Composite Details from Fe-Cu Powder Materials

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In this work, the peculiarities of the manufacturing of the details from powder materials with complicated shape by the method of magnetic pulse processing are presented. The special attention is given to the Fe-Cu powder materials which are used for complicated shape moulds manufacturing for thermoplastics casting. Magnetic pulse processing of materials (MIOM) include following operations, such as magnetic pulse pressing of powders and sintering with infiltration. The optimal values of the magnetic field intensity, discharge current and working voltage are determined. Post processing of the Fe-Cu details in the pulse electromagnetic field furthers the density rise на 7 % – 10 % and the additional changes of the detail shape.

Keywords: Fe-Cu powder materials, magnetic pulse pressing, discharge current.

1. INTRODUCTION

Fe-Cu powder materials are characterized by sufficient strength and plasticity in combination with high corrosion resistance and heat conductivity. These materials were investigated by V. Yeremenko and Y. Naydich [1], L. Tuchinsky [2], M. Rosso [3] and others scientists. Fe-Cu powder materials are typical representatives of materials which sinter with presence of liquid phase (in this case – with presence of copper or components on the base of copper). Under the circumstances the components diffusion speed significantly increase, the solid particles relative displacement become easier and rapid filling of capillaries occur.

In the 60 years of XX century Fe-Cu powder materials were widely used for antifriction and construction details manufacturing. But then these materials become out of interest of manufacturers through insufficiently mechanical properties and excessive shrinkage during sintering.

Fe-Cu powder materials reacquire popularity with appearance of alloyed iron powders such as Distaloy Cu and Astaloy Cu [4] and development of technology for infiltration of stainless steels by copper [5].

For manufacturing of complicated shape and large-size details the Fe-Cu powder materials were ones of the first used basic materials [6]. Application of new technology of the pulse magnetic pressing (MIOM) furthers the use of Fe-Cu powder materials too [7].

The aim of research is finding of the new technological schemes for forming of the powder details with complicated shape and determining of the technological parameters of the MIOM processes.

2. EXPERIMENTAL

2.1. MIOM technology

Magnetic pulse pressing of powders (MIOM) could be realized by several schemes. In one of the MIOM scheme compacting of powder proceeds in thin-walled conductive shell from copper or copper alloy [8].

During MIOM pressing the radial loading in the direction perpendicularly to axes allows us to receive the complicated shape of details that is very difficult or impossible to obtain on traditional hydraulic presses. For example, we produce the details with longitudinal holes, female thread or inside ribbing (Fig. 1). During sintering the shaping copper shell was used as infiltrate (Fig. 1, a – c) and was removed after preliminary sintering (Fig. 1, c) or remain on the detail (Fig. 1, d).

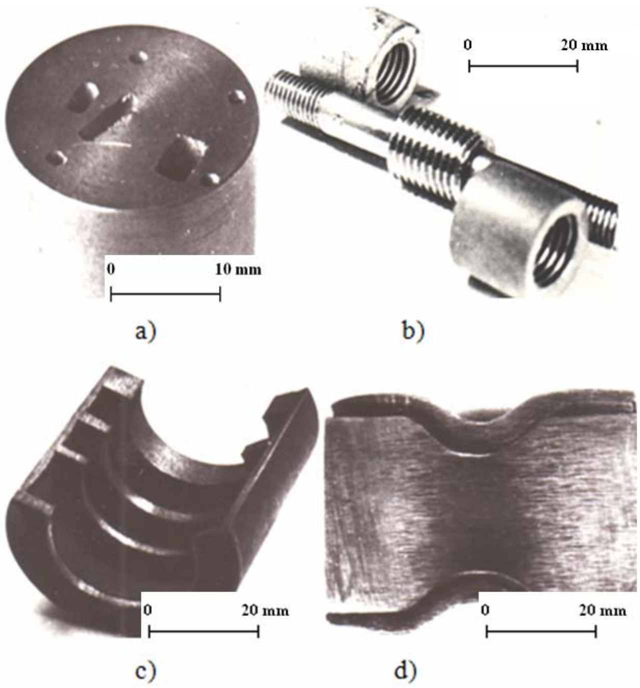

Fig. 1. Fe-Cu powder details with complicated shape achieved by MIOM technology

For pressing the powder ASC 100.29 (Höganas) with 2 % Cu and 0.8 % C was used. Pressing was realized using the MIU equipment [9], the pulse pressure was from 200 MPa to 700 MPa. Sintering was performed in two stages: preliminary sintering at temperature 950 ºC and

