INVESTIGATION OF MICROSTRUCTURE AND ENERGY-POWER PARAMETERS IN THE SIMULATION OF A NEW TECHNOLOGY FOR THE PRODUCTION OF HARDENED SCREW FITTINGS

Sergey Lezhnev[1], Abdrakhman Naizabekov[1], Andrey Tolkushkin[1], Evgeniy Panin[2], Alexandr Arbuz[3], Dmitry Kuis[4], Pavel Tsyba[5]

[1]*Rudny Industrial Institute, 50 let Oktyabrya str. 38 Rudny, 111500, Kazakhstan*
[2]*Karaganda Industrial University, 30 Republic Ave. Temirtau, 101400, Kazakhstan*
[3]*AEO Nazarbayev University, 53 Kabanbay Batyr Ave. Astana, 010000, Kazakhstan*
[4]*Belarusian State Technological University 13a Sverdlova str., Minsk, 220006, Belarus*
[5]*LLP "Promtech Perspective", 7/2 Prigorodnaya str. Karaganda, 100000, Kazakhstan*
E-mail: sergey_legnev@mail.ru

Received 19 July 2023
Accepted 10 November 2023
DOI: 10.59957/jctm.v59.i1.2024.22

ABSTRACT

The paper presents the results of a study of the microstructure and energy-power parameters of a new technology for obtaining hardened screw fittings by finite element modeling in the Deform program. To simulate the microstructure evolution, the Cellular Automata method was chosen, which allows to estimate the size and shape of grains. The analysis of the microstructure evolution on the surface and in the axial zone of the rod at various stages of deformation showed that at large values of compression, the deformation in the rolls has the main influence on the processing of the structure, at small values - in the matrix. With an initial grain size of 60 microns in one deformation cycle, the final size is 2-3 microns on the surface of the rod. With a decrease in compression in the rolls, the processing of the axial zone is significantly reduced. At the same time, in all the models considered, the gradient distribution of grain size is preserved along the cross-section of the rod. The analysis of axial forces in the matrix showed that the force values for all models are approximately at the same level of 5 - 7 kN.

Keywords: simulation, combined process, microstructure, Cellular Automata, load.

INTRODUCTION

The production of bar metal, especially rebar profile, is one of the most popular rolling production technology. So, for many years, the shape rolling mill of JSC ArcelorMittal Temirtau has been producing only fittings of different diameters, fully fulfilling its technological plan. This profile is very popular due to its use in a number of industries, such as residential construction, car building, shipbuilding, etc. At the same time, when creating new large or mini-productions of metal products, preference is given to energy- and resource-saving technologies. The most effective are the methods of metal forming, which in one deformation cycle allow to achieve a level of metal processing that was previously achieved only after several cycles.

The development of such energy-efficient technologies is associated with a number of difficulties, the main of which is the comprehensive study of all classical pressure treatment processes. A possible solution to this problem is to create new deformation schemes that include two or more simple metal forming processes. Such processes are called combined, because in them the deformation zones of simple processes are going sequentially one after another, or are combined into one common deformation zone. The effectiveness of such combined processes has been repeatedly proven by both theoretical works and experimental studies [1 - 5].

However, at the stage of developing such deformation schemes, there is a problem of studying the shape change, the parameters of the stress-strain state and other metal forming criteria. The use of analytical calculation methods is often too time-consuming task due to the complex metal flow. In this case, the use of the finite element method is an ideal option, which makes it possible to comprehensively assess all parameters of the deformation process.

With the development of modern software solutions for the implementation of computer modeling of metal forming processes, more tools appear that allow deeper study of the influence of technological parameters of processing processes and tools on the workpiece. One of such solutions is modeling the microstructure evolution occurring in the workpiece. For example, the Deform software package has two modules that allow this to be done: Johnson-Mehl-Avrami-Kolmogorov (JMAK) method [6] and the discrete lattice method implemented using the Cellular Automata algorithm [7, 8]. Based on the analysis of the simulation results from these studies, the Cellular Automata method was chosen in this study to simulate the microstructure evolution.

