The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 32, Pages 137-141

IConTES 2024: International Conference on Technology, Engineering and Science

Studying the Microstructure Evolution by Various Methods in the Development of New Combined Deformation Processes

Yevgeniy Panin
Karaganda Industrial University

Gulzhainat Akhmetova
Karaganda Industrial University

Aibol Esbolat
Karaganda Industrial University

Abstract: When studying the microstructure, the key parameters for the researcher are the size and shape of metal grains after one or another mechanical or thermal treatment. When developing a new technological process, one of the main tasks is to predict and possibly control the microstructure, which ultimately will allow to obtain products with specified properties. The paper presents the results of finite element modeling of the microstructure evolution obtained during the development and research of new metal forming processes "rolling-ECAP" with vertical and horizontal rolls and "ECAP-Linex", which are combined schemes of two discrete deformation processes. JMAK and Cellular Automata methods were used to model the microstructure. It is shown that both methods give good convergence results. At the same time, the use of the Cellular Automata method gives an advantage over the JMAK method in obtaining data not only on changes in grain size, but also its shape – in the longitudinal direction, the grains receive a slight elongation due to the advance when metal is captured by rolls or chain conveyor elements.

Keywords: Finite element modeling, Microstructure evolution, JMAK, Cellular automata

Introduction

In recent years, there has been a tendency to develop so-called "combined" metal forming processes, which are a combination of two or more conventional deformation processes. The main feature of combined metal forming processes is that often, when they are implemented, the disadvantages of conventional metal forming processes that are included in the combined process are reduced or completely eliminated. Also, recently, more and more attention has been paid to energy-saving technologies based on the use of active friction forces for deformation. Based on the analysis of these processes, the following new concepts of combined processes were proposed:

1) the combined ECAP – Linex process for continuous pressing of non-ferrous metals and alloys, the key difference from the classic Linex process will be the possibility of deformation without significantly changing the initial dimensions of the workpiece. Here, the workpiece is fed to the device, where movable tape blocks capture the workpiece and push it through the channels of the fixed matrix. Each belt gripping unit is mounted on two pulleys, one of which is idle, and the other is driven by an electric motor. It is due to this that the tape gripping blocks are set in motion. The horizontal forming of the tape gripping blocks is created due to their movement along the workpiece and fixed locking blocks that perform a clamping role. To reduce the deformation force, grease is applied to the walls of the fixed die, while there is no lubricant supply to the moving parts in order to increase the gripping ability.

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

2) the combined rolling-ECAP process with combined rolls. The usual "rolling-ECAP" deformation scheme with horizontal rolls, despite all its advantages, has one drawback. With multi-cycle deformation according to this scheme, the workpiece will be compressed several times in height, which as a result will lead to a significant change in the size and shape of the initial cross-section, which is often undesirable, and sometimes a negative factor. Therefore, this scheme has been improved by replacing the second pair of horizontal rolls with vertical rolls. Thus, after leaving the matrix, the workpiece will receive compression not in height, as before, but in width. As a result, the change in the shape and size of the cross section will not be as intense.

During investigation of new deformation process a comprehensive study using computer modeling by the finite element method is recommended to estimate the parameters of the deformation process. With this method, the researcher has much wider opportunities to study the parameters of the process. In particular, it becomes possible to study various parameters at any point of the workpiece and tool, analyze their values for exceeding permissible limits, which makes it possible to assess the possibility of various defects on the workpiece or the probability of failure of the deforming tool.

The purpose of this work was to study the evolution of the microstructure of the AD31 aluminum alloy during deformation by the ECAP-Linex method, described by Panin et al. (2023) and the combined rolling-ECAP method with vertical and horizontal rolls, described by Panin et al. (2024). The value of the channel junction angle in the matrix was chosen 140°. The rheological properties of aluminum alloy AD31 were taken from the Deform material database for the nearest analog (alloy 6063).

