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CHANGE OF BRASS STRUCTURE UNDER ITS EXPOSURE TO PULSED MAGNETIC FIELD

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Abstract. The structure change of the Cu-42% Zn alloy (brass) was investigated under its exposure to a pulsed magnetic field. Metallographic examinations have revealed that the alloy grains are refined with forming twins inside them. Compressive macrostresses are set up on the surface of the alloy samples under the action of a pulsed magnetic field. The alloy structure and properties are shown to change periodically depending on the value of discharge energy and the number of magnetic pulses.

Keywords: Magnetic field, macrostresses, twinning, brass

1. Introduction

The strength of metallic items and semifinished products is substantially affected by the value of internal stresses. For instance, as regard a thin wire it is known that the higher the value of surface compressive macrostresses the higher is its ultimate strength. Therefore, the urgent problem is to develop effective methods for changing the value of stresses in a surface layer. In this respect the potentialities of thermal and mechanical treatments are largely exhausted. To accomplish this end the methods based on exposure of materials to various physical fields including a magnetic pulsed field (MPF) appear to be promising.

At present in the process of metal cord production a wire is subjected to brass plating. In this case possible generation of compressive macrostresses, primarily, in a plated brass layer requires further investigation. The objective of the study was to elucidate the possibility of changing the structure and macrostresses of brass under its exposure to a pulsed magnetic field.

The data available in recent publications suggests that a magnetic field can be considered as effective means for changing the structure and properties of metals and alloys.

The majority of investigations devoted to structure formation of materials under their exposure to magnetic fields have been performed using iron-carbon alloys [1] and there is relative lack of knowledge concerning the structure change of nonferrous metals and alloys when they are under the action of magnetic fields. This in some way is due to a generally accepted opinion that only ferromagnetics are susceptible to changing their structures and properties under exposure to PMF. However, the investigations accomplished by the present authors over a period of years have demonstrated that the use of magnetic pulse processing (MPP) is highly suitable for changing the structure and properties of alloys based on copper [2], aluminum and some other nonferrous metals [3-5]. It is shown that MPP of copper and the Cu-2% Be bronze results in obtaining a more fine-grained and homogeneous microstructure. The structure thus formed ensures increased plasticity that in the process of mechanical tests can give rise to generating mobile dislocations [6].

From the results of the investigations performed earlier we can suggest that it is possible to change the brass structure and properties under the action of a pulsed magnetic field.

2. Experimental

The magnetic pulse processing was carried out using the experimental setup [6] the parameters of which are given in Table I.

The pulse of a magnetic field was formed due to discharge of capacity storage in internal inductor space. The energy generated in inductor was 1.8, 2.5 and 3.2

kJ. The temperature of samples during magnetic pulsed processing did not exceed 40°C.

Table 1
MPP experimental setup parameters

MPP experimental setup parameters	
Discharge energy of capacity storage, kJ	0,6-20
Frequency, kHz	20
Discharge current, kA	30-50
Magnetic induction, T	10-50
Current pulse duration, µsec	150-200
Current rise time up to maximum value, µsec	30

Samples were placed in an axial zone of inductor (Fig. 1).

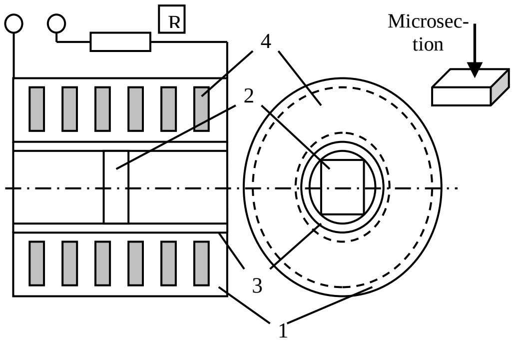


Fig. 1. Experimental setup diagram: (**1**) inductor; (**2**) sample; (**3**) separator; (**4**) copper bus; **R$_z$** total electric circuit ohmic resistance.

