MICROSTRUCTURAL EVOLUTION AND MECHANICAL PROPERTIES OF ALUMINUM IN THE PROCESS "PRESSING-DRAWING"

ЭВОЛЮЦИЯ МИКРОСТРУКТУРЫ И МЕХАНИЧЕСКИХ СВОЙСТВ АЛЮМИНИЯ В ПРОЦЕССЕ «ПРЕССОВАНИЕ-ВОЛОЧЕНИЕ»

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Abstract: *The aim of this work is to study the influence of the combined process of "pressing-drawing" on the microstructure and mechanical properties of aluminium wire. Analysis of the results of the research has shown that the proposed combined method of deformation "pressing-drawing" has a significant advantage over the existing technology of production of aluminium wire. This method of deformation due to combination of two ways: by severe plastic deformation in equal channel step die and the process of drawing through a drawing die, allows obtaining aluminium wire with ultrafine-grained structure and a high level of mechanical properties, required size and shape of the cross section at a small number of cycles of deformation. Also would like to mention that this method of deformation in implementing it in production does not require significant economic investments, and substantial refitting of existing drawing mills.*
***KEYWORDS**: PRESSING-DRAWING; COMBINED PROCESS; ALUMINIUM WIRE; MICROSTRUCTURE.*

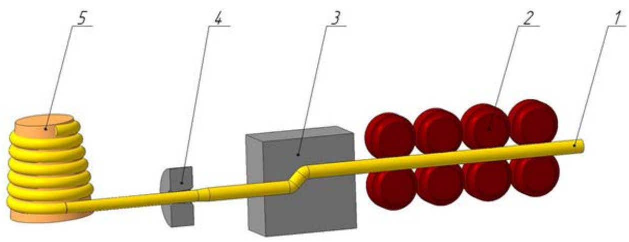
1. Introduction

The contemporary level of electronic technology development has led to the appearance of devices that often have moving parts and / or work in difficult conditions. Therefore, interest in the problems of forming physical and mechanical properties of functional conductor materials has recently grown abroad in connection with the need to stabilize the properties of current conductors and increase their reliability, including in heavily loaded cable systems, motor and generators windings and low-current computer networks [1-2]. The increased interest of researchers in such materials has greatly increased in recent decades in connection with the use of severe plastic deformation (SPD) methods to obtain bulk materials with fine grains characterized by high physical and mechanical properties [3-4].

Nowadays, the mechanical properties of bulk nanostructured materials generate particular interest. It is known that they are characterized by an increase in the yield point by 2-5 times compared with the corresponding values on SPD at coarse-cristalline state [5-6]. The paradox of SPD, consisting in the simultaneous growth of strength and plasticity as the degree of SPD increases, low-temperature and highspeed superplasticity, deviations from the Hall-Petch law to the higher values of the yield point [7-9].

The SPD method is free from disadvantages of other methods of obtaining such materials, such as the method of compacting powders obtained previously by various methods, and the method of depositing gas atoms on a substrate or electric deposition of atoms from an electrolyte solution. When the materials are compacted or deposited, impurities and pores flow into the boundaries of their grains, influencing the properties of the obtained materials. Among the SPD methods, the ECAP method is especially noteworthy [10-12].

A polycrystalline sample of a macroscopic volume subjected to ECAP retains its shape after multiple extrusions through a curved channel. As a rule, ultrafine-grained or nanocrystalline materials, obtained at the output, have nonequilibrium grain boundaries and a considerable density of lattice defects [13]. These features of the microstructure formed in the SPD process underlie the mechanical properties of the materials. However, the ECAP has a disadvantage – the impossibility of processing products of relatively large length due to loss of stability by a pressing punch. On the basis of a comprehensive analysis of the existing schemes of plastic structure formation and also taking into account the promising directions of their development [14-15], a new combined "pressing-drawing" process using an equal-channel step matrix (Figure 1) was proposed. It enables to obtain a wire with an ultrafine-grained structure and increased level of mechanical properties, required dimensions and shape of the cross section at insignificant number of deformation cycles.



