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DEVELOPMENT AND RESEARCH OF COMBINED PROCESS OF EQUAL CHANNEL ANGULAR PRESSING - DRAWING

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ABSTRACT

This paper presents a review of the literature and patents about equal channel angular pressing. The formation of ultrafine grain structure and phase composition of steels and alloys under the influence of intensive alternating strain is represented. The device and technology of combined process of equal channel angular pressing - drawing together with the extrusion of billet in equal channel angular die are developed and tested. The results of computer simulation and experimental research of the workpiece forming and evolution of grain structure during repeated deformation in equal channel die are described.

Keywords: ECAP-drawing, combined process, simulation, experiment.

INTRODUCTION

The required performance characteristics of the metallurgical products can be provided by the formation of the ultrafine grain (UFG) structure of steel and alloys. Materials with UFG structure divided into nanocrystalline (NC) (d < 100 nm) and submicrocrystalline (SMC) (0,1 < d < 1 mm). Segal V. and Schukin V. developed a new way of plastic deformation by simple shear [1, 2], called as an ECAP process (Fig. 1). A feature of this method is the plastic elaboration of the metal structure without changing the shape and size of the workpiece.

It has been found that the proposed method of intensive shear deformation localized at the joint of the channels (ab) contributes to the favorable structure formation [3], namely to the formation of subgrains with large corner subboundaries disorientation and grain size reduction after recrystallization. Subgrain structure with large corner subboundaries disorientation and high mobility of subgrain boundaries is called polygonized, and the subgrains later serve as centers of recrystallization [4, 5]. Because of this feature the method of intensive plastic deformation offered by Segal V. got interest and development in the research works of many scientists in Russia and abroad. Fig. 2 shows the change of the shape of the structural element during equal channel angular pressing (a) and alternate torsion (b). During alternate torsion process cylindrical sample has the hard undeformed ends, one of which is mounted in a fixed capture, and the other is connected to a drive motor. Plastic deformation is carried out in a narrow localized area of Δx thickness.

When the particle pass through the shear plane the simple shear occurs which includes the pure shear and hard turn of the element in a counter-clockwise direction to a φ angle. Similarly, the shear deformation of the element is occurred during torsion (b). When pressing the workpiece the element on the *abcd* area moves along a path without distortion, and a pure shear is occurred at the *cd* velocity discontinuity plane together with a hard

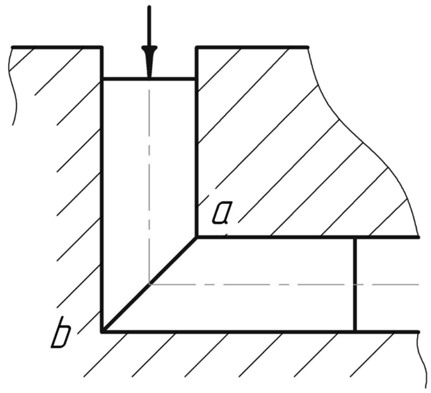


Fig. 1. Scheme of equal channel angular pressing.

turn in a clockwise direction, and the element acquires the original shape. The same thing occurs when the direction of torsion is changed, *abcd* element acquires the shape and size of the *abc'd'* element by pure shear and hard turn to an φ angle in the counter-clockwise direction on the first stage, the shape and dimensions of the element are restored on the second stage. This fact is important for the structure formation process understanding during intensive alternate plastic deformation.

In UFA academic center under the direction of Kaybyshev O. and Valiev R. the fundamental research of intensive plastic deformation method usage were made to develop production technology of submicrocrystalline and nanocrystalline materials with high mechanical properties and performance characteristics [6 - 15]. Thesis works aimed to the study and modernization of ECAP, performed at the National Research University of MISA, St. Petersburg Polytechnic University of Peter the Great, Magnitogorsk State Technical University named after Nosov G., Ural Federal University named after the first President of Russia Boris Yeltsin, and Institute of Metal Physics of Urals department of Russian Academy of Science. Some research works of foreign scientists should be mentioned [16 - 25]. In the performed patents of USA and England [16 - 19] the idea of Segal V. to carry out plastic deformation by simple shear is retained. The workpiece is deformed in the die without changing the shape and sizes. A distinctive feature of the proposed

