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Computer Modeling and Study of the Influence of Pre-Heat Treatment and Radial-Shear Rolling on the Evolution of the Structure of 5KHV2S Steel

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Abstract: An increase in the properties of various metals and alloys can be achieved by refining their microstructure using intensive plastic deformation and/or various heat treatment modes. Currently, a few studies have been conducted to identify the effect of radial shear rolling on the evolution of the microstructure and changes in the mechanical properties of bars made of various ferrous and non-ferrous metals and alloys. This paper is devoted to the study of the influence of various modes of pre-heat treatment of 5KHV2S steel on the evolution of its microstructure during subsequent radial-shear rolling using computer modeling in the DEFORM software package. The conducted studies have shown that under the selected modes of pre-heat treatment, although the initial grain size increased, the subsequent radial-shear rolling allowed the sludge to obtain a gradient fine-grained structure in 5KHV2S steel.

Keywords: Computer modeling, Pre-heat treatment, Radial shear rolling, Microstructure, Grain size

Introduction

It has long been proven that the development and application in practice of new methods for controlling the structural and phase state of traditional structural metal materials, even without changing their chemical composition, can improve their mechanical and functional properties. One of the main ways to increase the level of properties of various metals and alloys by refining their microstructure is severe plastic deformation, implemented during various methods of metal forming (Naizabekov et al., 2005; Puspasari et al., 2024; Volokitin et al., 2021; Grabovetskaya et al., 2022; Sidelnikov et al., 2024; Lezhnev et al., 2017), and heat treatment (both preliminary and final). Combining these two technologies into a single technological scheme should make it possible to intensify the process of grain refinement of the structure (Naizabekov et al., 2024).

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The technology of radial shear rolling has been successfully applied for more than 25 years. Many scientific papers have proved that this method of deformation is one of the main methods of gradient modification of long products made of ferrous and non-ferrous metals and alloys. Only a small part of the papers (Gamin et al., 2020; Mishin et al., 2020; Akopyan et al., 2022; Patrin et al., 2020) is devoted to the study of the effect of radial-shear rolling on the evolution of the microstructure and changes in the properties of various ferrous and non-ferrous metals and alloys. However, there are not so many works devoted to the direct study of the effect of radial-shear rolling on changes in the structure and properties of tool alloy steels. The aim of this work is computer modeling and study of the influence of various modes of pre-heat treatment of 5KHV2S steel on the evolution of its microstructure during subsequent radial-shear rolling.

Method

To perform computer modeling of the processes of pre-heat treatment (PHT) and subsequent radial-shear rolling (RSR) of samples made of 5KHV2S steel, it was decided to use the cellular automata mechanism [13] version 2.0, implemented in the Deform v. 13 system. This mechanism allows not only modeling grain size changes, but also predicting its shape during deformation or heat treatment. Since after preliminary heat treatment steel 5KHV2S will be subjected to several passes at the radial shear rolling mill RSP 10-30 of Karaganda Industrial University, a rod of circular cross-section with a diameter of 30 mm and a length of 150 mm was set as the initial blank. For 5KHV2S steel, the following PHT modes were selected:

- heating up to 880°C, exposure time for 35 minutes, cooling with a furnace (annealing № 1);
- heating up to 880°C, exposure time 35 minutes, air cooling (annealing № 2).

To create a model of microstructure evolution during pre-heat treatment, only static recrystallization should be used. The key parameters of the cellular automata algorithm are input of model constants, whose values depend on the nature of the material. For most steels, the suitable values of the Cellular Automata 2.0 model constants are considered in (Azarbarmas, 2020; Kugler et al., 2004). Table 1 shows the values of these constants.

Table 1. Constants of the Cellular Automata 2.0 model

Material	G, $N/^{m2}$	b, m	γ, $J/^{m2}$	δD_{0b}, $м^{m3}/ s$	Q_b, kJ/mol	$A1_1$	n_1	Q_{def}, kJ/mol
Steel	$4{,}21\times10\text{-}1^{-10}$	$2{,}56\times10\text{-}10^{-10}$	0,625	$7{,}5{,}5\times10\text{-}1^{-15}$	110	$2{,}0{,}0\times10^{44}$	7,6,6	275

Results and Discussion

The essence of calculating the evolution of the microstructure by this method is reduced to using a ready-made, calculated model. At the selected points, calculation windows with a certain resolution are set, in which both the grain size and shape change is observed. Considering that the initial grain size was set to 55.0 microns, it was decided to choose a square window with a face size of 200 microns, so that it would be possible to track the full sizes of several grains before and after the PHT.