The investigation was performed on the binary α+β brass. The samples were of 5 x 5 x 10 mm size (Table 2). The alloy was preprocessed by homogenization for ten hours.

Table 2.
Brass composition

Components, mass %		Impurities, mass %, max							
Cu	Zn	Pb	Fe	Sb	Bi	P	As	Sn	Total
57-60	Balance	0.5	0.3	0.01	0.003	0.01	0.01	0.2	0.9

The metallographic microscope with 400 and 2000 magnification was used to perform a microstructural analysis. The etching of samples was carried out by a reactive made up of 10 parts of saturated water solution of $K_2Cr_2O_7$ (potassium bichromate) and 1 part of H_2SO_4.

The X-ray structure analysis was done with the aid of X-ray diffractometer under CuK$_\alpha$ radiation with a graphite monochromator. The X-ray patterns were taken from smooth surfaces of metallographic sections.

The macrostresses were determined using a standard procedure from the relationship:

$$\sigma = -\frac{E}{\mu} ctg\theta\Delta\theta \qquad (1)$$

where E and μ are Young's modulus and Poisson's ratio, respectively; θ the position of the diffraction line maximum; Δθ the angular displacement of this maximum with respect to angular position of a standard sample line. In this investigation the sample that had not been exposed to magnetic field was taken as a standard one. The stresses of this sample were set equal to zero. The values of E and μ were taken equal to 900 МПа and 0.37, respectively. The line ($12\bar{1}$) of the CuZn compound (θ = 43,758^0) was analyzed.

The half-width of a diffraction line (b) was determined from the relationship:

$$b = \frac{S}{h} \qquad (2)$$

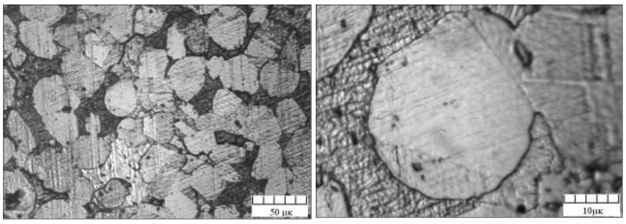
where S is the integral intensity; h the height of the diffraction line in maximum.

The correction for K$_\alpha$ - doublet was introduced.

3. Discussion

Brass has different-sized grain structure in initial state (Fig. 2 a). The grain area ranges from 23 to 1490 µm^2 (Fig. 3). The grains are of polygonal or round shapes (Fig. 2 b)

The main process of changing the microstructure during MPP is grain refinement. This is demonstrated by changing the average grain area depending on the number of magnetic pulses and due to varying the level of supplied energy (Fig. 4). The grain size is changed periodically when 1.8 and 3.2 kJ processing energies are used. The smallest average grain size is recorded after a 1.8- kJ single-pulse processing. On 2.5-kJ MPP the grain size is decreased with increasing the number of magnetic pulses.



a b

Fig. 2. Initial brass structure.

The histograms of grain-size distribution (Fig. 5) make it possible to analyze stages of structure rearrangement. When MPP is carried out at the energy of 1.8 kJ using only one pulse the proportion of fine grains is increased (Fig.5 a). The proportion of grains having area sizes in the range from 300 to 800 µm^2 is enhanced with increasing the number of magnetic pulses.

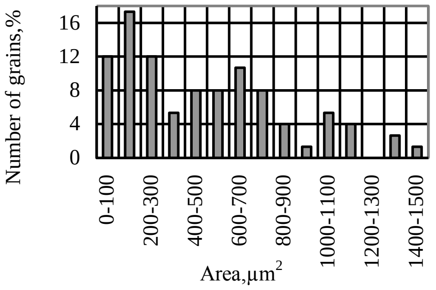


Fig. 3. Brass size distribution in initial state.

