Investigation of the structural state of pipe steel during thermo mechanical processing

S I Platov1,* , V A Nekit1, V N Urtsev2 and K B Maslennikov1

1Nosov Magnitogorsk State Technical University, 38, Lenin Street, Magnitogorsk city, Chelyabinsk Region, 455000, Russia
2Research and technology centre «Ausferr», Magnitogorsk city, Chelyabinsk Region, 455000, Russia

*psipsi@mail.ru

Abstract. The article is devoted to the research of the structural state of pipe steel during thermo mechanical processing on the line of the 5000 thick-sheet mill. The study of layer-by-layer structure formation depending on the temperature of the rolling end and the trajectory of accelerated cooling of the workpiece in the process line was carried out using theoretical thermodynamic methods. The technological parameters allowing to increase the dispersion of the microstructure and, accordingly, the strength characteristics of thick-sheet pipe steel are determined. It is revealed that the austenite grain is crushed due to the use of controlled rolling and the decay of a significant part of austenite in the temperature range of bainite transformation

1. Introduction
Consumer properties (strength, ductility, impact strength, cold brittleness) of steels are determined by the phase and structural state. The key task in developing new and improving existing technologies for the production of tube steels is to select a controlled rolling and heat treatment mode that ensures the necessary phase and structural state. Understanding the mechanisms that control the kinetics of austenite decay, the course of phase transformations and the formation of structures in steel is of great practical importance [1,2,3].

In most cases, high properties are achieved not as a result of isolation of equilibrium products of phase transformations, but due to the formation of certain metastable structures [1-2]. In low-carbon steels of classes X80-X100, high mechanical strength is provided due to the purity of the steel by impurities, the absence of perlite, the small size of the micro structural components and the optimal combination of all the mechanisms for strengthening the steel. Grinding of austenitic and ferritic grains is achieved by applying controlled rolling and performing the decomposition of a significant part of austenite in the temperature range of bainite transformation[4-8].

The construction of physically based models describing the processes of austenite decay and formation of the structural state can significantly speed up and reduce the cost of developing new steels.

The purpose of this work is to analyze the processes occurring during thermo mechanical processing of pipe steel on the line of the thick-sheet mill 5000 and develop mathematical models describing these processes.
2. Methodology
To obtain the best consumer properties of pipe steels, small micro structural components, the predominance of the bainite structure and its like are required. Of great importance is the content of bainite in the surface layers of the workpiece.

For model calculations of the final microstructure, the corresponding IT solution was used, developed by LLC ITC "Ausferr" (Magnitogorsk) in conjunction with Nosov MSTU and MMK PJSC’s 5000 sheet mill automated control system [9-14]. The model implements a phenomenological form of layer-by-layer prediction of structure formation depending on the temperature of the rolling end and the trajectory of accelerated cooling of the workpiece in the process line [15-19]. The initial data for the calculations were taken technological parameters of the production of pipe steel of the 06G2MB brand, corresponding to the standard strength class K60 [11]. The parameters of the accelerated cooling mode are shown in table 1.

| Table 1. Parameters of accelerated cooling mode |
| Parameter | Value |
| The thickness of the workpiece, mm | 21.6 |
| Temperature of end of rolling, °C | 820 |
| Speed at the accelerated cooling line, m/c | 1.994 |

3. Result and discussion
A number of calculations of the final workpiece microstructure were made for various parameters of accelerated cooling. Calculations have shown that the greatest influence on the distribution of the microstructural state and the overall dispersion has the speed of passage of the workpiece along the accelerated cooling line.

The greatest changes are observed in the upper surface of the sheet. When the speed of movement of workpiece decreases from 1.99 m/s to 1 m/s, the total increase in the bainite component is intended about 21% (Table.2, Fig. 1).

