DEFORMATION OF BIMETALLIC WIRE DURING COMBINED ECAP-DRAWING

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Abstract

In modern industry the most urgent problem is to increase the physical and mechanical properties of metal materials. One of the promising ways to improve such properties is to grind the elements of the grain structure to an ultrafine-grained (UFG) state. From all methods used to produce metal materials with ultrafine-grained structures, the most commonly severe plastic deformation (SPD) methods are used. Most of the currently existing methods of the SPD implementation have not been used in the real industrial sector due to the existing in this method of deformation of the disadvantage, which is the discreteness, i.e. the inability to process products of relatively long length and the need for a large number of processing cycles. And this determines the economic inexpediency of the introduction of this method in production. To solve these problems, technology of combined deformation "ECAP-drawing" have been developed. This work is aimed to investigation of bimetallic wire deformation during combined ECAP-drawing. Results of strain state study showed that layers of materials in the cross-section of wire have received different values of strain. Stress state of both materials is various in both deformation zones - in the ECAP matrix deformation area is divided for two sections (tension and compression) separated by diagonal. At all deformation stages the level of compressive stresses is much higher of tensile stresses.

Keywords: Severe plastic deformation, bimetallic wire, combined process, ECAP-drawing, FEM

1. INTRODUCTION

Currently, one of the tasks of many countries' economies is to provide the main industries with high-quality metal products with unique physical and mechanical properties. However, obtaining materials with such properties is often associated with high energy costs. Therefore, the issue of developing new energy-saving methods for obtaining materials with properties that combine both high strength and plasticity, which involve simple and inexpensive working tools, has great practical importance.

At the moment, research related to the metal deformation in one continuous line by combining two or more simple operations has become particularly relevant. Such combined processes are often able to overcome the disadvantages of the simple processes that make up them. So, in recent years, several combined processes have been developed, which are based on the ECAP principle [1-5]. Each of these processes can significantly increase the productivity of the deformation process by annihilating certain ECAP disadvantages. For example, it is possible to deform long-length workpieces, ensuring the continuity of the deformation process.

A special place among these methods is occupied by the "ECAP-drawing" combined process. Its key feature is that, unlike other combined methods, there is no rolling stage. The continuity of deformation is provided by the drawing process, which takes place immediately after the ECAP process (**Figure 1**). Due to this unique deformation scheme, a sufficiently high level of tensile stress develops in the section of the workpiece, while the wrong selection of technological parameters will lead to the breakage of the deformable wire. The paper [6] presents theoretical and experimental results of this process study for steel wire deformation.

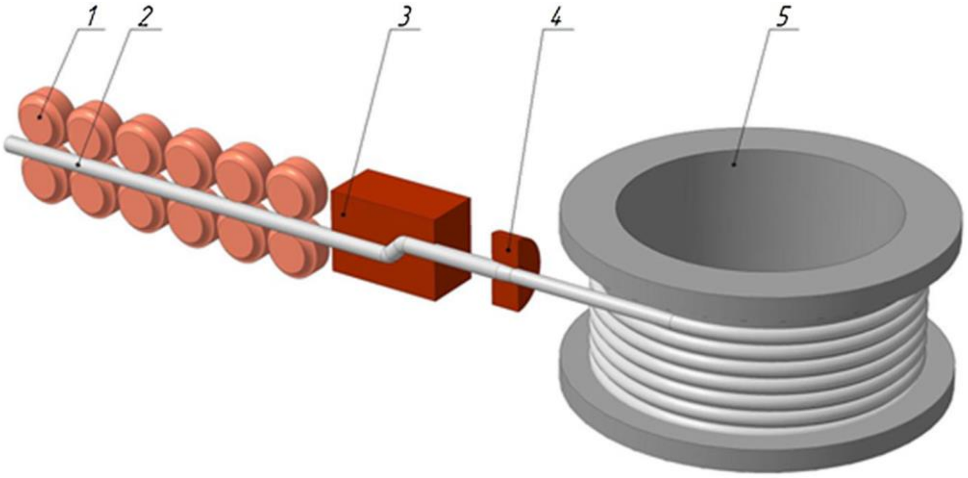

Figure 1 Scheme of "ECAP-drawing": 1 - wire; 2 - pushing device; 3 - ECA-matrix; 4 – drawing die; 5 - drum

However, at the moment, the development of this combined process was conducted only for homogeneous materials. At the same time, bimetallic wire is increasingly used as a source material for the production of wires – it's a long-length product of composite steel rolled products consisting of metals and alloys with different chemical and physical characteristics.

