APPLICATION OF ECA PRESSING FOR THE PRODUCTION OF THE FUSE LINKS

ПРИМЕНЕНИЕ РКУ-ПРЕССОВАНИЯ ДЛЯ ИЗГОТОВЛЕНИЯ ВСТАВОК ПЛАВКИХ ПРЕДОХРАНИТЕЛЕЙ

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Abstract: *The potential of using the ultrafine dispersion powder material obtained by the ECA pressing from a copper powder have considered for the production of fast-acting fuse links. The dependences of the density and microhardness along the length of the sample under different deformation conditions obtained. A deformation zone of constant density is determined and recommended for using in the production of fuse links. The dependence of the electrical resistance along the sample cross-section and across the deformation axis has determined. The fuse links calculation procedure has proposed.*

***KEYWORDS**: BILLET, POROSITY, DEFORMATION, DENSITY, HARDNESS, MICROSTRUCTURE, ELECTRICAL RESISTANCE, FUSE LINK, FUSE.*

1. Introduction

The equal-channel angular pressing allows production of bulk samples with a uniform ultrafine-grained (UFG) structure with a grain size of 100-200 nm and does not require complex equipment. There are three to eight passes needed to obtain a uniform UFG structure throughout the volume of billet, according to the results of most studies [1]. The UFG structure provides a substantial improvement in the mechanical properties of material [2]. At the same time, ECA pressing leads to the formation of a set of grain boundaries, which makes an influence on the material physical properties. As a result, such properties as electrical conductivity, coercive force decrease while increasing electrical resistance. Such physical dependences make it possible to recommend the material obtained by ECA pressing for parts with higher electrical resistance required.

The paper *is aimed to* study the potential of using the ultrafine dispersion powder material obtained by the ECA pressing from a copper powder have considered for the fabrication of fast-acting fuse links.

2. Research methodology

The stabilized PMS-1 grade copper powder has used for the experimental study. Prismatic billets of 0.5 x 0.5 mm in cross-section, 20 mm long, initial porosity 40%, 20% and 10% have produced by bilateral pressing on the hydraulic press model PD-476, force 1600 kN. The stepwise sintering was carried out in the synthesis gas medium. The deformation was performed in three passes using a special die tool for ECA pressing without removing the sample and changing the billet orientation [3]. The matrix had four prismatic channels of 0.5x0.5 mm, intersecting at 90° for ensuring continuity of deformation work. The inner curvature radius of the matrix channels was 1.0 mm, and the outer radius equal to zero. The compacting pressure was 480 MPa for the first pass and 550 MPa for the third while back pressure was 90 MPa [4].

Electrical resistance measurements of the samples obtained after ECA pressing in the longitudinal and transverse directions have carried out on a DC bridge device U39 designed for measuring electrical resistances from 1 · 10 -8 Ohm to 1,1111 · 10 8 Ohm. The measurement error of the device has not exceeded 0.209%. To exclude the influence of the thermo-contact electromotive force on the measurement results, the polarity change is provided in the device while changing within the forward and reverse.

The ECA pressing has accompanied by changing the shift direction to the opposite. Changing the deformation sign makes an influence on the structure formation. The main deformation axes undergo a rotation, and as the material passes through each subsequent pass, the axes rotation direction changes to the opposite during each pass. It contributes to the intensive fragmentation of structural components and isotropic structure formation at each deformation cycle [5]. Redistribution of the crystal lattice micro distortions occurs between the individual micro volumes of the plastically deformed material at each subsequent deformation zone and cycle, as a result of appearance a large number of directions along which an elementary shift in the micro volumes of the deformed material may occur. It also provides the intensive process of crushing mosaic blocks and individual crystallites, as the result of which a fine-dispersed structure has observed with the formation of many defective boundaries [6]. The density, microhardness, structure, and electrical resistance of samples have measured and investigated after ECA pressing.