EXPERIMENTAL

Earlier, when studying the parameters of the stress-strain state, the necessary parameters to ensure the successful process of obtaining a reinforcing profile by the combined process of radial shear rolling and pressing were determined [9]. When modeling the microstructure evolution to obtain a reinforcement profile for all models, the following parameters were taken: the distance of the matrix from the forming rolls is 1 mm; the friction coefficient on the rolls is 0.7, in the matrix is 0.1, the temperature of the workpiece is 1100°C. The initial size of the workpiece and the length of the matrix were chosen as the variable parameters. As a result, the following models were obtained:

- length of the matrix 50 mm and compression in rolls from 24 to 19 mm (model A);
- length of the matrix 33 mm and compression in rolls from 22 to 19 mm (model B);
- length of the matrix 33 mm and compression in rolls from 24 to 19 mm (model C).

The value of 60 microns was taken as the initial grain size (Fig. 1). The dimensions of the window for modeling were taken 150 x 150 microns for the correct display of the initial grain size. The microstructure was studied at two points - on the surface and in the axial zone after the workpiece leaves the rolls and the matrix (Figs. 2 - 5). This choice of points was made in order to study the effect of deformation in the rolls and in the matrix on the processing of the cast structure in cross-section, as well as to assess the uniformity of grain size distribution across the cross-section.

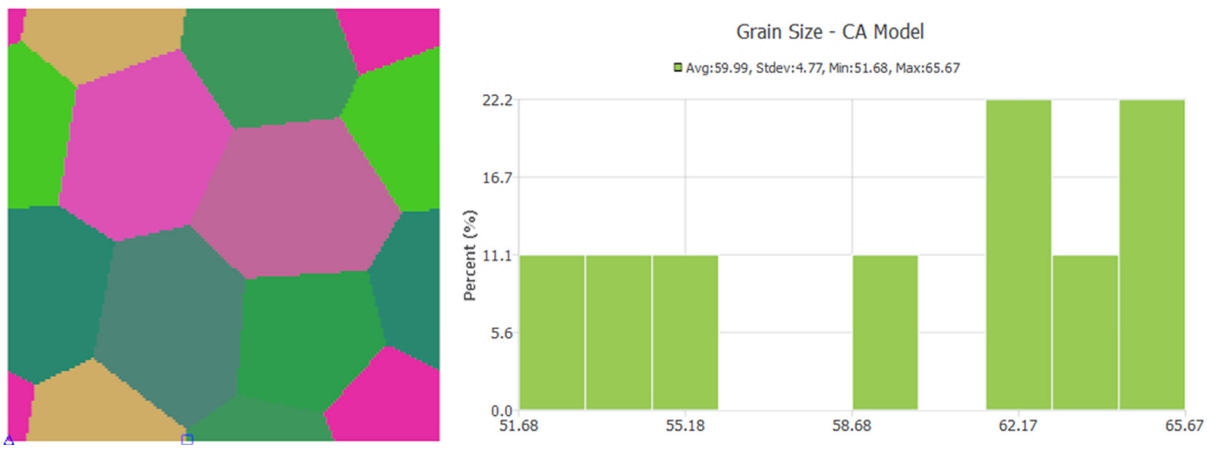

Fig. 1. Initial grain size.

RESULTS AND DISCUSSION

Fig. 2 shows the change in the microstructure on the surface after exiting the rolls. Since models A and C at this stage of deformation have the same geometric parameters, the processing of the cast structure has a similar character. The average grain size in these models was 2.36 microns and 2.28 microns for models A and C, respectively. Comparing the histograms of the grain size distribution, it can be seen that they also have a similar character and the structure is processed out fairly evenly. A slightly different nature of the study has model B, in which the processing of the cast structure occurs less intensively in comparison with the other two models due to the fact that in this case the workpiece receives a lower level of processing due to less compression in the rolls. The average grain size was 9.19 microns. And as can be seen from Fig. 2 and the histogram, although