Method

The study of the evolution of the microstructure was also decided to be carried out at two points (in the center and on the surface). The most effective way in this case would be to model the microstructure using Cellular Automata (CA). The key feature of this algorithm is the ability to predict not only the grain size, but also their shape. A detailed description of the calculation mechanism using cellular automata is presented in Hesselbarth (1991). The initial average grain size is used as the initial data for the calculation in this algorithm. In addition, several model coefficients should be introduced, the values of which depend on the nature of the material being processed. The official documentation of the DEFORM system presents a number of coefficients of the CA model, including for aluminum alloys. The value of 20 μm was taken as the initial grain size in the calculation. To display the structure during the calculation, the parameters of the 50 x 50 μm window were set.

When calculating the rolling-ECAP process model with combined rolls, the JMAK model, described by Fanfoni et al. (1998) was used. To use this method, it is necessary to initially calculate a model with the specified parameters of the initial grain size. By default, the model assumes an even distribution of the initial grain size over the entire volume of the workpiece. The initial grain size of the aluminum alloy AD31 was assumed to be 100 μm. Taking into account the variation in the values of the heating temperature and the circumferential speed of the rolls, the following models were built:

1) with a workpiece heating temperature of 100°C and a circumferential speed of rolls of 60 rpm;
2) with a workpiece heating temperature of 100°C and a circumferential speed of rolls of 35 rpm;
3) with a workpiece heating temperature of 20°C and a circumferential speed of rolls of 60 rpm;
4) with a workpiece heating temperature of 20°C and a circumferential speed of rolls of 35 rpm.

Results and Discussion

Figure 1 shows the initial structure and after each deformation cycle of ECAP-Linex process in both studied zones. After carrying out one deformation cycle, it was found that the initial grain is crushed to 6-7 μm in both zones. However, a slight elongation of the grains in the longitudinal direction was recorded on the surface. This is the result of both the rolling stage (where, along with compression, the workpiece receives a significant level of elongation) and the pressing stage in the matrix, where the surface layers receive a certain level of extraction due to an increased level of adhesion to the conveyor links. In the second and third cycles, the workpiece received a lower compression level of 1.5 mm, which was quite sufficient, since initially a matrix with an increased channel junction angle and, as a result, with a reduced back pressure level was used. After the second deformation cycle, the structure is crushed to 2-3 μm in both zones. On the surface, the level of grain pulling becomes more noticeable. After the third deformation cycle, the structure is crushed to 1 micron in both zones, individual grains have a size of 0.8-0.9 μm. On the surface, the grains become strongly elongated.

