# DEVELOPMENT AND RESEARCH OF COMBINED PROCESS OF "EQUAL CHANNEL ANGULAR PRESSING – DRAWING"

Sergey Lezhnev[1], Abdrakhman Naizabekov[1],
Andrey Volokitin[2], Irina Volokitina[2], Evgeniy Panin[3], Marcin Knapinski[4]

[1] Rudny Industrial Institute, 50 let Oktyabrya 38, Rudny, Kazakhstan
[2] Kazakh National Research Technical University n. a. K. Satpaev, Satpaev Street 22a, Almaty, Kazakhstan
E-mail: Sergey_legnev@mail.ru
[3] Karaganda State Industrial University, Republic avenue 30, Temirtau, Kazakhstan
[4] Czestochowa University of Technology, Czestochowa, Poland

Received 07 July 2016
Accepted 12 December 2016

## ABSTRACT

*The aim of this work is development and research of combined process of "equal channel angular pressing – drawing". The influence of this combined process on the microstructure and mechanical properties of aluminum wire was studied. The 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 aluminum 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 aluminum 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. It should be also noted that this method of deformation in implementing it in production does not require significant economic investments and substantial refitting of the existing drawing mills.*

*Keywords: pressing-drawing, combined process, aluminum wire.*

## INTRODUCTION

In the shortage of energy and raw materials there is an actual problem of energy saving technologies. The problem of resource-saving methods of obtaining materials with properties combining high strength and ductility, in terms of using relatively simple and inexpensive devices, allowing to spend the least possible amount of time when processing of the products is very important. Some results of application of methods of severe plastic deformation (SPD) in mechanical engineering, medical industries, which allowed to reduce expenses for energy resources by 20 - 30 % are already known.

Traditional techniques of deformation, such as drawing and cold rolling, is also accompanied by refinement of the structure. However, the substructure has a porous nature 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 produced by SPD contains a granular structure with relatively small grains with high angles of disorientation. This fact also has a positive effect on the dynamics of recrystallization, and thus on the thermal stability. Moreover, SPD is often held at low temperatures (environment), which makes it more attractive.

The most successful SPD method at present is the equal channel angular pressing/extrusion (ECAP/ECAE). This process has huge potential for production of UFG metal with homogeneous equiaxed structure with grain boundaries, which is dominated by high-angle disorientation. In this method, the workpiece retains the original dimensions. It is also important to note that to obtain a given structure, it is necessary to choose certain routes between passes. However, the disadvantage of the process lies in its discreteness, i.e. the impossibility of machining a relatively large length due to buckling, influence of the punch. Therefore, it is possible to eliminate this drawback and to carry out the process continuously.

Previously in works [1 - 4] has already considered the problem of continuity of the process of obtaining ultrafine-grained materials, including the manufacture of wire. So with the goal of producing high-quality wire of iron and non-ferrous metals and alloys with high mechanical and operational properties at the "Metal forming" department of Karaganda State Industrial University as a part of the implementation of joint scientific research with Ural Federal University named after First President of Russia B.N. Yeltsin (project manager from KSIU – D.Sc. professor Naizabekov A.B., project manager from URFU – D.Sc. professor Bogatov A.A.) developed a new method of metal forming - combined process "pressing – drawing", realizing intensive plastic deformation in the whole volume of the deformable workpiece [4].

But this process has several disadvantages, one of which is that when pulling wire through equal channel step matrix, due to the incomplete filling of the channel matrix, there is ovality that allows to control and observe the accuracy of the geometric dimensions of the cross section. Therefore, in future we proposed to improve this method of deformation. The improvement is to add in the earlier proposed technological scheme of deformation "pressing - drawing" of another technological process - the drawing of wire through a conventional sizing die (Fig. 1).

