https://doi.org/10.52150/2522-9117-2022-36-240-253
UDC 622.7.003.13:669

V. L. Mazur, Cor. Member of the NAS of Ukraine, D. Sc. (Tech.), Professor

Physico-technological Institute of Metals and Alloys of the NAS of Ukraine

V. I. Tymoshenko, Cor. Member of the NAS of Ukraine, D. Sc. (Phys.-Math.), Professor, ORCID 0000-0001-8588-2468

Institute of Technical Mechanics of the NAS of Ukraine and the State Space Agency of Ukraine

I. Yu. Prykhodko, D. Sc. (Tech.), Senior Researcher, ORCID 0000-0001-5651-8106

Iron and Steel Institute of Z. I. Nekrasov National Academy of Sciences of Ukraine

IMPLEMENTATION OF CALCULATION METHODS IN A SPECIALIZED COMPUTER SYSTEM OF THE STRESS-DEFORMATION AND TEMPERATURE STATE OF STEEL STRIP COILS

Summary. The theory of formation and transformation of the stress-deformation and temperature state of rolls of hot-rolled and cold-rolled steel bars during their winding-unwinding in the processes of rolling, heat treatment, training, transportation, storage, and performance of other production operations at metallurgical plants has been developed. Mathematical models, algorithms and a computer system implementing them are proposed. A description of the possibilities of using this system when solving various tasks is given. In the computer system, an approach to assessing the influence of the parameters of the process of cold rolling and winding the stock into rolls, the temperature and speed regimes of their heating and cooling during annealing in hood furnaces is considered. For the first time, the methodology for identifying patterns of influence of inter-turn gaps in rolls on their stress-strain state was disclosed. The procedure for detecting the effects of cold rolling speed, temperature, tension of the rods rolled and wound into rolls, and their surface roughness on the stress-strain state of the rolls is shown. In detail, the implementation of new ideologies and approaches to solving the problem of determining the stress-strain state (STS) of rolls is shown in the computer system. Models and algorithms for calculating VAT, which are the basis of the computer system, are developed on the basis of classic solutions in the field of materials science, theories of elasticity, metal pressure treatment, heat engineering, gas dynamics, numerical methods and other fields of knowledge. The computer system revealed the mechanisms of forming the temperature and stress-strain state of rolls of steel bars in the processes of rolling, heating, isothermal aging and cooling during annealing in hood furnaces; the influence of the temperature and speed regimes of rolling and annealing on the occurrence of critical inter-turn pressures in the rolls, which lead to surface defects of the «bend line» (breaks) and defects in the shape of the rolls, is taken into account. The possibilities of influencing the VAT of rolls during rolling by adjusting the tension of the staffs, and during annealing by adjusting the duration of isothermal exposure and the rate of subsequent cooling of the rolls, are revealed. References to literary sources are provided, which detail the results of research on scientific and technical problems implemented in the computer system. In the computer system, methods of winding cold-rolled bars into rolls are used, which exclude the loss of their stability and the formation of «bends», subsidence, «bird» defects during the production of thin sheet steel in industrial conditions. Recommendations are given regarding the choice of a rational technology for the roll production of hot-rolled and cold-rolled sheet metal. The developed solutions are implemented in the «CoilTemper3D» computer system and are used in production.

Key words: metallurgy, steel, headquarters production, quality, rolls, stress state, calculations, algorithms, computer systems, defect prevention.

For citation: Mazur V. L., Tymoshenko V. I., Prykhodko I. Yu. Implementation of calculation methods in a specialized computer system of the stress-deformation and temperature state of steel bar coils. *Fundamental and applied problems of ferrous metallurgy*. 2022. Collection 36. P. 240-253. DOI: 10.52150/2522-9117-2022-36-240-253.

Introduction. Currently, the main method of producing thin-sheet steel at metallurgical plants is the roll [1]. The main task in the production of this metal product is to ensure its high quality, to prevent defects of hot-rolled and cold-rolled rods wound into rolls. The tendency of the development of sheet-rolled production is to increase the mass of rolls. When the weight of rolls increases, the importance of winding and unwinding operations increases, which are used at the technological intersections of sheet steel production and significantly affect the quality of finished products. At the same time, the stress-strain and temperature state of the staff steel rolls changes repeatedly. Accordingly, the relevance of the topic of theoretical and experimental research of the stress state of rolls and the implementation of effective technical solutions in production practice is increasing. The theory and technology of the roll method of thin-sheet steel production, the formation of the stress-strain state of cold-rolled stock rolls are discussed in detail in the monograph [2]. Given the high complexity of theoretical and practical problems in this topic, the issue of using numerical modeling methods in solving them requires special attention.