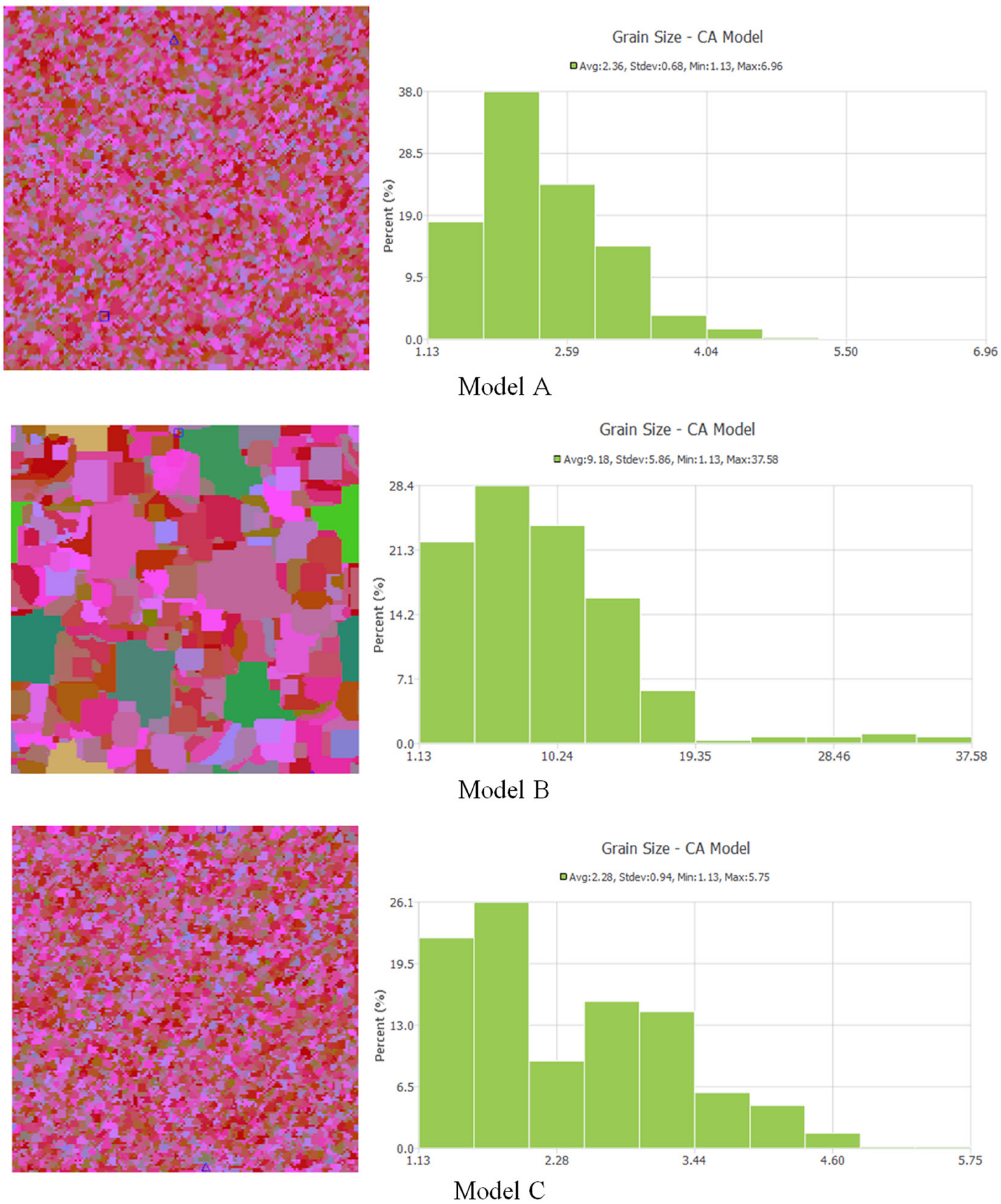

Fig. 2. Change of microstructure on the surface after deformation in the rolls.

the proportion of small grains occupies a larger volume, there are still quite large grains.