The essence of the proposed method of deformation is that pre-sharpened end of the wire is set in equal-channel step matrix, and then successively in a drawing die. Essentially the process of problem metal is not different from the task of wire in die standard drawing process. After the end of the workpiece is released from the dies, it is fastened with thrilling mites and is wound on drum of wire drawing mill. In this case, the process of pulling the workpiece through the equal channel step die and sizing die is implemented through application by the end of workpiece pulling force. Unlike other methods of materials processing pressure, the implementation of which can not be done without the presence of contact friction forces when pulling on the section of the metal tool against the movement of the metal are negative phenomena of the process, which involves the use of technological lubricants for reducing friction.

To assess the possibility of implementation of the

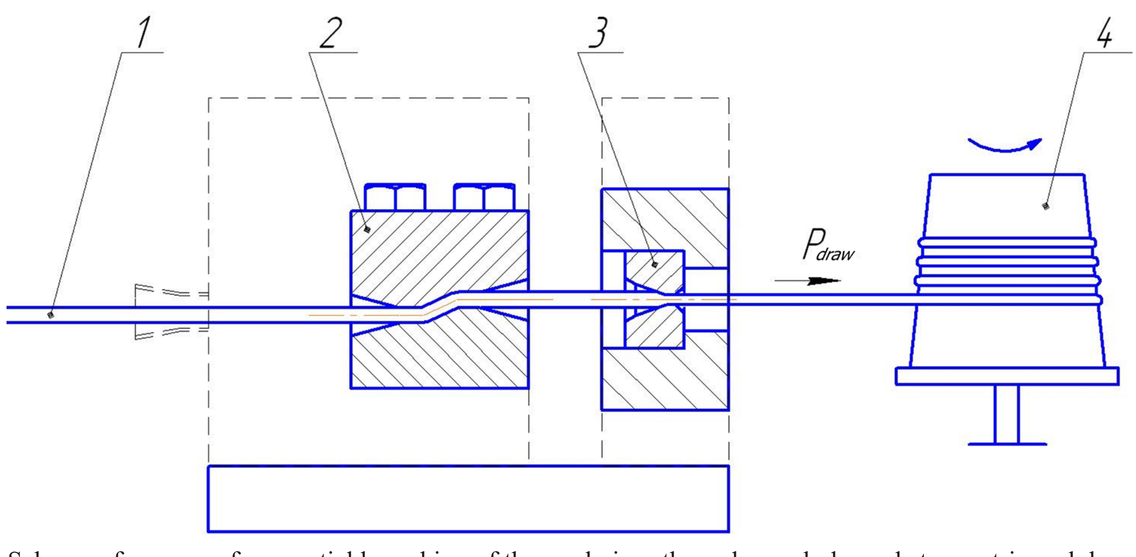


Fig. 1. Scheme of process of sequential broaching of the workpiece through equal-channel step matrix and drawing die: 1 - original billet, 2 - equal-channel angular step matrix, 3 - drawing die, 4 - drum of drawing mill.

