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Investigation of the Efficiency of Reversible Radial-Shear Rolling to Obtain a Gradient Ultrafine-Grained Structure in 5KHV2S Steel

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Abstract: It has long been proven that radial-shear rolling has a number of advantages over other methods of pressure treatment, which allows obtaining an ultrafine-grained structure, including gradient, in various ferrous and non-ferrous metals and alloys. Therefore, radial-shear rolling plays an important role in the production of high-quality bars with an increased level of properties. This work, carried out within the framework of grant № AP14869135, funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, is devoted to the study of reversible radial-shear rolling of 5KHV2C steel and the identification of its influence on the possible gradient modification of the microstructure of this steel grade. In the course of experimental studies, it was proved that during the deformation of a bar made of 5KHV2C steel with an initial diameter of 36 mm, a gradient microstructure is formed along the cross section of the bar on a radial-shear rolling mill with an extraction equal to 4, i.e. up to a diameter of 18 mm. The cross-section structure of the bar varies from an elongated rolling texture in the central part of the bar to an equiaxed ultrafine-grained microstructure in the peripheral layers of the bar. The gradient character of the microstructure is also confirmed by the distribution of microhardness over the cross section of the bar: microhardness in the peripheral layers of the bar is on average 1.7 times higher than in the central part of the bar.

Keywords: Radial-Shear rolling, Gradient Ultrafine-Grained structure, Microhardness, Alloy steel, Rod

Introduction

One of the main methods of gradient modification of long products made of ferrous and non-ferrous metals and alloys is their deformation on radial-shear rolling mills (Galkin et al., 2021). The widespread development of such a method of deformation as radial shear rolling (Galkin et al., 2014) began in the early 90s of the last century under the leadership of S.P. Galkin and represents to some extent a previously known process, namely transverse-helical rolling according to a three-roll scheme (Galkin, 2014). The main difference of proposed schemes from the previously known scheme are an increased feed angle $\alpha = 18\text{-}20°$ (with a normal rolling angle $\beta = 5\text{-}7°$), which, firstly, contributes to the development of the strongest vortex deformation from the surface to the center, and secondly reduces the likelihood of tensile stresses in the axial part of the workpiece. Based on the proposed deformation scheme, a number of rolling mills for radial shear rolling of solid round blanks were developed and put into small-scale production by the research team under the leadership of S.P. Galkin.

Currently, a number of studies have been carried out to identify the influence of radial-shear rolling on the microstructure evolution and changes in the mechanical properties of bars made of various ferrous and non-ferrous metals and alloys. For example, the study of the influence of radial-shear rolling on the microstructure evolution and the change in the mechanical properties of technical titanium was presented (Nayzabekov et al., 2020). Also the influence of radial-shear rolling on changes in the structure and properties of aluminum was studied (Gamin et al., 2020; Stefanik et al., 2015). In a number of scientific papers the results of a study on the effect of radial-shear rolling on grain size changes and mechanical properties of austenitic stainless steel are presented (Naizabekov et al., 2021; Naizabekov et al., 2021).

It should be noted that radial-shear rolling can be used not only to produce ultrafine-grained long-length products from various ferrous and non-ferrous metals and alloys, but also to produce such products from various composite materials. The effect of radial-shear rolling on the formation of the structure and mechanical properties of aluminum matrix composite alloys of the eutectic type Al-Ni and Al-Ca was investigated (Akopyan et al., 2021).

The main purpose of this work, carried out within the framework of grant № AP14869135, funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, is to study the process of radial shear rolling of alloy steel 5KHV2S and to identify the influence of this deformation process on the possible gradient modification of the microstructure of this steel grade.

Method

To achieve this goal, a laboratory experiment using a radial shear rolling mill SVP-08 was conducted (Figure 1).