1 – wire; 2 – pushing device; 3 - equal channel step matrix; 4 – calibrating drawing tool; 5 - winding drum
***Fig. 1.** Scheme of the combined process of "pressing-drawing"*

The gist of the proposed deformation method consists in the following. Preliminary sharpened end of the wire is set to equal-channel step die and then subsequently in the finishing die. At its core, process setting metal does not differ from the setting of the wire in a drawing die at a standard process of drawing. After the end of the workpiece exits the die it is fixed by means of gripping tongs and is wound on a drum drawing machine. In this case, the process of drawing the workpiece through an equal channel step die and a caliber die is realized by the application to the end of the workpiece stretching force. The external load is applied to the drawing metal and on the surface of the contact metal - tool contact stresses arise. Unlike other methods of material forming, the implementation of which cannot be carried out without the presence of the contact friction forces at drawing on metal-tool, directed against metal movement, are negative phenomena of the process, which undoubtedly involves the use of technology lubricants that reduce friction.

To determine the effects of a new combined method of deformation "pressing-drawing" on the changes in the microstructure and mechanical properties of aluminum wire laboratory experiment was carried out at an industrial drawing machine - I/550 M. For the first cycle of deformation before the draw plate with working diameter of 7 mm equal channel step die with channel diameter is 7 mm and the angle of the junction of channels equal to 135^o was fixed. The die was placed in a container for lubrication.

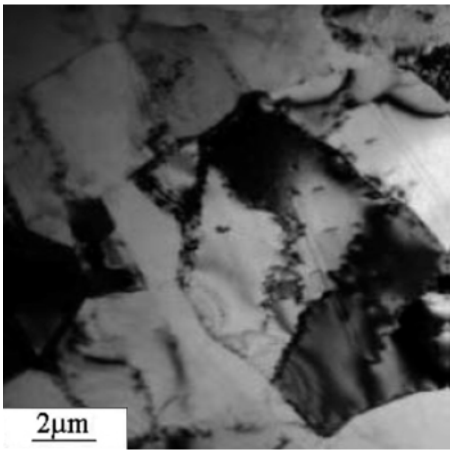
The initial diameter of the wire was 7.0 mm. After the process of pressing-drawing wire diameter has been 6.0 mm. All compression was carried out only in the drawing die, after exiting the workpiece from the equal channel step die wire diameter stayed unchanged at 7.0 mm. The experiment was duplicated four times. In this case after each experiment wire diameter was measured and cut templates for production of microsections in the transverse and longitudinal direction.

In order to identify the advantages of the proposed technology in comparison with the current technology of drawing three passes annealed wire of aluminum for each technology were carried out. I.e. clean drawing wire rod was carried out diameter of 7.0 mm in the drawing die on diameter 6.0 mm, equal channel angular drawing and combined process of "pressing-drawing". In this case also, after each experiment wire diameter was measured and cut templates for production of microsections in the transverse and longitudinal direction. As a lubricant chips of soap were used.

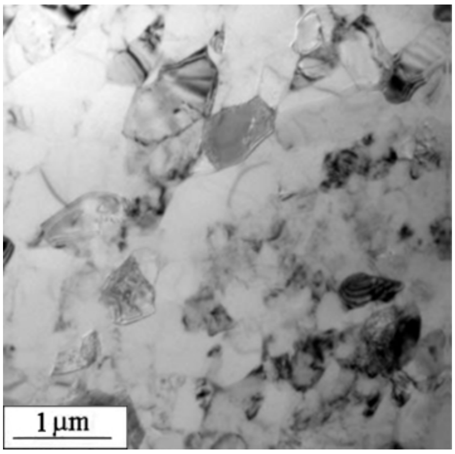
2. Results and discussion

Preparation microsections for metallographic investigations carried out by the standard method, for the study a scanning electron microscope JEOL JSM 5910 was used.

The results of the study of the microstructure of aluminum before and after the third cycle of deformation are shown in Fig. 2.



a



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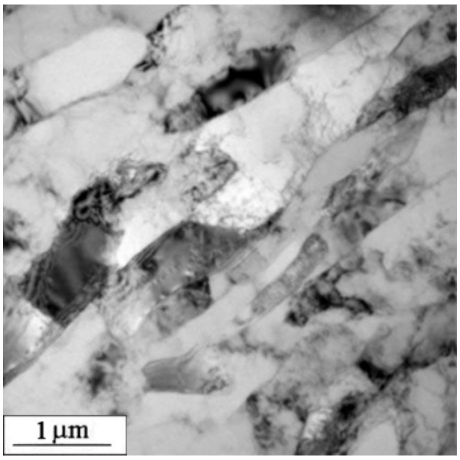

c

a – the initial structure, b – by the proposed ECAP-D technology, transverse direction, c - at existing technology of drawing, transverse direction

