Latest results in the development of tribological simulation models

The Quest for Excellence

An accurate and comprehensive understanding of the rolling process, particularly with respect to tribological factors and diverse friction regimes in the roll-bite, is essential for optimized and cost-efficient mill operations as well as high product quality. In a joint cooperation between renowned partners from different disciplines involved with rolling, new tribological simulation models are being developed and optimized to provide greater insight into the fascinating world of lubricants.

Rolling forces, mill-power requirements and strip surface quality are widely influenced by the composition of the lubricant and the manner in which it is applied. Therefore, in modern cold rolling a deeper knowledge of the interaction of tribological[1] parameters (roughness of work rolls and strip, asperity[2] flattening, lubricant composition, temperature evolution in the bite, plate-out[3], generation of boundary films, etc.) and their effect on friction in the roll-gap is decisive for the continuous optimization of the rolling process. These factors are particularly important for the rolling of high-strength steel grades and thin gauges.

Demands placed on tribological simulation models

A wide range of mathematical models already exist for simulating cold-rolling processes. From very basic analytical descriptions up to highly specialized, finite-element calculations, these models are based on the assumption that friction between a work roll and metallic strip may be characterized by a single parameter such as the coefficient of friction. In actual rolling processes, however, friction depends on many variables such as the rolling speed, surface roughness of strip and the work roll, steel grade, and the composition of the lubricant. Under normal rolling conditions, friction is expected to take place in a

5-stand cold-rolling mill of voestalpine Stahl – The Austrian steel producer contributes its operational experience to the development of tribological simulation models for improved cold rolling

of the world's leading suppliers of lubricants in the rolling industry, develops specialized lubricants for the pilot mill trials that allow the influence of various physical and chemical parameters to be investigated. Quaker also provides support in the mathematical description of lubricants. The Austrian steel producer voestalpine Stahl makes available its considerable know-how related to mill operations for the production of premium-quality steel products, and offers its profound insight into metal-forming processes and their impact on surface quality. The lion's share and the essential portions of the modeling activities are performed at the Institute of Computer-Aided Methods in Mechanical Engineering at Johannes Kepler University (JKU) in Linz, Austria.

Core components of tribological simulation models

Particular emphasis is placed on a modular approach for the development of a comprehensive model of friction and lubrication in cold rolling. This approach increases the flexibility of the process models with respect to the different degrees of complexity of the submodels (Figure 1).

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so-called mixed lubrication regime where the rolling force is affected by the boundary contact forces at the asperities and by the fluid forces of the highly pressurized lubricant between the asperities. Consequently, accurate modeling of fluid-structure interactions involving coupled and highly complex nonlinear equation systems is one of the key characteristics of a mixed-lubrication numerical simulation. The challenge for the simulation process is to find submodels that cover all of the decisive influencing factors while still being able to solve the related coupled equations within a reasonable calculation time.

Contributions from experienced partners

In order to improve the understanding of tribological interactions that influence friction and lubrication in the roll bite, several highly experienced and qualified partners from different backgrounds have been working closely together since early 2009. Siemens VAI contributes with its extensive know-how related to the engineering, supply and construction of rolling mills. In the company's pilot mill facility in Montbrison, France, the rolling process and tribological parameters are investigated. The results serve as the basis for model calibration and parameter identification. Quaker Chemical Corporation, one

