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Analysis of the influence of new combined process "Equal channel angular pressing-drawing" on the microstructure and properties of copper wire

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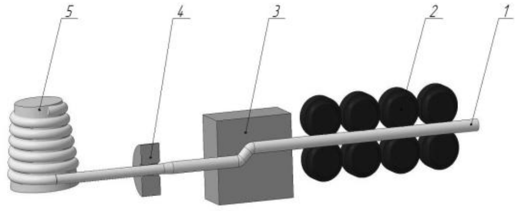
***Abstract* — This article is devoted of analysis of the influence of new combined process "Equal channel angular pressing-drawing" on the microstructure and properties of copper wire. In the result of investigation were obtained figures of microstructure of deformed copper wire after third cycle of deformation and graphs of mechanical properties. It is shown that proposed combined method of deformation of "pressing-drawing" has a significant advantage compared with the existing technology of production of copper wire.**

***Index Terms*—pressing-drawing, combined process, structure, mechanical properties, copper wire.**

I. INTRODUCTION

The modern level of development of electronic technology has led to the emergence of devices, often with moving parts and/or working in difficult conditions. Therefore, overseas recently increased interest in the problems of the formation of the physic-mechanical properties of the functional conductive materials in connection with the stabilization properties of conductors current and improved reliability, especially in heavily loaded cable systems, the windings of motors and generators and low voltage networks of computers. This necessitates the use of conductive materials with high strength, for example, in the form of wires, tires and foils. The most common material used pure copper, which has a relatively low strength. The advantages of copper as a conductor material are: low resistivity, resistance to corrosion, good machinability, easy welding and brazing. Copper rolled into sheets, strip and drawn into wire, the thickness of which can be reduced till micron. However, cables and wires made of copper is a significant proportion of the total weight of the electrical devices. So many foreign firms and domestic researchers pay great attention to finding and developing methods aimed at its strengthening, as this will reduce the diameter of the used wires. The area of application of hardened copper wires as the conductive and load-bearing elements of the suspension of the contact network of electrified roads, telephone wires, special cables, air and seismographic cables, radio components and electronic components. To increase the strength of wires made from copper alloys while retaining the electrical conductivity opens the possibility of their application in modern power transmission lines, contact lines for high-speed railways. This determines the larger perspective of the market of developing materials and a significant effect of their application. To increase durability is possible by using doping, but as you know, all the impurities lower the conductivity of copper. To achieve the enhancement of the mechanical properties of copper preserved when the conductivity value is possible by obtaining a fine-grained structure of these alloys. One of the possible ways of getting crushed patterns is to use a large plastic deformation. The traditional technology of deformation, such as drawing and cold rolling are also accompanied by the refinement of the structure. However, in general, the substructure is cellular with grains elongated in the direction of drawing or rolling, also containing a high proportion of low-angle boundaries. On the other hand, the material obtained by SPD contains a granular structure, with relatively small grains, with high angles of their disorientation. This fact also has a positive effect on the dynamic recrystallization, and thus on the thermal stability. Moreover, often SPD takes place at low temperatures (environment), which makes it more attractive. But now, none of the SPD methods does not allow obtaining products, acceptable in form and dimensions, for practical design. First of all this concerns the structuring of the metal in long products, such as rod and wire. In accordance of this, the scientists of "Metal Forming" Department of Karaganda state industrial university have developed a new combined process of deformation "Equal channel angular pressing-drawing" (ECAP-D) using the equal channel step matrix and calibrating tool (Fig. 1) to avoid out-of-roundness of the finished wire [1].



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 extrusion-drawing

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The essence of the proposed method of deformation is as follows: wire 1 is set in the pushing device 2, which provides pushing of wire into the equal channel step matrix and then in calibrating drawing tool. Essentially the process of pushing of metal does not differ from the standard process of drawing. After that the end of the workpiece will be exit from the portage it is fixed with the aid of exciting mites and wound on the drum of drawing mill. Earlier in works [2]-[5] have already been done studies of the effect of the new scheme of deformation on the quality of steel and aluminum wire. The purpose of this work, which was carried out in the framework of the state budget theme "Research and development of a combined process of deformation “pressing - drawing" with the aim of obtaining aluminum and copper wire with high mechanical properties and ultrafine-grained structure" for the program "Grant financing of scientific research for 2012-2014", is investigation of the effect of the new method of deformation on the possibility of obtaining a copper wire of the desired size and shape of the cross-sectional profile with an increased range of mechanical properties.

