Numerical Simulation of the Rolling Process at Swiss Steel AG

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Abstract

In the stress field between engineering science and industrial production, modeling and simulating techniques have emerged as primary and essential tools for science as well as for practice. A fast simulation program to calculate forming processes in a bar and wire mill is introduced. The description of the process chain starts with reheating, runs through different forming steps, finishing with cooling down to room temperature. In addition to temperature and forming conditions, the microstructure development of austenite is calculated with local resolution. The fundamental novelty of this simulation tool is that the local distribution over the profile of parameters such as temperature, deformation degree, state of recrystallization and grain size can be calculated throughout the entire production process.

The analysis of the phase transformation delivers the phase products and their properties, which allows a local prediction of the product's mechanical properties.

The program is based on modules and can therefore reflect any mill configuration.

The efficiency of the program is demonstrated on two steels, its variability is confirmed by the use of different rolling and cooling strategies.

The comparison between calculated and experimental results which were found admit the conclusion that the presented model is a suitable tool for process design and quality control.

1. Introduction and Object

Swiss Steel AG is a producer of steel long products. The product portfolio includes steel bar and wire rod made of unalloyed and alloyed engineering steels (Fig. 1). In addition to the engineering steels, the company also provides special steel solutions developed specifically for and with their customers. At the end of the production chain, approx. 60% of all Swiss Steel products go to the automotive industry and approx. 30% to the machine and engineering industry. Around 10% of the products are for consumer markets in the chain and construction industry.

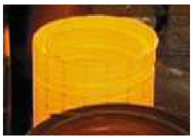
Steel Grades	Rolling Dimensions	Customers
• Free-cutting steel • Quenched and tempered steel • Case-hardening steel • Cold heading steel • Micro alloyed steel • Chain steel • Construction / mining	 Wire rod: 5.5 to 44 mm  Bar steel: 15.7 to 66 mm	• Drawing mills • Machining companies • Cold forging • Hot forging • Chain manufacturers • Construction (specialty products)

Fig. 1: Swiss Steel AG steel grades and dimensions

The Swiss Steel production process is that of a classic electric steel mill: virtually 100% of the raw material used is scrap. The scrap is smelted in an 80-t capacity electric furnace, refined in a ladle furnace, degased in a vacuum as needed and cast in a continuous-casting machine to billets with an edge length of 150 mm. Following reheating in a walking-beam furnace, billets travel to a single continuous high-performance rolling mill from which they are conveyed to a Garrett, Stelmor or bar steel line where they are rolled to the final desired dimension.

It is taken for granted today that conventional criteria are met in terms of quality and quantity. These include specifications regarding chemical analysis, shape, surface quality, internal defects, but also expectations related to an attractive price level, short delivery times, high delivery reliability and high flexibility (Fig. 2).

Over the past few years Swiss Steel AG has developed a simulation program that allows the mechanical and technical properties of their products to be predicted in advance as a function of rolling parameters and chemical analysis. In using this program, the company offers their customers an added value. As early as in the design stage of a new product to be jointly developed it is possible to introduce new production processes efficiently and effectively and to develop the relevant product characteristics affordably and rapidly in “virtual space”. The details of the simulation are discussed below.