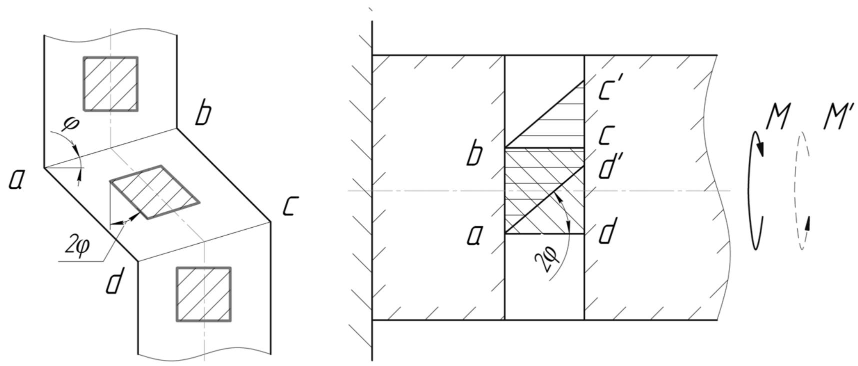


Fig. 2. Scheme of the alternate strain by simple shear:
a - equal channel angular pressing; b - alternate torsion of cylindrical sample.

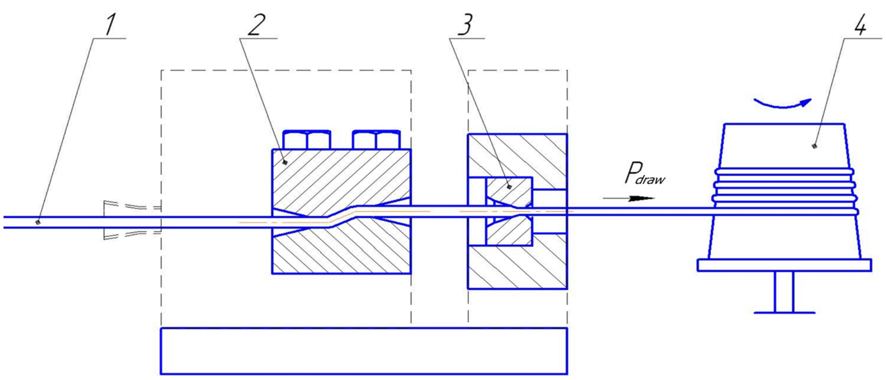


Fig. 3. Scheme of the combined process of extrusion-drawing:
1 - wire; 2 - equal channel step matrix; 3 - drawing tool; 4 - winding drum.

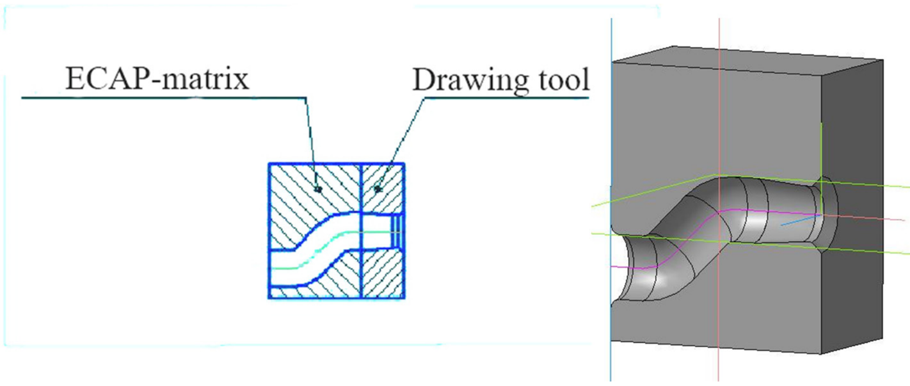


Fig. 4. Combined matrix.

technical solutions is to design the workpiece feeding device. Pressing force application is fulfilled by the active friction stresses on the contact surface of the master device and the workpiece before the forming die.

In the work [26] a lot of attention is paid to the size management of the local deformation zone and the amplitude of the alternate intensive strain by changing the friction stresses in a forming die, as well as the problem of the product destruction during repeated pressing without an intermediate heat treatment.