3. Research results

The sample density changing lengthwise, which allows determining dimensions of the deformation zone with UFG structure presented in Figure 1. Dimensions of the deformation zone at the initial porosity of 40% are much less than at the initial porosity of 10% despite the lower energy intensity of the operation. Therefore, we recommend using a billet with an initial porosity of 10-15 % for production of predetermined shape parts [7].

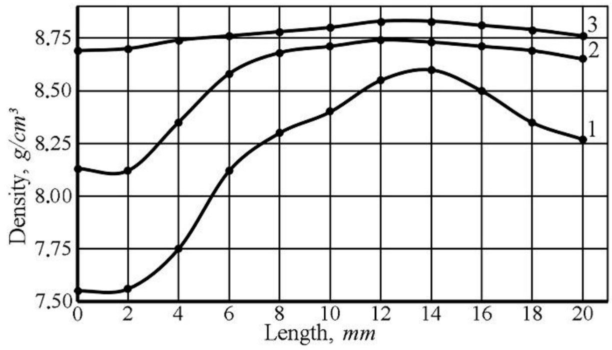

***Fig. 1.** Changing the density lengthwise the sample at initial porosity: 1 - 40 %, 2 - 20 %, 3 - 10 %.*

A homogeneous microstructure has formed as the result of the ECA pressing in the intensive metal flow direction, the grains elongation and the fraction of high-angle grain boundaries are determined by the number of passes and the degree of deformation [8]. The most ordered, equigranular, and banded microstructure with low-angle boundaries has obtained in the test sample after the third pass [9]. The smallest grain size in the deformation zone was ~ 80 nm while increasing the distortion level of all grains.

Experiments have shown clearly that nanostructured zone in the sample increases while decreasing the initial porosity value [10].

The density increase, as well as the presence of ultrafine-grained structure, provided increasing the strength of the powder material. The microhardness changing after the third pass presented in Figure 3. As seen, the microhardness in the central zone of the sample is almost homogeneous, but it varies by the cross-section, which obviously provides an anisotropy of physical and mechanical properties [11].

Fig. 2. The microstructure of the deformation zone after the third pass, x3000

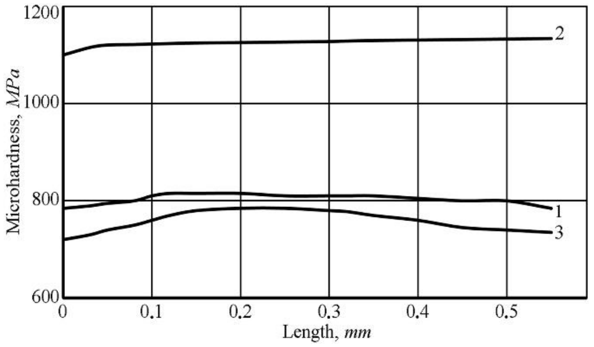

Fig. 3. The microhardness changing by the longitudinal section of the sample after the third pass: 1, 3 - are the upper and lower zones; 2 - is the central zone.

The direct current electrical resistance measuring results presented in Table 1.

Table 1

The direct current electrical resistance measuring results

Samples after ECA pressing	R, Ohm	R, Ohm, copper (tabulated value)
Longitudinal section	$2.8 \cdot 10^{-5}$	$1.72 \cdot 10^{-6}$
Cross-section	$4.9 \cdot 10^{-5}$	

A considerable variation in the electrical resistance measurements by the cross-section of the sample is explained by the formed elongated structure after the ECA pressing with the smaller number of grain boundaries in the longitudinal section than in the transverse section. The smaller number of grain boundaries and defects in the crystal lattice in the longitudinal direction corresponds to lower electrical resistance values.

4. Application of research results

Considerable reserves for increasing a speed of fuses in devices are in using of UFG powder copper for production of fuse links. Fuse links made of such material demonstrate a higher electrical resistance than the cast conductors and 15% lower heat capacity upon the average, which results in a much higher speed of fuses.

The fuse link is a plate with the thickness of 0.3 mm and cross-sectional dimensions of 0.5 x 0.5 mm. Such plates have obtained by electrical discharge sawing, which allowed preserve a UFG structure and high electrical resistance of samples.