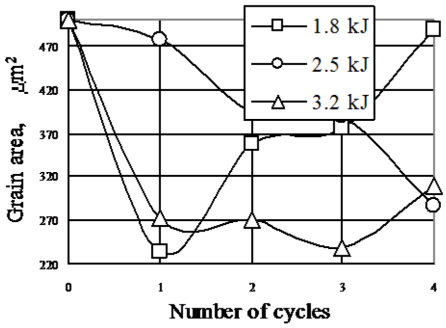


Fig. 4. The average grain area of brass as a function of the number of magnetic pulses

This is, probably, associated with coarsening of fine grains formed after the first processing pulse. In this case the number of fine grains is decreased (Fig. 5 b). When three magnetic pulses are used fine grains are formed in the structure in parallel with a further coarsening of separate grains. On using four magnetic pulses the grain growth processes are predominant.

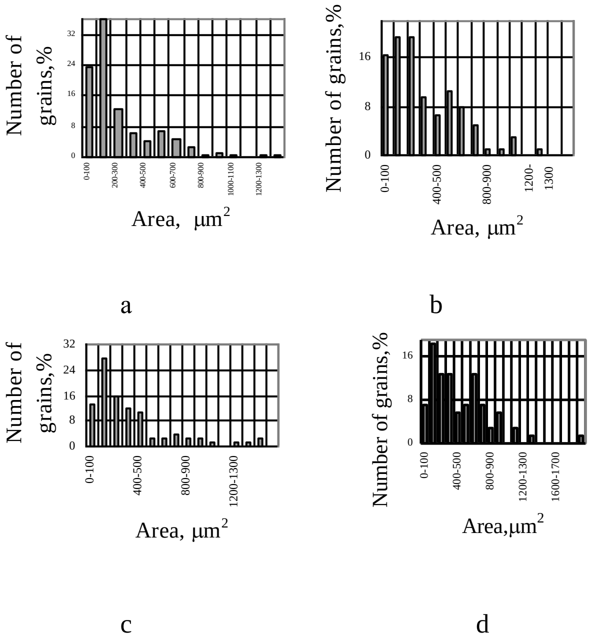


Fig. 5. Grain size distribution of brass grains after performing of 1.8-kJ MPP using one (a), two (b), three(c) and four (d) magnetic pulses.

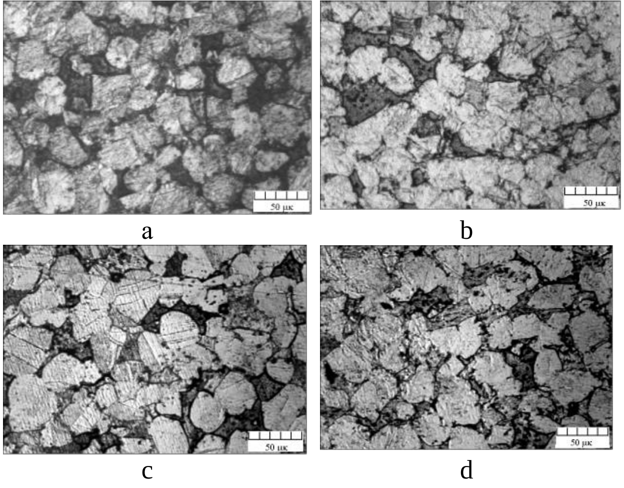


Fig. 6. Brass structure after performing of 1.8-kJ MPPusing one(a), two (b), three (c) and four (d) magnetic pulses.

MPP changes an internal grain structure (Fig.6 and 7). When MPP is carried out using three magnetic pulses the formation of twins is discernible in the structure (Fig. 6 c, 7 a). That twinning is intensified during MPP in the beryllium bronze (Cu-2% Be) has been observed in [6].

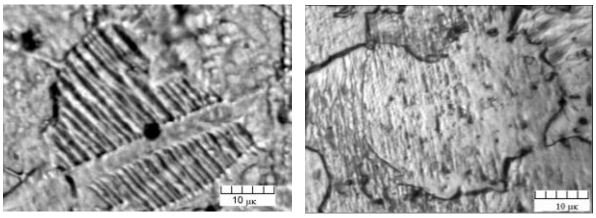


Fig. 7. Brass structure after performing of 2.5-kJ MPP using one (a) and four (b) magnetic pulses.

