Installation for Sintering Metal Powders in a Constant Magnetic Field

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Abstract: ***The installation scheme for sintering metal powder materials in a constant magnetic field is presented. The principal possibility to significantly reduce the duration of the sintering process for metal powder products is demonstrated. The method is based on the phenomenon of anomalous penetration of electromagnetic radiation into the depth of the sintering product. Comparison between the proposed method and most common technology of powder metallurgy as sintering in a muffle furnace has been shown. The presented technology allows sintering of electrically conductive powder materials at temperatures below the temperature in the case of sintering in a muffle furnace. The duration of the sintering process using the effect of anomalous radiation penetration has decreased several times in comparison with the traditional technology. The obtained micrographs of sintered powder blanks made it possible to confirm the effectiveness and feasibility of using the presented method. The totality of the obtained research results confirms the promise of studying the effects of anomalous radiation penetration during sintering of metal powders.***

Keywords: sintering, electron path, skin effect, magnetic field, visible radiation, iron powder, furnace

1. Introduction

The search for methods to accelerate the sintering process of metal powders is primarily associated with a decrease in the negative effect of the so-called skin layer on the surface of the metal being sintered. The transfer of heat energy from the heating source is concentrated in the surface layer of the metal and the transfer of heat into the depth of the sintered part occurs only due to thermal conductivity [1]. The absence of volumetric heating significantly increases energy consumption and time characteristics of sintering processes.

There are a number of studies that have shown that if the metal is placed in a constant magnetic field and heated by an electromagnetic field of very high frequency up to the visible range, the conditions of anomalous penetration of radiation to a considerable depth of the sintered part [2-3]. The behavior of electrons in the sintered metal and the nature of their interaction with each other and with the crystal lattice of the substance radically changes. The movement of electrons, which transfer energy to diffusing atoms, occurs due to the Coulomb force (alternating magnetic field) and the Lorentz force (constant magnetic field). In this case, electrons move along spiral paths, repeatedly returning to the surface skin layer. The length of electron’s path increases considerably and becomes thicker than the skin layer [4]. The transfer of radiation energy into the depth of the sintered metal powder is due to electrons, which "carry away" the high-frequency field from the skin layer and then "reproduce" it in the volume of the metal. As a result, in addition to the thermal and gradient components of mass transfer [5], an additional driving force of diffusion appears, which significantly accelerates the sintering process of metal powders. This additional diffusion component is determined by the atomic-electron interaction[6].

2. Materials and methods

An experimental setup was developed to determine the temporal characteristics and quality of sintered parts made of ferromagnetic metal powders from iron. Its main components are a vacuum steel chamber, a vacuum pump, radiation sources and a water pump. Fig.1 shows the scheme of an installation.

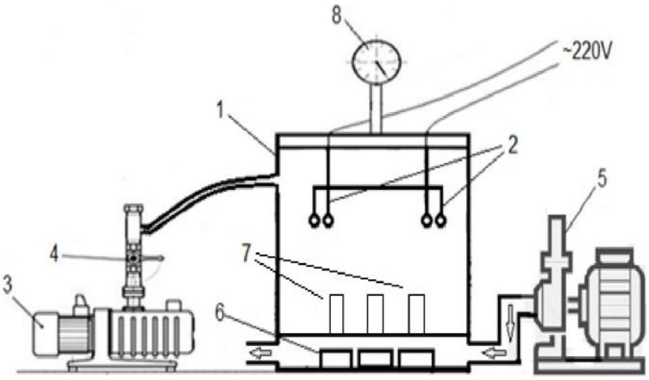

Figure 1: Technological installation for sintering metal powder materials: 1 - vacuum chamber; 2 - thermal emitters 4 pcs; 3 - vacuum pump; 4 - vacuum valve; 5 - water pump; 6 - neodymium magnets; 7 - sintered parts; 8 - vacuum gauge.

The vacuum chamber has the form of a cylinder which is made of hardened steel with thickness of 8 mm. Geometric dimensions of the chamber: height of the chamber (adjustable) – 0.25-0.8 m; diameter of the chamber – 0.38 m. Inner walls of the chamber are covered with mirror stainless steel in order to reduce heat loss on heating up of the chamber and focusing of lamps radiation on sintering blanks. Neodymium magnets 0.2-0.5 T were used to create a constant magnetic field in the chamber, which were placed in the lower part of the chamber with water cooling. The contour cooling system was created to prevent heating of magnets over 323 K and further loss of magnetic force of magnets. Vacuum pump was used to create vacuum in sintering chamber to prevent oxidation processes of sintering parts surface. The pressure in the chamber was controlled by a vacuum gauge and the value of pressure was about 0.8 Pa.