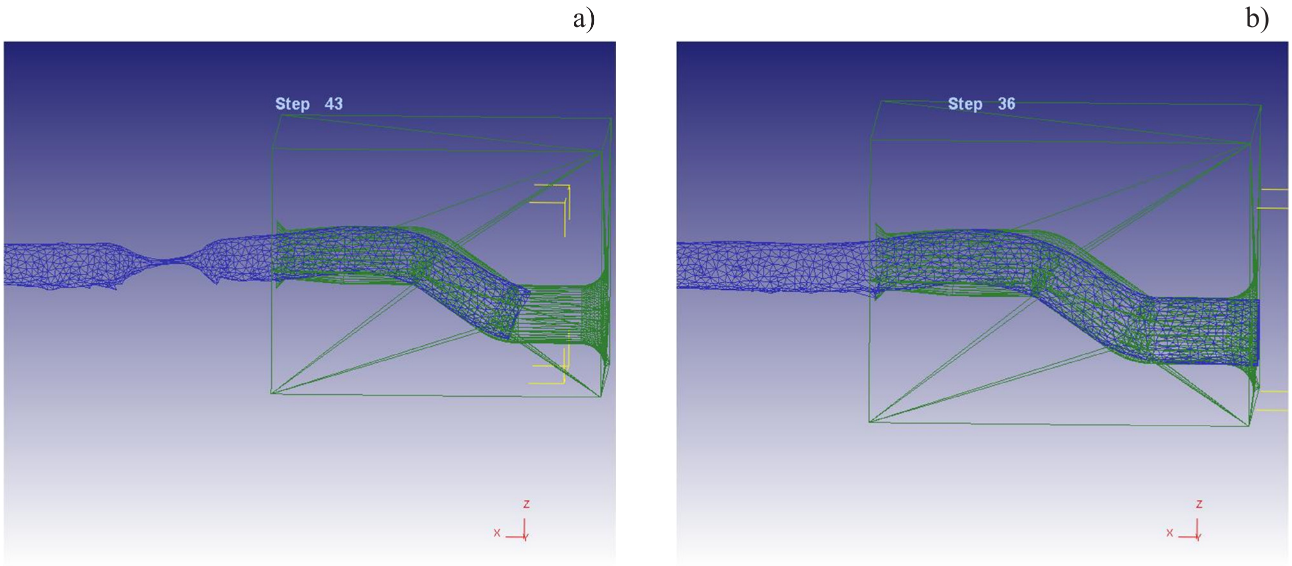


Fig. 2. Simulation of process.

proposed combined process «equal channel angular pressing-drawing», the process was simulated in the software complex DEFORM 3D. The input data for modeling: wire rod material - aluminum; initial rod diameter $d_0$ = 7 mm; final wire diameter d = 6 mm; the diameter of the channel equal channel step matrix $d_m$ = 7 mm; the angle of intersection and horizontal connecting channels θ = 135º; offset value of channels K = $d_m$ = 7 mm; diameter of the drawing die $d_d$ = 6 mm; drawing rate V = 94 m/min.

The simulation results showed that due to large values of drawing pressure arising in the transverse direction stretch the wire at its exit from the drawing die, wire thinning, and in some cases - interruption (when the stress drawing more of the yield point stretch material) (Fig. 2a); in addition, when pulling wire through equal channel step die and a matrix, as observed incomplete filling of the channel matrix, and accordingly the process of ovality (Fig. 2b), although significantly less than when using previously known technology.

For removing of identified disadvantages in modeling of this process we proposed to apply pushing effort to the rear end of the sample asked along with the effort of drawing. The deformation process on the proposed scheme is presented in Fig. 3.

To assess the possibility of realization of the combined process of "pressing-drawing" using equal channel step matrix, drawing dies and using pushes efforts, it has also been simulated in the software complex DEFORM with the same initial data.

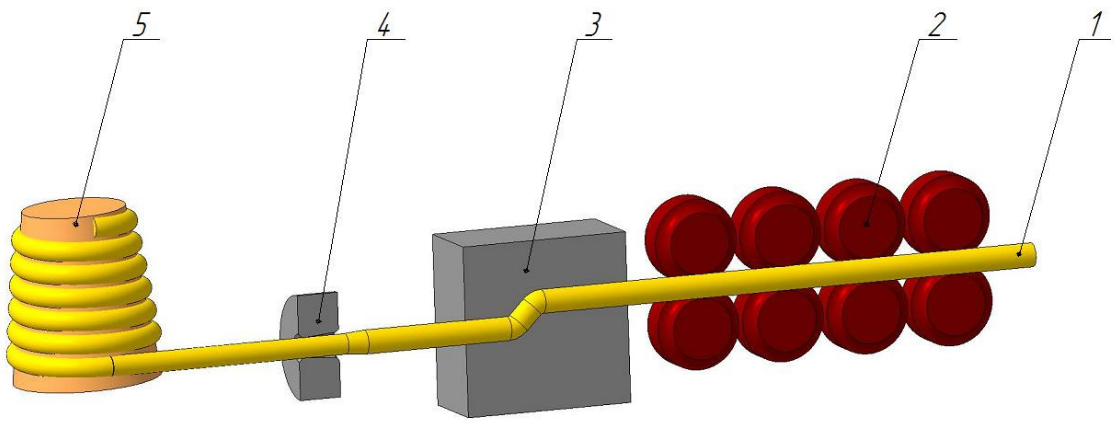


Fig. 3. Scheme of the combined process of pressing-drawing: 1 – wire, 2 - setting device, 3 - equal channel step die, 4 - draw plate in die holder, 5 - winding reel.