Fig. 3 shows the change in the microstructure in the axial zone after deformation in the rolls. For models A and C, the situation is similar with a change in the microstructure on the surface, although in this case the grain sizes in the axial zone in model A have slightly larger values than in model C, which were 4.53 microns and 3.2 microns, respectively. From the data of the histograms of the grain size distribution, it can be seen that there are sufficiently large grains in the axial zone of the workpiece after radial-shear rolling and their share occupies a significant value. In model B, the processing of the cast structure occurs less intensively due to a lower degree of deformation, as in the case of grain size changes on the surface of the workpiece. The average grain size was 21.26 microns.

Comparing the change in the microstructure on the

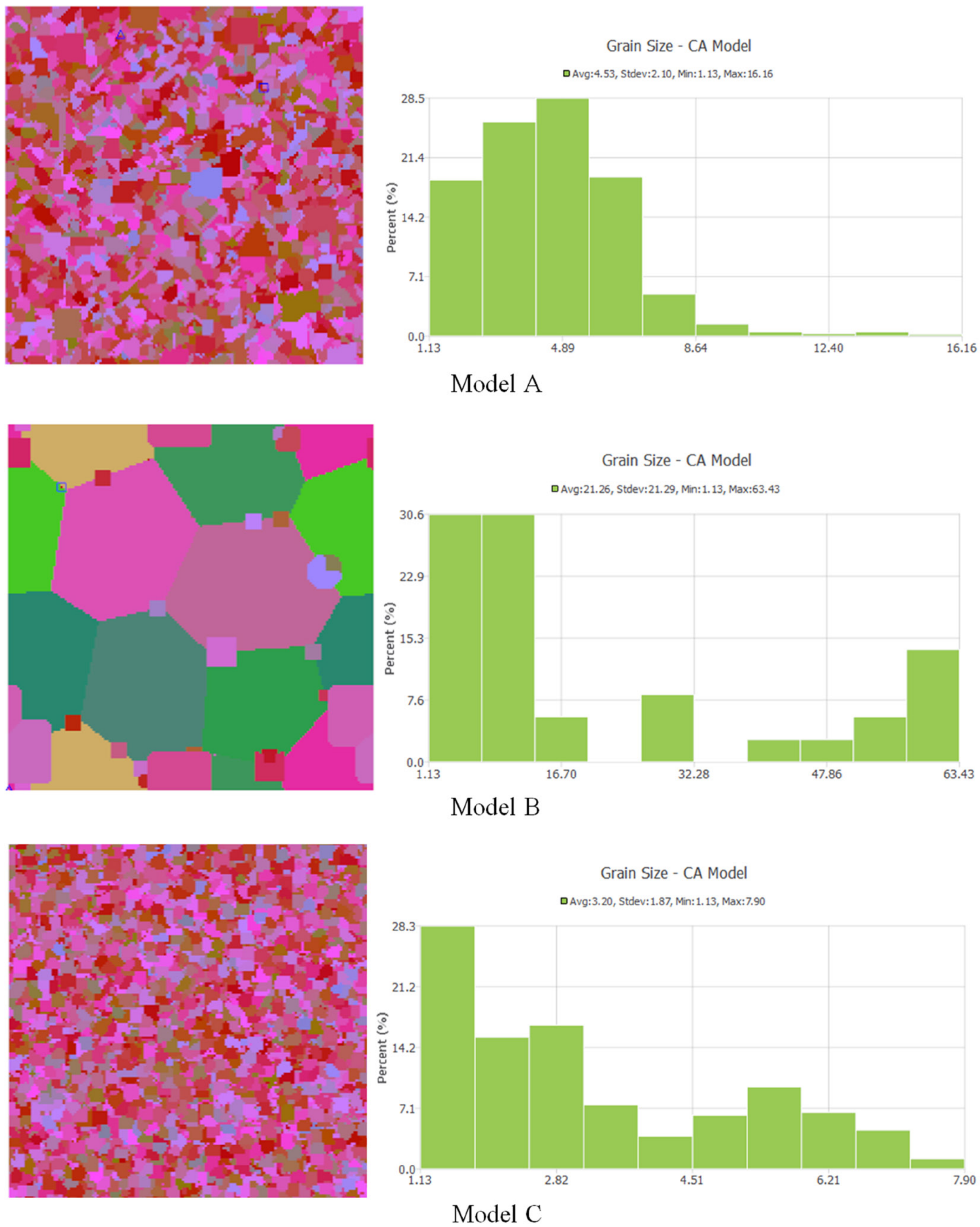

Fig. 3. Change of microstructure in the axial zone after deformation in the rolls.

