"Equal-channel angular pressing-drawing" technology

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Abstract: *This article describes the technology of the combined process "equal-channel angular pressing-drawing". The analysis of the influence of this process on the structure and mechanical properties of aluminum, copper and steel wires is given. The results of the study showed that the proposed combined deformation method "equal-channel angular pressing-drawing" has a significant advantage over the existing technology for the production of high-strength wire. This deformation method due to the combination of two deformations: severe plastic deformation in a matrix with parallel channels and the process of deformation through a drawing die, allows to get a wire with an ultra-fine structure and a high level of mechanical properties, the required size and shape of the cross section in a small number of deformation cycles.*

Keywords*: PRESSING-DRAWING, COMBINED PROCESS, WIRE, MICROSTRUCTURE*

1. Introduction

One of the urgent tasks of metallurgy and mechanical engineering is to improve the physical and mechanical properties of products and semi-finished products from metals and alloys. The solution of such problems lies in the creation of highly efficient technologies with the use of modern and advanced methods of metal processing. Therefore, studies aimed at solving the problems of obtaining long materials with properties that combine high strength and ductility at the same time, using relatively simple and inexpensive devices that allow to spend the minimum possible amount of time in the production of products are relevant.

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 [3-5].

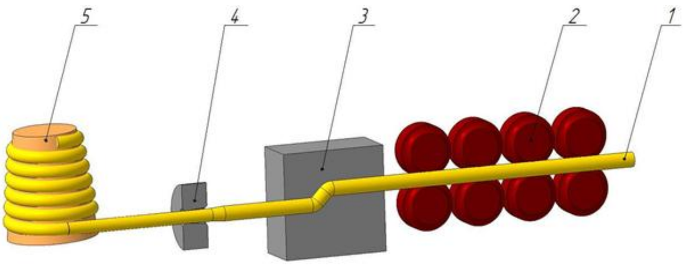
Nowadays, the mechanical properties of bulk nanostructured materials generate particular interest. It is known that they are characterized by an increase in the yield point by 2-5 times compared with the corresponding values on SPD at coarse-cristalline state [6-7]. The paradox of SPD, consisting in 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 [8-10].

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 [11-14].

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 [15]. 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.

2. Prerequisites and means for solving the problem

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 [16-20], a new combined "equal-channel angular pressing-drawing" (ECAP-D) process using an equal-channel step matrix (Fig. 1) was proposed.



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 ECAP-D*

3. Solution of the examined problem

The developed technology will make it possible to obtain in industrial conditions a long wire made of ferrous and non-ferrous metals and alloys with an ultra-fine-grained structure and an increased level of mechanical properties at lower energy and labor costs due to the implementation of the continuity principle [20-22].

To implement the combined "pressing-drawing" process, it is necessary to use additional equipment – an equal-channel step matrix made in accordance with the developed drawing of this matrix (Fig. 2).

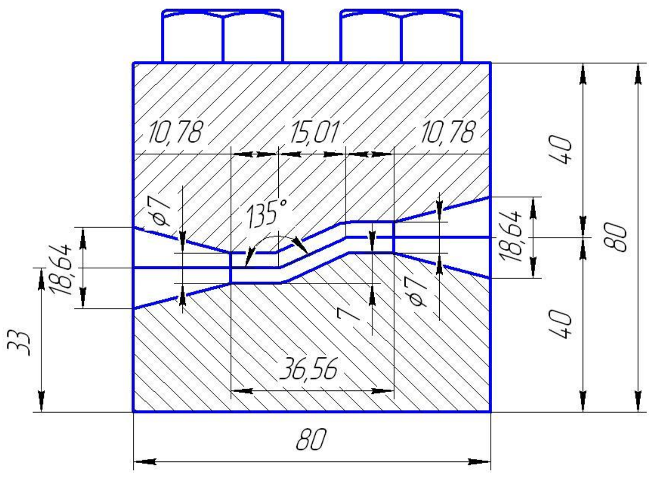


Fig. 2 *ECAP matrix drawing*

The matrix is recommended to be made of 5XB2C tool die steel. To increase the hardness and strength, the matrix must be subjected to heat treatment-hardening at a temperature that corresponds to the selected steel grade. The diameter of the channel is selected according to the diameter of the wire to be drawn. The channel lengths and the junction angle are selected in accordance with the drawing in figure 2, since the results of theoretical studies given in [20] show that the proposed channel junction angle and channel lengths provide the most favorable stress-strain state for obtaining an ultra-fine-grained structure and lower values of energy-power parameters.

To implement the combined ECAP-D process, an equal-channel step matrix must be placed in the lubrication container before the hauling. As lubricant in the implementation of the combined process of ECAP-D as a normal drawing, you need to use a shaving soap.

Since this paper has shown the need for multi-cycle deformation, the implementation of this combined process can be carried out according to the scheme proposed in this paper – to replace the matrix after each deformation cycle.

To successfully set the wire in an equal-channel step matrix and avoid breaking the original workpiece during the combined process of ECAP-D, it is necessary to use a setting (pushing) device. When implementing the process, you can use a converted cutting machine from the drawing mill (Fig. 3), in particular, to re-phase this machine, so that the rolls rotate in the direction we need and produce the capture of the wire and due to the active forces of friction, pushing it into an equal-channel step matrix. At the same time, for the successful implementation of the combined ECAP-D process, it is necessary to coordinate the speeds of pushing and pulling the wire.