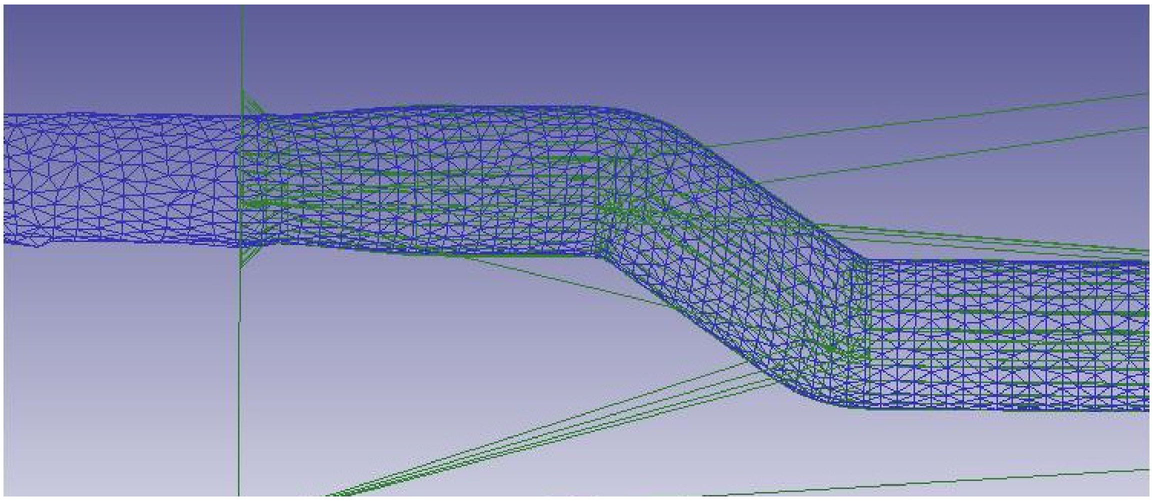

Fig. 4. Simulation results of combined process “pressing - drawing” with backpressure.

The peculiarity of this variant of the combined process of “pressing-drawing” process is the need to match the speeds of the pushing and pulling of the sample. For this purpose, to carry out the process sustainably must comply with the condition:

$$\frac{V_1}{V_0} = \mu \quad (1)$$

where $V_0$ and $V_1$ are the speed of pushing and the rate of extrusion of the workpiece;
μ - elongation coefficient.

It is shown from the eq. (1) that the rate of extrusion must be greater than the speed of pushing for the value equal to the elongation coefficient.

The elongation coefficient in the implementation of the combined process of "pressing-drawing" over the source data is:

$$\mu = \frac{F_1}{F_0} = \frac{38,46}{28,26} = 1,36 \quad (2)$$

where $F_0$ and $F_1$ are the area of the cross sections of the workpiece before and after drawing.

Therefore, during the simulation it was set to the following speeds: drawing speed V = 94 m/min; pushing speed $V_p$ = 69 m/min. The drawing speed was adopted taking into account the technical characteristics of the drawing mill B – I/550 M. The drawing speed is determined from the condition (1).

$$\frac{V_1}{V_0} = \frac{94}{69} = 1,36$$ i.e. condition is fulfilled.

The analysis of simulation results showed that when used pushing effort in the implementation of combined process «rolling-pressing», it is possible to achieve the stability of the flow of the process. Also as a result of back prop it is possible to achieve complete filling of the channel matrix, to improve the treatment of metal in the cross section (Fig. 4) and to eliminate breakage of the wire at the exit from the matrix.