Methods and equipment for the intensive plastic deformation have been developed in the Karaganda Industrial University for the performance of the national program in the field of nanotechnology in the Republic of Kazakhstan [27 - 37]. Particular attention in these research works is paid to the creation of continuous processes with equal channel angular pressing (ECAP), the study the influence of the metal alternate intensive deformation on the structure, properties and strength parameters of the process. One of such technology is combined process of "equal channel angular pressing – drawing"[1*] (Fig. 3) [38 - 40].

During the implementation of this combined process on a sloping channel of equal channel step matrix there is an intensive alternating deformation. The essence of the proposed method of deformation is as follows. Pre-sharpened end of the wire is set in equal-channel step matrix, and then successively in a calibrating die. Essentially the process of metal moving is not different from the task of wire in die standard drawing process. After the end of the workpiece will be 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 equal channel step die and sizing die is implemented through application by the end of workpiece pulling force.

For the purpose of determining the possibility of combined process «pressing – drawing» in practice, this process was simulated in the software complex Deform-3D. For this was simulated combined matrix, including equal-channel step matrix and drawing tool (Fig. 4).

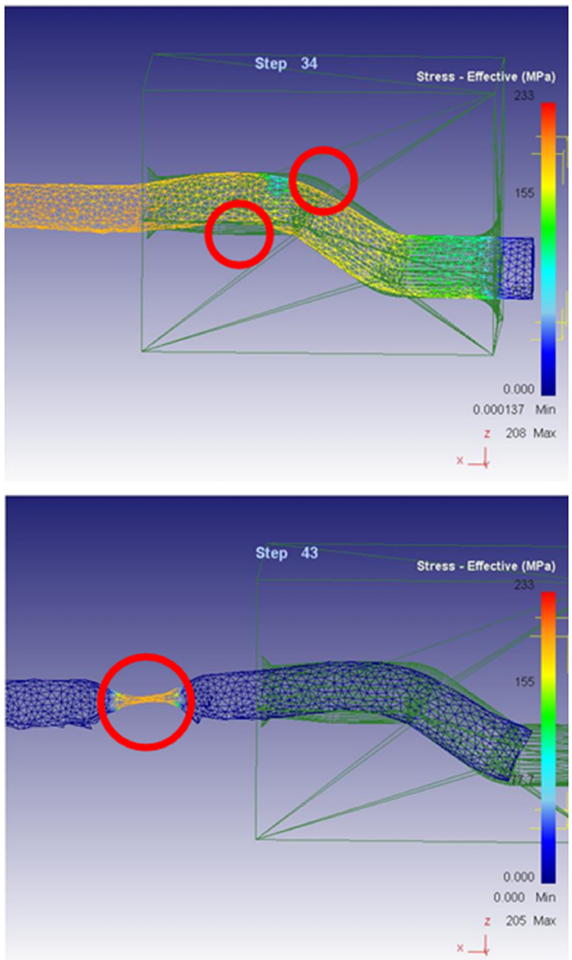
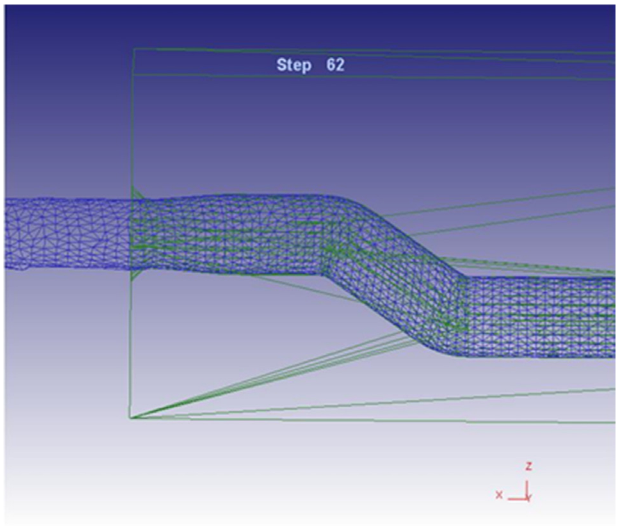


Fig. 5. The simulation process in combined matrix.