Bimetallic wire consists of two layers of metals, the properties of which complement and strengthen each other. The most commonly used connection types are steel-aluminum and steel-copper. The construction of a bimetallic wire consists of a core and a shell. The core is made of high-strength steel grades, the shell is a different metal or alloy in properties. The combination of two different metals gives the product universal performance characteristics (wear resistance, corrosion resistance, strength, electrical and thermal conductivity).

This work is devoted to the study of bimetallic wire deformation of "steel-aluminum" type by the "ECAP-drawing" combined process.

2. FEM SIMULATION

One of the most effective methods of theoretical analysis of any technological process currently is computer simulation using the finite element method. This method of research has several undeniable advantages:

- possibility to visualize the studied process, even inside the workpiece or tool, that is impossible in real conditions;
- complex analysis of several parameters at once at any point of the studied object, that is also often impossible with traditional methods, for example, in the absence of necessary empirical equations;
- ability to optimize the process by varying the values of certain geometric or technological parameters.

All these advantages have made FEM simulation a fairly common method of theoretical study. If we consider FEM modeling from the point of view of metal forming, then the leading position is occupied by the Deform program, which allows to simulate almost any deformation process. During modeling the deformation of a bimetallic wire using the "ECAP-drawing" combined process, it is necessary to solve two problems at once:

1) study the stress-strain state under complex loading, due to the combining two operations, that leads to the appearance of two deformation zones;
2) conduct a study of the stress-strain state for each material separately.

A bimetallic wire of "steel-aluminum" type with a diameter of 10 mm was used as the initial billet, diameter of the steel core was equal to 8 mm. The core material was chosen AISI-1010 steel (analogous to steel 10).

Aluminum alloy 1100 was chosen as the shell material. The deformation was performed at room temperature. The angle of junction of channels in the ECA-matrix was equal to 145°. At the drawing stage, 5% compression was provided, up to a diameter of 9.5 mm. The elastic-plastic type was chosen as the material model for the core and shell. Since both materials are stationary relative to each other in a bimetallic wire, a rigid unbreakable contact has been established between them. On the contact of the aluminum shell and both tools (ECA-matrix and drawing), a coefficient of friction of 0.1 was set, which corresponds to the polished surface with the use of grease.

During developing this combined process, it was found that in order to prevent wire breakage in the area between the matrix and the fiber, it is necessary to coordinate the pulling speed applied to the front end of the workpiece and the pushing speed applied to the rear end. At a given rear speed of 10 mm/s and reducing the cross section of the wire from 10 to 9.5 mm, the front speed will be 11.08 mm/s.

Before starting the stress-strain analysis, it is also necessary to decide which parameters will be studied. To assess the strain state, it is most convenient to consider the criterion "equivalent strain", the value of which depends on the values of the main deformations and is determined by the formula:

$$\varepsilon_{EQV} = \frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2} \qquad (1)$$

When considering the stress state, the "equivalent stress" criterion is often used to estimate the average level of stress that occurs, and this is often sufficient. This criterion depends on the values of the main stresses and is determined by the formula:

$$\sigma_{EQV} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2} \qquad (2)$$