The work of electric current $P(t,T)dt$ causes the fuse heating up from the temperature T to $T+dT$ while operating in short-circuit mode during the time interval from t to $t+dt$. Since the process is rapid, heat exchange with the environment may be neglected, and the following equality fulfilled:

$$P(t,T)dt = c(T)mdT, \tag{1}$$

where $P(t,T)$ - is the electric current power allocated in the volume of a fuse, W; $c(T)$ - is the specific heat of fuse material, J/(kg·K); m - is the weight of a fuse, kg.

Since the current power is:

$$\boldsymbol{P(t,T) = I^2(t)R(T)}, \tag{2}$$

where $I(t)$ - is the short-circuit current through the fuse, A; $R(T)$- is the fuse resistance changing during its heating, Ohm, obtained:

$$I^2(t)dt = \frac{c(T)mdT}{R(T)}. \tag{3}$$

Since the fuse operating time mainly determined by its heating time from the operating temperature T_0 to the T_s melting temperature of the material from the fuse is made of, and also neglecting the time dependence of the short-circuit current, we obtain the following expression for evaluation of the trip time:

$$t_s = \frac{m}{I_s^2}\int_{T_0}^{T_s}\frac{c(T)dT}{R(T)} = \frac{d_0 l_0 S_0}{I_s^2}\int_{T_0}^{T_s}\frac{c(T)S(T)dT}{\rho(T)l(T)}, \tag{4}$$

where Is - is the average value of short-circuit current, A; d_0 - is the fuse material density at the operating temperature T_0, kg/m^3; l_0 - is the fuse length at the operating temperature T_0, m; S_0 - is the fuse cross-sectional area at the operating temperature T_0, m^2; $\rho(T)$ - is the resistance of the fuse material, which changes during its heating, Ohm·m; $S(T)$ - is the cross-sectional area of the fuse m^2; $l(T)$ - is the fuse length, m.

Approximating dependences obtained by the experimental results for fuse links made of cast and UFG powder copper have used for verification of the proposed fuse trip time calculation technique.

The dependence of heat capacity on the temperature of cast copper, J/(kg·K):

$$c(T) = 259 + 0.363T - 1.3 \cdot 10^{-4}T^2. \tag{5}$$

The dependence of resistivity on the temperature of cast copper, Ohm·m:

$$\rho(T) = 9.78 \cdot 10^{-9} + 3.22 \cdot 10^{-11}T + 2.78 \cdot 10^{-14}T^2. \tag{6}$$

The dependence of density on the temperature of cast copper, kg/м^3:

$$d_0(T) = 9.03 \cdot 10^3 - 3.15 \cdot 10^{-1}T - 4.25 \cdot 10^{-5}T^2. \tag{7}$$

The dependence of the linear expansion coefficient on the temperature of cast copper, 1/K:

$$\alpha(T) = 1.35 \cdot 10^{-5} + 7.7 \cdot 10^{-9}T - 2.1 \cdot 10^{-12}T^2. \tag{8}$$

The tested fuses from UFG powder copper are in good compliance with the theory, which takes into account the dependence of heat capacity, resistivity, density, geometric dimensions and other parameters of the fuse-link on its temperature.

The trip time simulation results for fuses made of UFG powder copper depending on the resistance, cross-sectional area and short-circuit current of samples presented in Fig. 4 - Fig. 6.

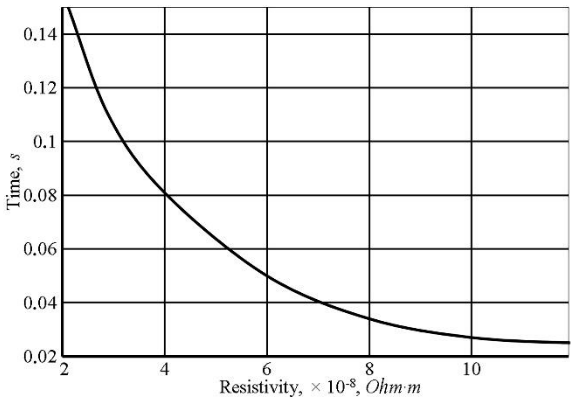

Fig. 4. The dependence of the fuse trip time on the electrical resistivity of UFG powder copper.