The formulation of the problem of determining the parameters of the stress and temperature state of the rolls proposed in works [3–5] made it possible to take into account the characteristics of the contacting surfaces of the coils, their non-planarity and roughness. Peculiarities are taken into account using the concept of generalized non-ideal contact introduced in work [6], which allows to take into account, on the one hand, the convergence of neighboring contacting surfaces as a function of inter-turn pressures [5], and, on the other hand, the temperature gap on adjacent surfaces under the conditions of common deformations surfaces of turns. The specificity of the task is determined by the fact that during cooling and heating of the roll, a variable temperature field occurs in it, which causes additional thermal stresses that can affect the stressed state of the roll. In turn, in the presence of thermal resistances on the adjacent surfaces of the turns, the values of which are largely determined by inter-turn pressures, the temperature change in the roll depends on its stress state. The interaction between the temperature and the elastic-deformed state of the rolls is significant. All this complicates the solution of the problem.

Numerical modeling methods are an effective means of overcoming the mentioned difficulties and reducing the costs of developing and optimizing technological devices and choosing rational modes of their operation. The use of numerical methods for modeling the processes of forming the stress-strain state of rolls of steel headquarters requires solving a large number of separate, rather complex problems, each of which, being part of a complex task, is also of independent interest [2]. At this stage, the purpose of research is to formulate physical and mathematical models that allow describing the technological process of winding, heating, and unwinding rolls with the completeness and accuracy necessary for practice. The goal is also the development of effective algorithms and the creation of software based on them, which allows you to perform calculations on existing computer systems with practically acceptable costs of machine time.

A component of the developed software-methodological support for calculations of the stress-strain and temperature state of rolls is a set of application programs that includes information about its purpose, structure, the possibilities of forming and memorizing the output data of the task for conducting current calculations and processing and storing their results. The complex of applied programs presented below is designed mainly for specialists working in the field of sheet-rolled production, who know the specifics of the technology of cold rolling, annealing, training, processing of thin sheet steel in rolls.

«CoilTemper3D» computer system for modeling the stress-strain and temperature state of cold-rolled stock rolls. Below is a set of «CoilTemper3D» programs, the use of which allows obtaining numerical solutions to the problems discussed above [2]. The «CoilTemper3D» program complex (figure 1) is a specific example of software that meets the above requirements.

The set of simulation modeling programs «CoilTemper3D» is designed to calculate the non-stationary thermal and stress-strain state of cold-rolled coils in the process of winding onto the winder drum, removing from the winder drum, heating and cooling the rolls at given heat transfer coefficients and temperature cyclograms of the high-temperature shielding gas in the hood furnace. Structurally, the «CoilTemper3D» program complex consists of two relatively independent parts. The first part of the complex includes application programs for the numerical determination of the stress-strain and temperature state of the rolls in the process of winding the rolls, removing them from the winder drum, heating in the hood furnace and cooling. Corresponding algorithms and computer programs are included in the «CoilTemper3D» complex in the form of executable EXE files. The programs of the first part are written in the algorithmic language Fortran. The solutions to the mentioned tasks and the analysis of the obtained results are presented in our publications [7–9] and monographs [2].

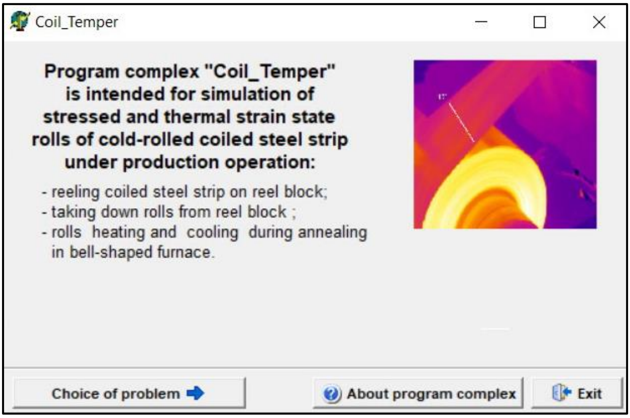

Figure 1 – Title window of the «CoilTemper3D» program complex.