However, in this combined process, the deformation scheme is such that if the initial parameters are incorrectly selected, the deformation may be unstable, leading to a wire break. Considering this fact, consideration of the equivalent stress in the ECAP-drawing is insufficient. Therefore, for a full assessment of the resulting stresses, it is also necessary to study the criterion "average hydrostatic pressure", which allows you to estimate the value of the stress taking into account the sign, i.e., to estimate the value of tensile and compressive stresses. This criterion is derived from the values of the main stresses and is determined by the formula:

$$\sigma_{AV} = \frac{\sigma_1+\sigma_2+\sigma_3}{3} \qquad (3)$$

3. RESULTS AND DISCUSSION

3.1. Strain state

When considering the ECAP stage of this combined process, it was found that passing through the channels of the ECA-matrix, the shell and core receive different levels of strain (**Figure 2a**). The largest amount of equivalent strain, reaching ε=1.5 in some areas, the aluminum shell receives in the zones of the junction of channels – when moving and rubbing against the rounded zones of the corners of the joint. The core gets a much smaller deformation - the central zone of the core is processed to ε=0.4, the surface layers of the core get a higher deformation, to ε=0.6. Despite the fact that both materials are in a rigid engagement with each other and must deform the same way, such a significant difference in the development of strain is due to the different amount of deformation resistance of both materials. In other words, in this case, one material is much softer and more pliable than the other. After the drawing stage (**Figure 2b**), a small increase in strain is observed only in the shell to ε=1,7, the level of strain in the core almost does not change.