Figure 1. SVP-08 radial-shear rolling mill

The technical characteristics of SVP-08 radial-shear rolling mill are presented in Table 1. This mill is equipped with 3 rolls, the shape of which is shown in Figure 2. This form of rolls allows for the deformation of rods on the SVP-08 radial-shear rolling mill to ensure the reversible nature of the rotation of the rolls and to change the direction of metal movement in the rolling stand. This mill has two replaceable roll groups with different roll diameters, which ensure rolling of the initial billet up to a diameter of 8 mm. The material for the study was

5KHV2S steel after homogenizing annealing. For the experiment, blanks with a diameter of 36 mm and a length of 200 mm were prepared, which were heated to 1100°C in a Nabertherm R120/1000/13 tubular furnace with an exposure time of 36 minutes to equalize the temperature along the cross section.

Table 1. Technical characteristics of SVP-08 radial-shear rolling mill

Characteristic	Value
Rolling speed, mm/s	70
Rolls rotation speed, rpm	56
Torque on one roll, N·m	890
Force per roll, kN	100
Rolling angle, deg	7
Feed angle, deg	20
Taper gauge of roll groups, deg	8-12
Extraction coefficient	1,1-4,5
Workpiece length, mm	100-2000
Product length, mm	till 6000
Product diameter, mm	8-35
Product accuracy, %	till 1
Deviation from straightness (curvature), %	till 1
Productivity, t/h	0,1-2,0

The technology of rolling blanks made of 5KHV2S steel on a radial-shear rolling mill was as follows. The preheated workpieces are fed into the working cage of the rolling mill, in which it is compressed with an absolute compression step of 3.0 mm in diameter. After the workpiece has completely exited the cage, the rolls are arched and the direction of their rotation is switched. The workpiece is fed into the rolls in accordance with the scheme shown in Figure 2, in which it is compressed again with an absolute compression step of 3.0 mm in diameter. According to this deformation scheme, rods with a diameter of 18 mm and a length of about 800 mm were obtained from the initial blanks with a diameter of 36 mm and a length of 200 mm in 6 passes. The temperature of the workpieces during deformation was monitored using a CEM DT-9897 thermal imager. After the 6th rolling pass, the temperature of the workpieces lay in the range of 830-850°C.

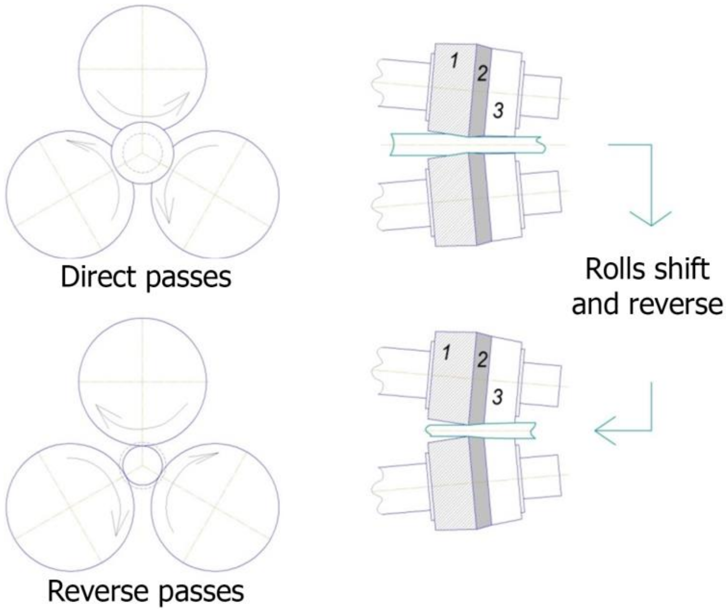
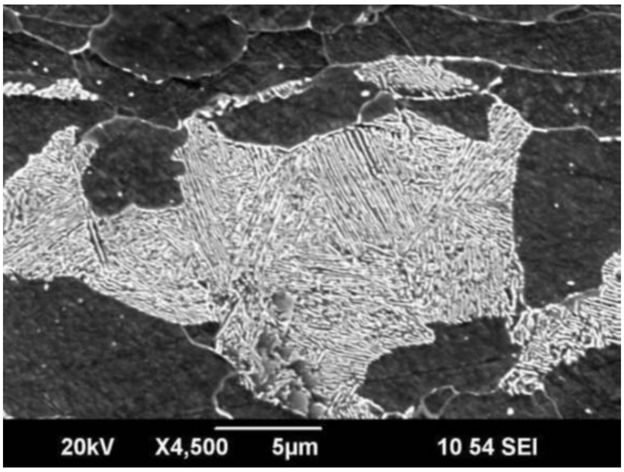