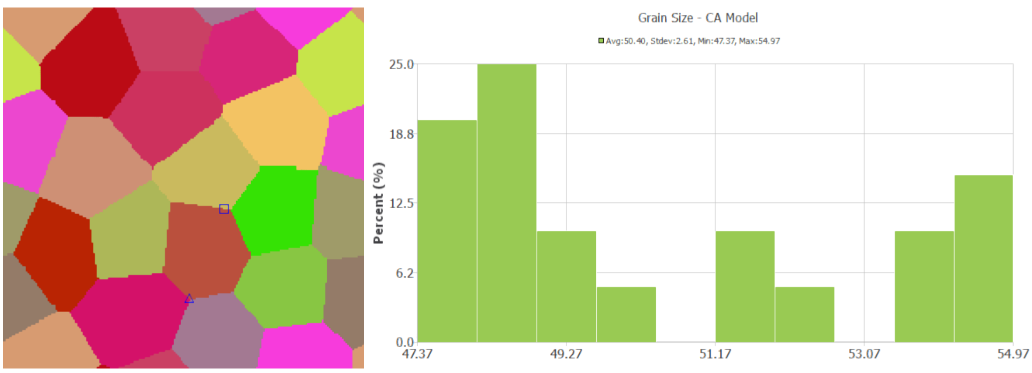

Figure 1. Initial structure

After two different PHT tests, the following results were obtained (Figure 2).

a)

b)

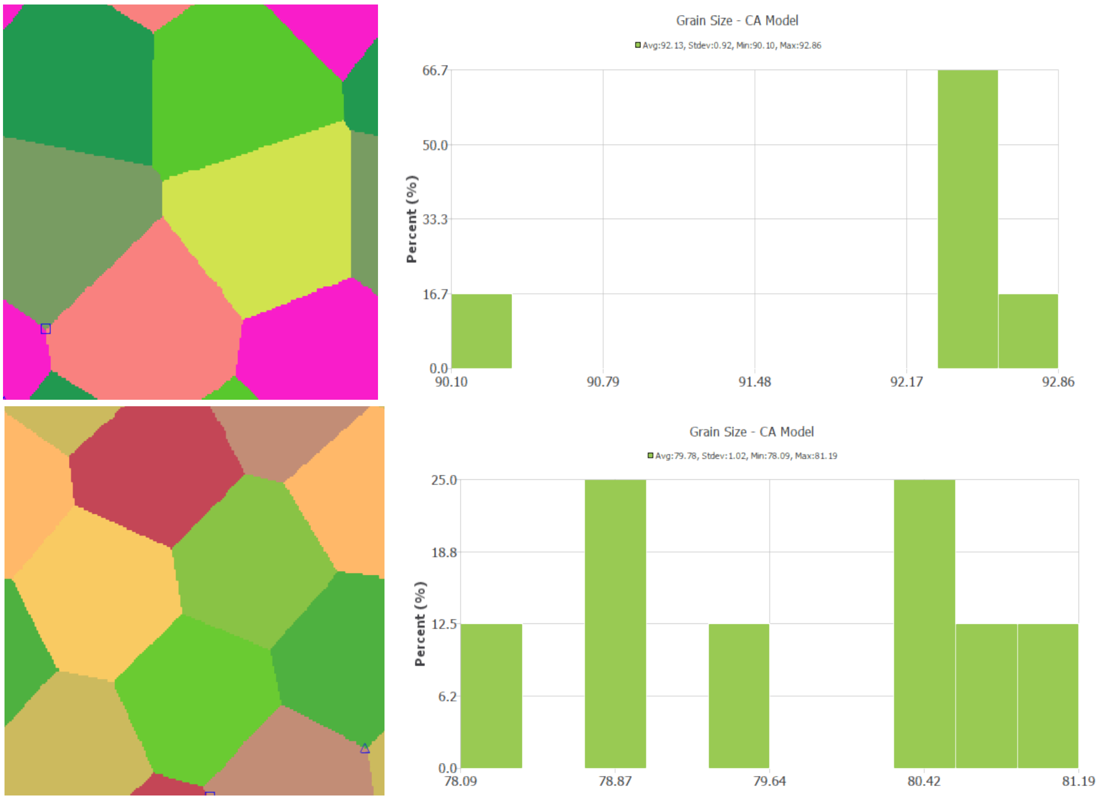

Figure 2. Structure of 5KHV2S steel after various technical tests:
a - after annealing № 1 b - after annealing № 2

After annealing № 1, the initial grain size of 5.0 microns increased to about 92 microns, while after annealing № 2, the initial grain size increased to about 80 microns. Based on the results obtained, it can be concluded that the most effective mode of PHT of the two selected ones is annealing № 2, which is heating to 880°C, holding for 35 minutes and then cooling in air.