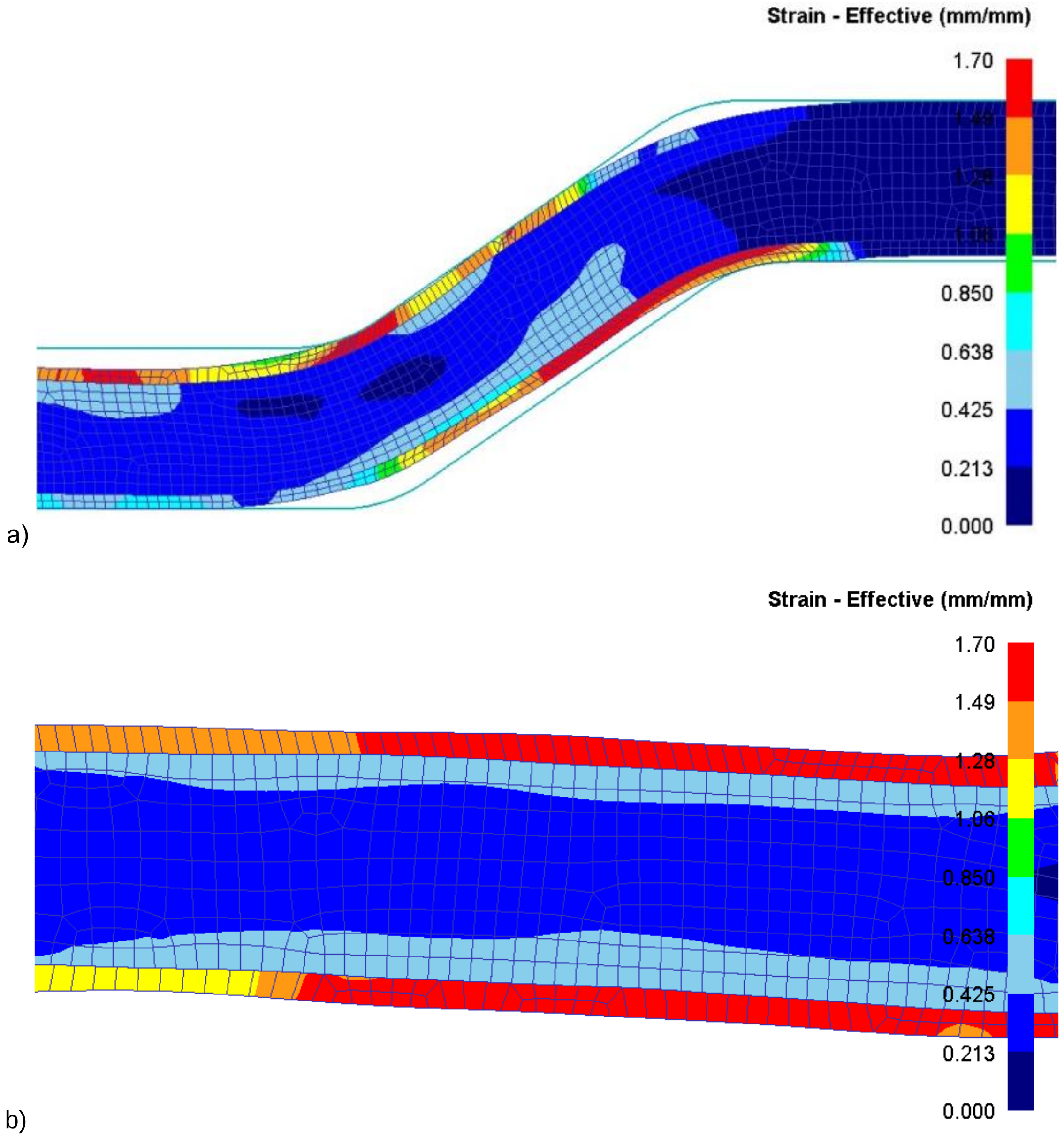

Figure 2 Equivalent strain: a – ECAP stage; b – workpiece after the drawing stage

3.2. Stress state

When studying the equivalent stress at the ECAP stage, it was found that when passing through the channels of the ECA-matrix, different stress levels develop in the shell and core (**Figure 3a**), covering the entire zone of the junction of the channels. In an aluminum shell, the average value of the equivalent stress is 110÷120 MPa. In a steel core, due to the simultaneous action of the pulling speed at the front end, which causes stretching, and the backing speed at the rear end, which causes compression, there is an alternating distribution of stress. When passing the intermediate channel, the highest stress occurs in the lower part of the core, reaching 480 MPa. But, in the output channel, when the influence of the back speed weakens, the maximum stresses are realized already on the upper part of the core (490 MPa), generally balancing the entire deformation zone.

When drawing (**Figure 3b**), the deformation zone is completely symmetrical. In the shell, the average value of the equivalent stress is 130 MPa. The average stress level in the core is significantly reduced to 280 MPa.

