Property and Structure Changes of Sintered Powder Materials by Treatment in the Pulse Electromagnetic Field

Mironovs, V.; Boiko I., Lapkovsky V.

Riga Technical University .Address: Kalku str., 1
LV-1658, Riga, Latvia ,Ph/Fax: +371-67089270, e-mail: mironovs@bf.rtu.lv.

ABSTRACT

The treatment of materials in the pulse electromagnetic field "Magnetic impulse compaction" (MIC) is well-known method and it was used for connecting of tubular details and for powder compaction [1].

By use of the method MIC it is possible to obtain the plastic deformation of sintered powder details changing their form, properties and structure. Pulse electromagnetic field, created by the generator of pulse currents in theinduction coil, concentrates in the gap between the coil and the billet depending on the current frequency and electrical conductivity of material. Different degree of penetration of electromagnetic field inside the billet takes place.

As the object for a study are selected the samples made of the sintered powder bronze (Sn - 1,0-1,2%, F - 1,0%, Cu - rest, size of particles 150-200 μm). Billet is forming sintered of powder with the free filling in the atmosphere of endogas.

Billets were pressed on the press by 1000 kN and were sintered in the atmosphere of endogas at temperature of 920-950ºC. The MIC treatment was accomplished on labour device IG-18/5 with current frequency of 50 kHz, P_{max} – 250 MPa, duration of impulse 20-25 μs. A study of microstructure shows the presence of the strong plastic deformation of the bronze particles.

INTRODUCTION

Yu. Barbarovich for the first time reported the executed by it experiments on the working in the pulse magnetic field (MIC) of the cylindrical powder sample made from copper [1]. They established that by MIC on the device with the energy content 20 kJ density of sample increases from 6,84 to 8,2 g/m^3.

In the papers [2, 3] it is shown that the process MIC depends on many factors, most important of which are the tension of electromagnetic field and its time characteristics, and also properties of the workable material.

High productivity of the MIC process, absence of the mechanical contact between tool and billet, possibility of designing of pressure with the assigned distribution law on the surface and other special features of MIC method opening the perspectives for its using in powder metallurgy for treatment of the sintered materials.

THEORY

The degree of MIC action on the sintered powder billets is strengthened by increased electrical conductivity and plasticity of the material. To establish the quantitative connection between electrical conductivity and porosity of the sintered body is possible to approximate.

The dependence of electrical conductivity on the porosity it is possible to present by the following equation [4]:

$$\lambda_\gamma = a\lambda_k\left(1 - b\gamma\right) \quad (1)$$

where λ_γ, λ_k - specific conductivity of porous and compact materials;
γ – porosity of powder component;
a, b - coefficients, which depend on the properties of the powder materials.

By the method MIC the value of electromagnetic pressure can be determined from the expression:

$$p(t) = \frac{1}{2} H_m^2 \mu e^{-2\beta t} \sin^2 \omega t \tag{2}$$

where H_m - the tension of magnetic field in the gap between coil and details;
μ - magnetic constant;
β – decrement of damping discharge;
ω – current frequency;
t – time.

The porosity of details decreases the pressure of pulsed field. In this case it changes towards centre of details (Fig. 1)

In the zone 1 value of pressure is negative, which in a number of cases can lead to the exfoliation of surface layer.

In zone 2 pressure increases also during exceeding of the limit of the strength of material.

In zone 3 occurs the plastic deformation of billet.

In formula (2) tension of magnetic field H_m can be expressed through the energy of electromagnetic generator W.

According to the law the full current I_m:

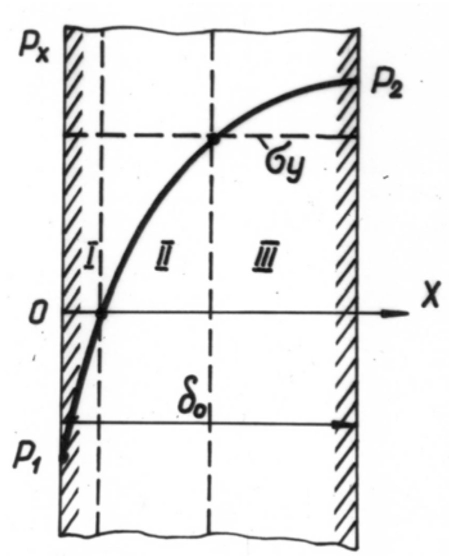

Fig. 1 Change of the electromagnetic pressure on the powder billet.

$$H_m = \frac{I_m n}{l} \tag{3}$$

where I_m – amplitude value of the coil current;
l – length of the working zone of coil;
n – number of coil turns.

It is the possible to use concentrators of electromagnetic field (fig. 2). In this case:

$$I_m = \sqrt{\frac{2W}{LK_c}} \tag{4}$$

where L – equivalent inductance of system generator-coil-concentrator-detail;
K_c – coefficient, which characterizes the effectiveness of the conversion of energy of generator into the energy of concentrator.