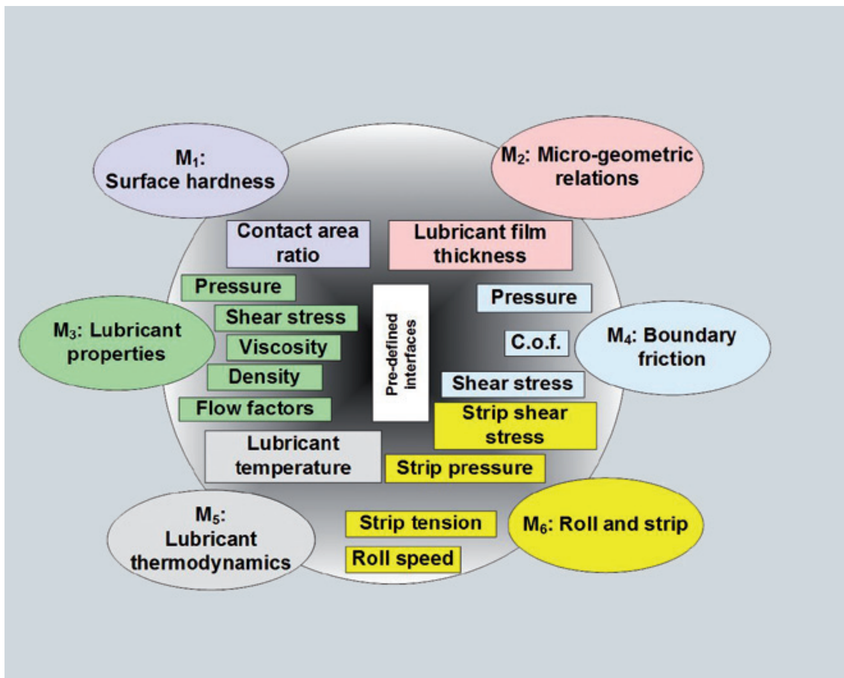

Fig. 1: Examples of parameters and their interaction considered in the tribological modeling of cold-rolling processes

1) Tribology is the study of interacting surfaces in relative motion with respect to friction, lubrication and wear.
2) Asperities are roughness peaks of strip and roll surfaces.
3) Plate-out is the spread-out of oil droplets from the emulsion on the surface of strip and work rolls.

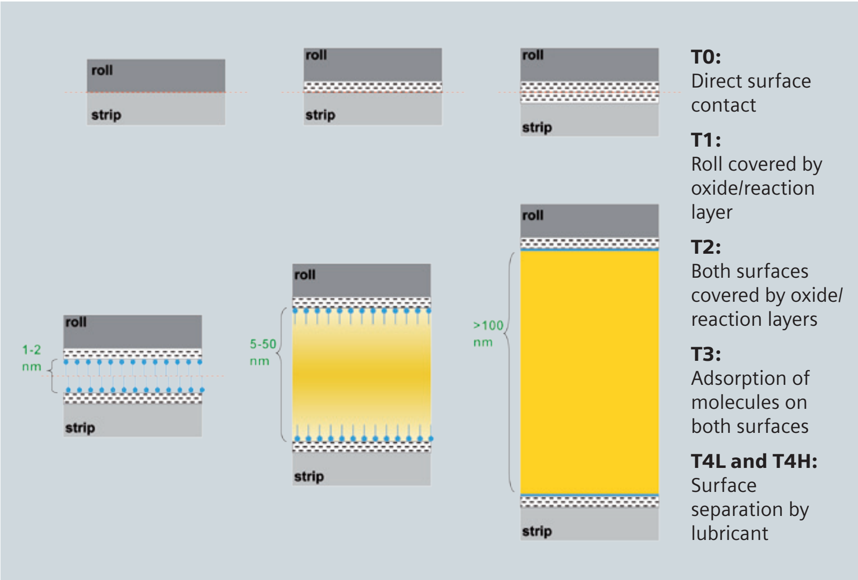

Fig. 2: Definition of contact conditions between strip and roll surfaces

>> An accurate description of the evolution of the surface geometry during a rolling pass is essential for an analysis of local friction types and their relative contribution. This is also important for accurate predictions. The model describes how the surface geometry evolves as a function of the lubricant properties, among other factors. Complex interaction mechanisms between local strip-surface deformation and bulk plastic yielding, which usually require the application of time-consuming, 3D finite-element simulations, are calculated by a simplified yet effective analytical "hardness model" that incorporates the combined influence of fluid and contact pressures. Due to strip deformation, friction and fluid effects (e.g., heat dissipation), the temperature in the contact area is expected to significantly increase compared to ambient conditions. For this purpose, a comprehensive, highly efficient thermodynamic submodel is used that considers the strip, roll surface and lubricant film. The overall tribological model is formulated in a way that it can be coupled with different cold-rolling models.