Fig. 3 *Cutting machine*

The technology of wire production according to the proposed technology on the drawing mill is as follows: a cage of bunts of the workpiece prepared for drawing (etched, limed) up to 1000 kg is hung on the bunt holder with the help of shop vehicles.

From the bunt holder, the bunt is placed on one of the figures, and the lower end of the workpiece is pulled up to the sharpener for sharpening. On a cutting machine, the end of the workpiece is sharpened to the desired diameter by a length of 150 ... 180 mm. the Pointed end of the billet is fed into a pushing device, with which the billet is pushed through a multi-channel step matrix and a drag set in the fiber holder and is captured by filling tongs, the hook of which is inserted into one of the slots on the drum. The foot pedal pushes the mill to the refueling speed (the pushing device is also started at the same time). After a set of 5-7 turns of wire on the drum, the mill must be stopped. The filling pliers are removed, and the end of the wire is securely attached to one of the drum racks. Then the mill and the pushing device turn on the speed set by the technology and work until the drum is filled.

After filling the drum mill stop, give the drum a reverse in 2-3 turns, the wire between volontariamente and the drum is cut, and the finished coil grab crane is removed from the drum of the mill on the rack. The finished skein is dumped on the rack for tightening and tipping the riots, and the grab is installed back in the slots of the drum.

The mill is controlled from the control panel.

In the multi-cycle combined pressing-drawing process, it is recommended that the deformation mode shown in table 1 be changed after the first deformation cycle in the lubricant container to an equal-channel step matrix and a fiber carrier for drawing to a smaller diameter.

Table 1. Modes of deformation of the wire.

ECAP					**Drawing**								
№	D_0, mm	V_0, m/sec	F_0, mm^2	ε_{ln}	D_1, mm	D_2, mm	λ	V_2, m/sec	V_1, m/sec	ε, %	F_1, mm^2	F_2, mm^2	ε_{ln}
1 pass	7,0	1,29	38,465	0,6	7,0	6,5	1,16	1,5	1,29	13,78	38,465	33,166	0,12
2 pass	6,5	1,28	33,166	1,2	6,5	6,0	1,17	1,5	1,28	14,79	33,166	28,260	0,13
3 pass	5,5	1,26	23,746	1,8	6,0	5,5	1,19	1,5	1,26	15,97	28,260	23,746	0,14
4 pass	5,0	1,24	19,625	2,4	5,5	5,0	1,21	1,5	1,24	17,36	23,746	19,625	0,16
ε_{ln}(sum)				2,4				ε(sum), %		48,97	ε_{ln}(sum)		0,39
ε_{ln}(total) = 2,8													

4. *Results*

This technology of metal processing by pressure can be used for production of high-quality wire from any non-ferrous metals and alloys. This method of deformation when introduced into production does not require significant economic investment and can be implemented at industrial enterprises of the Republic of Kazakhstan for the production of wire, as it does not require re-equipment of existing drawing mills. Since the implementation of this combined process requires only the addition of a specially made equal-channel step matrix to the equipment design, designed for pulling material through it.

To study the effect of the "pressing-drawing" process on the structure and mechanical properties of the wire, laboratory experiments were conducted on copper, aluminum and steel wires.

The selected metals had completely different properties in their nature, which made them ideal model materials for studying the new technology. So the steel of the St.3 brand is a mechanical mixture with a melting point above 1000°C (BCC grid), aluminum of the A0 brand with a melting point of 660°C (HCC grid) and copper of the M1 brand with a melting point of 1083°C (HCC grid). In addition, these materials are characterized by different development of recrystallization processes. In steel, the recrystallization temperature is much higher than in other metals. Copper has a low recrystallization temperature due to the low energy of packaging defects, which facilitates the development of twinning, while aluminum, on the contrary, has a very high energy of packaging defects, which makes it difficult to recrystallize and polygonization develops in the deformed metal.

In the course of the study of the formation of UMP structure and mechanical properties in the wire obtained by the "pressing-drawing" method, the following was established:

– in the "pressing-drawing" process, the structure of all the materials under study is significantly crushed to ultra-fine-grained, so St. 3 steel with an average grain size of 12 microns after deformation was crushed 20 times, the average grain size was 0.6 microns; M1 copper with an average grain size of 50 microns after deformation was crushed 125 times, the average grain size was 0.4 microns; A0 aluminum with an average grain size of 17 microns after deformation was crushed 22 times, the average grain size was 0.8 microns [20-23];

- the combination of the rcup method with subsequent drawing allows for high strength characteristics of St.3 steel: the temporary tear resistance increases by 360 MPa, the conditional yield strength increases by 460 MPa. the relative contraction after the break decreases by 8 %; but the drop is not as significant as in classical drawing [20];

– the values of the temporary break resistance and the conditional yield strength for copper wire after 4 passes of ECAP-B increase from 260 to 570 MPa (absolute increase is 310 MPa) and from 190 to 490 MPa (absolute increase is 300 MPa), respectively [21];

– the strength of aluminum wire increases almost 3 times after 4 passes. The temporary break resistance and the conditional yield strength increase from 145 to 400 MPa (absolute increase is 255 MPa) and from 100 to 360 MPa (absolute increase is 260 MPa), respectively; the relative elongation decreases by 7%, the relative contraction by 5% [22-23].

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