After processing at the energy of 2.5 and 3.2 kJ the structure changes observed inside a grain are less marked and confined to formation of fine grains while the brass still retains its different-sized grain structure (fig. 8). When four magnetic pulses are used the grain size distribution is not sufficiently changed.

The common feature of structure formation during MPP is formation of “serrated” boundaries (Fig. 6 b, d; Fig. 7) that are complex twin boundaries with segments of various-order twin orientation. The twin boundary is a special case of a high-angle boundary with a great degree of mismatch [7]. The formation of “serrated” boundaries is associated with the development of recrystallization process.

The structure change that occurs during MPP is accompanied by the change of halfwidth of diffraction lines in the alloy X-ray pattern (Fig. 9) which depends on the presence of microstesses.

In the case considered when heating is absent the phase transformation and ageing effects can not contribute to changing the diffraction line halfwidth. The diffraction line broadening can be increased due to microplastic deformation associated with substructure change.

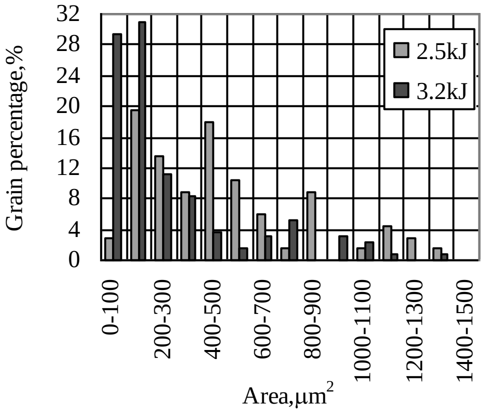


Fig. 8. Grains size distribution of brass after performing of one-pulse MPP using 2.5 kJ (1) and 3.2 kJ (2) discharge energies.

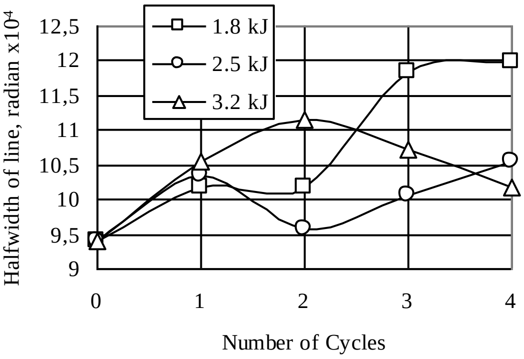


Fig. 9. Dependence of halfwidth of diffraction line on the number of magnetic pulses.

The change of diffraction line broadening is attributed to accumulation of crystal structure defects and proportional to a shearing stress [9], i. e. the broadening increases with increasing the work hardening energy. Bragg has shown in [10] that work hardening energy is conditioned by generation of localized dislocations or intercrystalline boundaries. The intergrain is a geometric locus of mismatch of atomic bonds of neighboring grains. This mismatch is responsible for initiating the surface energy of intergrain or interphase boundary [11].

The comparison of figure 4 and 9 indicates that the formation of a fine-grained structure is accompanied by increasing the diffraction line half-widths. They are most probably changed owing to formation of new grains during magnetic pulse processing. As has been shown in [6] new grains have low dislocation density and grain boundaries make up the main structure defects. Furthermore, the grain boundary can be represented as a local pile-up of high-density dislocations. In this case the broadening can be considered proportional to the density of dislocations arranged in a definite way. The increase of diffraction line broadening for the Cu-2% Be alloy under its exposure to magnetic field is shown in [6]. The decrease of line broadening results from the alloy grain coarsening.

The MPP-initiated structure changes lead to changing the level of the macrostresses in samples (Fig. 10).The realization of practically all processing conditions results in generation of compressive stresses in samples. When the discharge energy is 3.2 kJ the sign of macrostresses is reversed with changing the number of pulses. The value of stresses is periodically varied which is characteristic of metals exposure to pulsed energies of various nature [6].