After the joint solution of equations 1-4 and introduction of the coefficients (K_1 and K_2) the pressure on the powder billet is:

$$P(t) = \frac{W \cdot \mu}{L \cdot l \cdot K_c} K_1 \cdot K_2 \cdot e^{-2\beta t} \sin^2 \omega t \qquad (5)$$

,

where K_1 – coefficient, which considers weakening the pressure as a result of weakening electromagnetic pressure on the porous billet.

K_2 – coefficient, which considers the influence of the concentrator of the electromagnetic field.

EXPERIMENTAL RESULTS

In our experiment concentrator of electromagnetic field was used, made of copper plates, packed to the metal housing with the special longitudinal section (fig. 2).

Fig. 2. Concentrator of electromagnetic field.

In this work the experimental methods of the measurement of the electrical resistance of powder billets were used. By this purpose were carried out the measurement of the specific resistance employing the procedure, presented into [5].

Under the action of electromagnetic field occurs compaction of the sintered powder component, and also change in its form and geometric dimensions (Fig. 3).

a) b) c)

Fig. 3. Deformation of the sintered bronze by the method MIC by different level of the specific energy of discharge W_e kJ/cm^3 (a – 2,3; b – 4,0; c – 4,5).

In the table 1 properties of any sintered materials for MIC treatment are shown.

It was established that for the effective application of MIC maximum of the specific resistance should be considered $15 \cdot 10^8$ Ω·m, and the limit of strength – 500 MPa.

Table 1. Properties of some sintered materials for MIC treatment.

Material	Data of powder billets			Pres-sure, MPa	Tempe-rature of sintering, K	Porosity, %	Specific electric resistance, $\times10^8$, Ω·m	Tensile strength, MN/m^2
	Contents	%	Particle size, μм					
Copper	Cu	100	40-50	-	1030	30	30	70-80
Copper	Cu	100	40-50	400	1030	4	2	180-200
Bronze	Cu C	98 2	40-50	300	1180	18	18	100-200
Bronze	Cu Sn P	89 10 1	160-180	-	1020	31	20	80-90
Iron-carbon	Fe C	98 1.2	60-90	400	1370	18	28	120-140
Iron-carbon-copper	Fe C Cu	78 1.2 8	60-90	400	1320	2	8	150-170
Wolfram-copper	W Cu	60 40	10-20 40-50	400	1350	3	5	–

It was established that MIC grows with increasing of the energy level *W* of generator density and the hardness of the sintered materials (fig. 4).

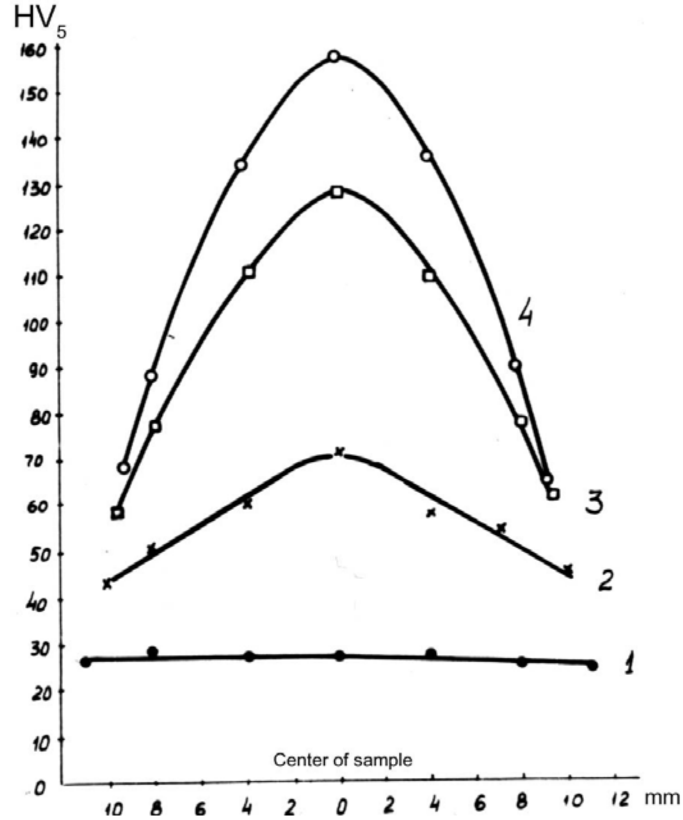

Fig. 4. Change of the hardness HV_5 along a radius of billets.
1 – initial state; 2,4 – after MIC. W =2,0, 4,0 and 6,0 kJ. Equipment IG-18/5.
Bronze materials (Sn = 1,0-1,2%, F = 1,0%), d = 20 mm, h = 30 mm, γ_0 = 6,3 g/cm^3.

The growth of hardness from the periphery to center is located in accordance with the theoretical prerequisites about the distribution of the magnetic pressure in the electrically conducting medium, whose maximum reaches at the depth of the skin-layer of Δf [6].

For the sintered bronze (porosity 25-30%) by the frequency of the discharge f = 5 kHz the value of Δf is 2,5 mm.

