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Original Research Paper

Influence of the impact sintering temperature on the structure and properties of samples from the different iron powders

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ABSTRACT

The studies of the consolidation, structure and mechanical properties of samples from two types of iron powder are carried out. The coarse and less pure PZH3M2 as well as fine and purer DIAFE5000 powders were used. The samples are obtained by means of impact sintering method in the temperatures range of 500–1100 °C. The impact energy was 1200 J/cm^3, and the initial deformation velocity - 6.5 m/s. Samples are obtained in the form of disks with a diameter of 25–27 mm and 9–10 mm high. For carrying out different mechanical tests the bars were cut out from disks. The tensile, compression, three-point bend of notched samples tests were carried out, as well as the Brinell hardness was measured after the corresponding processing of the bars. The characteristics of strength and plasticity of samples depending on the impact sintering temperature are determined. The polished surface of different samples and the fracture surface are investigated. It is established that the high density of samples is reached at a temperature of 600 and 700 °C respectively for fine and coarse powders. The samples obtained at these impact sintering temperatures possess rather low electrical resistivity, high strength, hardness, but the lowered plasticity. Namely, the samples from the PZH3M2 and DIAFE5000 powders sintered at the temperature of 700 °C have respectively: ultimate tensile strength - 406 and 336 MPa, yield stress - 353 and 190 MPa, contraction ratio - 26 and 78%, limit stress (at the fracture) - 501 and 933 MPa, the maximum crack tip stress – 738 and 876 MPa, the fracture energy at a bend of the notched samples - 4.8 and 51.2 J/cm^3 and also Brinell hardness - 1467 and 847 MPa. The increase of the samples impact sintering temperature leads to grain growth, decrease of the samples strength and increase of their plasticity. At the same time the structure of samples from the DIAFE5000 powder is more fine-grained than at samples from the PZH3M2 powder.

1. Introduction

Iron is one of the main elements in creation of different materials. Iron is also a basis of the strongest materials [1]. At the same time, the combination of high strength and hardness in a material is reached by introduction of ultrafine hard particles to an iron basis and obtaining so-called composite materials [2–4]. The highest characteristics of the strength and hardness in a material are realized in case of keeping of ultrafine-grained or nanocrystalline structure in it [5–7]. Such composite materials can be obtained by using powder metallurgy methods and the impact sintering method, in particular, which is based on the process of impact consolidation of powder in vacuum at a specified temperature [8–11]. High level of pressure and a certain extent of shear deformation allow obtaining of high density and strength samples at lowered temperatures. The decrease in the consolidation temperature of powders allows to keep more fine-grained structure and to provide higher strength of samples when using fine powders.

This research was interesting in studying of possibility to obtain qualitative samples from iron powders of different granularity and purity at rather low temperatures. Therefore the purpose of this work was investigation of the structure and properties of samples from coarse and fine powders of iron obtained by impact sintering method in the wide range of temperatures and the establishment of the minimum of the consolidation temperature providing strong samples.

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2. Experimental procedure

Two iron powders from different producers were chosen for carrying out the researches – first one was coarse with particle size 50–150 μm (PZH3M2, Ukraine) and the second one - fine with particles of 3–10 μm (DIAFE5000, Germany). The chemical composition and particle size distribution of powders are presented in Table 1 and the photographs of the chosen powders are shown in Fig. 1.

Before carrying out of impact sintering process there were researches conducted on volume shrinkage of previously pressed briquettes. Briquettes were obtained at three levels of pressure - 300, 500 and 700 MPa. Conventional sintering of the briquettes was carried out at temperatures of 900 and 1100 °C within 20 min. Results on the volume shrinkage of briquettes are presented in the Table 2. Apparently from Table 2, sintering of briquettes leads to different densification degree of coarse and fine powders at rather high temperature. Coarse powder is hardly densified as the greatest volume shrinkage makes 0.82% at the temperature of 1100 °C for briquettes that were obtained at the minimum pressure and fine powder is densified at a considerable volume which depends on the densification pressure of briquettes. The shrinkage is maximum and equals 27% at the low pressure (300 MPa) and the shrinkage is minimum at the level of 15% at the high pressure (700 MPa). The mentioned data allows us to estimate a condition (the sizes and relative density) of a briquette (green samples) before the subsequent impact sintering. More detailed researches on conventional sintering of the chosen iron samples weren't conducted.

