STAN 2000: COMPUTER MODEL FOR SIMULATION OF STEELS HOT ROLLING ON MILL 2000 OF SEVERSTAL

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Abstract

An integral computer model/program for simulation of steels hot rolling on mill 2000 of SEVERSTAL was developed. The model provides for the following calculations:

- temperature distribution over the cross section of a rolled strip at any location along its length;
- rolling forces and torques;
- austenite microstructure evolution under hot rolling taking into account grain growth, dynamic/static recrystallization and strain induced carbonitrides precipitation;
- austenite transformation during accelerated strip cooling at the run-out table accounting for formation of polygonal ferrite, pearlite, bainite of different morphology, and martensite;
- mechanical properties of rolled strips (yield stress, ultimate tensile stress and relative elongation).

The present model was calibrated using an extensive data base on rolling regimes and energy-force parameters, measured temperatures and final mechanical properties for a number of steel grades rolled on mill 2000 of SEVERSTAL with chemical compositions covering the following ranges of alloying elements content: C(≤0.65); Mn(≤2.0); Si(≤1.0); Cr(≤0.9); Ni(≤0.6); Cu(≤0.5); Mo(≤0.4); Nb(≤0.08); V(≤0.08); Ti(≤0.08) (mass.%). The calculation results for temperatures, rolling forces and mechanical properties are in good agreement with the experimental data. The computer program STAN 2000 has a well-designed and user friendly interface. The program is widely used in industrial strip production on mill 2000 of SEVERSTAL for working out new and optimizing existing hot rolling and accelerated cooling regimes.

Keywords: modeling, microstructure, mechanical properties, steels, hot rolling

1. INTRODUCTION

Over the past decades substantial attention has been focused on the development of integral mathematical models for predicting the microstructure and mechanical properties of hot rolled steels. Since the time the first such models were introduced [1,2], there has been a tendency to apply more physically sound models for describing the complex processes of austenite microstructure evolution under hot rolling, as well as its transformation during subsequent accelerated cooling with formation of various structural components such as polygonal ferrite, pearlite, bainite and martensite. The advantage of these models is their higher ability to predict the complex effects of alloying. Creation of a new generation of integral hot rolling models is possible when using physically justified sub-models of the separate processes of structure formation based on reliable approaches to calculating the thermodynamic and kinetic process parameters with an accurate account of the alloying effects. A set of such sub-models, which employ new effective approaches to a quantitative description of the dependence of key kinetic parameters of the analyzed processes on chemical composition, was created by the authors and introduced elsewhere [3−5]. By combining the above-mentioned models, as well as the model for temperature prediction, an integral computer model STAN 2000 has been created for predicting the microstructure and mechanical properties of steel strips produced on mill 2000 of SEVERSTAL in accordance with the given hot rolling and accelerated cooling regimes.

Present paper briefly describes developed integral computer model STAN 2000 and a set of the implemented sub-models. Some results obtained using this model are presented and compared with the corresponding experimental data.

2. BRIEF DESCRIPTION OF THE INTEGRAL MODEL AND SUBMODELS, CALCULATION RESULTS

Computer model/program STAN 2000 is off-line model designed to address a number of technological challenges in the rolling mill 2000 of SEVERSTAL (**Fig. 1**). The capacity of the model includes, for example, the following features:

- control of power parameters and temperature depending on selected rolling and accelerated cooling regimes;
- follow-up of the evolution of steel microstructure at all stages of strip production and prediction of ultimate mechanical properties;
- optimization of rolling regimes for existing steel grades and developing them for a new ones.

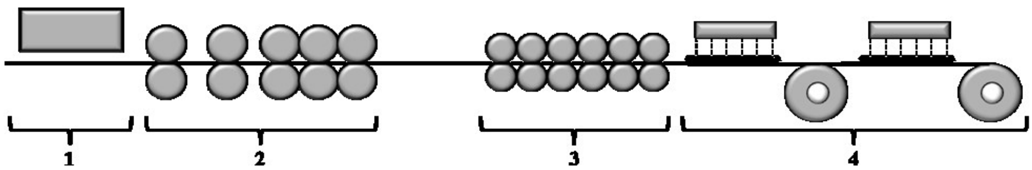


Fig. 1 Layout of the equipment of rolling mill 2000. 1) section of heating furnaces; 2) roughing mill, consisting of 5 stands, 3 of which are combined in a continuous group; 3) finishing mill, consisting of 7 stands united in a continuous group; 4) accelerated cooling section, including 2 section cooling system and 2 groups of coiling devices.