The choice of the radiation source was one of the most important decisions in experimental research. This is primarily due to questions of economic feasibility, practicality and reliability. A quartz halogen thermal emitter of far infrared and visible radiation with power of 2 kW was chosen as such a radiation source. The chamber contained four thermal emitters. The surface temperature of the sintered part is regulated from 673 K to 1373 K by the number of lamps on. Figure 2 shows the emission spectrum of such a lamp.

The lamp is powered by a 50 Hz AC. These lamps can operate continuously for 60 minutes without any cooling.

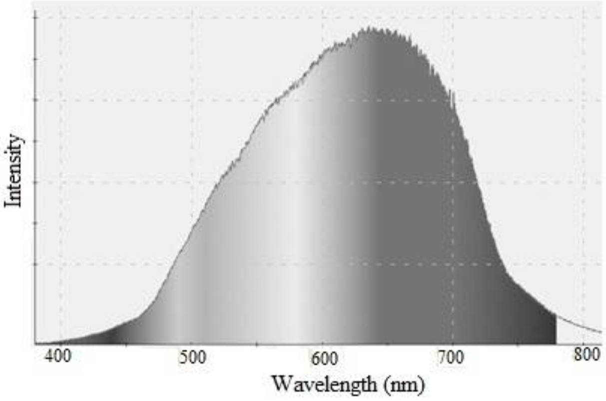

Figure 2: The emission spectrum of the QHT 2000-3 lamp

As can be seen from Fig. 2, the emission spectrum includes the full infrared range, fully visible and captures the beginning of the ultraviolet. The highest intensity of radiation is in the range of 600-700 nm, which belongs to the visible frequency range. A chromel-alumel thermocouple was used with a measured temperature interval of 473-1643 K to measure the temperature of the sintered billet during the sintering process.

Two pressed parts made of PC-10 iron powder with a microparticle size of 20-50 µm were used for sintering. The parts were placed on the bottom of the vacuum chamber. The magnetic field in the chamber volume was made by neodymium magnets which were placed in cooling circuit system. For comparison and evaluation of the efficiency of proposed method, annealing was performed using the traditional method in muffle furnaces. Samples of parts had initial porosity of 8.5 % and were sintered in a vacuum muffle furnace with power of 30 kW and temperature of 1473 K for 8 hours. The total sintering time devided by steps: furnace heating (3 hours), isothermal heating (2 hours) and sample cooling in the furnace (3 hours). Electronic graphs of billets before and after sintering with 1000-x magnification are shown in the fig. 3 и 4. The measured porosity decreased to 3.8 %. The porosity was determined by the metallographic method from the change in the areas of microparticles occupied by dislocations. The experimental diffusion coefficient (CD) was $D = 6.77 \cdot 10^{-12}$ m²/s. For comparison, the calculated CD for these sintering conditions was:

$$D = D_0 \cdot \exp(-E_a / R \cdot T) = 2.714 \cdot 10^{-13} \text{ m²/s}, \qquad (1)$$

where $D_0 = 2 \cdot 10^{-4}$ m²/s is the preexponential factor, $E_a = 250$ kJ/mol is the activation energy of self-diffusion for α-Fe, R is the gas constant, T is the temperature of isothermal heating. The experimental CD is slightly higher than the calculated value. This difference may consist in an approximate estimate of the activation energy for iron self-diffusion, which was adopted in calculating the CD.

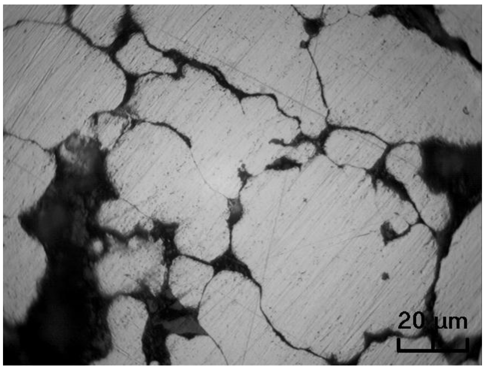

Figure 3: The microstructure of the powder blank before sintering in a muffle furnace.

