

Abstract of
dissertation for the degree of Doctor of Philosophy (PhD) in the educational
program 8D07111 – «Digitalization of engineering manufacturing»
Sovetbayev Rail Ayanovich «Development of technology for manufacturing
aluminum alloy rods with a fine-grained structure»

Aluminum alloy 6082 is widely used in mechanical engineering, aircraft construction, shipbuilding and power engineering due to its high combination of strength, corrosion resistance and processability. It is in demand for the manufacture of critical components and structural parts, however, traditional methods of thermomechanical processing do not always ensure the formation of a fine-grained structure and an increase in the mechanical properties of the material, as a result of which the resource of such products may decrease. Modern requirements for reliability and durability of critical structures require materials to have high strength, ductility and corrosion resistance at the same time. Achieving an optimal balance of properties is possible with a significant improvement in the structure of the metal, in particular by grinding grain. Therefore, an urgent scientific and technical task is to develop new technological processes for manufacturing products made of EN AW-6082 alloy with predictable properties and fine-grained structure over the entire cross-section.

One of the promising ways to solve this problem is the method of three-roll radial shear rolling (RSR), a process of intense plastic deformation that significantly grinds the grain of the material and increases the strength characteristics of the rolled bars. Radial shear rolling provides a stress state close to all-round compression with active shear, which is favorable from a technological and economic point of view.

Thus, the study of the RSR alloy 6082 process is aimed at improving the quality and durability of aluminum products by obtaining a uniform fine-grained structure and improving the complex of mechanical properties. The scientific and practical significance of the work lies in the development of technology for the production of high-strength rods from alloy 6082 by methods of intensive plastic deformation, which is in demand in modern metallurgy and mechanical engineering.

The purpose of the study is to develop scientifically proven modes of three-roll radial shear rolling of rods made of aluminum alloy 6082, providing grain grinding and improving the mechanical properties of the deformed metal.

To achieve this goal, the following tasks have been solved:

- to determine the rheological properties of alloy 6082 (by thermomechanical tests) and to establish the dependence of the deformation resistance on the temperature and velocity parameters of the deformation process;

- to develop a numerical model of the rolling process of a 6082 alloy bar in the Forge NxT software environment and conduct computer modeling in order to optimize technological parameters (the model should adequately describe the distribution of deformation, stress and temperature in the metal);
- perform experimental rolling of bars made of alloy 6082 on an experimental three-roll radial shear mill;
- to carry out metallographic studies of the resulting structure and test the mechanical properties of the rolled material;
- To verify the numerical model by comparing the calculated data with the experimental results and, on this basis, optimize the rolling modes.

The object of the study is the process of intensive plastic deformation of aluminum alloy 6082 by three-roll radial shear rolling (the technological process of rolling rods from alloy 6082 on a radial shear mill).

Provisions to be defended:

– Patterns of deformation of alloy 6082. The dependences between the parameters of the deformation-velocity regime of three-roll radial shear rolling and the characteristics of plastic deformation of aluminum alloy 6082 are established. For the first time, the effect of temperature and deformation rate on the deformation resistance of this alloy in the RSR process (in the range of 350-500 °C) has been experimentally determined. It is shown that a decrease in the heating temperature to ~350 °C. Increasing the angle of inclination of the rolls increases the resistance to deformation, however, they ensure the achievement of a fine-grained structure with sufficient plasticity of the material.

– Numerical simulation of the process. A numerical model of three-roll rolling of bars made of alloy 6082 has been developed and verified using physical experiments. It is revealed that the results of computer modeling (distribution of strain, stress, temperature) They are in good agreement with experimental data on the structure and properties of rolled metal, which indicates the correctness of the chosen model and its suitability for predicting process parameters and final material characteristics.

– Optimal rolling modes. Rational technological modes of radial shear rolling of alloy 6082 have been determined, which make it possible to obtain a fine-grained structure without defects. It has been found that the greatest effect is achieved when rolling at a heating temperature of about 350 °C; under these conditions, due to the dynamic softening of the material, it is possible to carry out up to three consecutive passes without additional heating of the metal. The selected modes ensure significant grain grinding of alloy 6082 while maintaining the integrity and specified geometry of the rolled bar.

– The effectiveness of an integrated approach combining plastometric testing and experimental rolling with computer modeling for the development of pressure treatment technologies for aluminum alloys is shown. The use of digital and physical experiments made it possible to reduce the material and time costs for selecting process parameters while increasing the reliability of the results.;

The scientific novelty of the work is determined by the following results:

– The conditions of intensive deformation treatment of alloy 6082 by three-roll radial shear rolling, under which a fine-grained structure is formed in deformed bars, are determined. For the first time, it has been experimentally shown that a certain combination of rolling parameters ensures that the grain of alloy 6082 is crushed to a submicron level without disturbing the continuity of the material.

– The rheological behavior of aluminum alloy 6082 under radial shear rolling conditions has been studied for the first time. Based on the data obtained, a numerical model of the process was developed and verified, which is a prototype of a digital twin of a three-roll DSP and adequately describes the deformation of alloy 6082. The model made it possible to establish the influence of the deformation-velocity parameters of rolling on the resistance to plastic deformation of the material (in the temperature range 350-500 ° C) and to justify the optimal processing modes.

The reliability of the obtained results is ensured by conducting a wide range of experiments, verifying the numerical model and a good match between the results of computer modeling and the data of the physical experiment. All the main conclusions are confirmed by both calculated and experimental data, which indicates the reliability of the conducted research.