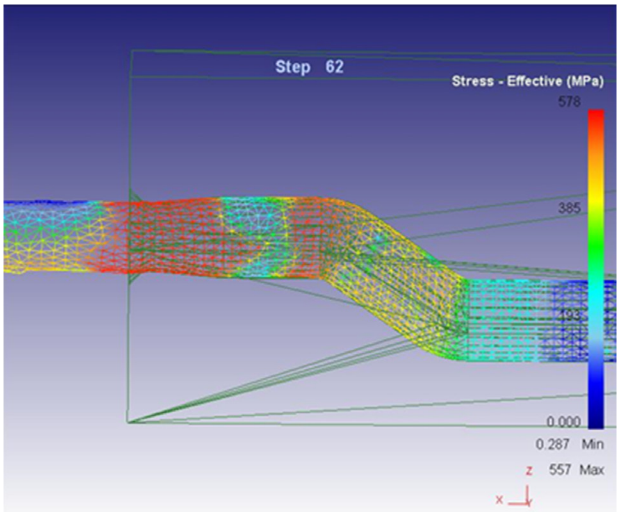


Fig. 6. The model combined the process with back effort.

As a result of the simulation, it was found that the possibility of this process is not possible due to excessive growth of the efforts of the drawing, which exceeds the tensile strength of the sample material, leading to breakage of the wire.

The plastic deformation continues after the release of the workpiece from the tool and, as a consequence, there may be tightening (thin places) and cliffs (Fig. 5b). This is due to the fact that to maintain a sustainable (uninterrupted) of the drawing process the entire process must be strictly observed inequality $\sigma_{DR} < \sigma_{0.2}$, that is, the pressure of drawing that occurs in the transverse direction of the workpiece extend at its exit from the die should be less than the yield strength of the material extend, which in our case was not executed.

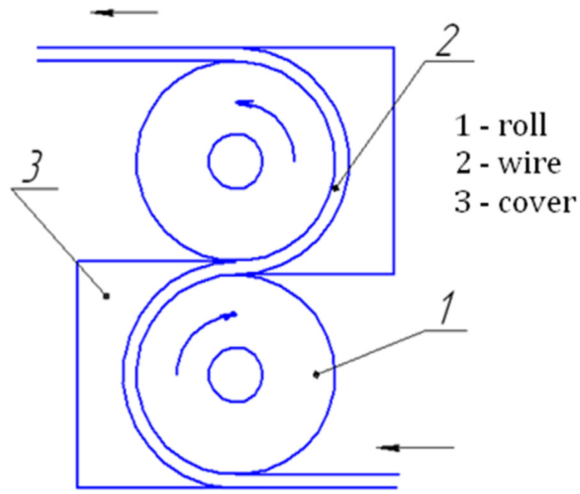


Fig. 7. The design of the setting device.

Also due to the thinning of the wire during the passage of the channel matrix is not full filling his space, which also adversely affects the working of the cross-section of the sample (Fig. 5a).

In the course of the modeling process the disadvantages of this process are identified and we proposed to the rear end of the sample to apply pushing effort. The deformation process according to the proposed scheme, i.e., the pressing-drawing using equal-channel step matrix, dies and using pushing effort was modeled in the software package DEFORM. During the simulation it was achieved stability of the process. Also using pushing effort it was achieved complete filling of the channel matrix, which will improve the study sample in the cross section (Fig. 6) and to eliminate breakage of the wire at the exit from the matrix.

The next task was to develop an optimal design setting device for realization of the combined process of «pressing-drawing» on the drawing line to get their pushes strength and prevent breakage of the wire.

After analysis of scientific-technical and patent literature as a basis of our reference device, it was decided to choose the scheme of the process Conform [41]. But unlike Conform scheme our developed device consists of two wheels and respectively from two pressure pads (covers) (Fig. 7).

For the purpose of verifying the operability of the proposed stand to setting the workpiece in the implementation of the combined process «pressing-drawing» a computer modeling in program complex Deform was conducted.