Investigation of the contact zone between roll and strip surfaces

Several types of contact that exist between strip and roll surfaces in cold rolling have to be distinguished for proper prediction of friction regimes (Figure 2).

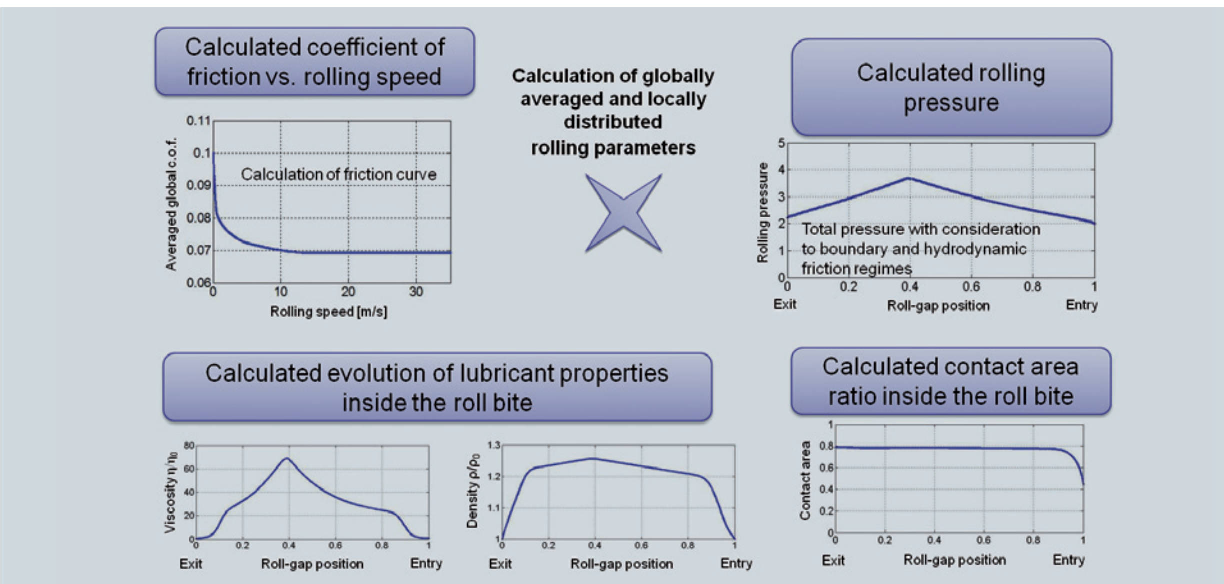

Fig. 3: Distributed and averaged roll-bite parameters

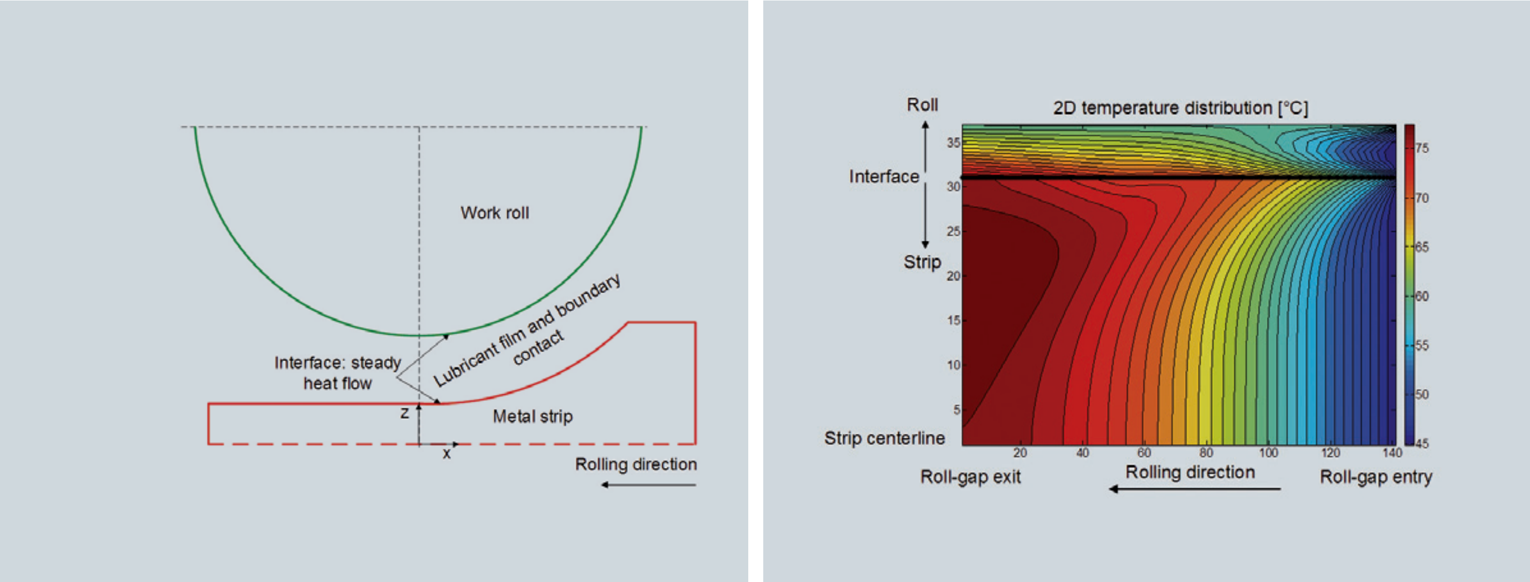

Fig. 4: Temperature development and distribution at the interface between the roll and strip surfaces

Friction and surface protection (i.e., avoidance of defects) are affected by a surface coverage of adsorption layers and layers of reaction products, especially during the occurrence of intensive, high-pressure contacts between the work roll and strip. Significantly reduced frictional forces arise in film-dominated contacts, the thickness of which depend on the applied lubricant and the prevailing rolling conditions.

Joint investigations between the project partners have led to a classification of these types of contact. Using these classifications and by applying state-of-the-art theories on the underlying physical and chemical effects, the respective mathematical formulations could be developed and integrated into the overall tribological model. As the interactions at a lubricated contact are strongly affected by physical and chemical mechanisms, one of the major challenges in modeling is the integration of these mechanisms into the descriptive equations. In this context, the participation of Quaker in the project team is an immense asset as this lubricant manufacturer provides valuable laboratory equipment and evaluation methods necessary for the tribological investigations.

Solution aspects and simulation results

The calculation algorithm (i.e., sequence of calculation steps) is based on several iterations during which the contact conditions, lubricant, strip properties and roll shape are continually updated. Model results comprise the distribution of local lubrication values along the roll bite related to, for example, viscosity, density and temperature (Figure 3). These values are strongly affected by the distribution of the fluid pressure and the temperature along the roll bite (Figure 4).

From these value distributions a global characteristic value can be extracted through integration. For example, an accurate prediction of the relationship between the rolling speed and friction (with consideration to the specific lubricant and rolling conditions of a particular mill stand) eliminates the need to enter any assumptions into the pass schedule calculations with respect to the coefficient of friction.

Benefits from enhanced friction modeling

The application of specialized tribological models contributes to a considerably improved understanding of the relationship and interaction between various rolling and lubricant parameters. Results obtained from tribological process simulations may be used in a wide range of applications. The development of new rolling oils will be facilitated, leading to enhanced and customized lubricants to meet the exact requirements of a rolling mill. Furthermore, the utilization of accurate simulation tools will enable improved predictions of force and power requirements for new mills and for the optimization of existing mills. Mill operators will benefit from improved pass-schedule calculations and optimized mill-operation regimes; higher productivity; improved and uniform strip surface quality; and reduced energy costs. ■

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