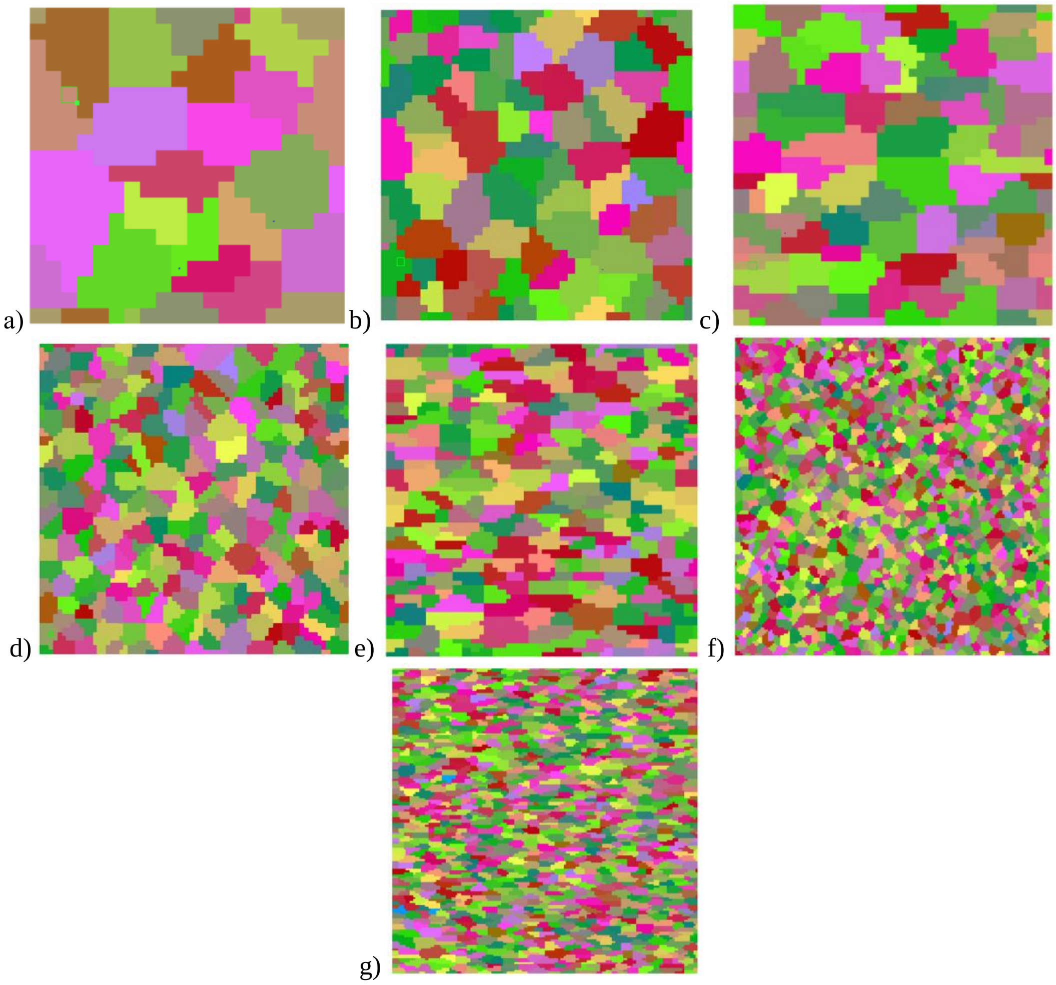

Figure 1. Structure in multi-pass modeling using the ECAP-Linex method: a – initial; b – 1st cycle, center; c – 1st cycle, surface; d – 2nd cycle, center; e – 2nd cycle, surface; f – 3rd cycle, center; g – 3rd cycle, surface

When analyzing the rolling-ECAP process model with the parameters "100°C / 60 rpm", it was revealed that after one deformation cycle, the initial grain size of 100 μm is refined to 40 μm (Figure 2). At the same time, it should be noted that modeling the microstructure in this way has one distinctive feature – the grain size distribution pattern over the volume of the workpiece is similar to the distribution pattern of equivalent deformation in inverse dependence, i.e. the higher the deformation level at a given point, the lower the grain size value. Accordingly, the minimum grain size of 40 microns is observed in the central zone after leaving the second pair of rolls. On the surface, the grain size is slightly higher, about 47 μm.

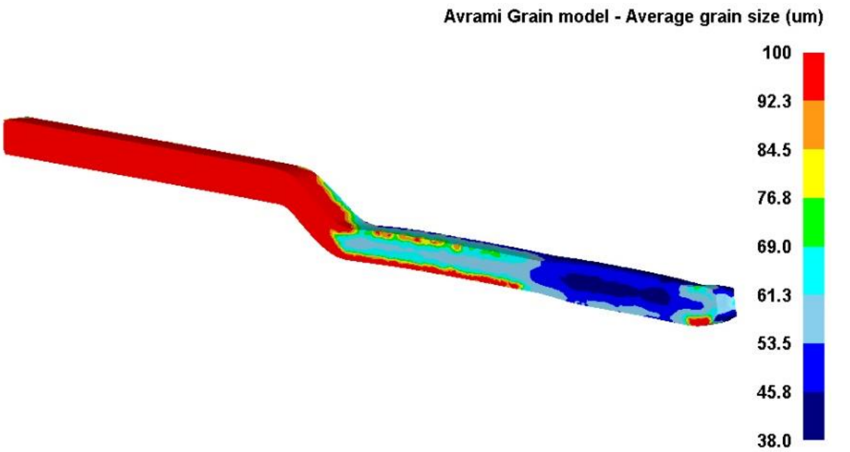

Figure 2. Microstructure evolution according to the JMAK method in the rolling-ECAP process model with parameters "100°C / 60 rpm"