The theoretical and practical significance of the work is due to the development of scientific ideas about the processes of intensive plastic deformation and the possibility of direct application of the results obtained in industry. The revealed patterns of deformation and structure formation of alloy 6082 under RSP conditions expand the database for modeling metalworking processes by pressure and the formation of fine-grained structures. The developed numerical model and certain optimal rolling modes can be used in the design and modernization of manufacturing technologies for deformed rolled products (rods, blanks) made of aluminum alloys with enhanced performance properties. The implementation of recommendations based on the research results will allow metallurgical enterprises to produce products with a fine-grained structure and improved mechanical characteristics, increasing the reliability and service life of critical parts. The proposed integrated approach (numerical modeling + experiment) can be extended to other alloys, reducing the cost of pilot testing.

Approbation of the work. Main publications. 8 scientific papers have been published on the topic of the dissertation, including 1 article in an international peer-

reviewed journal (indexed in Scopus) and 4 articles in Committee for Quality Assurance in the Sphere of Science and Higher Education of the Ministry of Education and Science of the Republic of Kazakhstan. In addition, 2 articles have been published in other scientific journals and 1 publication in the conference proceedings.

Articles in journals included in the Scopus and WOS databases: 1) Sovetbayev, R.; Nugman, Y.; Shayakhmetov, Y.; Abilmazhinov, Y.; Kawalek, A.; Ozhmegov. Analyses of the Rolling Process of Alloy 6082 on a Three-High Skew Rolling Mill. Materials 2025, 18(11), 2618. <https://doi.org/10.3390/ma18112618>.

List of articles published in journals recommended by the Committee for Quality Assurance in the Sphere of Science and Higher Education: 2) R. A. Sovetbayev, Y. Y. Shayakhmetov, Y. T. Abilmazhinov, D. K. Dukenbayev, S. S. Shakhova. Algorithm for predicting the roughness of the inner surface during turning process. Science and Technology of Kazakhstan. №4 (2023). ISSN 2788-8770. C.103-113 <https://doi.org/10.48081/WUTY7402>.

3) R. A. Sovetbayev, Y. Nugman, Y. Y. Shayakhmetov, A. Kawalek. Obtaining the necessary mechanical properties of blanks of parts made of aluminum alloy 7075 by physical modeling. Science and Technology of Kazakhstan. №1 (2024). ISSN 2788-8770. C.73-81 <https://doi.org/10.48081/KBNH3045>.

4) R. A. Sovetbayev, Y. Nugman, Y. Y. Shayakhmetov, A. Kawalek. Computer simulation of the stress strain state of bar blanks made of alloy 7075. Science and Technology of Kazakhstan. №3 (2024). ISSN 2788-8770. C.109-119 <https://doi.org/10.48081/IYNS2338>.

5) Rail Sovetbayev, Yerik Nugman, Yerzhan Shayakhmetov, Anna Kawalek. Preparation of AlMgSi1 (6082) aluminum alloy for the study of mechanical and physico-chemical properties in the rolling process. Technical Sciences and Technologies Series. №2 (147)/ 2024. ISSN: 2616-7263. eISSN: 2663-1261. C.231-244. <https://doi.org/10.32523/2616-7263-2024-147-2-231-244>.

Articles published in other scientific journals and publications: 6) R.A. Sovetbayev, Y. Nugman, Y. Shayakhmetov, A. Kawalek. Analysis of methods for obtaining wire products, advantages of technological processes at radial shear mills. Bulletin of Shakarim University. Technical Sciences Series. №1 (13) (2024). ISSN 2788-7995 (Print) ISSN 3006-0524 (Online). C.54-62. DOI: 10.53360/2788-7995-2024-1(13)-8.

7) R.A. Sovetbayev, G.M.Kudaybergenova, Y.Z. Nugman. Problems of nanostructuring of blanks and their solution by methods of intensive plastic deformation. Bulletin of Shakarim University. Technical Sciences Series. №1 (17) (2025). ISSN 2788-7995 (Print) ISSN 3006-0524 (Online). C. 329-335. [https://doi.org/10.53360/2788-7995-2025-1\(17\)-42](https://doi.org/10.53360/2788-7995-2025-1(17)-42).

International scientific and practical conferences: 8) R.A. Sovetbayev, Y.Y. Shayakhmetov. Investigation of the features of known technological processes for the production of wire products: an overview. International Scientific and Practical Conference «Promising areas of the agricultural and food industry». ISBN 978-601-313-178-8. C.293-298.

Personal contribution of the author. All stages of the research were carried out by the author personally. The author independently analyzed literary and patent sources on the topic, formulated the purpose and objectives of the work. The experimental part (carrying out plastometric tests of alloy 6082 on the Gleeble 3800 installation, as well as rolling bars on an experimental three-roll radial shear mill) was performed personally by the author or with his direct participation. The author carried out the formulation and implementation of numerical modeling of the rolling process in the Forge NxT 2.1 environment, performed a series of calculations, processed the results, as well as metallographic analysis of deformed samples, measuring their hardness and other properties. All the main results submitted for defense were obtained with the direct participation of the author, publications and reports were prepared based on the materials of the dissertation. Thus, the personal contribution of the dissertation is reflected at all stages of the research – from setting the task to interpreting the results.

The volume and structure of the dissertation. The dissertation is presented in Kazakh and includes an introduction, four chapters, a conclusion, a list of sources used and appendices. The work consists of 112 pages, contains 66 figures, 6 tables and a list of 125 references.