Figure 2. Radial-shear rolling scheme: 1 – crimping section for straight passes; 2 – calibration section for all passes; 3 - crimping section for reverse passes

Results and Discussion

Samples were cut from the initial bars and the bars obtained after rolling with a diameter of 18 mm and slots were made for metallographic studies and microhardness measurements. Microstructural analysis was carried out using a scanning electron microscope JSM-5610 LV, and the determination of the values of microhardness was carried out on a Duramin microhardness meter (Struers, Denmark) by the Vickers method with a load on the indenter of 10-2000 g, exposure time of 10 s. This analysis showed that the microstructure of the initial bars made of 5KHV2S steel, subjected to homogenizing annealing, represents a distribution of perlite about 63% and ferrite about 47% (Figure 3a).



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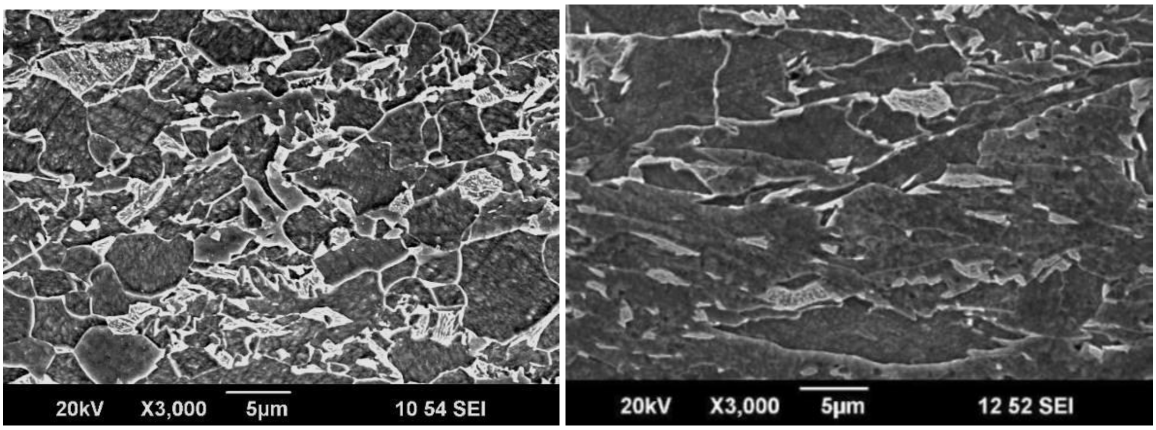

b c

Figure 3 - Microstructure of 5KHV2S steel after radial-shear rolling up to a diameter of 18 mm: a - initial, b – surface zone, c – central zone

The microstructural analysis of the diameter bars obtained at the radial-shear rolling mill showed that the initial grain size of steel 5KHV2S after rolling significantly decreased. At the same time, the microstructure of the peripheral zone of the bars formed at the radial-shear rolling mill has a predominantly equiaxial ultrafine-grained character with grain sizes of about 1.8-3.2 microns. In the central zone of the bars being formed, grains elongated in the direction of rolling are observed with dimensions lying in the range of 6÷10.5×1.1÷1.9 microns. Also, in order to confirm the gradient nature of the microstructure evolution along the cross-section of radial shear rods made of 5KHV2S steel formed on the mill, microhardness measurements were carried out along the cross-section of the rods. Analysis of the results of the study showed that the difference in microhardness values between the peripheral and central zone after the 6th pass showed that the microhardness in the peripheral layers of the bar is on average 1.17 times higher than the central part of the bar. At the same time, the highest value of microhardness was 265 HV (a point at a distance of 1 mm from the edge of the rod), and the minimum value was 224 HV at one of the points in the central zone of the rod.

Conclusion

In the course of the conducted research, the process of reversible radial-shear rolling of alloy steel 5KHV2S was studied and the possibility of obtaining a gradient ultra-fine-grained structure in alloy steel 5KHV2S during deformation at the SVP-08 radial-shear rolling mill was proved.

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 or Notes

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