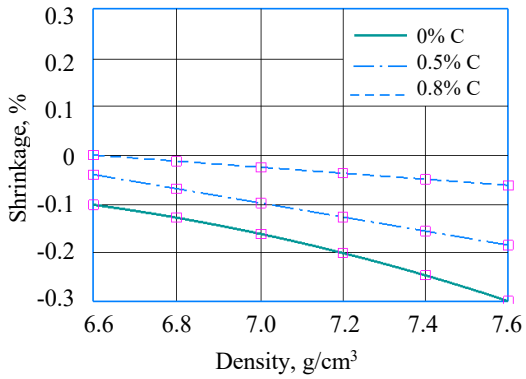


Fig. 6. Dependence of shrinkage on the density of samples during sintering at T = 1200°C for 30 minutes of the PL-N4D2M alloy (0% C, 0.5% C, 0.8% C)

Now let us analyze the dependence of the mechanical properties of the alloy grade PZHRV 2.200.26 on the density of the manufactured samples and the amount of carbon introduced into the charge (Fig. 7). Sintering was carried out at a temperature of 1100°C for 30 minutes. 0.5 and 0.8% carbon were added to the charge, respectively.

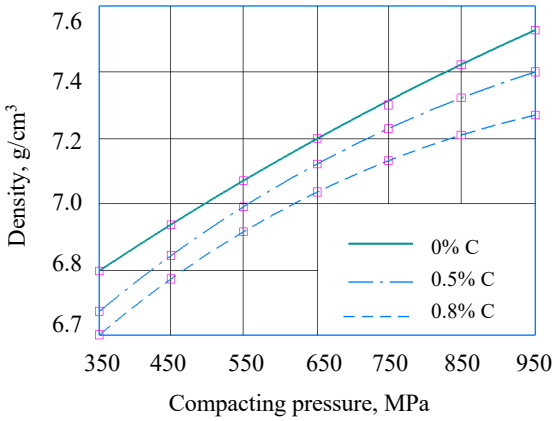


Fig. 7. Compaction of the charge of the PZHRV 2.200.26 alloy depending on the compacting pressure and the amount of carbon introduced

The stretching samples were made with different densities (from 6.7 to 7.6 g/cm^3), with different carbon content and sintered in a medium of dissociated ammonia for 30 minutes at a temperature of T = 1100°C.

The results of the experiments are shown in Fig. 8-10.

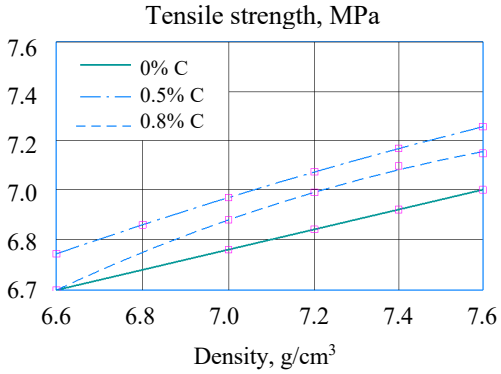


Fig. 8. Dependence of the tensile strength on the density of samples during sintering at T = 1100°C for 30 minutes of the PZHRV 2.200.26 alloy (carbon content in the charge 0% C, 0.5% C, 0.8% C)

Strength characteristics of this alloy are inferior to those of the PL-N4D2M alloy. So, at a density of 7.6 g/cm^3, the strength limit of pure PZHRV 2.200.26 alloy is only 200 MPa.

Next, let us consider the dependence of hardness on the density of samples and the carbon content for the PZHRV 2.200.26 alloy.

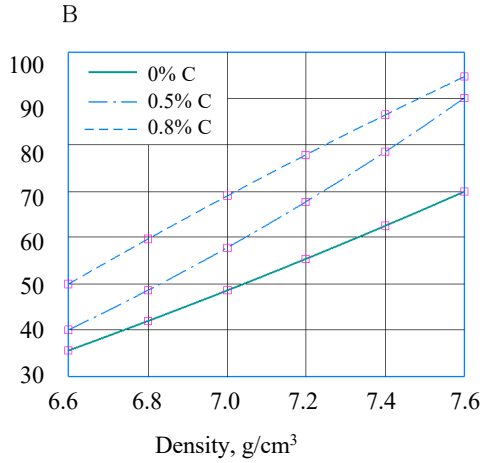


Fig. 9. Dependence of hardness of HRB on the density of samples during sintering at T = 1100°C for 30 minutes of the PZHRV 2.200.26 alloy (0% C, 0.5% C, 0.8% C)

Let us consider the change in the relative elongation of samples at break depending on their density and the amount of carbon in the charge.

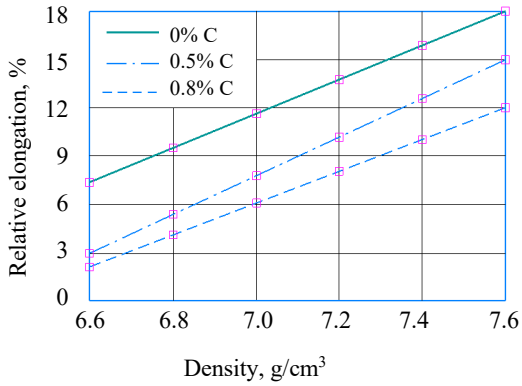


Fig. 10. Dependence of the elongation at tension on the density of samples during sintering at T = 1100°C for 30 minutes of the PZHRV 2.200.26 alloy (0% C, 0.5% C, 0.8% C)

The results presented in Fig. 10 show that this alloy has better plastic characteristics under tension than the alloy of the PL-N4D2M brand. With a carbon content of 0.8% in an alloy with a density of 7.6 g/cm^3, the elongation index is 12%.

Evaluation of the mechanical properties of alloys after sintering has showed that with an increase in the carbon introduced into the charge, the strength properties increase by 25-30% compared to pure alloys. An increase in density also strongly affects the strength and plastic properties of such materials [19-20].

Conclusions. Experimentally, the authors determined the dependences of the strength and plastic characteristics of sintered alloys on the density of samples, as well as on the carbon introduced into the charge. It has been established that sintering for 30 minutes for pure iron alloys is the minimum time at which carbon homogenization occurs in a metal matrix. The sintering temperature of 1,100°C for such materials is absolutely reasonable, and an increase in temperature will not matter to accelerate the sintering process. The paper shows strength properties of the alloys under consideration depending on the percentage of carbon in the initial charge. For the PL-N4D2M alloy, the optimal sintering temperature is 1,200°C, which is 100°C higher than the sintering temperature for iron alloys. The results obtained show that the best strength properties are achieved by sintering the PL-H4D2M alloy +0.8% C for 30 minutes at a temperature of 1200°C.

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Received 15.04.2022
Revised 20.05.2022
Accepted 20.05.2022

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Claimed contributorship

M. S. Egorov — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions, R. V. Egorova — scientific supervision, analysis of the research results, revision of the text, correction of the conclusions.