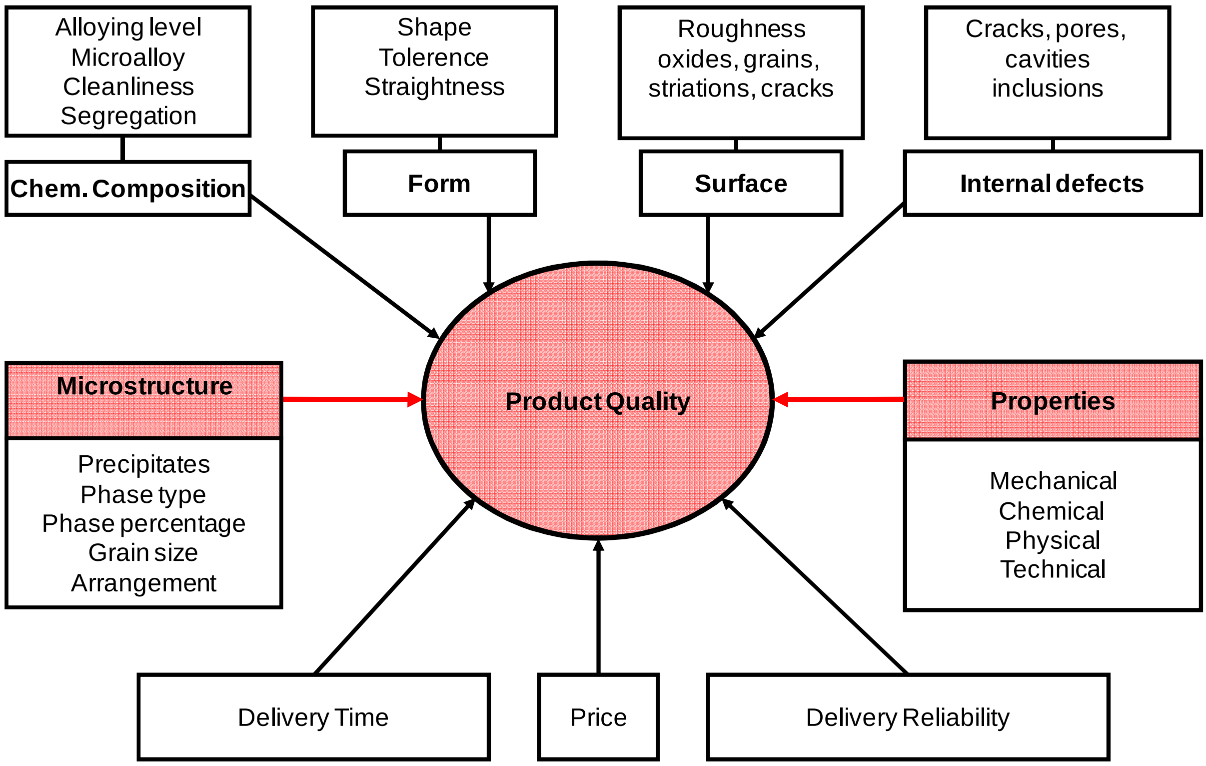


Fig. 2: Quality map for the production of sophisticated long products (red = content of the Swiss Steel AG microstructure model)

2. The importance and advantage of numerical simulation during caliber rolling

The plant layout of the Swiss Steel rolling mill is shown in Fig. 3. Important elements of the rolling mill are:

- High-pressure descaling unit (water pressure: 150 to 400 bars),
- Reducing & sizing block (high tolerance conformity and productivity),
- Option of performing thermo-mechanical treatment,
- Finishing for steel bars, hot-rod wire testing system, and wire coating unit.

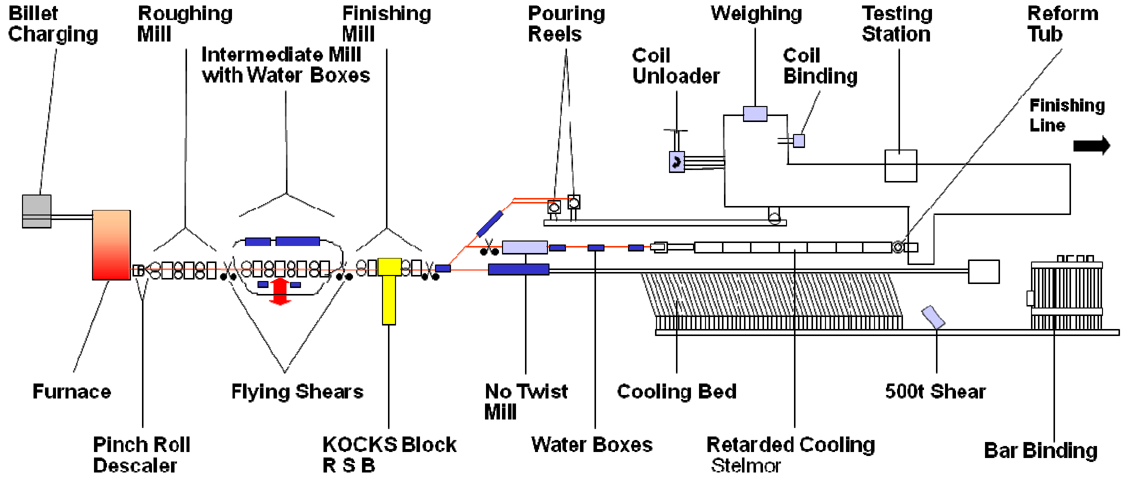


Fig. 3: Layout of the Swiss Steel AG rolling mill

The technical degree of freedom during the rolling of steel bars and wires is limited. Generally, the only factor that can be controlled is the forming temperature. The product quality (mechanical properties and microstructure) is the result of sophisticated metallurgical processes which are interdependent and upstream/downstream of one another (Fig. 4) [1-3].