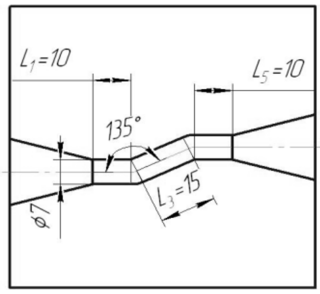
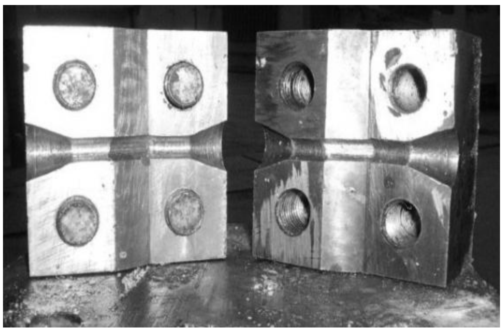


Fig. 2 - Equal-channel step matrix


Fig. 3 - The location of matrix in the drawing mill

II. LABORATORY EXPERIMENT

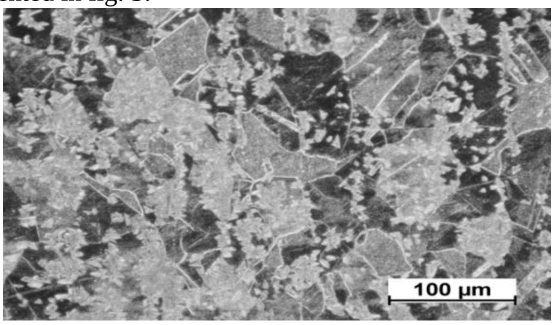
To determine the impact of the new continuous method of deformation “pressing-drawing” on the mechanical properties of copper wire was conducted a laboratory experiment in industrial drawing mill B- I/550 M. Pre-sharpened end of the wire is set in equal-channel step matrix, and then successively in the sizing die installed in draw die holder and is filling her grip pliers, a hook was put into one of the slots on the drum. After dialing in the drum 5-7 turns of wire, the mill was stopped. In this case, the process of pulling the workpiece through equal channel step die and sizing die is implemented through application by the end of workpiece pulling force. An external load is applied to stretch the metal, and the contact surface metal - tool contact stresses occur. In this case, after each pass was made measuring the wire diameter and were produced samples to study the mechanical properties of each of the samples. For the implementation of the first cycle of deformation before drawing tool with a working diameter of 6.5 mm was installed equal-channel step matrix from the channel diameter of 7 mm and the angle of junction of the channel in matrix is 135º (Fig. 2). The matrix was placed in a container for lubricant (Fig. 3). The shavings of soap were used as lubricant.



After pressing-drawing the wire diameter was 6.5 mm. All compression was carried out only in drawing tool, after the output of workpiece from equal-channel step matrix wire diameter remained unchanged and was 7.0 mm Experiment was duplicated three times. After the first cycle of deformation for further research changed as drawing tool as equal-channel step matrix. So when the implementation of the second cycle of deformation of the working diameter in the drawing tool was 6.0 mm, and the diameter of the channels in matrix was 6.5 mm; in the implementation of the third cycle - 5.5 mm and 6.0 mm respectively. To identify the advantages of the proposed technology compared to the existing wire production technology was conducted simple drawing of aluminum wire in the drawing tools with diameters 6.5; 6,0; 5,5 mm. Experiment was duplicated three times. After each stage was measuring the diameter of wire and cut templates for the manufacture of thin sections in transverse and longitudinal direction. In conventional drawing also was used a shaving soap as a lubricant. Preparation of thin sections for metallographic studies were carried out according to standard methods, we used an optical microscope Leica.