Micro-structural studies (fig. 5), executed on the billets made of bronze show that the powder sintered in the state of free filling has particles of the spherical form, which possess several contact areas, in this zone the inosculation of metal is occurred.

The diameter of the contact area composes $^1/_3$ – $^1/_4$ the size of particle.

With the MIC working at the small energy level (W = 2,76 kJ/cm^3) body density increases. Old particle connections begin to be destroyed. In the contact zone the deformation of particles grows. Packing in the center is observed.

The particles are deformed more noticeably with the energy level (W = 4,24 kJ/cm^3). In the center section of the body the increasing of the density in comparison with the near-surface zone is observed.

With the energy level (W = 6,37 kJ/cm^3) in the center of body appear the cracks, which, being developed, lead to the destruction of body. The characteristic shape of particles in the contact zone shows the elastic-plastic nature of deformation and the presence of residual elasticity.

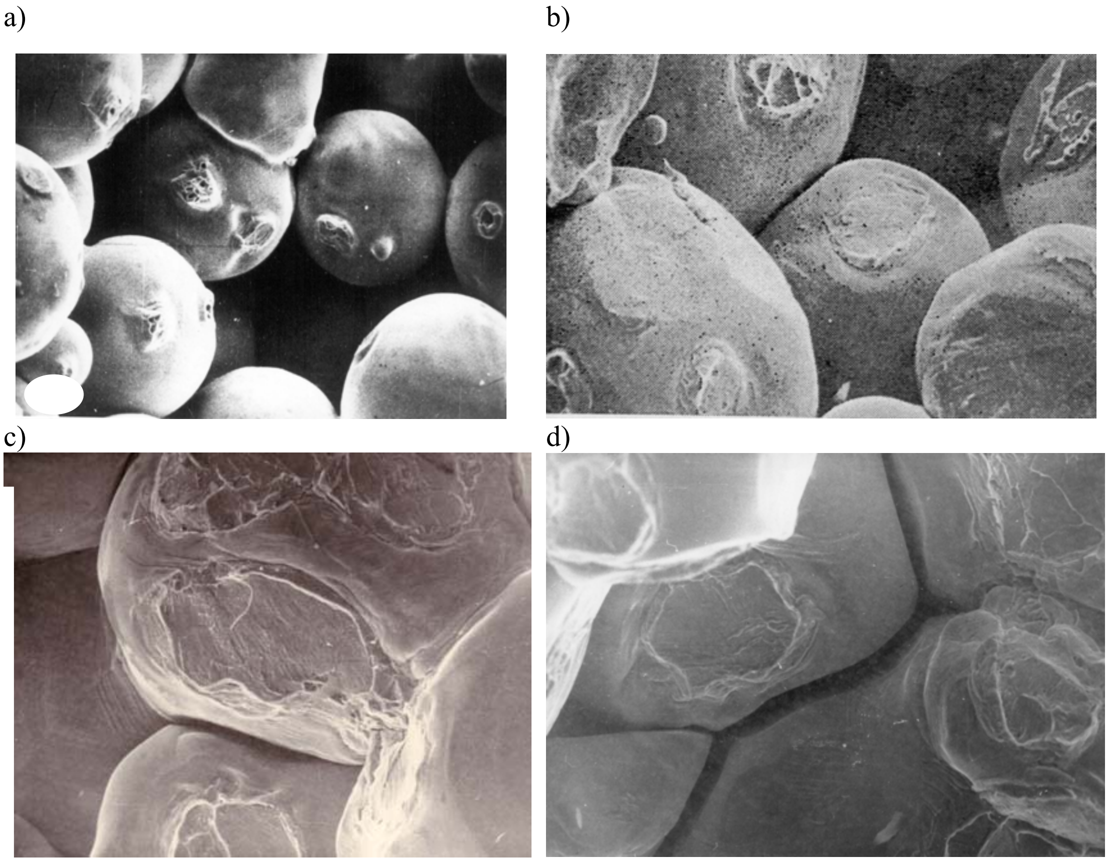

Fig. 5. SEM of the sintered powder bronze.
a – before MIC; b,c,d – after MIC. Energy level W 4,24 kJ/cm^3 (b) and 6,37 kJ/cm^3 (c, d).

DISSCUSSION

Method MIC can be used for treating the sintered powder components. The higher the electrical conductivity of component and the ferromagnetic properties of its material, the more strongly the effect of electromagnetic pulse action appears.

Since the electromagnetic field is extended in the powder parts according to the separate laws of physics, final properties will depend on intensity and duration of electromagnetic field, properties of material and form of components.

Using the concentrators of electromagnetic field, it is possible to focus the action of field in the narrow section, which leads to the local deformation of component.

With the levels of specific energy of more than 6.0 kJ/cm^3 were observed processes of the destruction of the sintered components, which shows existence of the critical level of specific energy.

CONCLUSION

1. Possibility to change the density (porosity) of the sintered powder materials with the action of pulse electromagnetic field is shown.
2. The nature of the deformation of the sintered powder material with MIC depends on electrical conductivity, porosity and strength of the powder component, as well as the parameters of pulse field.

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