The integral model was calibrated using an extensive data base on measured rolling forces, temperatures and final mechanical properties for 31 steel grades rolled on mill 2000 of SEVERSTAL with chemical compositions covering the following ranges of alloying elements content: C(≤0.65); Mn(≤2.0); Si(≤1.0); Cr(≤0.9); Ni(≤0.6); Cu(≤0.5); Mo(≤0.4); Nb(≤0.08); V(≤0.08); Ti(≤0.08) [5]. The STAN 2000 program was written in C++ programming language and can work on all modern Microsoft Windows family operating systems. Well-designed and user-friendly interface of the program facilitates its practical use.

The computer model under consideration includes a set of sub-models described in [3−6]. In this section a brief description of the sub-models is given and some results of calculations performed for the steel Grade #1 (0.11C; 1.54Mn; 0.31Si; 0.12Cr; 0.054Nb; 0.024V) are presented.

Temperature model. Temperature model implemented in the program STAN 2000 allows to calculate temperature distribution over the cross section of a rolled strip at any location along its length at the stages of roughing and finishing rolling, as well as under accelerated cooling on the run-out table. The model is based on differential equations of heat conduction solved by the finite difference method with account of the following mechanisms determining heat losses and generation at different rolling stages:

- heat loss as a result of a strip contact with work rolls;
- heat loss by radiation and convection;
- heat loss due to water descaling, inter-stand cooling and accelerated cooling at run-out table;
- heating by plastic deformation and phase transformations during cooling.

The model takes into account the dependence of heat transfer coefficients and emissivity on temperature, the degree of strip surface oxidation and rolling speed. In addition, account is taken of the temperature dependence of thermodynamic parameters of steel. Model was calibrated using a data base on strip surface temperatures measured by pyrometers of mill 2000. Some results of strip temperature calculation for the Grade #1 steel are displayed in **Fig. 2**. Comparison of the calculated and measured temperatures as presented in **Fig. 3** demonstrates good quantitative agreement.

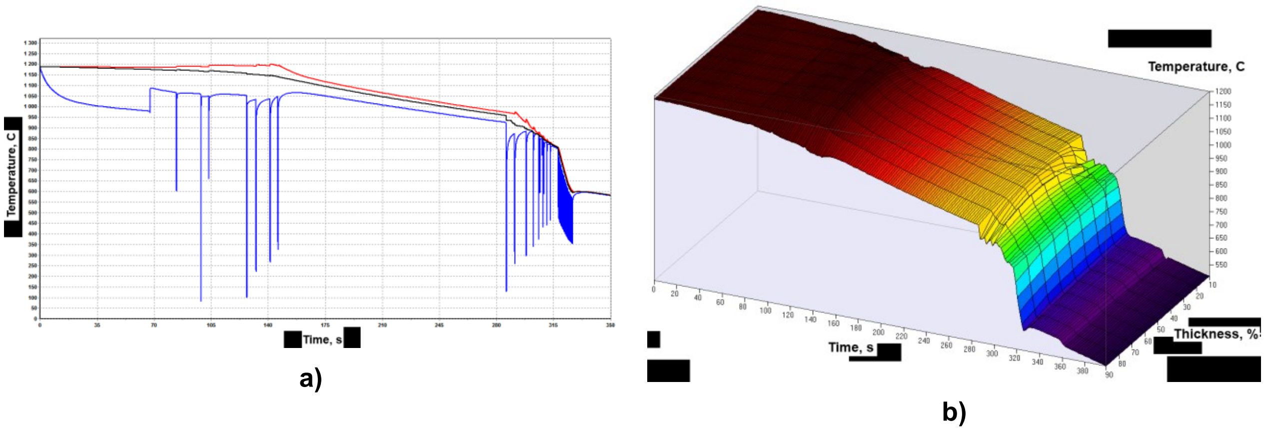
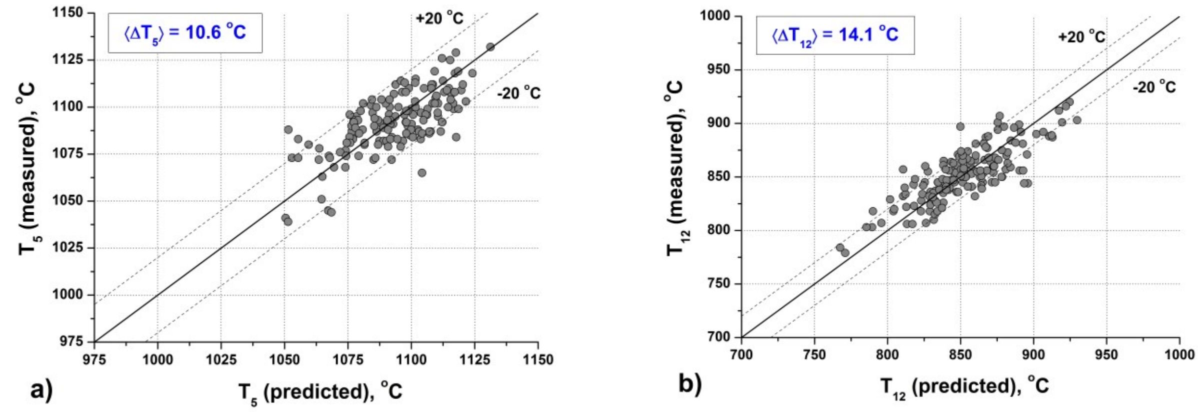