surface and in the axial zone after radial-shear rolling, the following conclusion can be done: due to the fact that the workpiece in the contact zone with the rolls undergoes greater deformation than in the axial zone, the processing of the initial structure occurs more intensively. As a result, a gradient distribution of grain size is created along the section of the workpiece.

After deformation in the matrix, the following microstructure evolution on the surface can be seen (Fig. 4): in all three models, the level of structure processing is approximately at the same level, the average grain size was 2.61 microns, 2.59 microns and 2.16 microns for models A, B and C, respectively. In addition, according to histograms on the surface, the proportion of grains smaller than 1 micron occupies a larger percentage. If we compare the grain size after deformation in the rolls and after deformation in the matrix, it can be seen that in the case of model B, the most intensive processing

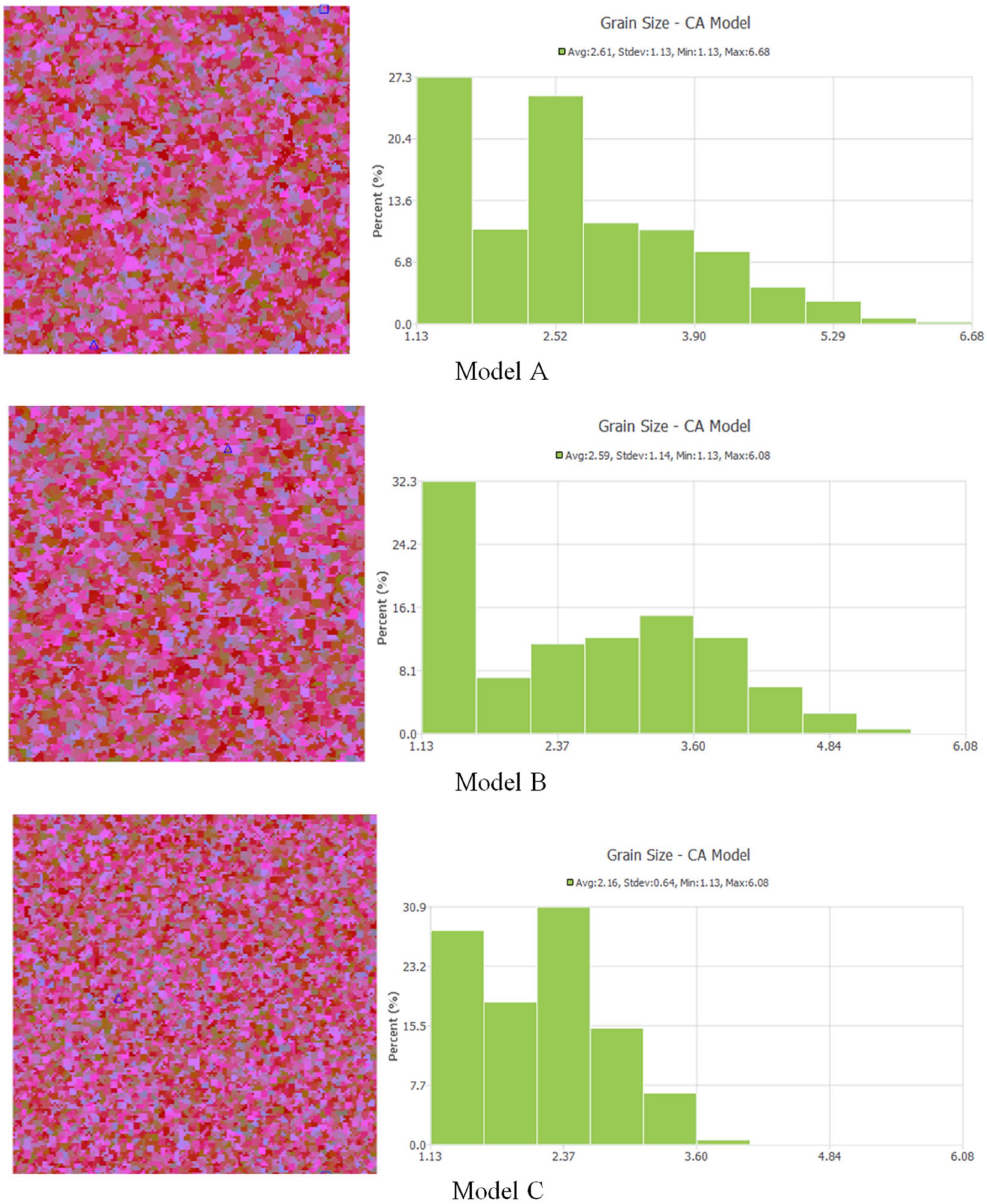

Fig. 4. Change of microstructure on the surface after deformation in the matrix.

of the structure takes place, bringing the grain size to the same level with models A and C. Thus, it can be concluded that in order to obtain a reinforcing profile by a combined method of radial-shear rolling and pressing, the main deformation in the matrix plays a role in the formation of a fine-grained structure.

Fig. 5 shows the results of the microstructure evolution in the axial zone after deformation in the matrix, from which it can be seen that deformation in the matrix positively affects the processing of the structure in the axial zone for models A and C, reaching almost the same level of processing as for surface layers after deformation in rolls, with an average grain size of 2.74 microns and 2.19, respectively. For Model B, the deformation in the matrix has the greatest effect, the average grain size was 2.79 microns, which is several orders of magnitude less than after deformation in the rolls.

