ABSTACT
of the thesis for the degree of Doctor of Philosophy (PhD)
on the specialty 6D071000 – Material science and technology of new materials

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Research of formation of ultra-fine-grained structure and properties of the metal materials subjected to pressing in an equal-channel step matrix with the subsequent drawing

The relevance of the research topic. To implement the plans facing the economy of the Republic of Kazakhstan it is necessary to provide the main industries with high-quality metal products with unique physical, mechanical and other operational properties. Often the solution of these problems is associated with high energy costs. In the conditions of economical use of energy and raw materials, the problem of energy and resource-saving methods of obtaining materials with properties that combine both high strength and plasticity, in the conditions of using relatively simple and inexpensive devices that allow to spend the minimum possible amount of time in the processing of products has great practical importance.

Recently, more and more attention is paid to materials with ultra-fine-grained structure, which have unique properties. This opens up prospects for improving existing and creating fundamentally new structural materials, as materials with ultra-fine-grained structure provide an optimal combination of strength and plastic properties. Moreover, the positive effect is achieved not by expensive alloying elements, but only by changing the structure. This leads to the improvement of many technical and economic indicators and provides low material and energy intensity of production.

The scientific basis for the creation of new methods of materials processing is the study of the relationship between the composition, structural state and properties of metals and alloys, as well as experimental and theoretical analysis of the mechanisms of phase and structural transformations in metals and alloys occurring under various external influences, including deformation.

Traditional deformation technologies such as drawing and cold rolling are also accompanied by structure grinding. However, basically, the substructure has a cellular character with grains elongated in the direction of drawing or rolling, and also contains a high proportion of small-angle boundaries. On the other side, the material obtained by severe plastic deformation (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 thermal stability. In addition, often SPD takes place at low temperatures (environment), which makes it more attractive. At the same time, it is known that their ultra-fine-grained and nanostructured states with grains less than one micron in size and a special state of the boundaries can significantly (2-3 times) increase the strength of technically pure metals and 1.5-2 times alloys in combination with a sufficiently high plasticity. The most well-known method for producing metals with ultra-fine-grained structure is

the ECAP method, which under conditions of multi-cycle processing provides the formation of ultra-fine-grained structure in billets with a high metal utilization rate, which is important for industrial use. Although some results of the application of SPD methods in the engineering and medical industries are already known, which allowed to reduce the cost of energy resources by 20-30%, but they have not been widely used, since obtaining such a structure by most of the known methods is labor - and energy-intensive, as well as imposes restrictions on the geometric dimensions of the resulting product, which significantly reduces their productivity.

One of the ways of high-quality processing of metal blanks is drawing a long wire. Drawing is aimed at obtaining geometrically correct products, with a smooth and clean surface, usually of small cross-section. The result of the process is a decrease in the diameter of the wire and an increase in its length. This is relevant for the production of wire of different profiles and other wire products used in all areas of human activity. But with modern processing technology, the total compression during drawing the wire rod into the wire is large enough (up to 99.2%), which requires additional intermediate heat treatments. Therefore, improving the strength and plastic properties of the metal without intermediate heat treatment while maintaining the necessary final characteristics of the wire while improving existing technologies is relevant task. In the last 25 years, research has been actively developing, focused on the production of ultra-fine-grained and nanocrystalline materials with high physical and mechanical properties, which are promising structural and functional materials of a new generation. At the moment there are whole scientific schools, actively developing science in this direction, both in Russia and abroad. It is enough to list such authors as V.M. Segal, V.V. Rybin et al., V.I. Levit et al., R.Z. Valiev et al., R.R. Mulyukov et al., A.M. Glaser et al., S.V. Dobatkin et al., V.N. Chuvildeev et al., V.N. Varyukhin et al., E.V. Kozlov, N. Koneva, A. Vinogradov, T.G. Langdon, M. Furukawa, M. Nemoto, Z. Horita and others, it becomes clear the scale of the research. Nevertheless, the issue of obtaining long-dimensional bulk nanostructured materials remains relevant.

The relevance of this work is confirmed by the demand for this subject by the state programs of different levels, financed from the state budget.

Novelty of the theme is in the study of the impact of severe plastic deformation on the grain structure of metals and alloys, developing in an equal-channel angular step matrix when combined with the classical drawing, which allows realize shear and tensile schemes. The formation of a bulk ultra-fine-grained structure in metal materials processed by the new technology is more effective than the previously known methods for producing metal with an ultra-fine-grained structure. This makes it possible to create a new effective technology for producing wire with high technological and operational properties.

The aim of the dissertation research is the investigation of the influence of new combined process of plastic deformation pressing-drawing on the formation of ultra-fine-grained structure and properties of metal materials.

Tasks of the research:

1. Development of optimal technology of combined process "pressing-drawing" to receive a wire of various metals with a high (improved) strength with sufficient ductility parameters.

2. Modeling and theoretical justification of the continuity condition of the pressing-drawing process.

3. Development of a new combined process "pressing-drawing" by the methods of computer modeling of the finite element model and study of the influence of the parameters of the combination on the stability of the process and the wire forming.

4. Analysis of the stress-strain state of the resulting model of the deformation process in order to determine the possibility of forming an ultra-fine-grained structure.

5. The assessment of the feasibility of the combined process of "pressing-drawing" at the drawing mill B- I/550 M.

6. Evaluation of the effectiveness of the combined process "pressing-drawing", providing increased mechanical properties due to grinding of microstructural components.

The object of research. Combined process "pressing-drawing", designed to form an ultra-fine-grained structure in the deformable metal.

