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SIMULATION SYSTEM OF MULTISTAGE HOT ROLLING PROCESS OF FLAT PRODUCTS

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By means of numerical simulation of process it is possible to predict the global and local properties of profiles after each step of deformation. Determination of the influence of each certain stage in experimental way is rather cost-based and therefore resource-demanding. This is the reason why in the past years and decades took place the significant advancement of modeling in connection with the application of the numerical approach. On basis of physical approach it is possible for example to predict the development of material and properties of deformed working piece at every one by one following stage of deformation. The great necessity consists in creating of fast simulation systems, which can rapidly estimate the influence of parameters of deformation process on the properties of product and devices. The significant attention is dedicated to the calculation in real time so that In-Line-Simulation makes it possible to control and to operate the processes and devices.

Key words: hot rolling process, flat products, simulation system

Simulacija višestupnjastog procesa valjanja plosnatih proizvoda. Pomoću numeričkog simuliranja procesa, moguće je predvidjeti ukupno i mjestimično svojstvo poslije svake provlake kod deformacije. Određivanje utjecaja svake pouzdane etape u eksperimentu je zapravo temelj cijene i dakle pitanje resursa. To je razlog da je prošlih godina i dekada došlo do značajnijeg modeliranja povezanih s primjenom numeričkog pristupa. Na temelju fizikalnog pristupa moguće je na primjer predvidjeti stanje materijala i svojstava oblikovanih komada u svakom kao i u slijedećem stupnju deformacije. Visoki zahtjevi sadrže ustrojstvo brzih simulacionih sustava, pomoću kojih je moguće brzo prosuditi utjecaje deformacionih procesa na svojstva proizvoda i unapređenje. Značajna pozornost je posvećena izračunu stvarnog vremena tako da lanac simulacije ostvari mogućnost kontrole i unapređenje datih procesa.

Ključne riječi: topli postupak valjanja, plosnati proizvodi, simulacijski sustav

INTRODUCTION

The properties of each deformed product are decisively influenced by production process. By means of directed control of the various steps of process it is possible to obtain the desired properties. In order to reach this purpose and to estimate the properties of the end product the whole process chain must be presented as the whole set. This integrated approach starts with the solidified melt and following the each production stage from the transport and deformation phase up to the end product.

In order to increase constantly quality and quantity demands already on the stage of planning and also during the production, the models with appropriate software can be used, which allow to predict the local and global processes in interactive connection. For this reason it is necessary to develop a tool that is enough precise and reliable for a variety of materials (steel, non iron and other alloyed materials) as they are being deformed at the various stages. In addition this instrument must offer an opportunity to calculate the processes approximately in real time.

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AIMS OF THE DEVELOPING OF THE SIMULATION SYSTEMS FOR PRODUCTION OF SEMI-FINISHED PRODUCTS

The developed system are purposed to serve as a tool which could be used by both of the technicians and scientist for the designing of new technologies and concepts of devices; also by the testing of new materials. The application of simulation systems allows reaching the goal of optimization and that is important for the reduction of the duration of the process stages. The system helps also to intensify the productivity by the raising of the efficiency at the same time; this contributes significantly into protection of the environment. In the majority of models the separate steps or phenomena will be taking into consideration independently from each other. By means of the developed software the general design of the whole process must be obtained and also interaction of various stages of the process must be determined. Here it is possible to ascertain the behavior of the material across the cross section under practice-oriented conditions.

The modularly structure of the software allows presenting every rolling mill (for flat products and profile) as the chain of models for each technological step. For this reason follows the calculation strategy the process of hot rolled semi-finished product. The simulation of forming processes consists of two loops. There are the loop over process steps and the loop over time steps. In each step are observed the development of temperature, microstructure, deformation and the interactions of these physical fields. The last calculation phase is modelling of finale mechanical properties of product due to end microstructure state and calculation of the surface quality of the hot rolling product. The software gives the possibility to vary the parameters of process. This is important for the reason that owing to the great number of deformation parameters countless number of combinations is possible. These combinations are impossible to be kept in attention and further to be predicted. This is the reason for the developing of the simulation system with required exactness, which could operate in real-time and when if necessary to control the processes.