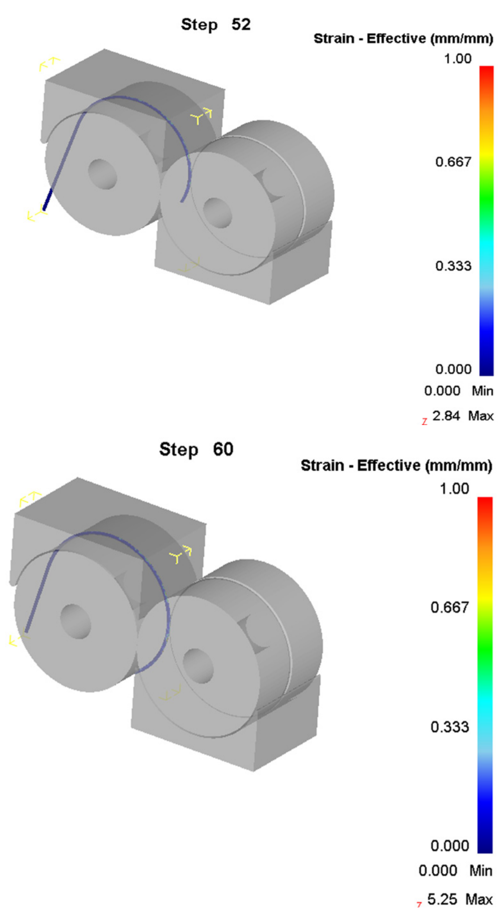


Fig. 8. The breaking process (wire is wound on the first roll).

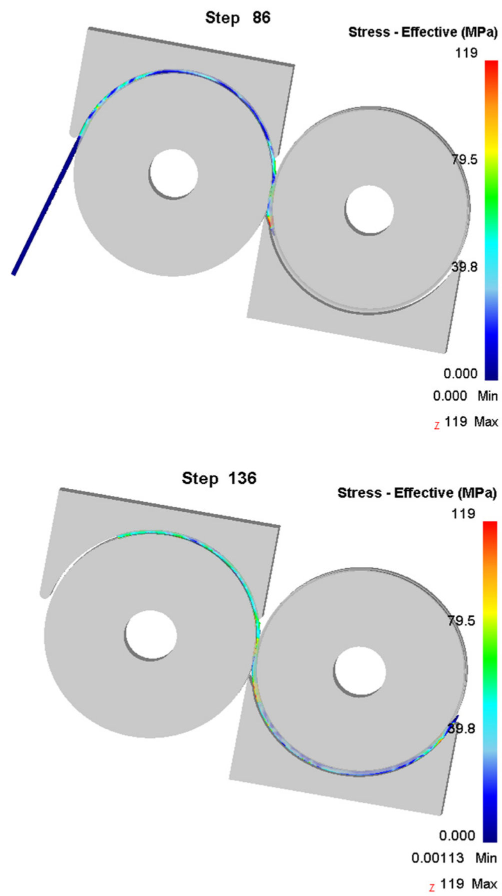


Fig. 10. Passage of the wire through the setting device.

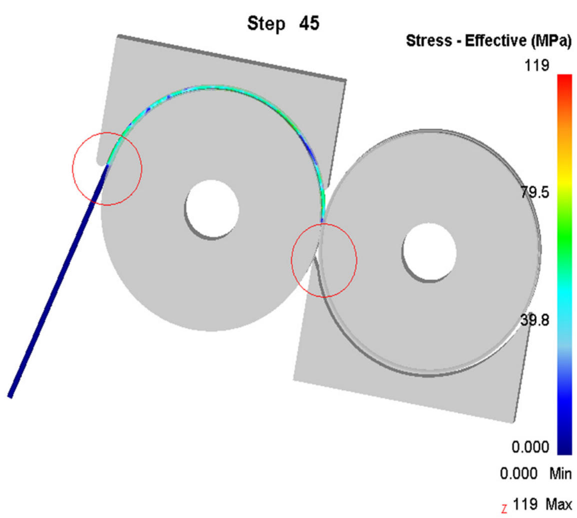


Fig. 9. The difference of structures of the first and the second covers.

During the simulation of the proposed setting device some problematic issues of the design of the stand were identified.

The first problem is the cutting of wire by the cover from sharp edges on the cover, whereby we changed the design of cover, in particular the edges of the casing were rounded and due to this wire was successfully tightened on the wheel.