When modeling the process of radial-shear rolling at the RSR 10-30 mill and studying the evolution of the structure, as already noted above, a billet with a diameter of 3.0 mm and a length of 150 mm was adopted. The deformation cycle consisted of 6 passes with a compression of 3 mm in each pass. The structure was studied after 3 passes, when the diameter of the resulting bar was 2.1 mm, and after all 6 passes, i.e., when the bar diameter was 12 mm. The structure obtained earlier after annealing № 2 was chosen as the initial state of the billet, since this mode allowed us to obtain a finer-grained initial structure. The roll rotation speed of 100 rpm was chosen as the speed characteristic. As a temperature characteristic, the heating temperature of the billet before rolling was chosen to be 1000°C.

It was decided to consider the microstructure in the longitudinal direction, since this approach gives a complete picture of the change in grain shape over the entire cross-section of the billet during radial shear rolling. To study the structure, two points were considered: in the axial zone and in the surface zone (at 3 mm from the surface). This is since experiments have repeatedly proved the presence of a gradient distribution of grain size and a significant difference in their shape along the diameter of the billet after the RSR. Figures 3-4 show the results of modeling the microstructure of 5KHV2S steel after 3 and 6 passes of RSR.

After annealing № 2 and three RSR passes, the average grain size was approximately 40 microns in the transverse direction and 57 microns in the longitudinal direction. In this case, in the transverse direction, the grain shape is close to equiaxial, and in the longitudinal direction, the grains are stretched in the rolling direction.

After annealing № 2 and six RSR passes, the average grain size was approximately 10 microns in the transverse direction and 35 microns in the longitudinal direction. In the transverse direction, the grains retain an equiaxial shape, and in the longitudinal direction, the grains are strongly elongated in the rolling direction.

