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Investigation of the Temperature Field during Radial-Shear Rolling of Technical Copper

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Abstract: Radial-shear rolling is one of the most promising methods of metal forming, allowing to develop a level of strain in the rolled bar sufficient to obtain an ultrafine-grained structure. At the same time, it has already been theoretically and experimentally confirmed that after metal processing by this method, a gradient distribution of grain size is observed in the cross section of the rod, which is a consequence of the laminar-turbulent flow of metal in the deformation zone. This work, carried out within the framework of grant №AP14869128, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, is devoted to the study of the temperature field during radial-shear rolling of M1 technical copper at an initial workpiece temperature of 20°C. To study the temperature distribution over the bar cross section, finite element modeling of radial-shear rolling of M1 technical copper was performed in the Deform program. A rod with a diameter of 30 mm and a length of 150 mm was set as the initial workpiece. It was decided to conduct three passes of radial-shear rolling with compression of 3 mm per pass. In addition to studying the temperature fields on the workpiece, the temperature distribution on the rolls was also considered. Analysis of the simulation results showed that the temperature distribution over the cross-section of the rod has a gradient character.

Keywords: Radial-Shear rolling, Gradient distribution, Simulation, Temperature, Rod

Introduction

Scientific works on obtaining high-quality metal with various methods of severe plastic deformation (SPD) are among the most cited publications in the world (Valiev et al., 2000; Valiev & Langdon, 2006; Sakai et al., 2014). The implementation of SPD due to the intensification of shear and alternating strains makes it possible to achieve the refinement of the initial structure to an ultrafine-grained state and obtain unique mechanical characteristics, which are sometimes paradoxical (Tsuji et al., 2002; Valiev et al., 2002). At the same time, the most well-known SPD methods – high-pressure torsion (HPT) and equal-channel angular pressing (ECAP) - allow deforming samples of limited geometric dimensions, which significantly reduces the possibility of using these methods on an industrial scale.

For the possibility of deformation of long-length samples, a number of ECAP-based combined processes have been developed, which also ensure the continuity of the process (Naizabekov et al., 2020; Naizabekov et al., 2019). However, their implementation requires the modernization of existing rolling or drawing equipment. From this point of view, the most promising SPD method for deforming long workpieces is radial-shear rolling, which has been studied in many works, including in recent years (Petrova et al., 2023; Lezhnev et al., 2023; Mashekov et al., 2021).

The main content of these studies is the influence of this method on the structure and properties of the processed material and the study of the stress-strain state. At the same time, very little attention is paid to such a factor as the distribution of temperature fields in the workpiece at various geometric and technological parameters of the process. This work is devoted to the study of this problem.

Method

The study of the temperature fields distribution in the workpiece during radial-shear rolling was carried out using FEM modeling in the Deform program. The parameters of the SVP-08 mill from the Rudny Industrial Institute were used as the geometry of the rolls. M1 copper alloy was chosen as the workpiece material at a temperature of 20°C. To study the influence of geometric and technological parameters of the process, it is advisable to vary their values. The following conditions were simulated:

1) The workpiece diameter was 30 mm, the rolls rotation speed was 100 rpm, compression is 1 mm;
2) The workpiece diameter was 30 mm, the rolls rotation speed was 100 rpm, compression is 1.5 mm;
3) The workpiece diameter was 30 mm, the rolls rotation speed was 50 rpm, compression is 1.5 mm;
4) The workpiece diameter was 20 mm, the rolls rotation speed was 100 rpm, compression is 1.5 mm.

The workpiece length in all models was equal to 100 mm, the friction coefficient at the contact of the workpiece and the rolls was equal to 0.5. The heat exchange coefficient of the workpiece with the tool was 5000 W /(m^2 • °C); the heat exchange coefficient of the workpiece with the environment was 0.002 W/(m^2 • °C).

Results and Discussion

To analyze the temperature distribution in the workpiece, a cross section was made at a distance of 50 mm from the front end. The temperature measurement was carried out at the moment of deformation of this section in the deformation zone of the rolling rolls. At the same time, the "point tracking" tool was used, measuring the temperature from the center of the workpiece to the contact zone of the metal with the roll.

When considering Model 1 with a workpiece diameter of 30 mm, a roll rotation speed of 100 rpm and a compression of 1 mm, an extremely uneven temperature distribution was noted over the entire section of the workpiece (Figure 1a). The center of the workpiece heats up to 32°C, while the surface zone heats up to 124°C, i.e. the temperature difference under these conditions is 92°C. For comparative analysis, this model was adopted as the basic one.

In Model 2, with an increase in compression in the rolls up to 1.5 mm (Figure 1b), a general increase in temperature was indicated in the entire section of the workpiece. The central zone of the rod heats up to 54°C, while the surface zone heats up to 191°C, i.e. the temperature difference under these conditions is 137°C. The general increase in temperature over the entire section of the workpiece is a direct consequence of an increase in absolute compression. However, the increase in the temperature difference between the center and the surface is due to a change in the kinematic parameters at the contact of the workpiece and the tool. Due to the fact that the rolls have a mushroom shape, with increasing compression, the length of the deformation focus also increases, while the metal receives a higher linear velocity.

All subsequent models had an increased compression value in rolls of 1.5 mm. When the rolls rotation speed decreased to 50 rpm (Model 3 – Figure 1b), a significant decrease in the temperature difference between the center and the surface was noted. With almost identical heating of the central area of the workpiece to 55°C, the surface of the workpiece in the area of contact with the rolls warmed up to 133°C, i.e. the temperature difference under these conditions is 78°C.