III. RESULTS AND DISCUSSION

The result of the study of the microstructure of the copper wire before and after the third cycle of deformation is presented in fig. 3.



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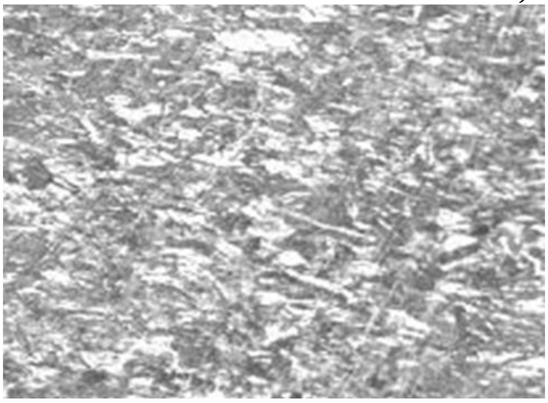

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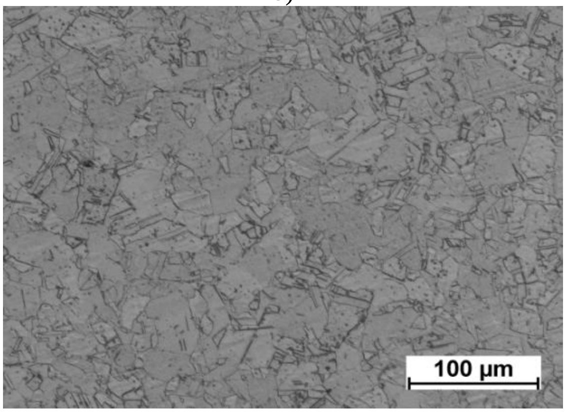

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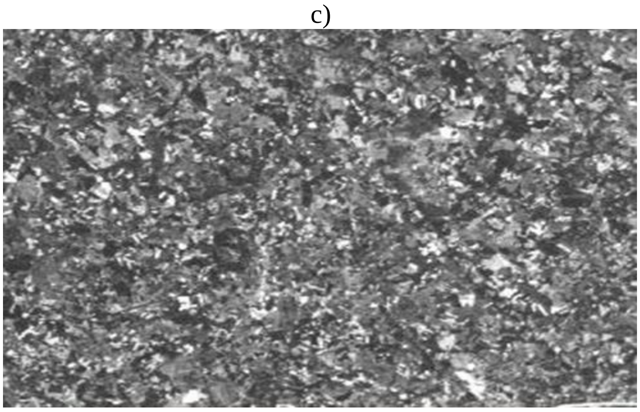

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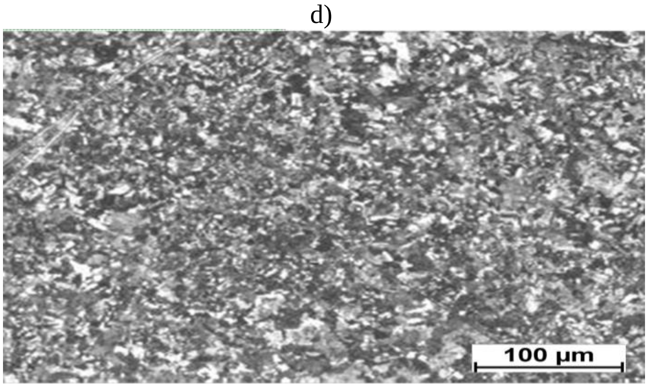

e)

a - initial structure, 56 μm; b – drawing, longitudinal direction;
c – drawing, transverse direction 24 μm;
d - "pressing-drawing", longitudinal direction;
e - "pressing-drawing", transverse direction 7 μm.