| Speed of accelerated cooling, m / s. | 1 | 1,1 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 | 1,8 |
| The content of ferrite and pearlite, % | 0.056 | 0.07 | 0.084 | 0.102 | 0.113 | 0.127 | 0.141 | 0.149 | 0.156 |
| The content of martensite, % | 0.035 | 0.03 | 0.027 | 0.025 | 0.022 | 0.021 | 0.02 | 0.019 | 0.017 |
| The contents of the lower bainite, % | 0.647 | 0.652 | 0.646 | 0.625 | 0.625 | 0.611 | 0.598 | 0.598 | 0.597 |
| The contents of the upper bainite, % | 0.262 | 0.248 | 0.244 | 0.248 | 0.24 | 0.24 | 0.242 | 0.235 | 0.23 |
| Total bainite content, % | 0.909 | 0.9 | 0.89 | 0.873 | 0.865 | 0.851 | 0.84 | 0.833 | 0.827 |

This increase is accompanied by an equivalent decrease in the proportion of ferrite/pearlite, which significantly increases the strength characteristics. The proportion of martensite remains relatively small (near 2%).

These results, in general, correlate with our studies of the microstructure and crystallographic texture of the results of a number of experimental production modes[2,3].
Figure 1. Effect of the workpiece speed of driving at the accelerated cooling line on the structural composition of the upper surface

The cooling mode of the workpiece lower surface is quite intense; the share of bainite on the lower surface of the workpiece was near 98%.

On the lower surface (Table 3), an increment of the bainite fraction is also observed, but by a smaller amount of near 8%.

| Speed of accelerated cooling, \( m / s \) | The content of ferrite and pearlite, % | The content of martensite, % | The contents of the lower bainite, % | The contents of the upper bainite, % | Total bainite content, % |
|------------------------------------------|--------------------------------------|-----------------------------|----------------------------------|----------------------------------|-------------------------|
| 1                                        | 0.001                                | 0.004                       | 0.969                            | 0.027                            | 0.996                   |
| 1.1                                       | 0.002                                | 0.003                       | 0.968                            | 0.027                            | 0.995                   |
| 1.2                                       | 0.004                                | 0.003                       | 0.965                            | 0.028                            | 0.993                   |
| 1.3                                       | 0.005                                | 0.003                       | 0.964                            | 0.028                            | 0.992                   |
| 1.4                                       | 0.007                                | 0.003                       | 0.962                            | 0.029                            | 0.991                   |
| 1.5                                       | 0.007                                | 0.002                       | 0.963                            | 0.028                            | 0.991                   |
| 1.6                                       | 0.009                                | 0.002                       | 0.959                            | 0.03                             | 0.989                   |
| 1.7                                       | 0.011                                | 0.002                       | 0.957                            | 0.03                             | 0.987                   |
| 1.8                                       | 0.011                                | 0.002                       | 0.957                            | 0.03                             | 0.987                   |

This is due to the high content of bainite in the initial state. The ferrite content also is decreased by an equivalent amount. The proportion of martensite remains insignificant. This dynamics of the content of micro structural components on the lower surface of the workpiece increases the strength characteristics of rolled products.

The average distribution of micro structural components over the entire thickness of the workpiece is changed slightly, but for the lower (more dispersed) bainite it increased by near 5% displacing the proportion of the upper bainite and ferrite / perlite by the corresponding amount. At the same time, the share of ferrite/perlite fell by near 2%.
This distribution and other results of calculations indicate a fairly significant degree of heterogeneity of the microstructure of the thick sheet in thickness. The average content of ferrite/perlite practically does not exceed 40% and the main share of it falls on the central layers.

4. Summary

Using the results of atomistic modeling and methods of theoretical thermodynamics, the analysis of physical processes occurring in the rolling workpiece during its passage through the technological line of thick sheet mill 5000 of MMK PJSC was carried out.

Controlling the workpiece speed of driving at the accelerated cooling line allows achieving a significant increase in the dispersion of the microstructure. Increasing the dispersion of the microstructure increases the strength characteristics of thick sheet workpiece. The use of methods for describing the influence of technological parameters on the formation of micro structural components allows you to adjust the technological process in order to increase its efficiency.

Acknowledgments

This work is carried out within a framework of the government order (No. FZRU-2020-0011) of the Ministry of Science and Higher Education of the Russian Federation.