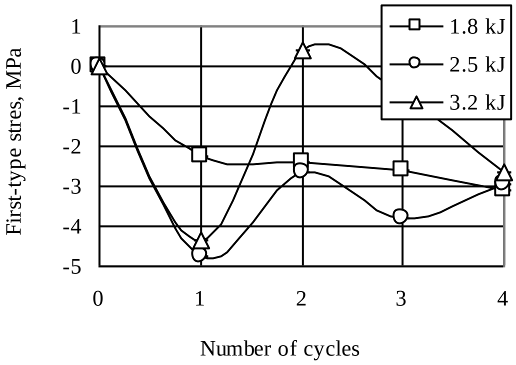


Fig. 10. Dependence of microstresses on the number of magnetic pulses.

The change of macrostresses that occurs during magnetic pulse processing can be explained on the basis of investigation results given in [12]. In a sample placed in a magnetic field the deformation increases with increasing the distance from its external surface (Fig. 11). The negative volume density increment of the magnetic field energy for non-ferromagnetic materials corresponds to positive pressure increment: $dp = -dW$ .The average pressure value of a sample at a point with x coordinate is as follows [12]:

$$p_x = \frac{B^2}{2\mu}\left(1 - e^{-2\alpha x}\right), \tag{3}$$

where B is the induction; μ the magnetic permeability; α the damping factor.

As for copper the pressure inside a sample 3 mm thick is up to 6.25 MPa for the frequency of 50 kHz [12]. If the sample width exceeds the half of electromagnetic wave length in the material the pressure increases only in the region where $x<\lambda/2$ and remains constant at $x>\lambda/2$ (Fig. 11). In case the limit of elasticity is exceeded the residual deformation increases. The stresses of the region 3 are low and $\sigma>\sigma_{elasticity}$ only there where $x>x_k$. The value of x_k is decreased with α increasing. Therefore, the region of tension (3) is reduced and that of compression (4) is increased.

The region of tensile stresses is 0.5 to 1 μm at the frequency above 5 kHz. In accordance with the estimates made for copper in [13] when the pulse duration is 10^{-4} sec, the current density $6 \cdot 10^3$A/m^2 and the induction 1 T the temperature increment is about 20 K and that of the pressure ~ 15 MPa.

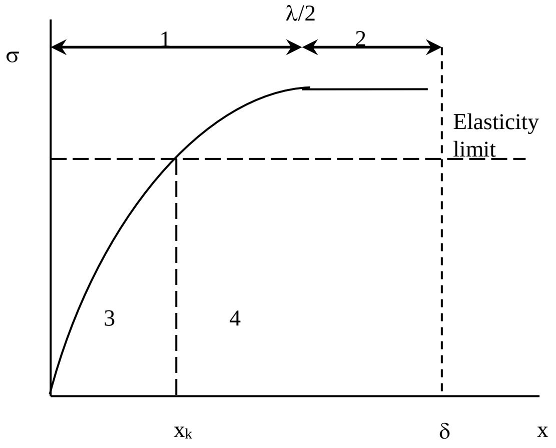


Fig. 11. Pressure distribution in a sample under its exposure to magnetic pulses: the regions of (1) increasing pressure; (2) constant pressure; (3) tension and (4) compression [12].

The region of tensile stresses is 0.5 to 1 μm at the frequency above 5 kHz. In accordance with the estimates made for copper in [13] when the pulse duration is 10^{-4} sec, the current density $6 \cdot 10^3$A/m^2 and the induction 1 T the temperature increment is about 20 K and that of the pressure ~ 15 MPa. Thus, a force action of a pulsed magnetic field is quite sufficient to cause structure changes [13] but not to achieve the elastic limit and ultimate strength values.

4. Conclusions

The study performed has found that:

1. The grain refinement is observed in the Cu-42% Zn alloy under its exposure to a pulsed magnetic field. The grain size of obtained structure depends on the number of magnetic pulses and the value of discharge energy.
2. The formation of a new fine grain is accompanied by increasing the broadening of diffraction lines.
3. The compressive macrostresses are generated in samples on their exposure to a pulsed magnetic field.

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