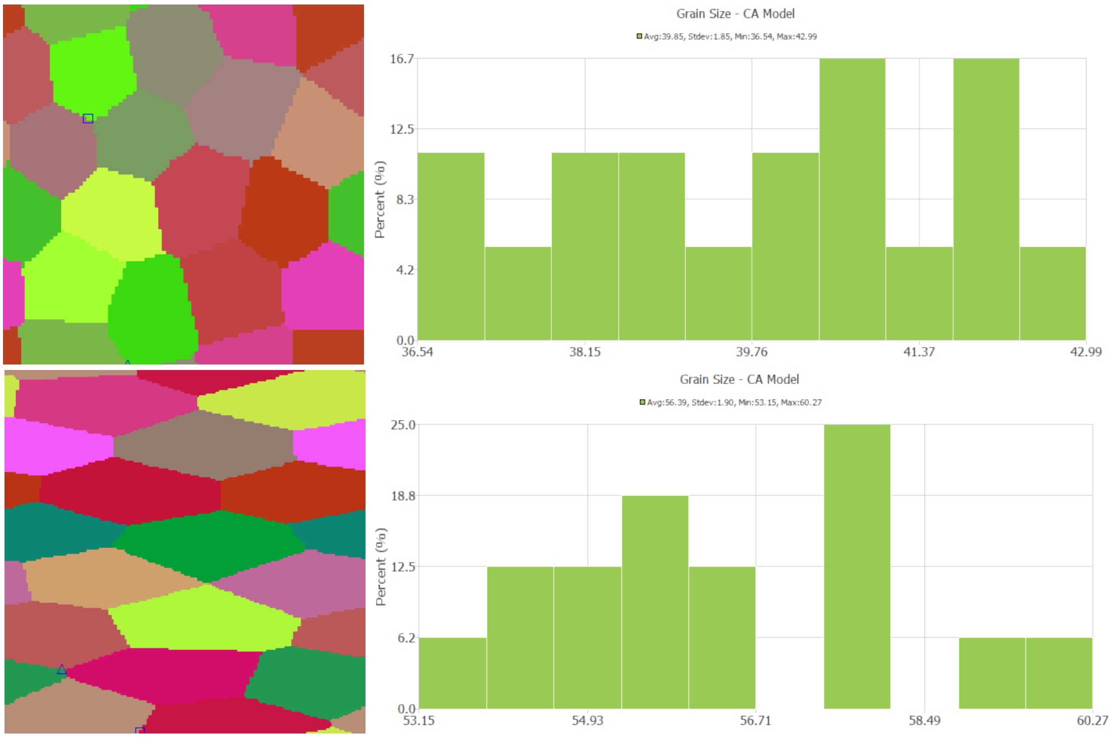

Figure 3. Structure of 5KHV2S steel after 3 RSR cycles
a – surface; b – center

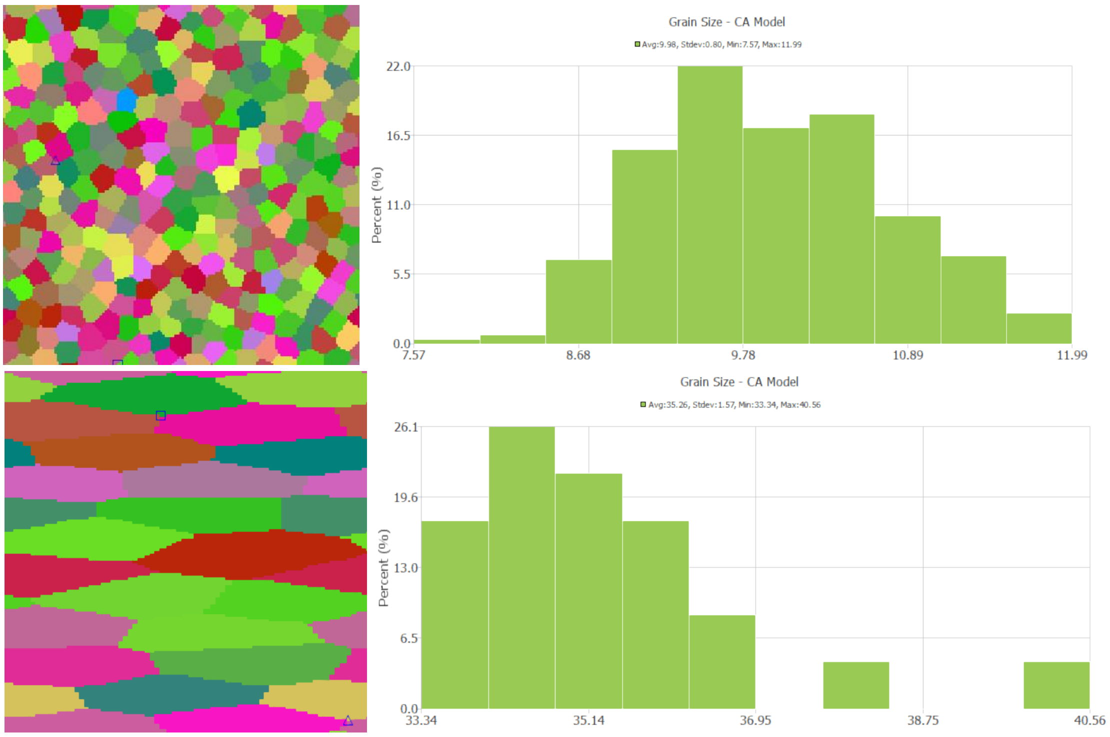

Figure 4. Structure of 5KHV2S steel after 6 RSR cycles
a – surface; b – center

Conclusion

The computer simulation of thermomechanical processing, including pre-heat treatment and subsequent radial shear rolling, of 5KHV2S steel showed that although PHT leads to the initial grain growth, the subsequent deformation of billets made of this steel in a radial shear rolling mill allows them to obtain a gradient fine-grained structure. The role of pre-heat treatment of 5KHV2C steel in practice - is in our case not to refine the initial grain size of the structure, but to remove internal stresses, and eliminate other defects in the steel, which during further pressure processing, in particular, during radial shear rolling, will allow deforming the initial billets with large compressions (50% or more) without destroying them and get metal products in the form of bars with a given level of properties.

Scientific Ethics Declaration

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

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