A comparative analysis of the microstructure

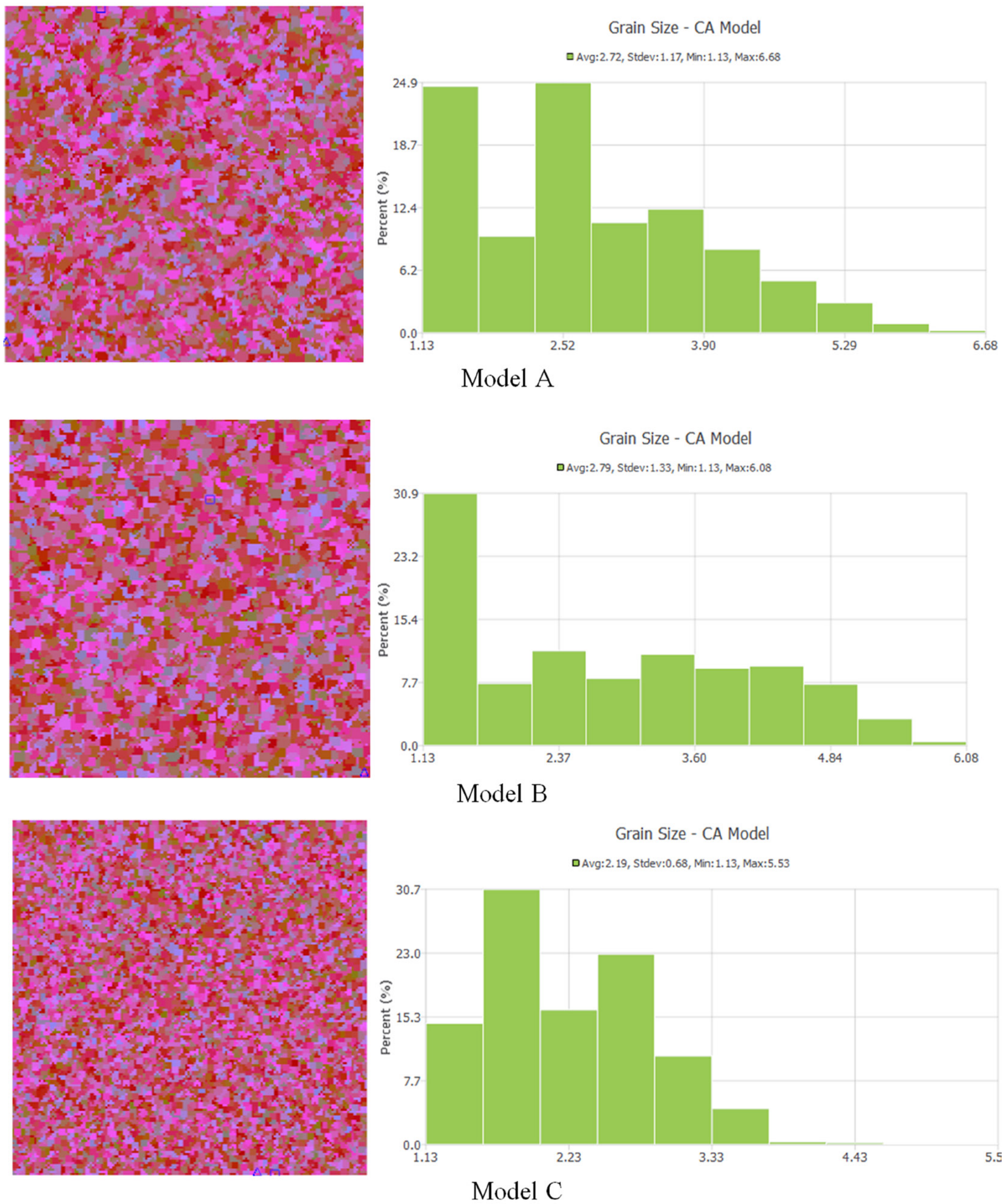

Fig. 5. Change of microstructure in the axial zone after deformation in the matrix.

evolution after deformation in the rolls and in the matrix allows to make the following conclusions: in the surface layers of the workpiece for models A and C, the main processing of the structure is carried out precisely after radial-shear rolling due to large compression values, but after deformation, the proportion of small grains in the matrix increases and their distribution on the surface is more uniform. For model B, the situation is reversed - after deformation in the rolls due to a small degree of compression in comparison with other models, the main processing of the structure is carried out by deformation in the matrix, bringing the degree of study of the structure to the same level with models A and C. In the axial zone, the processing of the initial structure does not occur so intensively, since the main feature of the radial-shear rolling process is the intensive processing of the surface layer. After deformation in the matrix due to its structural features, the deformation penetrates to the axial zone, thereby increasing the level of structure processing in this area. However, the average grain size values here remain larger than on the surface, which allows to conclude that the gradient structure along the section of the workpiece is preserved.

In addition to analyzing the microstructure evolution, the values of axial forces arising from the deformation of the workpiece in the matrix were also compared. Fig. 6 shows a graph of the forces that arise in the axial zone of the matrix for models A, B and C, from which it can be seen that for models B and C, due to the design features of the matrix at the initial stage of deformation, the values of axial forces are higher than in the case of model A. The situation is leveled at the moment when the workpiece completely fills the channel matrices for all models. The maximum values of axial forces on the matrix for models B and C are approximately the same and equal to about 7 kN, whereas for model A the maximum force value is about 5 kN.

CONCLUSIONS

Analysis of the microstructure evolution on the surface and in the axial zone at various stages of deformation showed that with large values of compression, the deformation in the rolls has the main influence on the structure processing, with small values - in the matrix. Also, the deformation in the matrix has a major effect on the uniformity of the microstructure in the zones (surface and axial), while maintaining a gradient pattern of grain distribution over the cross-section of the workpiece. The analysis of axial forces in the matrix showed that the values of forces for the compared models are approximately at the same level.