The subject of research. The microstructure of the steel wire of St.3 brand, aluminum of A0 brand and copper of M1 brand, obtained by a combined method "pressing-drawing".

Methodological basis of research. Among the main methods of research and analysis used in the performance of the thesis are:

- calculation of the stress-strain state using simulation in the software complex DEFORM-3D;
- electron microscopic studies of the microstructure of the deformed samples on the transmission microscope JEM-2100 by Jeol;
- EBSD analysis using Philips XL-30 SEM with field cathode;
- determination of the microhardness of the wire on a Leica DM IRM NS microscope equipped with special attachments;
– the test specimens on the uniaxial tension on the device Instron 5982.

Studies were carried out using instruments and measuring instruments that have passed the state metrological verification.

Scientific novelty:

1. A new combined technology of deformation "pressing-drawing", combining the method of severe plastic deformation and classical drawing, providing an increase in the complex strength properties of the wire while maintaining the plasticity resource.

2. The regularities of changes in the stress-strain state under complex loading, which occur when combining several operations in a single deformation zone.

3. The regularities of formation of ultrafine-grained structure and mechanical properties in steel of St. 3 grade, aluminum grade A0 and copper grade M1 are

revealed depending on the deformation conditions in the "pressing-drawing" process.

4. The modes of deformation of steel grade St.3, aluminum grade A0 and copper grade M1, providing a uniform UFG structure and enhanced mechanical properties in the combined process "pressing-drawing".

5. It is experimentally proved that the use of a new combined technology of deformation "pressing-drawing" allows to provide an increase in the complex of mechanical properties in comparison with traditional drawing. In particular, in the processing of wire of steel grade St.3 rupture strength is increased to 360 MPa, yield strength is 460 MPa, relative narrowing after the break is lowered by 8 %, but the decline is not as significant as at classical drawing.

The practical significance of work is that the developed combined technology "pressing-drawing" will allow to obtain high-quality wire with ultra-fine-grained structure and high mechanical properties, and this in turn will replace expensive alloyed steel grades with conventional structural ones. The practical value is confirmed by the act on carrying out pilot testing of the results of research work in the conditions of JSC "Almaty Heavy Engineering Plant". It is shown that the use of combined technology "pressing-drawing" allows to obtain a long wire with ultra-fine-grained structure of steel grade St.3, A0 aluminum grade and M1 copper grade. The proposed technology makes it possible to obtain defect-free bulk blanks with a homogeneous ultra-fine-grained structure and a different combination of strength, plasticity and functional properties of the material. The results of the experimental data implemented in the educational process Karaganda State Industrial University and used by preparation of bachelors, undergraduates and lecturing at the department "Processing of metals by pressure".

Statements for the defense:

1. Combined technology "pressing-drawing", the design of the deforming unit and forming tool for its implementation, allowing to obtain a wire with increased strength and performance properties.

2. Modes of deformation of steel grade St.3, aluminum grade A0 and copper grade M1 in the process "pressing-drawing", providing the formation of ultra-fine-grained structure and high mechanical properties in the wire.

3. The results of combining the technology of ECAP and traditional drawing. New technology allows you to create a structure with small, uniform, equiaxed grains with a predominantly large-border borders. To achieve these results allowed the use of shear deformations occurring in the equal-channel matrix, which led to the formation of the structure of the material other than formed by standard methods.

4. Regularities of formation of ultrafine-grained structure in St.3 steel grade, A0aluminum grade and M1copper grade in the process "pressing-drawing", can significantly improve the strength characteristics of mechanical properties while maintaining ductility and toughness at a level that meets the requirements of standards.

5. The mechanism of formation of ultra-fine-grained structure in bulk metal materials subjected to deformation by the combined method "pressing-drawing".

The relation of the work with funded research programs.

1. Development and research of the combined process of deformation "pressing – drawing" in order to obtain aluminum and copper wire with high mechanical properties and ultra - fine-grained structure" under the program "Grant funding of research for 2012-2014.

Approbation of the work. The main results and provisions of the dissertation were reported and discussed at the following international scientific and technical conferences: XVIII International scientific conference "New technologies and achievements in metallurgy, materials science, technology and physics" (Czestochowa, Poland, 2017); International Satpayev readings "Scientific heritage of Shakhmardan Esenov" (Almaty, Kazakhstan 2017); IX scientific and practical International conference "Third modernization of Kazakhstan-new concepts and modern solutions" (Temirtau, Kazakhstan 2017); XIX international scientific conference "New technologies and achievements in metallurgy and materials science and production technologies and physics" (Czestochowa, Poland, 2018); International conference "Latest achievements in metallurgy for sustainable development "(Vadodara, India, 2018); International scientific Congress "Machines. Technologies. Materials" (Sofia, Bulgaria, 2018).

The author's contribution. The author was directly involved in the discussion and formulation of the problem and analysis of the results, in the organization and conduct of theoretical and experimental studies, the manufacture of practical designs of drawing tools. All experimental results included in the dissertation are obtained either by the author or with his direct participation.

Publications. Based on the materials of dissertation research, 19 works were published, including 4 articles in journals with non-zero impact factor (Scopus, Web of Science), 4 articles in scientific journals recommended by the Committee for control in the field of education and science of the Ministry of education and science of the Republic of Kazakhstan for the publication of the main results of scientific activity, 6 publications in conference materials and collections of abstracts at conferences, patent application was performed (formal examination had done).

The structure and volume of the work: Dissertation is presented on 129 pages of typewritten text, including 81 figures and 10 tables. It consists of the table of content, list of symbols and abbreviations, introduction, five chapters, conclusion, list of sources used in the number of 131 items.