After calculating the model with the parameters "100°C / 35 rpm", it was found that after one deformation cycle, the initial grain size of 100 μm is refined to 49 μm in the central zone and to 55 μm on the surface (Figure 3). After calculating the model with the parameters "20°C / 60 rpm", it was found that after one deformation cycle, the initial grain size of 100 μm is refined to 51 μm in the central zone and to 59 μm on the surface (Figure 4). After calculating the model with the parameters "20 °C / 35 rpm", it was found that after one deformation cycle, the initial grain size of 100 μm is refined to 53 μm in the central zone and to 63 μm on the surface (Figure 5).

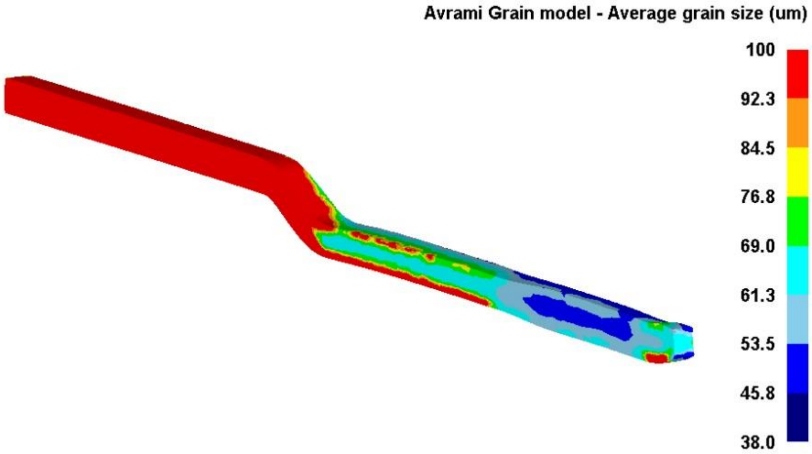

Figure 3. Microstructure evolution according to the JMAK method in the rolling-ECAP process model with parameters "100°C / 35 rpm"

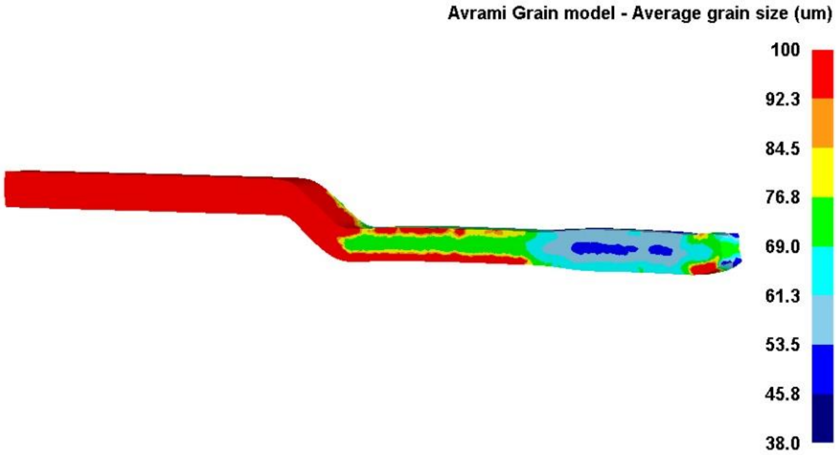

Figure 4. Microstructure evolution according to the JMAK method in the rolling-ECAP process model with parameters "20°C / 60 rpm"