The second problem is the difficulty of the wire transition from the first wheel to the second. So the wire going to the second wheel, never entered the stream of the second wheel, and continued to retract on the first (Fig. 8a), while slotting the cover of the second wheel, resulting in inhibition of the process (Fig. 8b).

The solution of this problem required a modification of the second cover relative to the first (Fig. 9). The distinctive feature of the second cover is that, to ensure tightening of the wire on the second roll and to avoid cutting of wire, the second input channel of the cover is made with an additional input pad and is more rounded. This design covers ensure the normal operation of the process drawing extrusion and performance

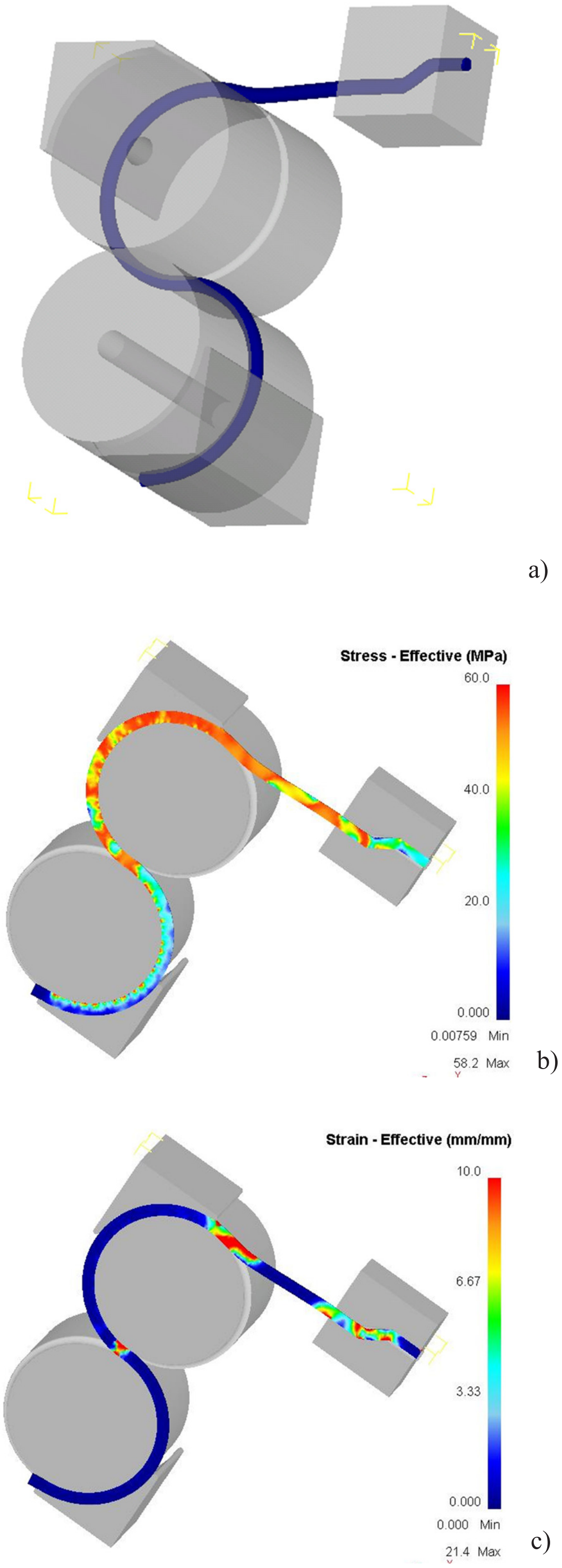


Fig. 11. Results of modeling in program complex DEFORM: a - functional scheme of setting device; b - distribution of effective stress; c - distribution of effective strain.