The second part (service part) represents a set of visual components (window forms, text windows, command buttons, keys, etc.) and specially developed software. A window form is an appropriately decorated Windows window. These windows, together with the visual components placed on them, are a tool for selecting tasks, generating output data, comparing results, saving them and using them in Windows programs (Microsoft Word, Excel, etc.).

Window forms appear on the screen sequentially as necessary during the user's work with the program. Only the form that allows you to perform actions necessary for the current stage of work with the program is displayed and active on the screen. Switching to the next form (after performing all the necessary actions in the current form) or returning to the previous form (perhaps to make corrections) occurs after clicking on the corresponding buttons. Individual window forms are presented below the text as an illustration of the information presented. The functioning of window forms and other visual components is provided by programs written in the Object Pascal algorithmic language. In addition, the complex includes programs that implement algorithms for preparing output data files for the application program, based on the information entered by the user in the text windows, and also ensure the launch of the application program, visual presentation of the obtained results in the form of graphic dependencies, tables, etc. These programs make maximum use of Delphi integrated environment objects.

The complex is equipped with an extensive help system that provides the user with: information about its purpose and structure; a brief description of the physical and mathematical formulation of the problems to be solved; a description of the possibilities of forming and memorizing initial data, conducting current calculations, processing and storing calculation results. The service part of the complex ensures the user's work in an interactive dialog mode using terms and definitions from the subject area of the complex's purpose. As illustrations below the text, there are options for window forms that provide input data and individual calculation results.

The package of «CoilTemper3D» programs includes (figure 2):

- a program for calculating the stress state of cold-rolled rolls when they are wound on a winder drum [5, 10, etc.];
- a program for calculating the stress state of cold-rolled rolls after removing the roll from the winder drum and cooling [3, 4, etc.];
- a program for calculating the temperature field and inter-turn pressures and the tension of the turns of the roll during its heating and cooling in the hood furnace [7, 9].

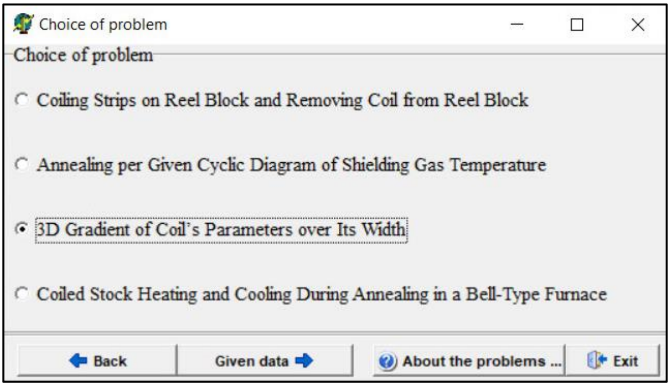

Figure 2 – Task window form of the task being solved.

Work order. The complex of programs works in an interactive dialogue mode using technical terms and definitions from the subject area of the complex's purpose. Practical work with the complex does not require the user to have any special training in the field of programming and to study special instructions for working with the complex.

The user's work with the complex is reduced to the following sequence of actions:

- task selection;
- assignment of the initial data of the task in accordance with their default

values presented by the prototype;

- starting a task on the account;
- selection of types of presentation of results from the list of types of problem solution processing proposed by the complex;
- presentation of the results of solving the selected problem on the monitor screen in the form of numerical or graphic information depending on the selected types of solution processing;
- comparison of the results with the previously obtained results of the selected problem with other initial data of the problem.

Determining parameters (figure 3)**.** The defining parameters of the task of calculating the stress-strain and thermal state of the rolls are:

- geometric parameters that specify the inner and outer radius of the roll, the thickness, width of the staff and the number of turns (at the same time, the theoretical weight and length of the staff in the roll are visualized); when setting the outer radius of the roll, the number of turns is automatically calculated and vice versa;
- parameters of winding the staffs into a roll: modulus of elasticity and Poisson's ratio of the material of the staffs, radial stiffness of the winder drum, the law of change of tension of the staffs during winding and rolling parameters (graph of the speed and temperature of the staffs during winding) [7–8, 10, etc.];
- thermophysical parameters and temperature (temperature and thermophysical parameters are set: thermal conductivity coefficient, thermal conductivity coefficient, initial temperature of the roll before the technological operation; gas heat transfer coefficients in the hood furnace, protective gas temperature cyclogram, heat transfer coefficients on the external, internal surfaces and from the ends are also specified roll) [9];
- parameters of the surface of the shafts (the dependence characterizing the convergence of the surfaces of the turns when the micro-uniformities of the surfaces of the shafts are crushed on the inter-turn pressure, the dependence of the value of thermal resistance on the pressure, the roughness of the surface of the shafts, as well as the temperature of the beginning of adhesion (welding) of the contacting surfaces of the turns of the shafts in the roll) [11–14];
- account management parameters (the first group of parameters: the time of the end of the technological process, the step of the marching account by time, the number of points along the radius of the roll and the number of sections along the width of the staff in the roll for calculating the temperature; the second group of parameters: the conditions for outputting results - the time step for printing of radial parameter distributions, the number of cycles between printing parameter dependences on time, step by turns for printing parameter distributions in the radial direction).

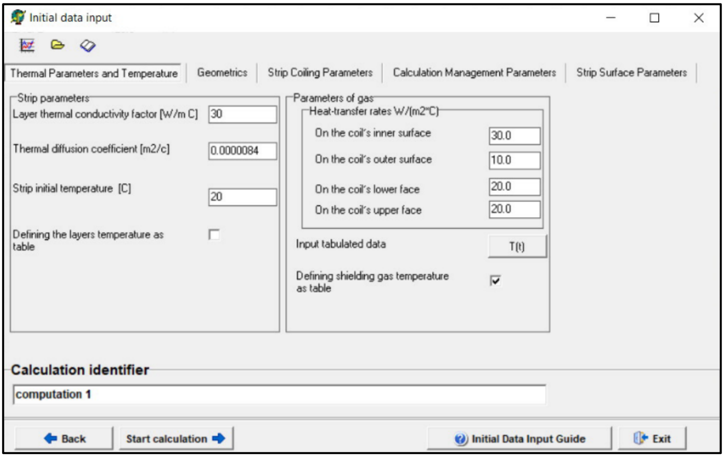

Figure 3 – The output data task window form.

The initial data is set in the tabs of the «Input of initial data» form. By default, the data entered in the corresponding text boxes are used. There is an opportunity during a new session of working with the program (when starting the program) to use the original data, based on which the last calculation was made in the previous session of working with the program. To do this, in the top menu on the form, click with the left mouse button on the yellow «opening book» icon.

As a result of the calculation, the following are determined [2]:

- inter-turn pressures and tangential stresses in the roll in the process of winding the staffs onto the winder drum;

- inter-turn pressure and tangential stresses in the roll after removing the roll from the winder drum;

- the temperature distribution of the coils along the radius of the roll and the width of the staff, the amount of thermal stress in the roll, taking into account the imperfection of thermal and mechanical contacts of the adjacent surfaces of the turns, due to the roughness of the surface of the staff;

- depending on the temperature of the cores at the characteristic points of the roll, as well as the maximum inter-turn stresses and predicted separation forces of the surfaces of the bonded (glued) contacting surfaces of the turns of the cores in the roll during annealing;

- predictive assessments of the conditions of setting, sticking and welding of coil turns during recrystallization annealing, depending on the temperature and duration of annealing, as well as the inter-turn pressure and the roughness of the core surface.

Parameters of winding staffs into a roll. The law of changing the tension of the staff during the coil is given in the form of a tabulated piecewise linear function. A constant value of the tension of the staff during winding is set. All voltages are assigned to this value as a scale: the tension of the shafts at the coil with a variable tension law and the calculated inter-turn pressures and tangential stresses. With variable tension, a table of tension values divided by the corresponding numbers of turns is specified. Linear interpolation is used to calculate the tension of the staff in the intermediate turns. To set tabular values, check the appropriate box on the form and enter tabular data.

Winding of staffs in rolling conditions with variable speed takes place in non-isothermal conditions. The roll has different winding temperatures. When the temperature of the windings is further equalized, its stress state changes due to different thermal expansion – compression of the windings that initially have a higher temperature and expansion of the windings or initially have a lower temperature. In this regard, the program implements the task of rolling parameters: the function of changing the temperature of the staffs depending on the rolling speed, the cyclogram of the accelerations (decelerations) of the rolling process or the law of changing the temperature of the turns of the staffs during winding.