SEGMENTATION OF THE ENTIRE PRODUCTION PROCESS INTO THE SEPARATE STAGES OF DEFORMATION TECHNOLOGY

In the manufacturing engineering it is possible to classify the production process and processing technologies from the point of view of various criterions. The criterion presents the evolution of the material. Therefore under the evolution of material means the totality of state changing, which describes the whole process beginning from the initial material up to the end product. To these belong the changing in geometry, surface and structure and also the resulted properties. Every part of the process consists of multitude of segments, in which changes of the state of material, geometry, structure and properties take place. These set in for example by rod and wire production with variety of forming stages along with the reducing of cross section, amongst others cyclic alterations of strain hardening and strain softening processes. By means of proper alloying these processes will be accompanied by precipitation processes, which are induced by the deformation. The change of the strain hardening and strain softening processes induce in the interdependency with transformation processes to the changes of the microstructure and in this way to difference in mechanical properties und their dependence on the direction.

In the Figure 1 one can see an example of the process chain for strip production with all separate steps, sub-processes and the resulted alteration of deformed product beginning from the continuous casting, the following forming and up to the finish rolled product. Each of this separate step influences specified product properties as geometry, structure, texture and the quality of surface. It is clear that it is not possible to observe the properties, dimensions and other parameters that influence on the finish product, only in the last production step.

Complexity of changes of the material and the diversity of regarded options with various depths is possible. They are connected with the various methods and approaches and need different calculation time.

MODELING AND SIMULATION OF THE PROCESS CHAIN OF THE HOT-ROLLED STRIP

The software takes into account all the phenomena along the technological line of the rolling process in which a single cross section disc is examined through the deformation stages and transport phase up to the cooling line.

In the various steps of the process several ways of heat transmission (convection, radiation and heat conduction) are possible, single or combination of them. These processes are taken into account by the FEM. Coefficient of heat transfer can be obtained from the literature references. Significant numbers of experiments were carried out and the temperature topography inside of the rolled product (by means of integrated/welded a thermocouple in the middle of the strip) and the surface of the strip (by means of the pyrometers or thermography camera) can be measured. This facility is possible to diagnose the temperature profile along the cross section in experimental way.

As a result of the increasing demands on quality for the rolled product and also high deformation rates, the prediction of the material flows becomes more important. In order to fulfill these requests the local strain and local temperature distributions of the deformed volumes were analyzed with the theory of visioplacticity or the strategy of FEM. Based on these findings the process forces and the resulting torque can be forecast and so it can gives some conclusions of the wear of rolls, the friction and of the production rate.

The widening and stretching of the specimen can be described by means of the model. According to it, depending on the application of the layer model for flat products or the widening model, which was developed in Freiberg, will be used. Depending on the diameter of rolls the widening behavior changes. At the same time the chemical composition of the material, friction conditions and also the geometry of the rolled product have significant influence on the material flow. [1-5]

The predicted mechanical properties (Figure 3), for example tensile strength, yield stress, fraction strain, fraction stress, are very important criterions for the fur-

Process step		Sub process		Influenced	Characteristic value	
	Continuous casting	Heat transfer / Scale development	- Solidification	- Shape - Initial structure - Surface	Temperature field / Scale thickness	- Dimensions - Concentration - Dendrite interspace
	Heating		- Austenitisation			- Austenite grain size - Solution state
	Hot rolling		- Descaling - Deforming - Transport	- Shape - Microstructure - Surface		- Dimensions - Strain - Austenite grain size - Precipitations
	Cooling		- Phase transformation	- Shape - Microstructure - Surface		- Phase fraction - Grain size - Properties - Roughness
	Pickling			- Surface	- Roughness	
	Drawing	- Deformation - Heat treatment		- Shape - Texture - Surface	- Dimensions - Roughness - Mechanical properties	

Figure 1 Classification of the production chain by the example of strip of non-alloyed steels

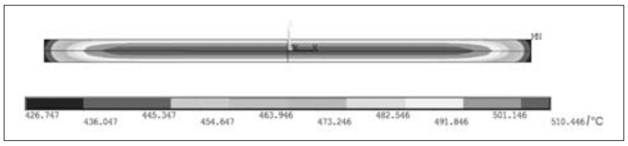

Figure 2 Example for temperature distribution across the section

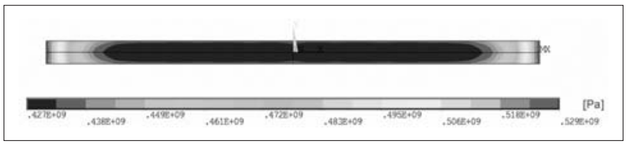

Figure 3 Example for strength distribution across the cross cut section

ther process stages. These properties of the deformed materials could be determined by the combined observation of austenization condition, the whole deformation process, conditions of cooling and the analysis of the microstructure (parts of the different phases). At the same time the chemical composition, grain growth of austenite and ferrite, art of perlite initiation (for example, distance of perlite lamellas) play an important role for the characterization of the final mechanical properties of the rolled product.