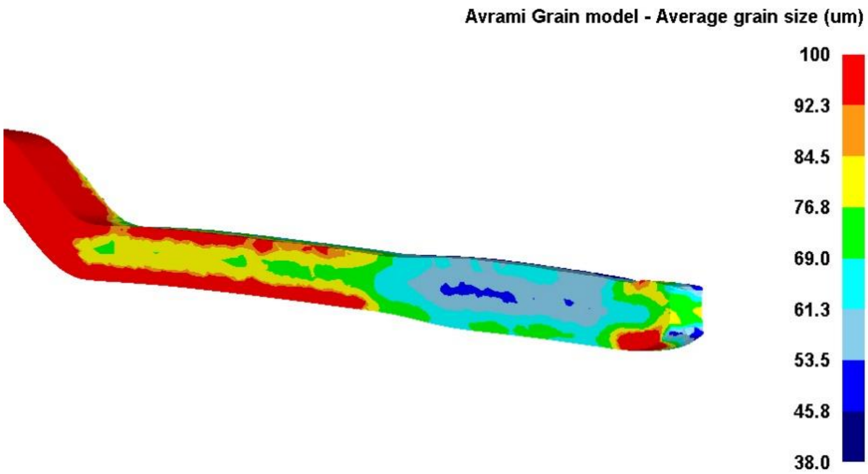

Figure 5. Microstructure evolution according to the JMAK method in the rolling-ECAP process model with parameters "20°C / 35 rpm"

Conclusion

In this section, finite element modeling of the evolution of the microstructure of the combined rolling-ECAP process with combined rolls and ECAP-Linex was carried out using JMAK and Cellular Automata methods. An analysis of the microstructure evolution of the rolling-ECAP process showed that the most optimal option is a model in which the workpiece was heated to 100 °The deformation was carried out at a circumferential speed of the first pair of rolls of 60 rpm. At the same time, options with a single temperature reduction to 20°C or a deformation rate of up to 35 rpm also give good results in grain grinding, only slightly inferior to the basic model in the intensity of grinding. As a result of multi-pass modeling, it was found that using the combined ECAP-Linex deformation method, it is possible to obtain an ultrafine-grained structure after at least three deformation cycles. The difference in the shape of the grains in the thickness of the workpiece indicates the gradient factor of the structure. At the same time, using the Cellular Automata method gives an advantage over the JMAK method and obtaining data not only on changes in grain size, but also its shape.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 14-17, 2024.

* This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant № AP13067723).

References

Fanfoni, M., & Tomellini, M. (1998). The Johnson-Mehl-Avrami-Kolmogorov model: A brief review. *Nuovo Cimento della Societa Italiana di Fisica D - Condensed Matter, Atomic, Molecular and Chemical Physics, Biophysics, 20*(7), 1171-1182.

Hesselbarth, H.W., & Gobel, I. R. (1991). Simulation of recrystallization by cellular automata. *Acta Metallurgica et Materialia, 39*(9), 2135-2143.

Panin, E., Volokitina, I., Volokitin, A., Naizabekov, A., Akhmetova, G., Lezhnev, S., Tolkushkin, A., & Esbolat, A., Yordanova R. (2023). Finite element modeling of ECAP-linex combined process of severe plastic deformation. *Modelling and Simulation in Engineering, 2023*, 1573884.

Panin, E., Volokitina, I., Volokitin, A., Naizabekov, A., Akhmetova, G., Lezhnev, S., Tolkushkin, A., & Esbolat A. (2024). FEM simulation of rolling-pressing process with horizontal and vertical rolls. *Tehnički Vjesnik, 31*(6), 1805-1814.

Author Information

Yevgeniy Panin
Karaganda Industrial University
Republic 30, Temirtau, Kazakhstan
Contact e-mail: *ye.panin@tttu.edu.kz*

Gulzhainat Akhmetova
Karaganda Industrial University
Republic 30, Temirtau, Kazakhstan

Aibol Esbolat
Karaganda Industrial University
Republic 30, Temirtau, Kazakhstan

To cite this article:

Panin, Y., Akhmetova, G., & Esbolat, A. (2024). Studying the microstructure evolution by various methods in the development of new combined deformation processes. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 32*, 137-141.