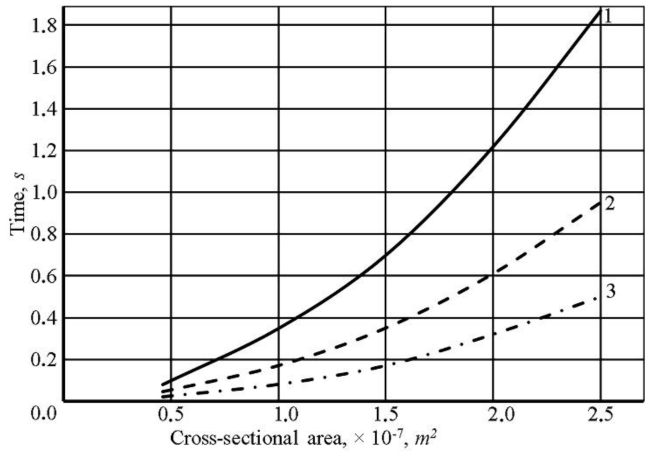

Fig. 5. Dependences of the fuse trip time on the cross-sectional area for different values of the resistance of the samples:
1 - is the cast copper, $\rho = 1.7 \cdot 10^{-8}$ Ohm·m; 2 - is the UFG powder copper, longitudinal section, $\rho = 8.9 \cdot 10^{-8}$ Ohm·m; 3 - is the UFG powder copper, cross-sectional area, $\rho = 17.5 \cdot 10^{-8}$ Ohm·m.

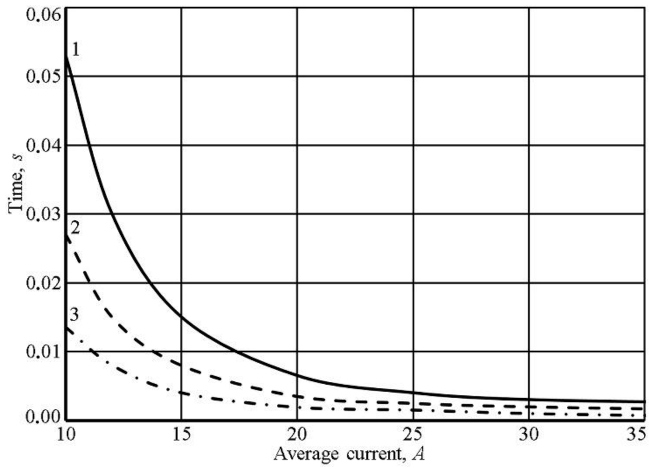

Fig. 6. Dependences of the fuse trip time on the average value of a short-circuit current for various resistivity values of samples:
1 - is the cast copper, $\rho = 1.7 \cdot 10^{-8}$ Ohm·m; 2 - is the UFG powder copper, longitudinal section, $\rho = 8.9 \cdot 10^{-8}$ Ohm·m; 3 - is the UFG powder copper, cross-sectional area, $\rho = 17.5 \cdot 10^{-8}$ Ohm·m.

The UFG copper powder material has recommended for the fabrication of fuse links.

5. Conclusions

The problem of using the UFG powder material obtained by the ECA pressing from a copper powder for the production of fast-acting fuse links has been solved.

The dependences of density and microhardness of the sample under various deformation conditions have obtained lengthwise. A deformation zone of constant density is determined and recommended for using in the production of fuse links. The dependence of the electrical resistance along the sample cross-section and across the deformation axis has determined. A fuse links calculation has proposed.

Implementation of the UFG copper powder material for the production of the links will ensure a significant increase in the speed of the fuse link at negligible electric power loss compared to the payload.

6. References

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