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final sintering at temperature 1150 ºC. Preliminary sintering allows to increase the strength of the iron frame and, if necessary, remove the shell.

2.2. Multilayer parts

For tubular parts with interior profiled surface with high hardness and increased surface quality manufacturing preliminarily the thin layer (so called "facing layer") from Ni-Co alloy (Co maximally 20 %) was plated on steel or plastic workholder. The thickness of layer was 150 µm – 200 µm, hardness – 50 HRC – 54 HRC. Then workholder was placed into the belt, which was preliminarily produced from powder material on the basis of iron with residual porosity after sintering from 15 % to 20 %. For pressing the tubular scheme was used as shown on Fig. 2.

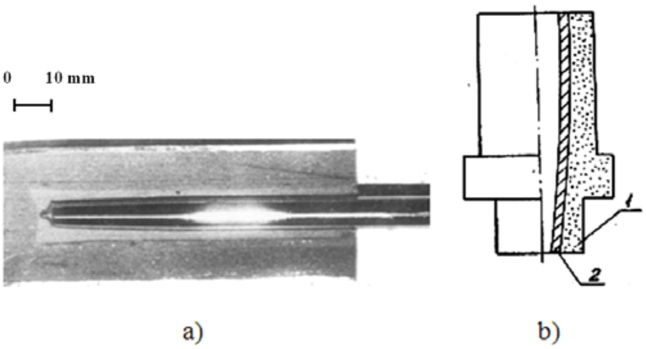


Fig. 2. Multilayer part: a – section; b – scheme; 1 – frame from Fe-Cu powder material; 2 – facing layer from Ni-Co alloy

The MIOM method for the workholder compression with facing layer was realized on the equipment MIU-40 (specific energy 6.2 kJ/cm^3). After compressing the workholder was removed. By this method the bonding strength from 2 kN/mm^2 to 3.5 kN/mm^2 was achieved. The belt porosity was only 6 % – 10 %.

To find the optimal regime the frequency and energy of the discharge, detail porosity and surface roughness were varied. Frequency and energy of the discharge were changed by increasing or decreasing the capacitor bank capacity or working voltage. The achieved joints were tested on the tensile machine and the bonding strength of bush with rod was determined.

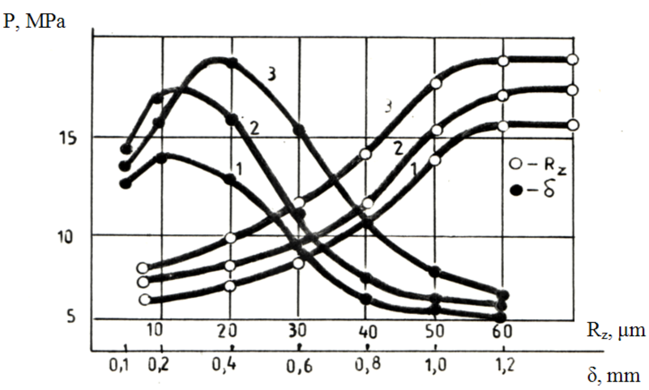


Fig. 3. Dependence of the bonding strength P on energy of the discharge W, rod surface roughness R_z and gap between the details δ. Energy levels: 1 – $W = 6$ kJ/cm^3; 2 – $W = 8$ kJ/cm^3; 3 – $W = 10$ kJ/cm^3 (MIOM equipment with discharge frequency 6 kHz)

Changes of the micro geometry of rod surface and gap between the rod and powder detail significantly influence on the bonding strength (Fig. 3).