After receiving the successful model we have taken the decision on carrying out of laboratory researches on the influence of a new continuous method of deformation «equal channel angular pressing-drawing» on the evolution of microstructure and mechanical properties of the finished wire.

To determine the effects of the new combined method of deformation «pressing-drawing» on the changes in the microstructure and mechanical properties of aluminum wire a laboratory experiment was carried out at an industrial drawing machine B-I/550 M. The source material was an aluminum rod with a diameter of 7 mm. For the first cycle of deformation before the draw plate with working diameter of 6.5 mm equal channel step die with channel diameter is 7 mm and the angle of the junction of channels equal to 135º was fixed (Fig. 5). The die was placed in a container for lubrication (Fig. 6). As lubricant shavings a soap was used.

After the process of pressing-drawing wire diameter was 6.5 mm. All crimping was carried out only in the draw plate after leaving of the workpiece from equal channel step die wire diameter was unchanged at 7.0 mm. The experiment was duplicated three times. Thus after each test the wire diameter and cutting of templates for making microsections in the transverse and longitu-

Fig. 5. Equal-channel step matrix.

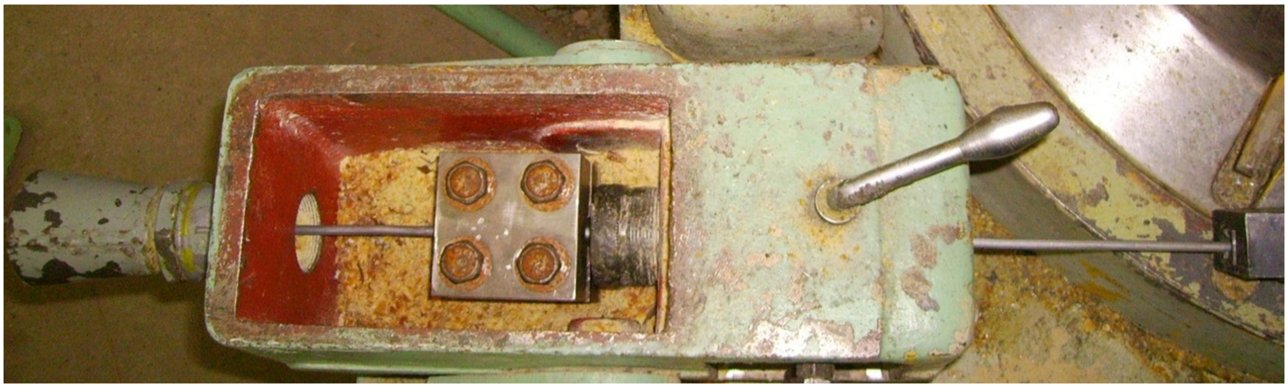

Fig. 6. The location of matrix in the drawing mill.

dinal direction were measured.

After the first cycle of deformation for further research the draw plate and equal channel step die were changed. Thus, when implementing the second deformation cycle, the working diameter in draw plate was 6.0 mm, and the diameter of channels of the equal channel step die was 6.5 mm, in the implementation of the third cycle they were 5.5 mm and 6.0 mm, respectively.

For identifying advantage of the proposed technology compared with the existing production technology of wire, ordinary drawing aluminum wire was carried out at drawing dies with working diameters of 6.5, 6.0 and 5.5 mm. The experiment was also duplicated three times, and after each test the diameter of wire was measured, cutting of templates for making microsections in the transverse and longitudinal direction was.

As a lubricant for ordinary wire drawing is used shaving soap.

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. 7.