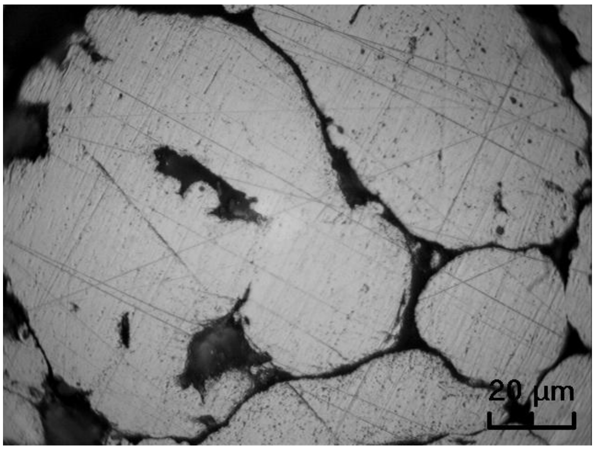

Figure 4: The microstructure of the powder blank after sintering in a muffle furnace.

In Fig. 3 and Fig. 4 show electronic photographs of billets before and after sintering in a muffle furnace. These two images show that individual microparticles, as a result of sintering, have combined into large structural formations what leads to internal pores decrease.

The cross section of a sintered sample in the presented installation for 30 min at a temperature of 1030 K is shown in Fig. 5.

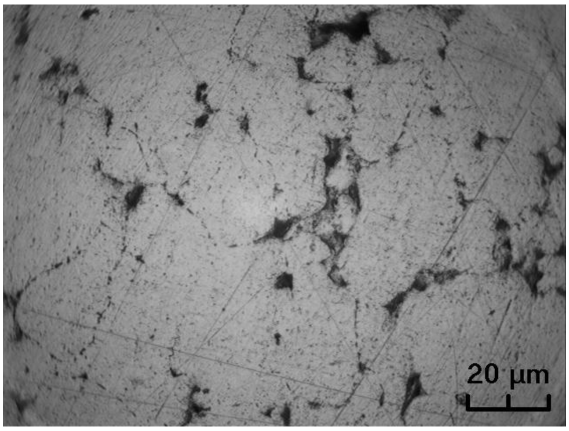

Figure 5: The microstructure of the powder blank after sintering using presented method.

As can be seen from the micrograph that the microparticles are combined into larger formations. Increasing the volume of microparticles leads to decreasing of the attenuation coefficient of the electromagnetic radiation in the powder medium of a metal billet [4]. In a result, energy absorption increase which allows achieve porosity 3.9 % after 30 minutes of sintering Meanwhile the same value of porosity with isothermal muffle heating achieved after two hours at a significantly higher temperature (higher than 1400 K).

The experimental CD was found by metallographic method and it is equal to $D = 1.62 \cdot 10^{-12}$ m²/s. The obtained value of CD is four times higher in relation to CD at muffle heating. There are non-thermal effects which lead to the appearance of additional diffusion driving forces apart from thermodiffusion in the sintering powder medium by obtained experimental data.

3. Conclusions

It is shown that the interaction of visible electromagnetic radiation and a constant magnetic field of 0.2-0.5 T in the processes of sintering at temperatures close to the Curie point causes the acceleration of the diffusion. The proposed method can significantly reduce energy consumption by reducing the heating temperature and sintering duration. The developed experimental installation can become the basis for the creation of industrial equipment for a wide range of powder materials, including a ferromagnetic component.

References

[1] Geguzin Y.E. Sintering physics. 2nd ed. Moscow: Nauka, 1984.312 p.
[2] Abrikosov A.A. Foundations of the theory of metals. Moscow: Nauka, 1987.520 p.
[3] Lifshits I.M., Azbel M.Y., Kaganov M.I. Electronic theory of metals. Monograph. Moscow: Nauka, 1971.416 p.
[4] Kaner E.A., Gantmakher V.F. Abnormal penetration of an electromagnetic field into metal and radiofrequency dimensional effects. Volume 94, no. 2. "Advances in physical sciences" // Chernogolovka: Institute of Solid State Physics, Academy of Sciences of the USSR, 1968. P. 193-241.
[5] Libenson G.A., Lopatin V.Y., Komarnitskiy G.V. Powder metallurgy processes. Volume 2. Forming and sintering: Textbook for universities. Moscow: MISIS, 2002.320 p.
[6] Kharanzhevsky E.V. High-speed laser sintering of highly dispersed metal powders and composite materials with a metal matrix. Author's abstract. dis. doct. tech. sciences. Izhevsk: UB RAS, 2016.32 p.

Author Profile

Ihor Kolesnyk received the M.S. degrees in Electrical Engineering from Admiral Makarov National University of shipbuilding. He specializes in the study of the ferromagnetic powder materials sintering and problems about the anomalous skin effect. Currently works at Mitek Inc.