Fig. 2 Examples of calculation results of temperature variation versus rolling time obtained using STAN 2000 program for Grade #1 steel. a) temperature curves for the strip surface (blue), middle (red) and average strip temperature (black); b) variation in temperature distribution over the width of the strip with time of rolling.



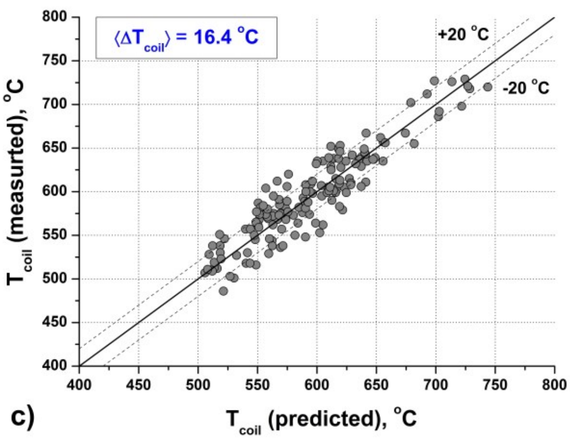


Fig. 3 Comparison of the predicted and measured surface temperatures for 164 strips rolled on mill 2000 of SEVERSTAL. T_5 and T_{12} are the temperatures after the 5th and 12th stands of the roughing and finishing mills, accordingly; T_{coil} is a coiling temperature. <ΔT> is an average absolute value of prediction accuracy.

Rolling force model. Rolling forces are predicted using the model for flow stress calculation in complexly alloyed austenite depending on its grain size and deformation temperature as described in [3]. One can see that this sub-model provides good agreement between calculated and measured rolling force values (**Fig. 4**).

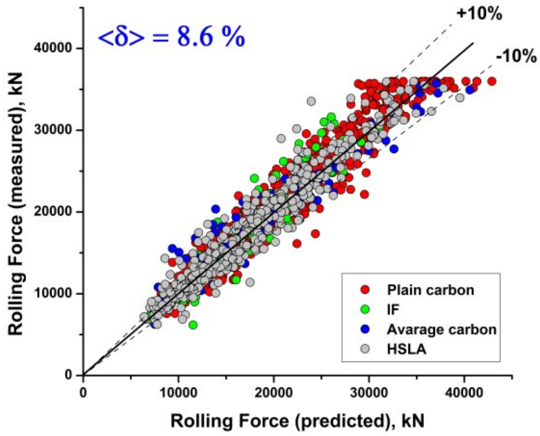


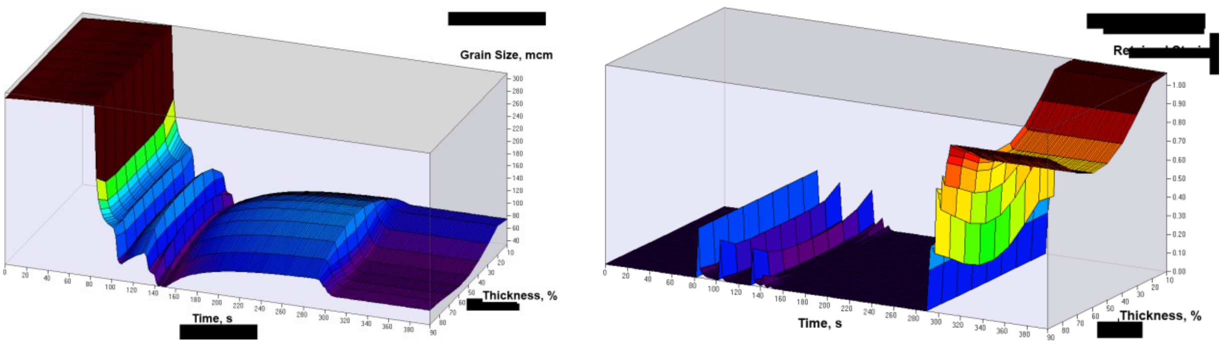
Fig. 4 Comparison of the calculated and actual values of rolling forces at the finishing mill for the steels hot rolled on mill 2000 of SEVERSTAL. <δ> is an average value of the relative prediction accuracy.