Maximal bonding strength was achieved at rod surface roughness $R_z = 60$ µm and gap between the joint details $\delta = 0.2$ mm.

2.3. Thermal activation

Thermal activation during powder belt pressing by MIOM method is necessary since it ensures:

1. increasing of plasticity and decreasing of deformation resistance;
2. additional activation energy in the contact zone with facing layer.

Multilayer tubular powder part heating was realized by pulse discharge current advancing sequentially through the inductor coil and steel workholder [10].

According to the mentioned scheme during 1 – 2 minutes the current pulses with amplitude from 2 kA to 15 kA and duration 100 msec were applied. Then the deformation of part up to permanent joint formation occurred. As a result of the thermal activation, the bonding strength increased by 20 % – 25 %.

For the planar objects the planar pressing scheme was used too (Fig. 4).

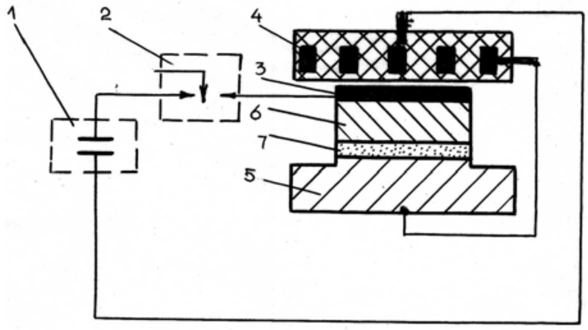


Fig. 4. Scheme of the planar pressing: 1 – current pulse generator; 2 – thyristor; 3 – electrically conducting coating; 4 – inducer; 5 – bottom die; 6 – upper die; 7 – powder

Preliminarily pressed and sintered part from Fe-Cu powder alloy (Cu – 18 %, C – 0.97 %) with initial density 60 % – 65 % was placed on the detail surface. The planar scheme allows to realize the pulse deformation of the powder layer simultaneously with the powder layer pulse heating by the pulse discharge currents. The following characteristics of discharges were used:

- discharge voltage – 5 kV;
- discharge pulse number – from 1 to 10;
- pulse sequence range – from 10 pulse/min to 30 pulse/min;
- discharge current amplitude – 2 kA – 15 kA.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Metallographic analysis has shown that after MIOM and thermal activation the density of material increases (porosity decreases). Material structure can be described as

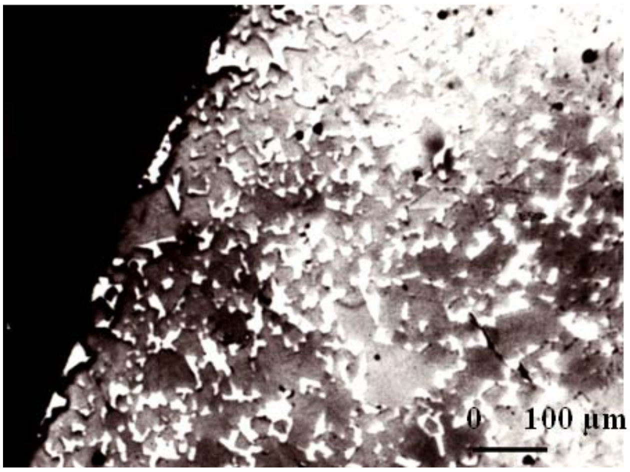
100 % pearlite in the contact zone (Fig. 5, a), but in the central part it looks like ferrite (Fig. 5, b).

It was revealed that the increase of the discharge pulse number leads to the increase of the final density and bonding strength. On the other hand, the increasing of the discharge current has definite limits. When discharge current is above 10 kA the electric breakdown occurs, that leads to the nonuniform heating due to the nonuniform current distribution in volume of the powder layer.