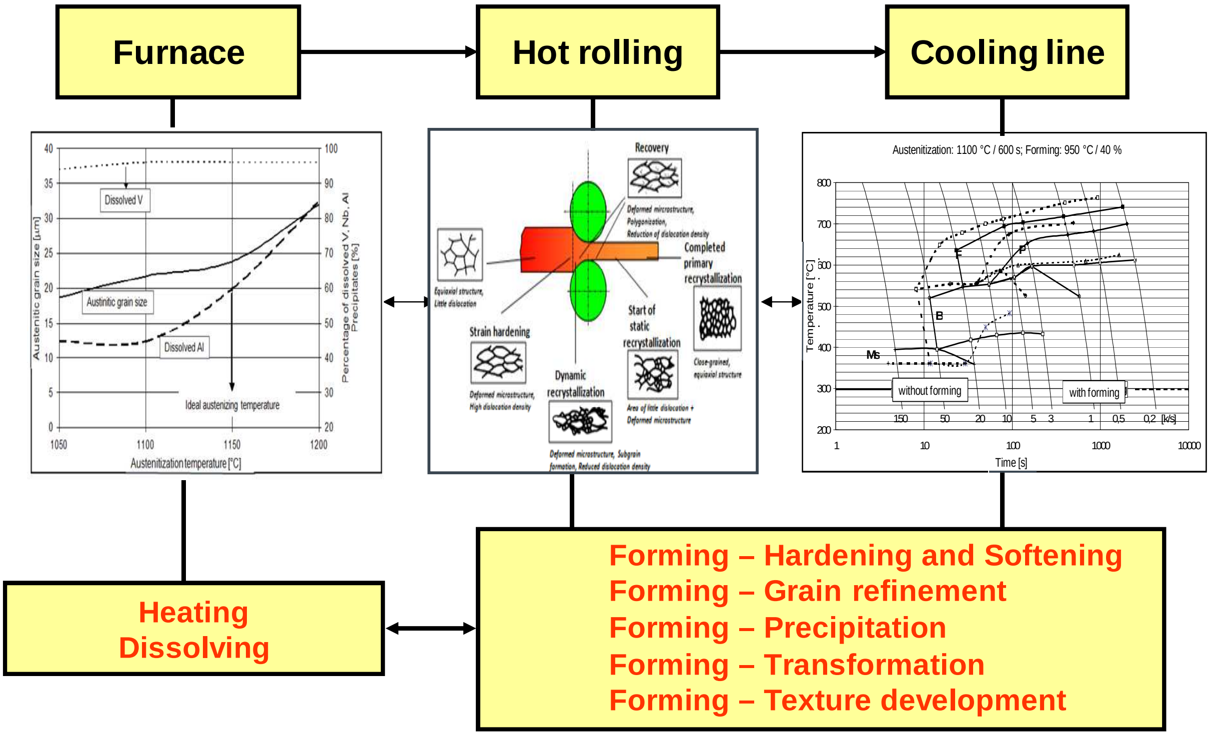


Fig. 4: Processes related to material science that occur during hot rolling [1-3]

In operating processes and real-time production, the interactions between process parameters and the development of material characteristics can almost not be recorded in their full complexity and dimension. For example, an evaluation of the results of a change in process parameters or the impact of new plant sections, such as the implementation of intermediate cooling can only be assessed by means of costly and time-consuming pilot production runs with subsequent material characterization.

In this context, the numerical simulation is an innovative option for cutting development costs as well as managing and/or controlling product quality. Table 1 lists examples of questions drawn from actual practice, their conventional operating solutions as well as the potential of the numerical simulation.