Parameters of the surface of the headquarters. On the «Stacks surface parameters» tab, adjusting factors are set for the functions of convergence of turns of a rough stand δ and changes in thermal resistance *RT* from the inter-turn pressure *q*, MPa. If the correction factors are equal to zero, then the calculation is carried out assuming an ideal fit of the turns. That is, the convergence of turns is zeroed and thermal resistances are not taken into account.

It is possible to set tabular values of δ and *RT* as a function of inter-turn pressures *q*. To use this option, you should check the appropriate box on the form and enter the necessary tabular data. With the task δ, it is possible to set the dependence on the compressive forces or the convergence of the surfaces or the gap between the surfaces.

On this form, the surface roughness parameter Ra is also specified, which is used in determining the specific separation forces and is a reference point when choosing the dependence of the convergence of the winding surfaces and thermal resistances on the compressive forces. A parameter is also set – the temperature of the beginning of setting (by default equal to 600 °C) of the turns, which is also used to determine the specific separation forces (separation of the glued surfaces of the contacting turns in the roll).

Thermophysical parameters and temperature in the furnace during annealing. Thermophysical parameters, heat transfer coefficients on the surfaces of the roll washed by protective gas, as well as the cyclogram of the temperature of the protective gas are set.

It is also necessary to set the temperature of the coils of the roll before the start of the technological operation being analyzed. At a constant temperature, it is necessary to enter the corresponding value of the initial temperature T °C. With a variable initial temperature of the staff, a table of temperature values T °C corresponding to certain numbers of turns is determined. Linear interpolation is used to calculate the core temperature in intermediate turns. To set tabular values, check the appropriate box on the form and enter the required tabular data. The corresponding graphical dependence is displayed in the figure.

Cyclogram of the temperature of the shielding gas in the furnace. Either a constant temperature of the environment or a variable temperature of the shielding gas in the hood furnace T °C is set. At a variable temperature of the shielding gas, a table of temperature values at the corresponding moments of time is determined – a cyclogram of the temperature of the shielding gas. Linear interpolation is used to calculate the shielding gas temperature at intermediate moments of time. To set tabular values, check the appropriate box on the form and enter tabular data.

Account management options. Account management options are divided into two groups. The first group of parameters defines the parameters of the grid and the time of the end of the account. The second group defines the conditions for outputting results. The first group: the time of the end of the process in clocks, the step of the march count by time in seconds, the number of points along the radius of the roll and the number of sections along the width of the roll for calculating the temperature. Second group: time step in seconds for printing radial distributions of parameters, number of cycles between printing dependences of parameters on time, step in turns for printing radial distributions of parameters.

Carrying out a series of calculations. The program allows you to carry out a series of calculations related to parametric analysis. To carry out the next calculation, it is necessary to return from the «Analysis of results» form to the «Input of initial data» form and enter new data. In the corresponding text window of the «Input of source data» form, you need to set the desired name of the variant for its identification. By default, the calculation number is set.

Analysis of calculation results (figure 4). While viewing the graphs, it is possible to compare the results of calculations and choose the desired options. If you need to view the source data file for one of the options, double-click the name of the option.

The user has the opportunity to submit the results of stress calculations in the isothermal roll in the form:

- graphs of inter-turn pressures in the roll on the drum and changes in pressure on the drum during the winding process depending on the number of wound turns;
- graphs of inter-turn pressures in the roll removed from the drum. The

temperature variation in this case is a consequence of the rolling and winding of the staffs at variable speed.

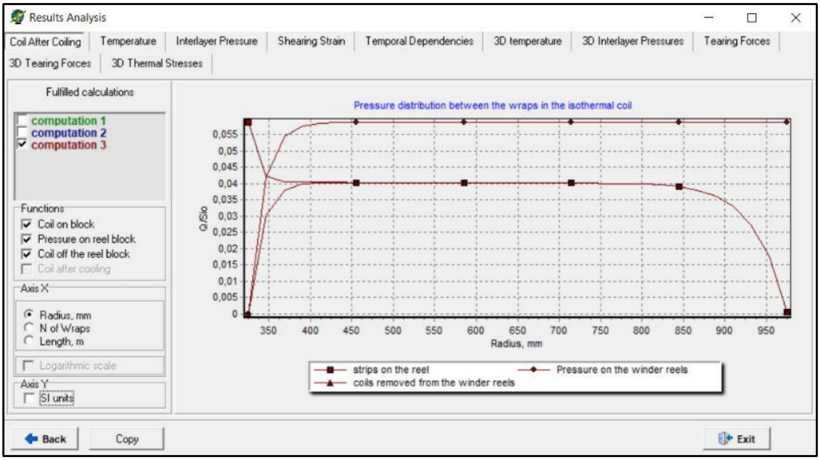

Figure 4 – Distribution of inter-turn pressures in the roll.