After spending a metallographic analysis of deformed samples, we can conclude that the cold deformation at drawing on the current technology with a moderate and high total reduction (from 50 to 85 % - depending on the size of the cross section) produces a pronounced grain-oriented 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 the metallographic analysis of the samples, resulting in an 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

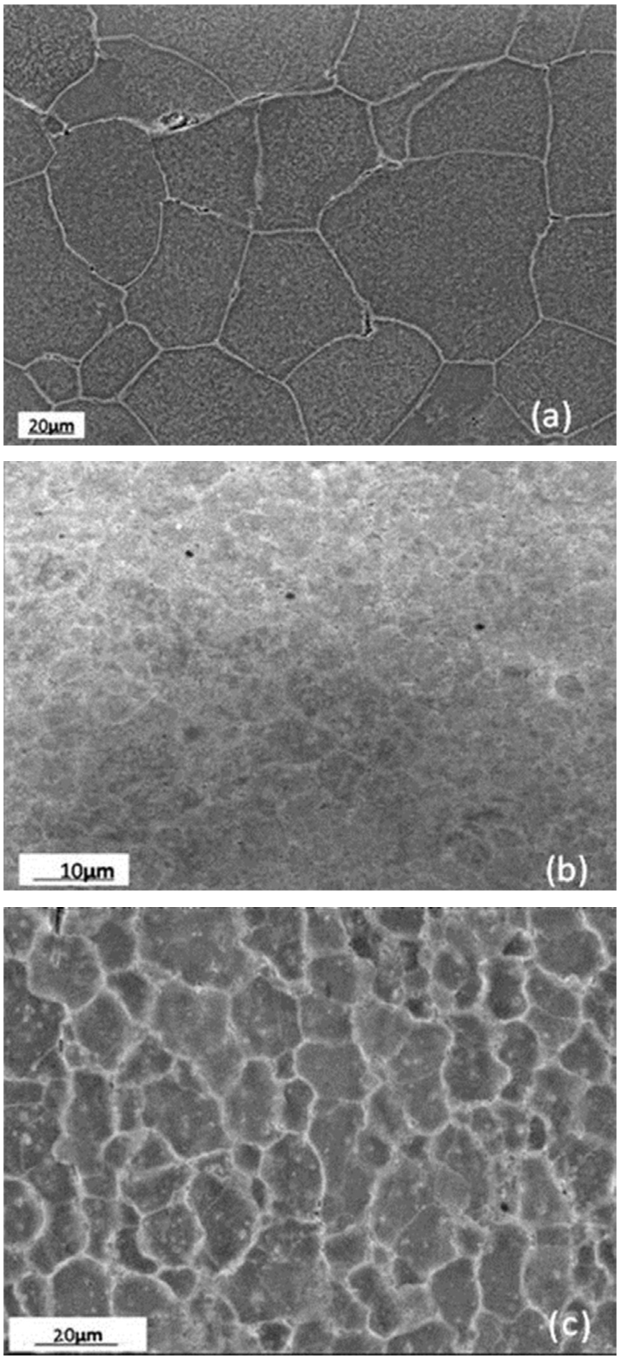


Fig. 7. Structure of aluminum wire: a - the initial structure, b - on the proposed technology "ECAP-D", the transverse direction, c - on the existing drawing technology, the transverse direction.

Fig. 7c it is shown that in this case deformation leads to insignificant 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.

To achieve ultra-fine grained structure only by a homogenous flow of dislocations is not possible: the accumulation of plastic deformation and growth of the dislocation density occurs disproportionately rapid increase in the stoppers and obstacles hindering their progress in crystal. The dislocation flow is gradually depleted, the level of internal stresses increases. This continues until a brittle fracture of the sample occurs. To avoid this, and the sample energy is not accumulated in the material mainly in the form of elastic distortion, we used equal channel step matrix, where shear deformation is realized and large-angle borders are produced, as a result, created conditions for continued plastic deformation at large strains.

The proposed combined technology of "pressing-drawing" eliminates the disadvantages of the drawing process, because the traditional drawing is characterized by heterotypic scheme principal strains. Tensile stresses contribute to the embrittlement of the metal during the drawing, and the maximum value $\sigma_1 \leq \sigma_T$ limits the degree of deformation per pass [5]. When using equal-channel step matrix creates fully compressive stresses in it at all stages of deformation, which reduces the tensile stresses and allows to increase the degree of deformation in one pass, and strength characteristics with it. As can be seen from Fig. 3b, after three passes there was a significant refinement of the structure of pure aluminium, compared with traditional drawing and not only on the surface, but in the center of the wire. Significantly to a lesser extent texture, and hence anisotropy, as, despite the high number of equivalent slip systems in FCC lattice the character of crystallographic textures formed as a result of line-drawing, depends on shear deformation taking place in the channel matrix after each passage, which can further fragment to the structure.