Question Challenge	Opportunities and limits in real-time production e.g. wire rod	Opportunities and limits of simulation e.g. of wire production
Product release	Sampling at the end of the coil	Calculation of the properties over the entire volume
Impact of process parameters on the final properties	Test rolling (several tons), sampling at end of the coil	Rapid implementation of parameter variations
Implementation of new production elements	Wording of product specifications "to the best of knowledge"	Forecast specifications
Development of new products with new process	Laboratory testing, prototype production, sampling	Shortening of the development phase by means of virtual product and process development
Develop in-depth understanding between the connections of process parameters and metal processes	Almost impossible in real time	With the numerical simulation of the rolling mill, know-how of the interaction between process parameters and product properties can be acquired rapidly and extensively
Gain understanding of the interaction between process parameters and product properties		

Table 1: Challenges, opportunities and limits of operating solutions compared to the commercial potential of the numerical simulation

3. Performance characteristics of the numerical caliber rolling model

The numerical model maps the metallurgical processes, starting with reheating of the billets in the rolling mill furnace to the actual rolling and to the transformation processes that occur when cooling the product to room temperature. This makes it possible to predict the development of austenitic grains as well as the final structure derived from them and the mechanical properties. The material results are supplemented by calculating the process parameters as well as the power and labor requirements. Using this simulation tool, it is possible to simulate virtually any rolling mill configuration.

As a solid base for the implementation of the calculation tool in actual practice, the following demands were made of the simulation model during the initial development phases:

- The software must be able to calculate the mechanical and technical product characteristics as a function of the process parameters of the rolling mill.
- The software must consist of separate modules (e.g. horizontal frame or cooling line). This is meant to ensure that every rolling mill configuration can be simulated e.g. for final diameters of 6mm or 64mm. The description of the product development, however, is to be incorporated in a complete model.
- The simulation is to be 3-dimensional. This means it must be possible to calculate e.g. the temperature field, the degree of deformation, the forming speed, microstructure

development (austenitic and final microstructure) as well as the mechanical properties (Fig 5).

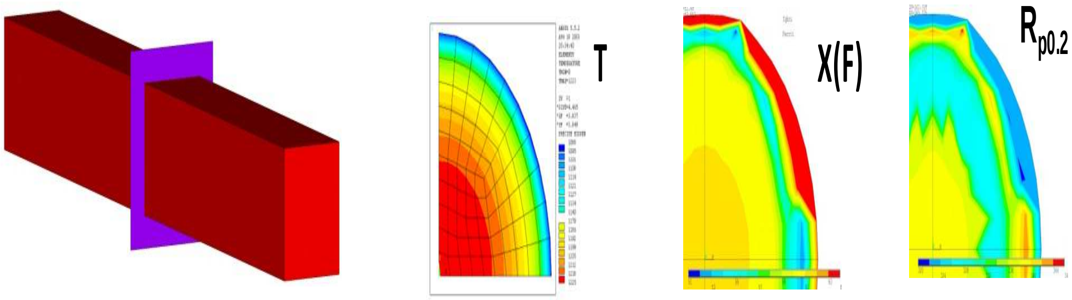


Fig. 5: 3-dimensional calculation principle

- The simulation model should be available during the complete process.
- The model's area of applicability must not only cover the current state-of-the-art, but also map possible future development trends (Fig. 6).