Austenite microstructure evolution model. STAN 2000 program allows quantitative modeling of the austenite microstructure evolution during hot rolling of modern HSLA steels including steels micro-alloyed by niobium, vanadium and titanium. The program implements an integral mathematical model of the following interrelated processes of the structuring of steel:

- grain growth;
- dynamic recrystallization;
- static recrystallization taking into account of the effects of recovery and micro-alloying elements carbonitrides precipitation on the dislocations of deformed austenite.

The mathematical models applied to the above-given processes of structuring were published elsewhere [3,5]. They are distinguished by a physically reasonable allowance for the influence of all practically important alloying elements. This feature makes the program effective for a large number of steel grades with a wide range of variations in their chemical composition.

Fig. 5 shows predicted variation in austenite grain size and retained strain over the strip width of Grade #1 steel with time of rolling.

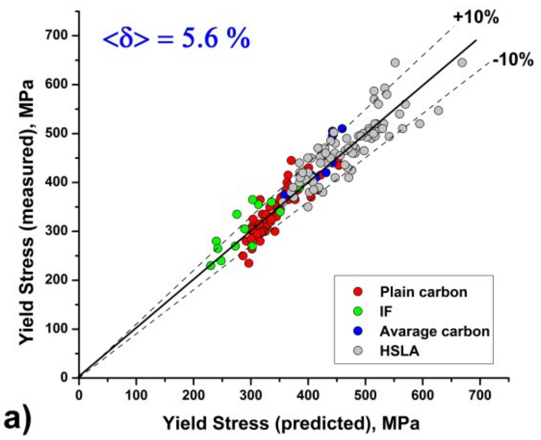


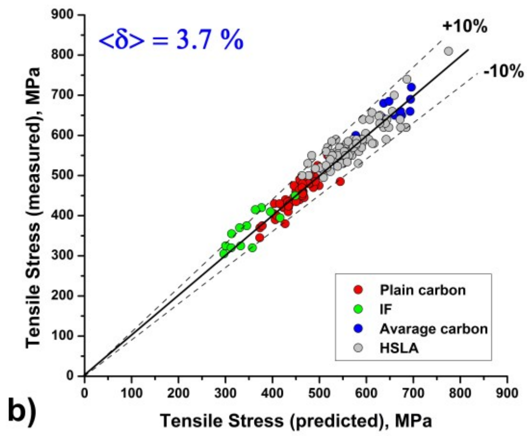
a) b)

Fig. 5 Predicted variation in austenite grain size (a) and retained strain (b) distributions over the strip width in Grade #1 steel with time of rolling.

Austenite decomposition model. This sub-model describes austenite decomposition under continuous cooling in low alloyed steels with formation of all practically important structural components (ferrite, pearlite, bainite of different morphology and martesite). Physically based mathematical models of ferrite, pearlite and bainite transformations are described in [4,5].

Mechanical properties prediction model. This model predicts ultimate mechanical properties of steel basing on the calculated set of significant microstructure parameters: volume fractions of the structural components, the average ferrite grain and bainite block sizes, characteristic transformation temperatures, volume fractions and sizes of carbonitrides in micro-alloyed steels. The mathematical model for the mechanical properties evaluation in modern steels with a complex microstructure implemented in the presented program is described elsewhere [6]. This model is an important component of the developed integral model STAN 2000, and it was calibrated using a mechanical properties data base for a number of practically important steels hot rolled on mill 2000 under different rolling regimes. A comparison of the predicted and measured values of mechanical properties for 31 steel grades shows a good agreement between calculation results and experimental data (**Fig. 6**).