A study by transmission electron microscopy (TEM) showed that the grain in equal-axis, their size is in the range from 1 to 4 μm. In some cases, they are disoriented relative to each other at a small angle. However there are some grains surrounded by large-angle boundaries with a characteristic for the equilibrium state borders banded contrast. In the structure obtained by traditional drawing large-angle boundaries are not observed, as in the matrix deformation by shear, with the passage of the workpiece through the zone of channels intersection, resulting in the workpiece accumulates shear strain, leading to the formation of the material in large-angle boundaries.

Besides investigating the changes in grain size during deformation on current and proposed technology we investigated the mechanical properties of aluminum wire after each cycle of deformation on the existing and proposed technologies of deformation graphs are presented in Fig. 8. Chart analysis of Fig. 8 showed that in both methods there is an increase of the strength characteristics with increasing number of passes, plastic characteristics also fall, but the proposed method elongation after the third pass is higher by 36 % than traditional drawing. Measurement of tensile strength showed that the combination of the method of "pressing-drawing" provides a significant increase in the level of strength (123 MPa) compared with the initial state (66 MPa) and 20 % exceeds the strength of traditional drawing after the third pass.

As it is known from the Hall-Petch relation, the grain size of polycrystalline metals has a great influence on the value of the yield strength and mechanical properties of the material. Crucial role in high strength ultra-fine grained alloy plays an additional hardening due to the high density of dislocations along grain boundaries. On this basis, we can conclude that the values of the mechanical characteristics of aluminum wire, deformed by the new technology of "pressing-drawing" higher than the aluminum wire is made according to traditional drawing, the level of the strength characteristics of conventional drawing achievable by new technology pressing-drawing in fewer passes, which creates prerequisites for reducing the intensity of use of the working tool, and, consequently, less wear, and the cost of energy and material resources.