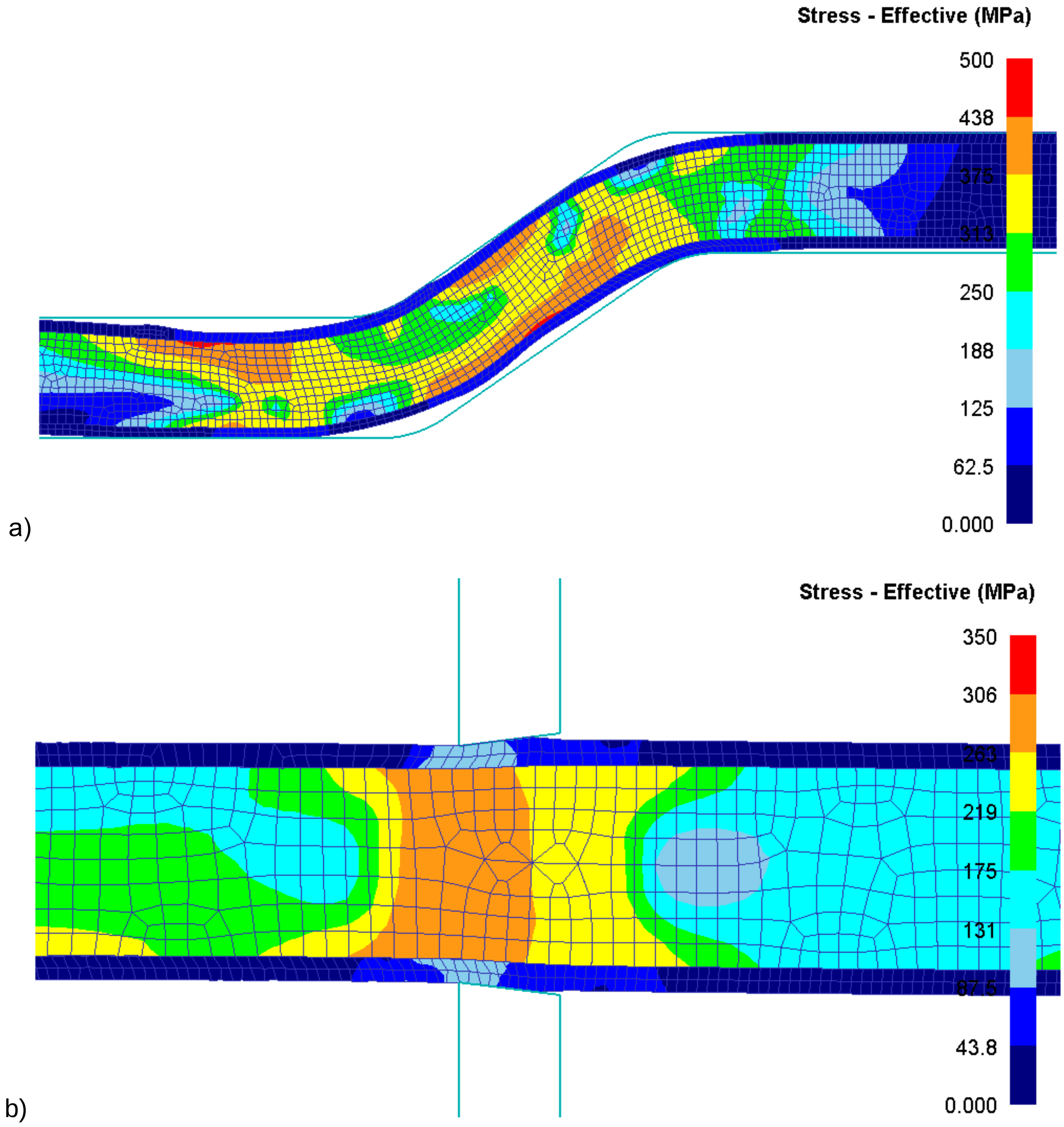

Figure 3 Equivalent stress: a - ECAP stage; b - drawing stage

When considering the average hydrostatic pressure at the ECAP stage, it was found that the distribution of this parameter is similar to the distribution of the equivalent stress (**Figure 4a**). In the aluminum shell, in areas without contact with the tool, there are tensile stresses of 100÷110 MPa. In straight sections with contact with the matrix, the shell experiences back pressure from the matrix, which leads to the creation of compressive stresses of -80÷-90 MPa. The maximum level of back pressure is created directly at the channel junctions – here the value of compressive stresses reaches a value of -350 MPa.

In a steel core, the distribution of tensile and compressive stresses can be called identical to the distribution in the shell. On the upper sections of the input and output channels, as well as on the lower section of the intermediate channel, there are tensile stresses, the value of which is about 230÷240 MPa. In the opposite sections, compressive stresses reaching -360 MPa are implemented in all channels.

When drawing (**Figure 4b**), the deformation zone, as well as when considering the equivalent stress, is completely symmetrical. Compressive stresses of approximately -160 MPa occur in the shell. In this case, the entire core creates tensile stresses at the level of 90 MPa. The reduction of these tensile stresses in the core is observed directly in the deformation zone, where their value is reduced to 40 MPa.