Fig. 3 - Structure of copper wire, ×100

Microstructural studies showed that in the initial state, the copper has a coarse structure with a large presence of twins (fig. 3a). Already after the first cycle of the lug structure of copper much ground compared to the original. Cross-sectional microstructure is rather homogeneous and dominated by approximately equal-axial grains. However, structure has some segregation banding in the radial direction, especially in longitudinal section of the workpiece, which leads to an inadequate level of plastic properties of the finished wire, and this in turn may adversely affect the operational parameters of the finished product. Even as a result of significant reductions obtained by the wire during drawing, not all of grains were ground and deployed in the direction of the axis of deformation due to uneven distribution of deformation. As well-known, to achieve ultrafine structure during the normal drawing only due to increasing the total degree of deformation cannot be, as this technological process is characterized by the scheme of the principal strains, the tensile stresses occurring during the deformation contribute the metal embrittlement during the drawing, and the maximum value $\sigma_1 \leq \sigma_T$ limits the degree of deformation per pass [6]. When applying a equal channel step die the full compressive stresses are generated in it at all stages of deformation, thereby reducing the tensile stresses and allows to increase the degree of deformation per a pass, and with that the strength characteristics. Our proposed combined technology "pressing-drawing" eliminates the disadvantages of the normal drawing process and to obtain a wire with ultrafine structure for a small number of cycles of deformation due to the use of the technological cycle of production of wire equal channel step die. During implementation of this deformation scheme the equal channel step die will be the principal tool for the deformation, i.e. to give the necessary microstructure and mechanical properties of wire. The draw die at the output of the equal channel step die is used more like a supporting role – the role of the sizing tool, i.e. it avoids the out-of-roundness of the finished wire, as well as implementation of a combined scheme of the deformation "pressing - drawing" the effect is achieved by the above given. The first, the metal deformation in the is equal channel step die occurs during the intense deformation scheme – the full non-uniform compression, which is achieved by harmonizing the objectives of the wire channels in the die channels and pushing it through the pushing device 2 (Fig. 1), with the process of pulling the wire through the die channels and draw die implemented by the winding drum 5 (Fig. 1). The second, when coming the wire through the equal channel step die on its joints of the metal channels are realized the shear deformation which promoting the formation of large-angle boundaries so that in this case the energy supplied to the sample material does not accumulate predominantly in the form of elastic distortion, and continues to dissipate. As a result of all this metal in its turn creates the conditions to obtain metal with sub-ultrafine-grained structure for a small number of cycles. As we can see from fig. 3b the pure copper structure refinement has essentially been occurred for the three passes comparing with the customary drawing and not only on the surface but also in the center of the wire. The

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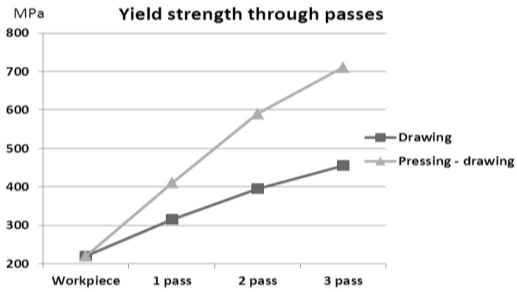
proposed technology after the first cycle of deformation decreases cross-boundary distances in the longitudinal and transverse cross sections. The decrease in cross-border distance due to geometric deformation, i.e. the compression of the original grains. The formation of new boundaries when drawing practically does not occur, all slicing structure occurs in the equal-channel step matrix under shear deformation by twinning. In accordance with of Hall-Petch rule drawing on the first passages leads only to increase the strength characteristics of copper by reducing the distance between the boundaries in the longitudinal and transverse cross sections. It was also found that the second cycle of pressing-drawing leads to the formation of patterns of mixed type. In the study of the obtained patterns were detected grains are of two types: small recrystallized and deformed. This structure is caused by the occurrence of two processes: recrystallization during wire drawing and fragmentation in equal-channel step matrix. The presence in the structure of two types of grains provides high strength and ductility. After the third cycle in the structure there is a significant increase in the share of large angle boundaries (~ 59%) due to a more active course of dynamic return and recrystallization. This is because with decreasing grain decreases the temperature at which recrystallization of copper. The grain boundaries become more distinct. Also with increasing number of passes, the trend is towards reducing the number of duplicates associated with a decrease in grain size of copper, which corresponds to an equation of Hall-Petch for the case of deformation twinning, which should be expected difficulties manifestations of twinning with decreasing grain size. In addition to studying changes in grain size during deformation under the current and proposed technology, we have investigated the mechanical properties of the copper wire after each cycle of deformation under the current and proposed technology of deformation; graphs are presented in fig. 4.