Green samples (briquettes) were obtained with the same pressure equal to 500 MPa for the subsequent impact sintering. Such pressure provided the relative density of briquettes from the powder PZh3M2 at the level of 80–82%, and from the powder DIAFe5000 - 74–75%. The briquettes were loaded into the vacuum camera, heated to the set temperature and after isothermal holding within 20 min were densified by the effect of impact loading. The impact energy was 1200 J/cm^3, and the initial deformation velocity – 6.5 m/s. The impact sintering was carried out at temperatures of 600, 700, 800, 900, 1000 and 1100 °C and for the coarse powder impact sintering was carried out also at the temperature of 500 °C. The specimens were obtained in the form of disks with a diameter of 25–27 mm and 9–10 mm high resulting from the impact sintering of briquettes at different temperatures. Fig. 2 shows the briquettes after cold pressing and also ready specimens after the subsequent impact sintering. Varisized rectangular bars were cut out by means of electro discharge machining (EDM) for carrying out mechanical tests from the disks obtained after impact sintering, Fig. 3. The bars were grinded by abrasive disc before tests. The density of polished bars was measured by the Archimedes method. The electrical resistivity was determined by comparing the voltage drop on the reference resistor and the studied samples. There were determined the strength and the plasticity of samples under tensile (diameter of a neck of 2.5 mm, length of a neck of 10–12 mm) and compression (4 × 4 × 8 mm), there were measured Brinell hardness for an assessment of mechanical properties. Besides, the three-point bend of notched specimens was executed on the samples intended for a bend (4 × 4 × 25 mm, distance between supports of 20 mm) for an assessment of fracture toughness. The notch of 1.2–1.5 mm in depth was executed in the electro spark way using a brass wire with a diameter of 0.1 mm. The microstructure of specimens was examined on the polished surfaces by means of the ZEISS EVO 50XVP of ZEISS AG firm (Germany) scanning electron microscopes. The fracture surfaces analyses were carried out using the JSM-6490-LV microscope of JEOL firm (Japan).

3. Experimental results and discussion

One of the main issues, which arise at consolidation of powders especially when using external pressure, low temperatures and vacuum, is density level. At the same time ensuring of high level of density is necessary, but not sufficient for powder samples. Also, extent of interpartial interaction or strength of interpartial boundaries are of great importance at low-temperature consolidation. The preliminary estimate of quality of interpartial interaction can be obtained by means of such physical characteristic as specific electrical resistivity of samples. First of all, not without interest are results of measurement of density and electrical resistivity of iron samples from coarse and fine powders depending on the impact sintering temperature, Fig. 4. From the data on Fig. 4a the attention is deserved, first, by higher level of density of samples from the powder DIAFE5000, and, secondly, almost constant value of density of the samples from the powder PZh3M2 obtained at 700 °C and above. Besides, the reference data of the compact iron density is slightly lower than density of samples from fine powder and slightly higher than density from coarse powder. Such situation can be connected not so much with porosity existence, as with a chemical composition of iron powder. For example, the raised content of impurity can reduce the absolute density of iron and increase its electrical resistivity. Really, resistivity of samples from coarse powder is higher than resistivity of samples from fine powder and more than resistivity of compact iron purity of 99.90%, Fig. 4b. The electrical resistivity of samples from fine powder is lower than resistivity of compact iron with the specified purity, but higher than resistivity of compact iron purity of 99,95%. It is necessary to pay attention also to the fact that the absolute value of the electrical resistivity of samples from fine powder practically doesn't change in all temperature interval of consolidation. Resistivity of samples from coarse powder becomes low at the densification temperature of 700 °C and at higher densification temperatures shows a tendency even to some growth. It is still difficult to explain such tendency. Thus, results of measurement of density and electrical resistivity of samples testify that samples have the high density and low resistivity in the range of the impact sintering temperatures of 700–1100 °C. In connection with this circumstance interest is caused by mechanical properties of samples from the coarse and fine powders obtained at different temperatures.

Table 1
The chemical composition and particle size distribution of the iron powders PZH3M2 and DIAFE5000.

Powder	O	C	P	S	Si	Mn	Ca	Ni	Cr	V
Chemical composition, mas.%										
PZh3M2	0.32	0.07	0.117	0.011	0.24	0.16	0.132	0.066	0.064	0.017
DIAFe5000	0.31	0.02	0.112	–	–	–	0.102	–	–	–
Particle size distribution										
Powder	−0.045 mm		+0.045–0.056		+0.056–0.071	+0.071–0.100		+0.100–0.160		+0.160–0.250
PZh3M2	25%		11.1%		8.1%	34.9%		19.7%		1.2%
DIAFe5000	*d*(10)-4.2 μm				*d*(50)-8.5 μm			*D*(90)-27 μm		