In the Figure 3 it is clear to observe, that there is inhomogeneity of the hardness across the given as an example cross section (800 mm wide and 20 mm high) as over height as over width of the strip. The maximum difference of about 100 MPa can be observed at the edge of the strip. Comparing to width of the strip the deviations of the mechanical properties over the height are negligible. As a result of the inhomogeneous strength distribution over the cross section various flow behavior of the material takes place. It is caused, for example, by temperature distribution (the edges cool down faster than the core – Figure 2), wherefore there is a difference in the phases distribution and stress-strain properties over the strip cross section. The respective irregularities can influence negatively the further processing. By the given example the central segregation is not to be taken into account. But this complex phenomenon can influence the processing of the product and in some cases the deformation process and application opportunities of the end product.

The description of the microstructure that forms at the cooling line is based on the CCT and D-CCT diagrams. In order to present these diagrams it is necessary to determine the temperatures of the beginning of structure transformation and the transformed parts of phases on the characteristically points of CCT. Because of the

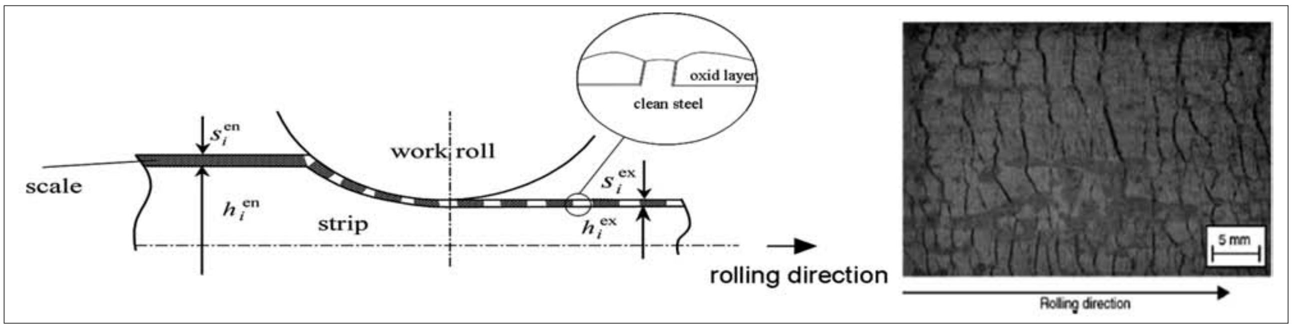

Figure 4 Schematic representation of the scale development [6] an example from an experiment of the top of scaled surface

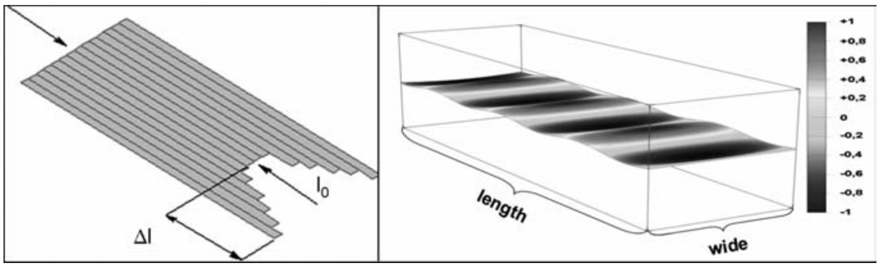

Figure 5 Example of calculation of the flatness at the end of the cooling line based on the residual stress (left: the theory; right: result of the simulation for waviness)

non-homogeneity of the temperature and deformation distribution over the cross section D-CCT diagrams for the characteristic point of the cross section must be prepared in order to interpolate the data across the profile. [6, 7] In this way it is possible to calculate the phase composition at the end of the production process. The modeling can be carried out by means of semi empirical models (options are presented by *Kuziak, Campbell* and *Umemoto*) and on basis of the completely recrystallized structure in order to don't increase the complexity of the calculations.