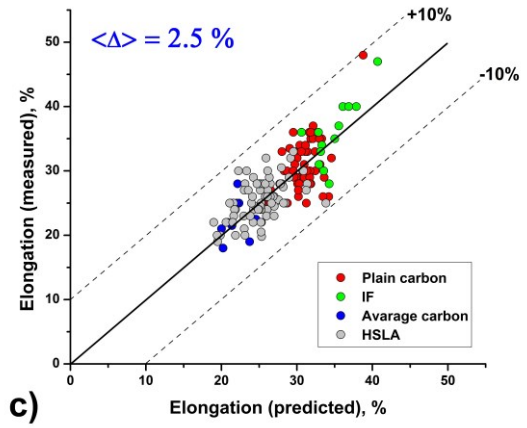
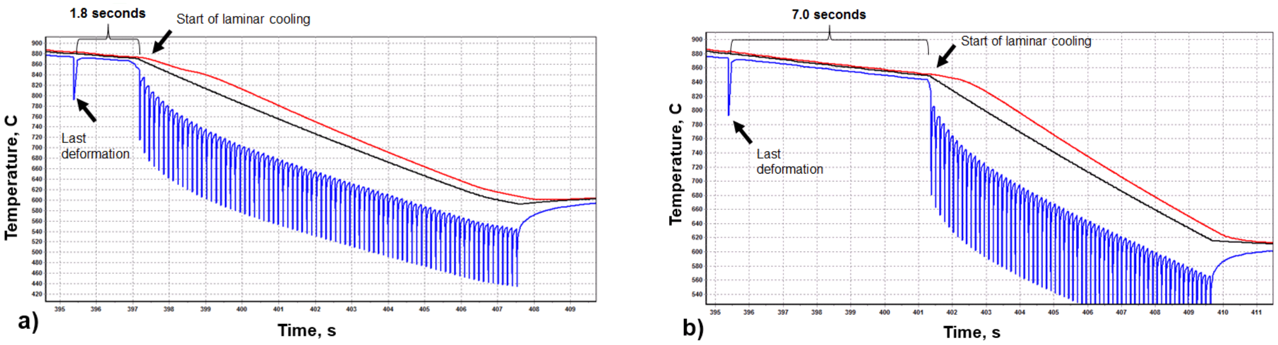


Fig. 6 Comparison of the calculated and measured values of yield stress (a), ultimate tensile stress (b) and relative elongation (c) for the steels hot rolled on mill 2000 of SEVERSTAL.

δ and Δ are, correspondently, average values of the relative and absolute accuracy.

Developed temperature model in combination with other models allows, for example, a quantitative simulation of different cooling strategy effect on final steel microstructure and mechanical properties (**Fig. 7**).

Using the developed integral model STAN 2000 has significantly reduced the time and costs while optimizing existing rolling regimes, as well as accelerated cooling strategies with the aim of producing strips with required properties.



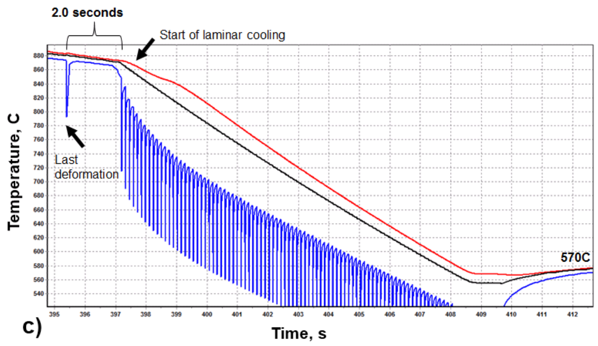


Fig. 7 Different strategies of accelerated cooling at run-out table. **a)** standard strategy: YS = 510MPa, UTS = 650MPa, RE = 25%; **b)** long after deformation pause strategy: YS = 450MPa, UTS = 540MPa, RE = 23%; **c)** fast cooling strategy: YS = 510MPa, UTS = 620MPa, RE = 25%.

3. CONCLUSION

An integral computer model STAN 2000 for simulation of steels hot rolling on mill 2000 of SEVERSTAL was developed. The model is widely used in industrial strip production on mill 2000 of SEVERSTAL for working out new and optimizing existing hot rolling and accelerated cooling regimes. The model STAN 2000 has greatly contributed to the development of new technologies for production of pipe steels, high strength steels for mechanical engineering and shipbuilding, as well as a number of structural steels. Using the developed program has significantly reduced the time and costs while optimizing existing rolling regimes and developing a new ones. For example, the enhanced use of this program by SEVERSTAL in 2013 brought economic benefits amounting to more than 40 million roubles.

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