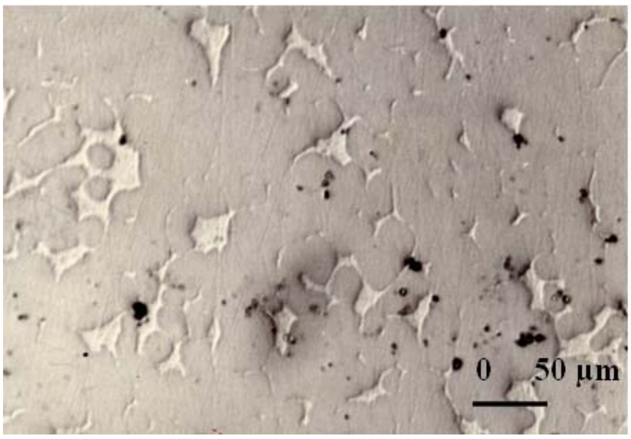
As a main technological factor of the electric discharge heating we recommend to use the pulse of current effective density:

$$J_{ef} = i \cdot N \cdot t, \qquad (1)$$

where i is the average density of the discharge current; N is the number of discharges and t is the duration of the discharge.



a



b

Fig. 5. Microstructure of the belt after sintering with infiltration: a – near-surface region; b – central part

The use of a method of magnetic pulse extrusion and subsequent impregnation with copper fusions, as well as the additional methods on the intensification of above mentioned processes enables to improve properties of the materials on the iron basis, as well as to expand the technological potential of the manufacturing of the articles of complex shape. Improvement of the properties is due to the higher density of the component during the packing and sintering as well as infiltration and subsequent treatment.

Experimental studies show, that an increase of the density due to increase of the compacting pressure (that is determined, first of all, by the energy level of the condenser (more than 10 kJ/cm^2)) leads to the appearance of uneven density in the sections of pressing, as well as to change in the form of article and reduction in the accuracy, or sometimes even to the destruction of articles. The cracks and macroscopic defects of the articles appeared in this case. This is first of all, because of the uneven deformation of technological of shell at the moment of extrusion. On the other hand, the reduction of the residual porosity of component after the extrusion of less than 5 %–7 % no longer ensures the effective infiltration of the fusion of copper. After sintering and infiltration the accretions and other defects of the form of component were observed.

The best properties for the material (Fe + 4 % of Cu + + 1.2 % of C) were obtained after single extrusion MIOM (magnetic pulsation treatment of metals) in the shell from the copper alloy (Cu + 0.8 % of Sn) with the value of the specific energy of the condenser of 8 kJ/cm^2, preliminary sintered at a temperature of 980 °C during 20 minutes, and final sintering at temperature 1180 °C. In this case, the residual porosity did not exceed 0.5 %–1.0 %. The hardness of material was 220 HV–240 HV, the strength to the tension of samples 450 MPa–500 MPa, strength to the break of annular samples were 320 MPa–330 MPa, and lengthening reached 6 %–8 %.

Deformation by MIOM of the sintered details in comparison with the earlier-obtained results [7] allows to increase the density of Fe-Cu powder details on 10 %–15 % and to obtain the details with more complicated shape.

Further intensification of the processes is possible in several directions:

1. Application of the alloying elements, first of all Ni and Mn, introduced into the charge before the extrusion of powder;
2. Heating component in the process of impregnation is combined with its rotation;
3. Heating powder at the moment of extrusion is achieved via pulse advancing of electric current.

Although two last proposals complicate the construction of the devices, utilised for the extrusion and the sintering, they make it possible to improve properties and quality of the articles.

4. CONCLUSIONS

1. Radial pressing (MIOM) allows to manufacture multilayer powder details with complicated shape.
2. Applying of the discharge current through the powder allows to activate pressing process, increase the strength of the belt and bonding strength of the facing layer with belt on 20 %–25 %.
3. Micro geometry of the contact surfaces significantly influence on the bonding strength. Maximal bonding strength was achieved at rod surface roughness R_z = 60 µm and gap between joined details δ = 0.2 mm.

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