Fig. 2. *Structure of wire of aluminum*

Having conducted metallographic analysis of the deformed samples it can be concluded that the cold deformation when drawing at the current technology with a moderate and high total compression leads to the formation of a distinct textured structure. However, even as a result of substantial compressions produced wire in drawing process, not all grains are crushed and are deployed in the direction of the axis of deformation. As shown by metallographic analysis of the samples, resulting in uneven allocation the deformation over the cross section in the central part of the longitudinal sectional of the wire area of large grains is retained, resulting in an inadequate level of the plastic properties of the finished wire, in particular elongation. Thus from figure 3c it is shown that in this case deformation leads to insignificant of grain refinement in the transverse direction, in the longitudinal direction grains are elongated and somewhat refined with the formation a visible axial texture. Also it should be noted that in the longitudinal direction of the deformed samples the texture is pronounced and has striated character. The appearance of texture of drawing leads to anisotropy of the material properties in the longitudinal and transverse directions, which may adversely affect the operation parameters of the finished product. To reduce the appearance of axial deformation texture it is necessary to carry out recrystallization annealing of obtained wire with correctly chosen heat treatment parameters.

When using the proposed technology of deformation, i.e. combined process of "pressing-drawing", as shown in Figure 3b, already in three passes change of the initial microstructure was a significant, at the same time significantly in the less degree texture expressed and anisotropy, respectively. The proposed combined technology "pressing-drawing" eliminates the disadvantages of drawing process. In the first stage of drawing to a 30-40% breakdown cellular structure is formed. The local increase in internal stress field causes the formation of stable microcracks. Intensive disclosure of stable microdefect leads to stress relaxation that during subsequent deformation opens previously blocked the Frank-Read sources. Simultaneously cellular structure being improved fibrous structure is arisen and texture is formed. To achieve ultra-fine grain structure only by the uniform flow of dislocations is impossible: the accumulation of plastic deformation and dislocation density growth there is disproportionately rapid increase detents and obstacles hindering their progress through the crystal. Dislocation flow gradually depletes the level of internal stress increases. This continues until cracks begin to appear, brittle fracture of the sample occurs. To avoid this, and the energy delivered to the sample is not accumulated in the material mainly in the form of elastic distortions, and continue to dissipate, equal channel step die will be applicable, where the shear deformation are and large-borders will be formed as a result of conditions for continuation of the plastic deformation at large strains creates.

Results of mechanical studies are presented in Tab. 1. The strength characteristics of aluminum represented by the values of tensile yield σ_T and yield strength $\sigma_в$; plastic characteristics represented by values of percentage reduction and elongation of samples before destruction.

Table 1 *- Results of mechanical testing of wire samples*

Designation processing technology	Yield strength $\sigma_в$, MPa	Tensile yield σ_T, MPa	Percentage of elongation δ_5, %	Percentage reduction ψ_5, %
Annealing	115	120	18,0	60,0
Classic drawing	203	198	15,5	44,0
ECAP-D Technology	316	312	16,0	49,0

The greatest change in the yield strength and tensile strength values (as changes in the microhardness) during the pressing-drawing occurs after the first pass. At subsequent passes, this increase occurs more uniformly. The values of tensile strength and yield increase for three passes from 115 to 316 MPa (absolute increase is 201 MPa) and from 120 to 312 MPa (absolute increase is 192 MPa), respectively.

As is known, the characteristic that most fully reflects the ability of the material to plastic deformation is a percentage reduction in the area of neck. Percentage reduction in the aluminum is changed from 60 to 49%.

From the analysis of carried out mechanical tests of samples by different technologies, we can conclude that the best mechanical characteristics there has a treated wire by the combined technology of "pressing-drawing". An increase in the yield strength and tensile strength values are observed and also index of the hardness, with the preservation of plasticity.

3. Conclusion

Based on this research we can conclude that the proposed combined method of deformation "pressing-drawing" has a significant advantage compared to previously known methods of producing a metal with subultrafine structure, because this method of deformation due to the combining two ways: severe plastic deformation in the equal channel step die and drawing process through a drawing die, allows to obtain the workpieces (aluminum wire) of required dimensions and shape cross section, having subultrafine structure at insignificant number of cycles and also removes restrictions on the length of the initial workpiece, and hence allows to obtain finished products length of up to several tens of meters.

Also would like to note that this method of deformation when introducing it into production does not require significant economic investment and can be implemented in industrial enterprises of the country for the production of wire so that it does not require retrofitting of existing drawing mills. Because for implementation of this combined process only the addition requires in construction equipment, equal channel step die, intended for drawing through it the material.

4. Literature

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