For a non-isothermal roll, it is possible to analyze the dependences of changes in the temperature of the turns, inter-turn pressures and tangential stresses, thermal stresses (figure 5) in the turns during the heating or cooling of the roll in the hood furnace.

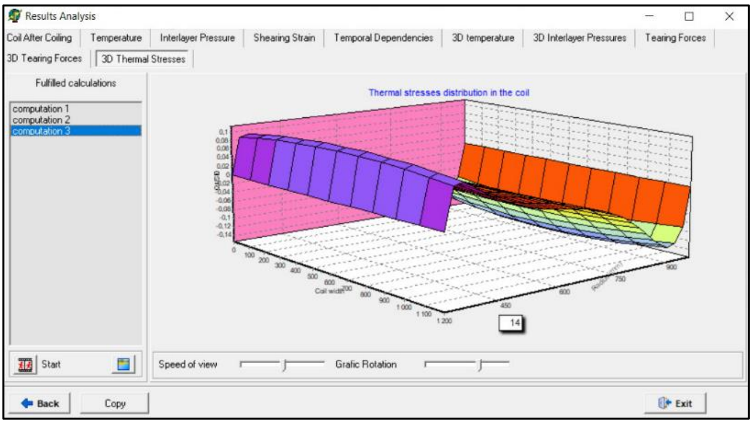

Figure 5 – Thermal stresses in the roll.

The results are presented in the form:

- graphs of dependences of parameters in the middle section of the roll on the radius of the roll or the number of turns at different moments of time. For a clearer presentation of the results, it is possible to change the step of time change during viewing;

- graphs of the temperature of the inner, middle and upper turns and the maximum value of inter-turn pressures in the roll as functions of time;

- graphs of the predicted specific forces of separation of the surfaces of the staffs during gripping, sticking and welding of turns of the roll during recrystallization annealing depending on the temperature and duration of annealing, as well as the inter-turn pressure q and surface roughness Ra of the staffs;

- 3D graphs of temperature changes by width and thickness of the roll during annealing.

A broader, detailed description of the features of the «CoilTemper3D» computer system and the nuances of determining the stress-strain and temperature state of rolls of cold-rolled steel bars is presented in our monograph [2].

Thus, for the first time in a single-program complex, the tasks of volumetric temperature and stress state of rolls during winding of the staff in the state of cold rolling and subsequent annealing with prediction of sticking conditions, relative slippage (relative displacement) of adjacent turns, as well as loss of stability of rolls at various intersections of the production process were realized.

We especially emphasize that the «CoilTemper3D» program complex is adapted for use in control systems of the technological process of cold-rolled steel production in industrial conditions. The system can be used in the form of an automatic module «coil winding strategy» at cold rolling mills, as well as in the form of means of checking and specifying the annealing modes of cold-rolled rolls in industrial conditions, depending on the winding modes, as well as the flatness and surface roughness parameters of cold-rolled rolls headquarters.

Extremely important issues that are solved with the help of the developed computer system «CoilTemper3D» are the prevention of sheet steel defects and ensuring the high quality of finished products. In particular, the computer system implements the ideology of prevention of bends (breaks) of thin-sheet steel [15, 16], solves this urgent problem facing almost all metallurgical plants [17]. The implementation of the algorithm and recommendations for choosing the optimal modes of rolling, annealing, winding-unwinding operations of rolls of thin sheet steel, provided in the computer system, excludes loss of shape and other defects of the rolls [18].

We especially emphasize that the scientific and technical solutions, which are the basis, the foundation of the «CoilTemper3D» system, have been implemented in the production practice of a number of metallurgical plants specializing in the production of sheet-rolled products [2].

Conclusions

The results of theoretical and experimental research in the field of production of thin sheet steel in rolls are presented in the form of a specialized computer system.