References

[1] Olson G, New directions in martensite theory, Mater. Sci. Eng. 1999. V. A273-275. P.11-20.
[2] Cahn R W, Haasen P, Kramer E I, (ed.), Materials Science and Technology, Vol. 5, VCH Weinheim, New York, 1991I2.
[3] Razumov I K, Boukhvalov D V, Petrik M V, Urtsev V N, Shmakov A V, Katsnelson M I and Gornostyrev Yu N, Role of magnetic degrees of freedom in a scenario of phase transformations in steel, Phys Rev B 90, 094101 (2014)
[4] Razumov I K, Gornostyrev Yu N, and Katsnelson M I, Autocatalytic Mechanism of Pearlite Transformation in Steel, Phys Rev App 7, 014002 (2017)
[5] Shmakov A V, Salganik V M, Denisov S V, Gareev A R. Pustovoitov D O 2012 Complex modelling of controlled pipe billet rolling technology based on simulation of process temperature conditions Steel 2 42 - 46.
[6] Gareev A R, Shmakov A V, Murikov S A, Urtsev V N, Devyatov D K 2012 Creation of a software package for calculating the thermal state of metal in a hot-rolling line Metallurgist: Springer. New York 55 11 - 12 935 - 940.
[7] Gareev A R, Murikov S A, Platov S I, Urtsev V N, Shmakov A V 2015 Study of the possibilities of rolling equipment to achieve thermal conditions on the example of SSGP 2000 OJSC " MMK " Fundamental and applied research in the modern world: Proceedings of the X international scientific.. Conf. - St. Petersburg: Publishing house Future Strategy 1 30-34.
[8] Gareev A R, Murikov S A, Platov S I 2015 Investigation of the possibilities of rolling equipment to achieve thermal conditions on the example of ShPMHR 2000 OJSC " MMK " Fundamental and applied research in the modern world 10-1. 30-34.
[9] Platov S I, Nekit V A, Maslennikov K B 2020 Strength, ductility and impact toughness of tube steels after hot rolling IOP Conference Series: Materials Science and Engineering
[10] Platov S I, Nekit V A, Krasnov M L 2020 The mechanical properties of the pipe steel after rolling at the plate mill Solid State Phenomena
[11] Nekit V A, Platov S I, Krasnov M L, Urtsev V N, Ivanushkin M V 2018 Study of the microstructure of the pipe steel after rolling in the plate mill 5000 IOP Conference Series: Materials Science and Engineering. C. 12063.
[12] Platov S I, Nekit V A, Ogarkov N N, Zhelezkov O S 2016 Improving the cooling of wire rod mill 150 OJSC BMK Proceedings of the II international scientific-practical conference 206-210.
[13] Platov S I, Ogarkov N N, Nekit V A 2016 Improving the controlled cooling after wire rod rolling in the finishing block of stands Materials Engineering and Technologies for Production and Processing II, Editors: A. A. Radionov, G. G. Mikhailov, D. A. Vinnik 620-624.

[14] Platov S I, Nekit V A, Ogarkov N N, Zhelezkov O S 2016 Investigation of technology of accelerated cooling of wire rod on the wire mill processing of solid and layered materials 2 (45). 45-48.

[15] Gareev A R, Murikov A S, Platov S I, Utseyev V N, Shmakov A V 2016 Development of a mathematical model of heat release during phase transformations for industrial applications. manufacture of hire. 7. P 20-26.

[16] Utseyev V N, Khabibulin D M, Kaptston A V, Platov S I, Voronkov S N 2002 Method of production of cold rolled strips of ultra-low carbon steel Patent for invention RUS 2212457.

[17] Morozov A, Nikiforov B, Salganik V, Pesin A, Platov S. Trahtengertz E 2001 Mathematical modeling of plastic deformation process in section rolling Proceedings of the 7th international conference on numerical methods in industrial forming process/ Simulation of Materials Processing Theory, Methods and Applications. Numiform, Toyohashi, Japan.

[18] Kaptston F V, Fomichev A V, Pronin A A, Voznesensky A A 2006 Management system technology warehouse technology data Technology improvements at OJSC "MMK" Proceedings Central lab. OJSC "MMK" Magnitogorsk 10 378-389.

[19] Gareev A R 2015 Improvement of thermo mechanical modes of deformation of continuously cast slabs and design of the cooling line SHSGP in order to improve the quality Diss. on competition of a scientific candidate degree techn. sciences. Magnitogorsk 136