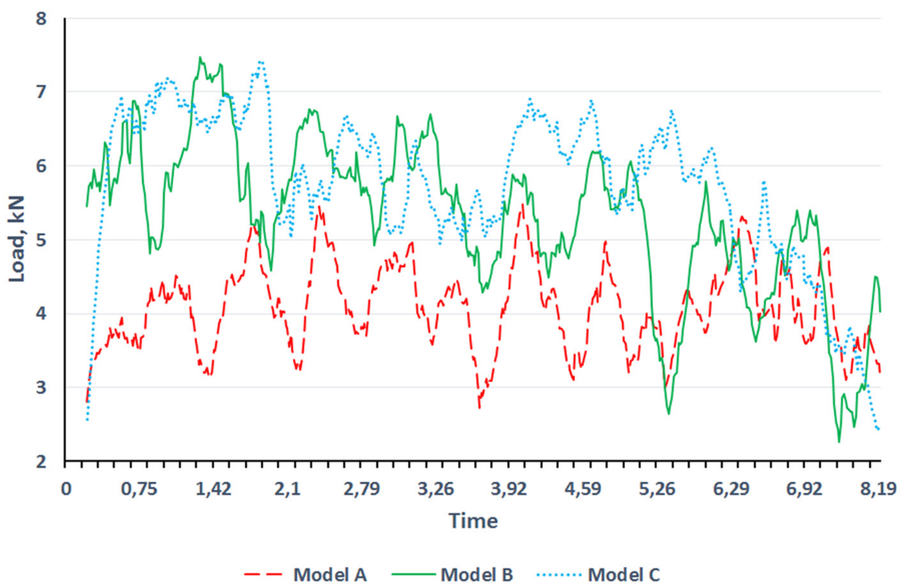

Fig. 6. Graph of axial forces during deformation in the matrix.

Only at the initial stage, when the workpiece is just beginning to fill the matrix channel, due to the design feature, a greater axial force acts on the shortened matrix, but when the matrix channel is fully filled, the situation is leveled.

Acknowledgements

This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14869135).

REFERENCES

1. A.A. Ershov, Y.N. Loginov, N.N. Zagirov, E.V. Ivanov, Simulation of the Consolidation of a Porous Material in a Combined Rolling-Extrusion Process, Metallurgist, 60, 5-6, 2016, 561-565.
2. C. Xu, S. Schroeder, P.B. Berbon, T.G. Langdon, Principles of ECAP-Conform as a continuous process for achieving grain refinement: Application to an aluminum alloy, Acta Materialia, 58, 4, 2010, 1379-1386.
3. I. Volokitina, A. Volokitin, A. Naizabekov, S. Lezhnev, E. Panin, Microstructure of bimetallic wire in the “ECAP-drawing» process, J. Chem. Technol. Metall., 56, 4, 2021, 857-866.
4. A. Naizabekov, S. Lezhnev, A. Arbuz, E. Panin, Combined process “helical rolling-pressing” and its effect on the microstructure of ferrous and non-ferrous materials, Metallurgical Research & Technology, 115, 2, 2018, 213.
5. A. Naizabekov, S. Lezhnev, E. Panin, T. Koinov, Theoretical grounds of the combined “rolling - equal - channel step pressing” process, J. Chem. Technol. Metall., 51, 5, 2016, 594-602.
6. T. Furu, K. Marthinsen, E. Nes, Modeling Recrystallization, Materials Science and Technology, 6, 1990, 1093-1102.
7. H.W. Hesselbarth, I.R. Gobel, Simulation of Recrystallization by Cellular Automata, Acta Metallurgica et Materialia, 39, 1991, 2135-2143.
8. R. Ding, Z. Guo, Microstructural modelling of dynamic recrystallization using an extended cellular automaton approach, Computational Materials Science, 23, 1, 2002, 209-218.
9. S. Lezhnev, A. Naizabekov, E. Panin, A. Tolkushkin, D. Kuis, A. Kasperovich, R. Yordanova, Development and Computer Simulation of the New Combined Process for Producing a Rebar Profile, Modelling and Simulation in Engineering, 2023, 2023, 7348592.