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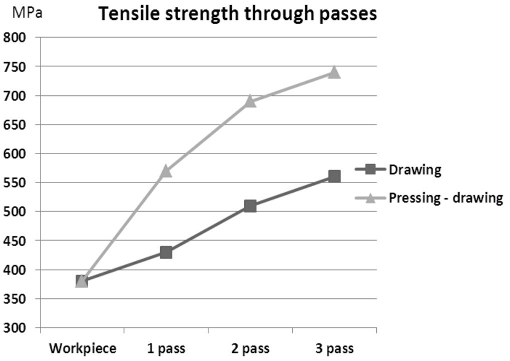

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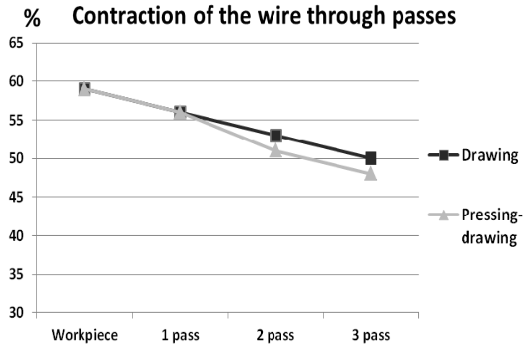

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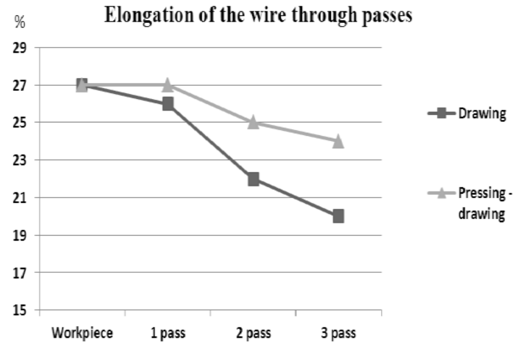

d)

Fig. 4 - Graphs of depending mechanical properties of the copper samples from number of passes

Analysis of the graphs showed that both methods increase the strength characteristics with increasing number of passes, plastic characteristics are reducing, but in the proposed method elongation after the third passage above 36% than at traditional drawing. Measurement of the tensile strength showed that the combination of the method of pressing-drawing provides a significant increase in the level of strength as compared with the original condition and 20% higher than the strength of traditional drawing after the third passage. From the graph shown in fig. 4 it is seen that the tensile strength of copper wire deformed to the combined process of "pressing-drawing" after the third passage is increased to 180 MPa compared with the wire after classical drawing. And the yield strength of the wire, after the third pass using the combined process increased by 255 MPa, compared with the wire after classical drawing. As known from the ratio of the Hall-Petch, the grain size of polycrystalline metals has a great influence on the value of the yield strength and mechanical properties of the material. A crucial role in high-strength ultrafine-grained alloy plays an additional hardening due to the high density of dislocations along grain boundaries. Based on this, we can conclude that the values of the mechanical characteristics of the wire, deformed of new technology of pressing-drawing" is higher than the wire obtained by a traditional drawing with the highest strength characteristics of conventional lug achievable by new technologies pressing-drawing in fewer passes, which creates the preconditions for reducing the intensity of use of the working tool, and, therefore, less its depreciation, and cost of energy and material resources.

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IV. CONCLUSIONS

On the basis of the conducted research it can be concluded that the proposed combined method of deformation of “pressing-drawing” has a significant advantage compared with the existing technology of production of copper wire. This method of deformation by combining two methods: intensive plastic deformation in equal-channel step matrix and the process of drawing through calibrating drawing tool, allows to obtain a copper wire with ultrafine-grained structure, the required dimensions and cross-sectional shape with an insignificant number of cycles of deformation. Just want to note that this method of deformation when implementing it in production does not require significant economic investment and significant retrofit existing drawing mills. As for the implementation of this combined process requires only the addition in the design of the equipment is specially manufactured equal-channel step matrix.

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