Thus, it can be said that the change in compression affects the temperature change over the entire workpiece section, and the change in rolls rotation speed affects the temperature change mainly in the surface layers. Also, these differences may be the result of the fact that when the compression changes, the configuration of the deformation zone in the rolls changes.

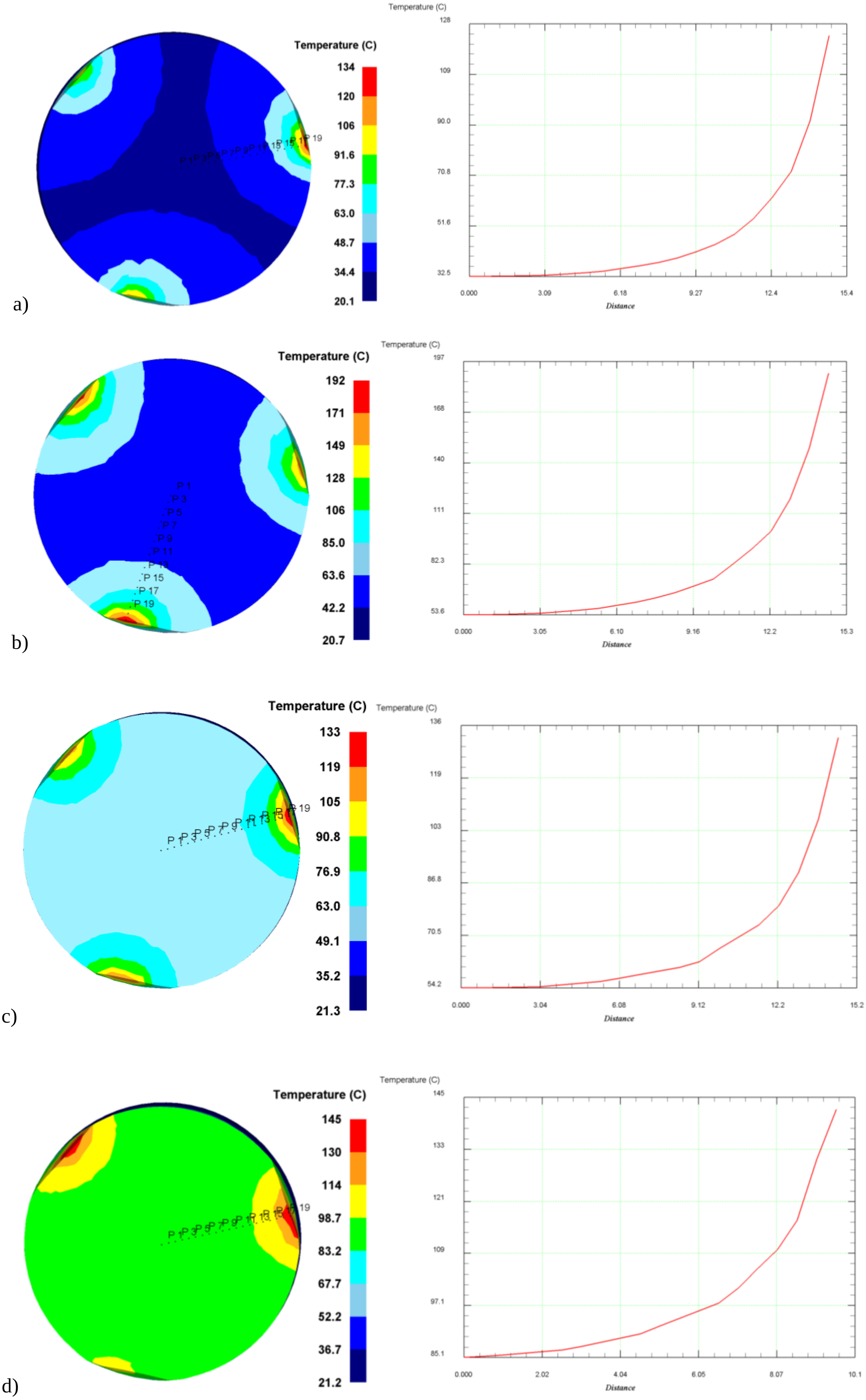

Figure 1. Temperature distribution in the workpiece section: a – model 1; b – model 2; c – model 3; d – model 4

To verify this statement, Model 4 was considered, where a workpiece of a smaller diameter of 20 mm was used to change the parameter of the deformation zone (Figure 1g). In this model, the center of the workpiece is heated to 85°C, while the surface zone is heated to 143°C, i.e. the temperature difference under these conditions is 58°C. A more uniform temperature distribution with increased compression and rotation speed of the rolls became possible due to the fact that due to a decrease in the initial diameter of the rolls, the location of the deformation zone on the radial-shear rolling mill shifts to a more gentle area of the rolls, where kinematic conditions are more uniform. It is this factor that makes it possible to obtain a sufficiently smooth surface of the workpiece without screw edges, even at high compressions.

Conclusion

The study of the temperature distribution in the workpiece during radial-shear rolling has shown that the overall temperature level and the nature of its distribution over the cross-section depend on both the geometric parameters of the process and the technological parameters. At the same time, it was noted that a change in the parameters affecting the change in the configuration of the deformation focus leads to a change in the temperature distribution gradient between the center and the surface. Information about these patterns will allow you to control the temperature change in the required conditions.

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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