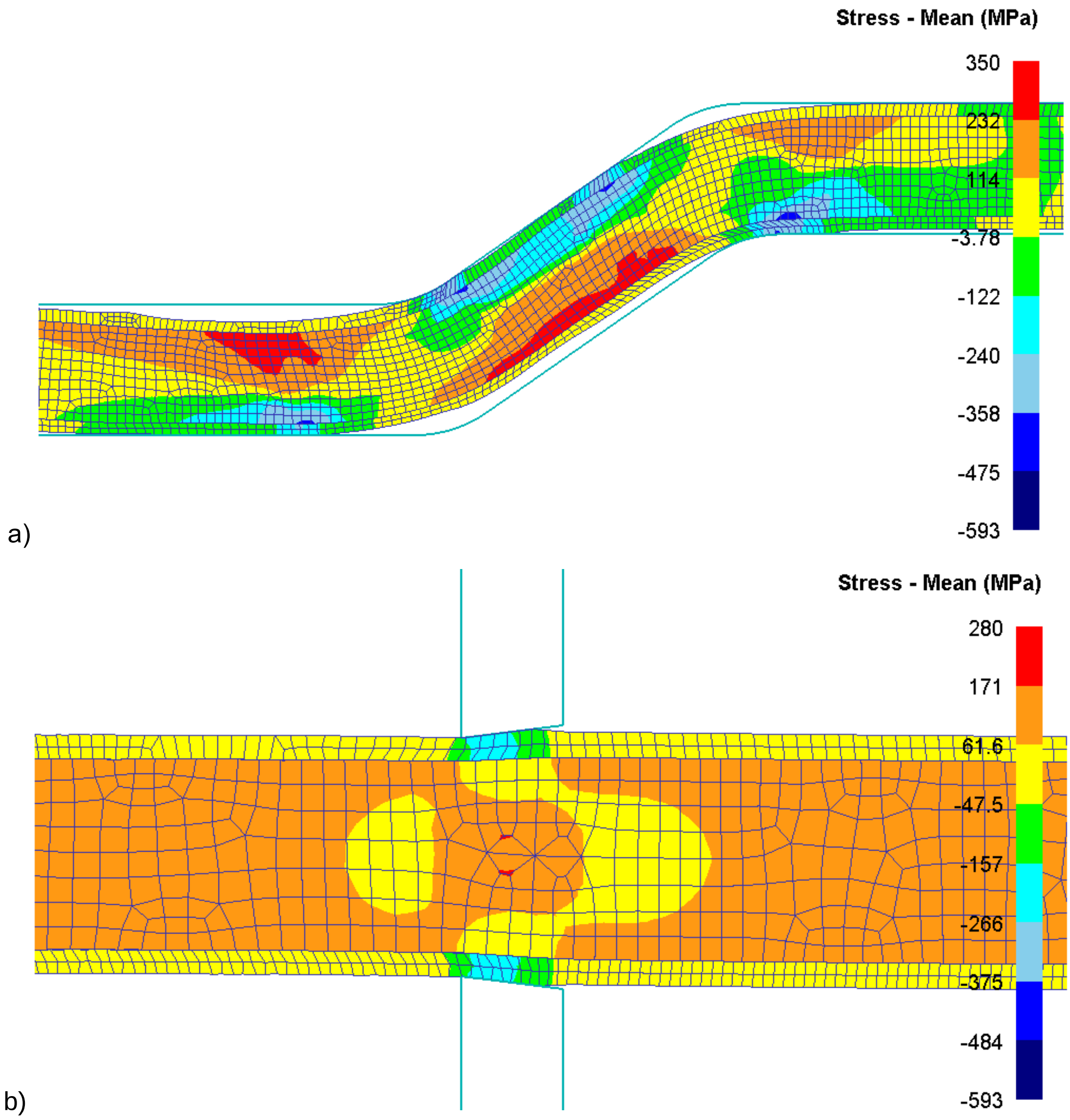

Figure 4 Average hydrostatic pressure: a - ECAP stage; b - drawing stage

4. CONCLUSION

The considered combined process "ECAP-drawing" is quite interesting from the point of view of the possibility of deforming such a material as bimetallic wire. When analyzing the strain state, it was found that each material in a bimetallic wire receives different values of strain in a single cycle, which is due to the difference in the strength and plasticity levels of these materials. The stress state of both materials is different in both zones of deformation - in the ECAP zone, the deformation zone is divided into sections of tension and compression, divided diagonally. In the drawing zone, the deformation zone is completely symmetrical. At all stages of deformation, the level of compressive stress is significantly higher than the tensile stress.

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