References

1. Mazur V. L., Nogovitsyn O. V. Theory and Technology of Sheet Rolling. Numerical Analysis and Applications. London – New York. CRC Press.Taylor and Francis Group, 2019. 479 p.
2. Mazur V. L., Timoshenko V. I., Prihod'ko I.Yu. Theory and technology of rolling (stress-strain state of steel strip coils). Kyiv: Phoenix Publishing House, 2021. 416 p. [in Russian].
3. Mazur V. L., Timoshenko V. I. Stress-strain state of rolls of cold-rolled strips. Message I. *Izvestiya vuzov. Ferrous Metallurgy*. 1979. No. 4. P. 55–59 [in Russian].
4. Mazur V. L., Timoshenko V. I. Stress-strain state of rolls of cold-rolled strips. Message II. *Izvestiya vuzov. Ferrous Metallurgy*. 1979. No. 6. P. 52–55 [in Russian].
5. Mazur V. L., Timoshenko V. I. Calculation of the stress state of rolled cylinders. *Mechanics of Composite Materials*. Riga: Zinatne, 1982. No. 5, P. 880–886 [in Russian].
6. Timoshenko M. V. Numerical simulation of heat transfer in multilayer structures with a generalized non-ideal contact. *Inzhenerno-fizicheskij zhurnal (IFZH)*. 1996. Vol. 69. No. 5. P. 773–778 [in Russian].
7. Mazur V. L., Prihod'ko I. Yu. Influence of Pulling Modes and Temperature of Coiling Cold-Rolled Strips. *Steel in Translation*, 2020. Vol. 50. Issue 9. P. 618–628.
8. Mazur V. L., Timoshenko V. I., Prihod'ko I. Yu. Efficient Cold Rolling and Coiling Modes. *Steel in Translation*. 2019. Vol. 49, Issue 8. P. 548–558.
9. Mazur V. L., Timoshenko V. I., Prihod'ko I. Yu. Influence of Annealing Modes in Bell Furnaces on the Stress-Strain State of Rolls of Cold Rolled Steel. *Steel in Translation*. 2021. Issue 9. P. 648–657.
10. Mazur V. L., Timoshenko V. I., Prikhod'ko I. Yu. Regulating the Coil Stress by Adjusting the Rigidity of the Winding Drum. *Steel in Translation*. 2018. Vol. 48. Issue 8. P. 528–535. DOI: 10.3103/S0967091218080090
11. Mazur V. L. (2018). Ensuring Specified Surface Roughness in the Production of Thin Cold-Rolled Steel Sheet. *Steel in Translation*. 2018. Vol. 48. No. 1. P. 49–54. DOI: 10.3103/S0967091218010102
12. Mazur V. L., Timoshenko V. I. Theory and technology of rolling (hydrodynamic effects of lubrication and surface microrelief). Kyiv: ID "ADEF Ukraine", 2018. 560 p. [in Russian].
13. On the mechanism of influence of the rough surface of coldrolled strips on the conditions of sticking of coils during annealing and the formation of surface defects / I. Yu. Prihod'ko et al. *Metallurgical and mining industry*, 2002. No. 8-9. P. 92–101 [in Russian].
14. Investigation of the influence of the temperature of winding strips into rolls during cold rolling on the formation of defects in the surface of strips / P. P. Chernov et al. *Metallurgical and mining industry*. 2002., No. 8-9. P. 101–108 [in Russian].
15. Mazur V. L. Preventing Surface Defects in the Uncoiling of Thin Steel Sheet. *Steel in*

Translation. 2015. Vol. 45. No. 12. P. 959–966. DOI: 10.3103/S0967091215120062

16. Mazur V. L., Pargamonov E. A. Formation and Prevention of Flexure Defects at the Surface of Cold-Rolled Steel Strip. *Steel in Translation.* 2016. Vol. 46, No. 8. P. 595–601. DOI: 10.3103/S096709121608012X
17. Mazur V. L. Quality problems of thin sheet steel: prevention of surface defects. On Coll. "Materials Science: Achievements and Prospects". In 2 vols. Vol. 2 / Editor L. M. Lobanov (head) et al; Kyiv: Akademperiodyka, 2018. P. 51–75 [in Russian].
18. Mazur V. L., Timoshenko V. I., Prikhod'ko I. Yu. Stability Loss and Defects in Coils of Cold-Rolled Strip. *Steel in Translation*. 2019. Vol. 49. No. 1. P. 58–65. DOI: 10.3103/S096709121901011X [in Russian].