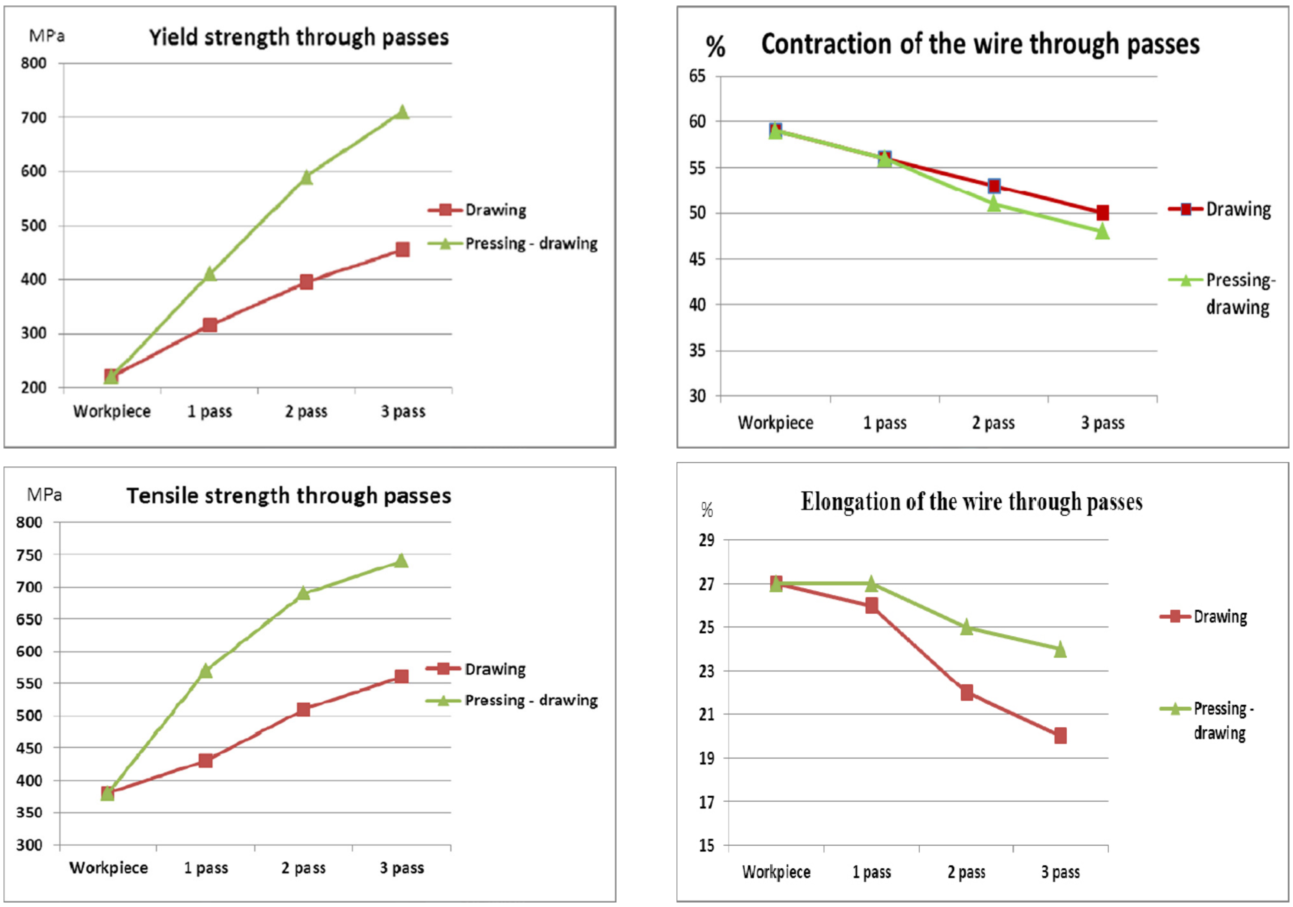


Fig. 8. The graphs of dependence of mechanical properties of the aluminum samples from the number of passes.

## CONCLUSIONS

As a result of simulation of the combined process "pressing-drawing" using equal channel step matrix in the software package DEFORM-3D it was able to achieve a sustainable process that allows to make a conclusion about possibility of implementation of this process in laboratory conditions, in relation to an existing equipment line of the drawing mill B- I/550M.

On the basis of the conducted research it can be concluded that the proposed combined method of deformation "pressing-drawing" has a significant advantage compared with the existing technology of production of aluminum wire. This method of deformation, by combining two methods: severe plastic deformation in equal channel step matrix and process of drawing using the drag allows to obtain aluminum wire with subultrafine grained structure, of required size and shape of the cross section at small number of cycles of deformation. It should be noted that this method of deformation when introduced into production does not require significant economic investments and significant modifications to existing drawing machines. As for the implementation of this combined process requires only the addition in the design of the equipment a specially manufactured equal-channel step matrix.

## REFERENCES


1. A.B. Naizabekov, S.N. Lezhnev, E.A. Panin, Izvestiya VUZ. Chernaya Metallurgiya, 6, 2008, 22-26, (in Russian).
2. A. Naizabekov, S. Lezhnev, E. Panin, I. Volokitina, Influence of Combined Process "Rolling-pressing" on Microstructure and Mechanical Properties of Copper, Procedia Engineering, 81, 2014, 1499-1504.
3. A. Naizabekov, S. Lezhnev, E. Panin, T. Koinov, Study of broadening in a combined process "rolling - pressing" using an equal-channel step die. J. Chem. Technol. Metall., 50, 3, 2015, 308-313.
4. A.B. Naizabekov, E.M. Azbanbaev, Technology of production of metals and recycled materials, 1, 2011, 178-186, (in Russian).
5. L.A. Krasilnikov, A.G. Lysenko, The wire drawer, 1987, (in Russian).