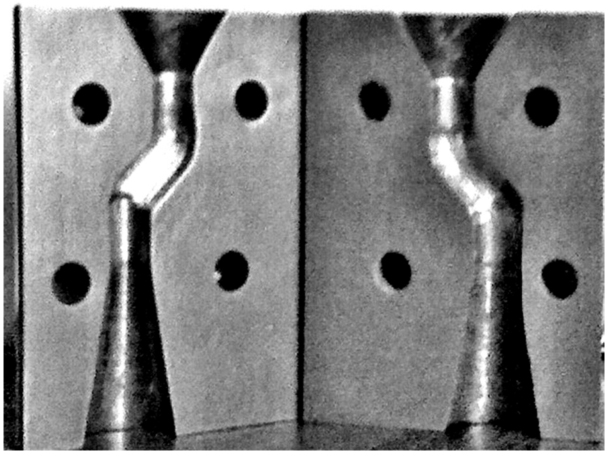


Fig. 12. Equal-channel step matrix.

of the device pushes.

As a result of changing the design of the second cover, the winding wire on the first cover was averted and the process is moving in the right direction (Fig. 10).

The output wire from the setting device does not mean the success of the process of pushing the wire in equal channel step die and punching through it. So the next step was an imported equal-channel step matrix in software complex DEFORM. The simulation results are presented in Fig. 11.

The results of simulation confirmed that the developed scheme of the setting device provides a pushing the wire in equal-channel step matrix and next pushing the wire through its channels.

It is worth noting that for a successful implementation of the combined process of «pressing-drawing», presented in Fig. 3 but with additional setting device, you must still perform the same mandatory conditions, namely the harmonization of speeds of pushing and pulling of the sample. For this purpose, in order the process to be stable, it must comply with the condition:

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

where V_0 и V_1 are the speed of pushing and the speed of pulling, respectively;

μ - the elongation coefficient.

To confirm the possibility of the proposed scheme of deformation and determine the effect of the new scheme of deformation on the evolution and mechanical properties, a semi-industrial experiment on deformation of aluminum A0 grade wire with diameter of 7 mm in the combined scheme of deformation «pressing-drawing» was carried out.

For the experiment we used a construction of equal-channel step matrix (diameters of the channels of the matrix 7.0 mm), shown in Fig. 12. The matrix was located in the container for lubrication before the drawing tool.

In carrying out this assessment a semi-drawing mills B-1/550M was used. We used the remade sharpening machine of wire drawing mill, in particular we had done the phasing of the machine so that the rolls rotate in the required direction and produce the capture of the wire due to the active friction forces, pushing her in equal channel step matrix shown in Fig. 12.

The drawing of aluminum wire was made as follows: the end of the wire using sharpening machine was pointed. Thereafter, the wire was fed into the device, and pushed at the expense of contact friction forces created upon contact of the wire with the rolls and the wire was taken into the gap of the rolls, the output from it pushed through the channels of equal-channel step matrix and drawing tool set in container and made her grip the filling with the pliers, the hook of which entered in one of the slots on the drum. After dialing in the drum 5 - 7 turns of wire, the mill was stopped.

A shaving soap was used as a lubricant in the implementation of the proposed combined process of “pressing-drawing”. The initial wire diameter was 7.0 mm. After pressing-drawing wire diameter was 6.5 mm. The compression was done only in pushing device (grooved rolls) and in drawing tool, after the output from equal-channel step matrix the wire diameter was slightly changed to 6.9 mm. The experiment was repeated three times. After each experiment we measured the wire diameter and cut templates for producing microsections in the transverse and longitudinal direction.

The experiment confirmed the possibility of implementing the proposed combined process of "pressing-drawing" using equal channel step matrix and setting device. The metallographic analysis of the deformed samples showed that when using the proposed technology of deformation after the first cycle of deformation there is an intensive milling of the starting microstructure with an uniform treatment in the whole volume.

CONCLUSIONS

In this paper we propose a new process of equal channel angular pressing-drawing, which provides a reliable implementation of this process, satisfactory filling of equal-channel step matrix, high precision wire and intensive elaboration of the structure.

During intensive alternating plastic deformation in the processes of equal-channel angular pressing-drawing and alternating torsion, in structural elements of the workpiece are subjected to intense shear deformation, the shape and their sizes do not change significantly. This creates sub-grains with large angular disorientation and high mobility boundaries, which serve as centers of recrystallization.

The study of microstructure showed that grains are 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 is by shear, with the passage of the workpiece through the zone of channels intersection, resulting in accumulation of shear strain leading to the formation of large-angle boundaries in the material. As a result, the conditions for the ultrafine grain (UFG) structure formation are created.

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