In order to be able to characterize all the properties of the semi-finished product not only after the deformation but also at the end of the cooling line one obtains the information about the tension conditions in the strip and also the scale growth. The both characteristics are important for the further processing of the flat profile.

The scale development is an important part in the describing of the surface roughness. In order to be able to estimate the surface quality of the hot rolled product the scale development must be controlled along the whole process chain, beginning from the furnace up to the cooling line, because the scale can seriously damage the surface quality. The scale layer will be deformed plastically during the deformation process but it can be limited due to the insignificant ductility of the oxide. That's why the scale layer breaks up after every processing step in various places, for the reason that the hot core material comes out towards the surface and gets in contact with the relatively cold rols (Figure 4). At the free surface of material the scale grows more intensive than the original iron oxide.

The amount of the scale cracks increases by the reason of higher pass reduction, greater cooling rate and thicker initial oxide film. Therefore the roughness of surface of the end product grows.

The other characteristic of the strip quality by the hot rolling especially by the hot rolling of flat products can be obtained from the possible stresses that can be developed during the processing at the cooling line. The run-out table in this model is described with some mathematical lows. For each kind of cooling (air, water from headers etc.) are specified the zones lengths and heat transfer coefficients for zones. The model of temperature field during the cooling line is solved in the cross section of the strip as a 2D thermal problem, where the lineal 2D thermal elements with logarithmic rule of distribution of elements length in the width direction are used. The temperature distribution can be the reason for such stresses and creates defects of the rolled metal as dents, curvature and waves in the middle and at the edges of the strip. The researched residual stresses are stresses of the first-order [8-10]. The information about the possible stress in the particles is important not only for the describing the geometry but also for proper implementation of the further production process and determination of the strip properties (Figure 5). The theory is based on the strip model which takes in account the thermal expansion. The basis of this model is a rectangular sheet. The strip is divided into n longitudinal strip elements in the width direction of the strip. For each strip element is assumed the deflection function. Where are the sine wave form in rolling direction and waves distribution in the width direction can be expressed as the third-power spline function. After that will be solved the problem of minimum potential energy principle of elastic system. The consequence from this information is to change the process parameters or to interlink subse-

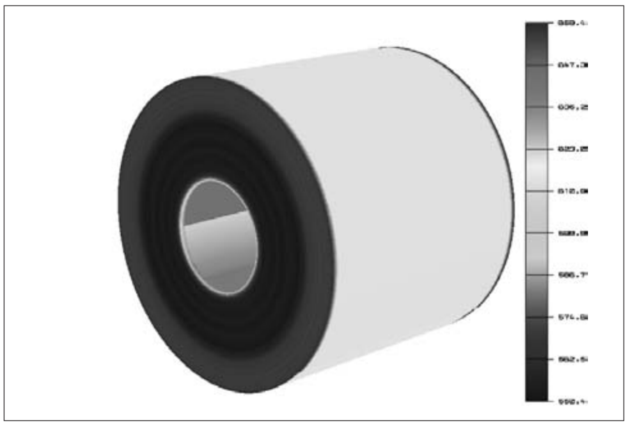

Figure 6 Solution results for coil in the moment of the end of coiling

quent the heat treatment for the decrease of the stresses. The example of the calculation with the software is presented in the Figure 6. With this software and edge masking device the cooling process can be optimized. The residual stress produces the formation of the waves in the middle of the strip.

At the end of every hot rolling process came the cooling of material is usual. The results from the calculation of cooling line are being transported to modules for stress and temperature estimation during cooling of coil. The temperature field transfer to coil is based on Archimedes spiral and is as input for the calculation of precipitations too. [10]

CONCLUSION

The simulation model considering the stages of the process is a very important tool in the area of the deformation technology, which serves for creating of the new products with significant potential.

By means of the presented rapid simulation system one must gather the extensive understanding of all process stages along the processing line itself. The knowledge gained will be used for the optimization of the production steps and technology.

Due to the variable arrangement of various segments the system can be applied for different deformation technologies for processing of rolled products.

After completion of the model and forwarding to the physical simulation it is possible to describe more precisely and stable the particular steps or the procedures of the ever increasing complexity process.

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Note: The responsible translator for English language is BAFreiberg, Germany.