В. Л. Мазур, чл.-кор. НАН України, д.т.н., проф.

Фізико-технологічний інститут металів та сплавів НАН України

В. І. Тимошенко, чл.-кор. НАН України, д.ф.-м.н., проф., ORCID 0000-0001-8588-2468

Інститут технічної механіки НАНУ України
і Державного космічного агентства України

І. Ю. Приходько, д.т.н., с.н.с., ORCID 0000-0001-5651-8106

Інститут чорної металургії ім. З. І. Некрасова НАН України

РЕАЛІЗАЦІЯ МЕТОДІВ РОЗРАХУНКУ В СПЕЦІАЛІЗОВАНІЙ КОМП'ЮТЕРНІЙ СИСТЕМІ НАПРУЖЕНО-ДЕФОРМОВАНОГО І ТЕМПЕРАТУРНОГО СТАНУ РУЛОНІВ СТАЛЕВИХ ШТАБ

Анотація. Розроблено теорію формування та трансформації напружено-деформованого та температурного стану рулонів гарячекатаних та холоднокатаних сталевих штаб при їх змотуванні-розмотуванні у процесах прокатки, термічної обробки, дресирування, транспортування, складування, виконання інших виробничих операцій на металургійних комбінатах. Запропоновано математичні моделі, алгоритми та комп'ютерна система, що їх реалізує. Наведено опис можливостей використання цієї системи при вирішенні різних завдань. В комп'ютерній системі розглянуто підхід до оцінки впливу параметрів процесу холодної прокатки та змотування штаб у рулони, температурно-швидкісних режимів їх нагрівання і охолодження при відпалі у ковпакових печах. Вперше розкрито методологію виявлення закономірностей впливу міжвиткових зазорів у рулонах на їх напружено-деформований стан. Показано процедуру виявлення ефектів швидкості холодної прокатки, температури, натягу штаб, що прокатуються і змотуються в рулони, шорсткості їх поверхні на напружено-деформований стан рулонів. У деталях показано реалізацію в комп'ютерній системі нових ідеології та підходів до вирішення ключової в технології листопрокатного виробництва задачі визначення напружено-деформованого стану (НДС) рулонів. Моделі та алгоритми розрахунку НДС, що покладені в основу комп'ютерної системи, розроблені на основі класичних рішень у галузі матеріалознавства, теорій пружності, обробки металів тиском, теплотехніки, газової динаміки, чисельних методів та інших сфер знань. У комп'ютерній системі розкрито механізми формування температурного та напружено-деформованого стану рулонів сталевих штаб у процесах прокатки, нагріву, ізотермічної витримки та охолодження під час відпалу в ковпакових печах; враховано вплив температурно-швидкісних режимів прокатки та відпалу на виникнення критичних міжвиткових тисків у рулонах, що призводять до дефектів поверхні штаб «лінії перегину» (злами) та дефектів форми рулонів. Розкрито можливості впливу на НДС рулонів при прокатуванні регулюванням натягу штаби, а при відпалі регулюванням тривалості ізотермічної витримки та швидкості подальшого охолодження рулонів. Надані посилання на літературні джерела, в яких детально викладені результати досліджень науково-технічних задач, що реалізуються у комп'ютерній системі. В комп'ютерній системі використані способи змотування холоднокатаних штаб у рулони, що виключають втрату їх стійкості та утворення дефектів «перегини», просідання, «пташка» при виробництві тонколистової сталі в промислових умовах. Дано рекомендації щодо вибору раціональної технології виробництва рулонним способом гарячекатаних та холоднокатаних штаб, жерсті. Розроблені рішення реалізовані в комп'ютерній системі «CoilTemper3D» і використовуються на виробництві.

Ключові слова: металургія, сталь, виробництво штаб, якість, рулони, напружений стан, розрахунки, алгоритми, комп'ютерні системи, запобігання дефектам.

Посилання для цитування: Mazur V. L., Tymoshenko V. I., Prykhodko I. Yu. Implementation of calculation methods in a specialized computer system of the stress-deformation and temperature state of steel bar coils. *Фундаментальні та прикладні проблеми чорної металургії*. 2022. Вип. 36. [In English]. С. 240-253. DOI: 10.52150/2522-9117-2022-36-240-253.

Стаття надійшла до редакції збірника 26.10.2022 р.
Рекомендовано до друку редколегією збірника (Протокол № 5 від 20.12.2022 р.)