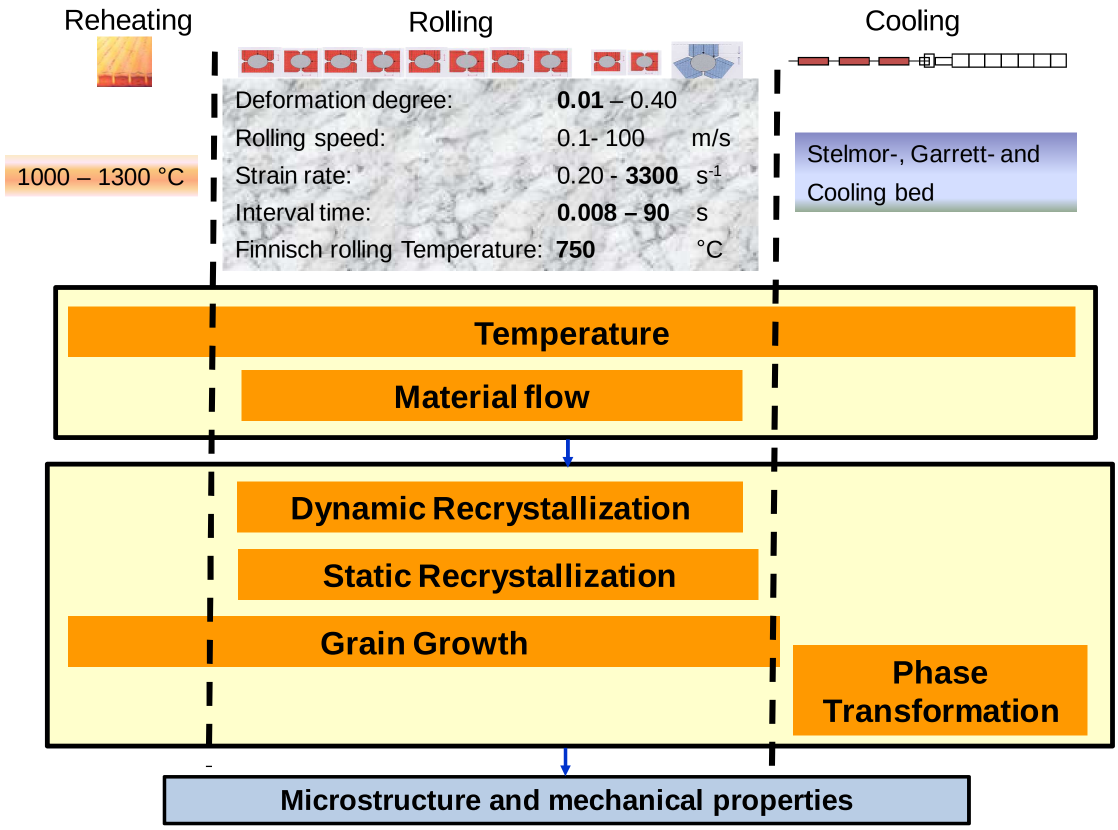


Fig. 6: Validity range and program structure of the calculation tool (Swiss Steel AG)

Based on phenomenological and semi-empirical models [4-6], a slice of material is tracked throughout the entire rolling process (Fig. 5) [7-8]. All production elements are mapped and numbered. The link between the process model and the material model is correspondingly guaranteed The process model and the material model are thus correspondingly connected (Fig. 6).

4. Validation - Experiences in Actual Practice

The implementation of simulation models in actual practice largely depends on the degree of confidence enjoyed by these tools. In this context, the rolling simulation model presented was tested and validated on all rolling lines (compare Fig. 3) and under different operating conditions of the Swiss Steel rolling mill. For this purpose as a basis of comparison, rolling logs, the results of material testing (tensile tests, metallography), different production orders and random samples at the shears were used.

In addition to an exact calculation of the material flow, the degree of deformation and distribution of the deformation rate across the cross section, the focus of the simulation is the calculation of the temperature profile. The development of temperature over time is decisive for the simulation of material development and for interpreting the rolling mill process parameters.

Fig. 7 is an example of the temperature profile at selected points of the cross section during the thermo mechanical rolling of 21.0 mm wire. The calculation considers the heating process, 13 rolling steps prior to the targeted reduction in temperature by means of a loop, the 5-stage final forming in the reducing & sizing block (RSB) and cooling on the Garrett line. Auxiliary systems such as the descaling unit or breaks are also included in the simulation.

Among other things, it documents that the temperature gradient core - edge prior to and after final deformation is a maximum of 40°C with the selected rolling parameter setting. Thus the first prerequisite in the production of a homogeneous final microstructure is fulfilled across the cross section. To verify this result, measurements of numerous rolling passes were conducted. A comparison example is shown in Fig. 8. The temperature model meets the final rolling temperature with a maximum deviation of ± 20 K. These findings were included, among other places, in the design and start-up of the loop for thermo mechanical treatment at Swiss Steel [9].

Another very important variable is the calculation of the development of the austenitic grain during the entire heating, deforming and cooling process. It is the main requirement for predicting product quality. The structure of the final product and the associated mechanical properties greatly depend on the austenitic state prior to transformation.

Figure 9 shows the development of the average austenitic grain size along the rolling mill during the rolling of 16MnCrS5, 27.0 mm, on the Garrett line. Good qualitative (metallurgical tendencies) and quantitative agreement can be determined between calculations and measurements.

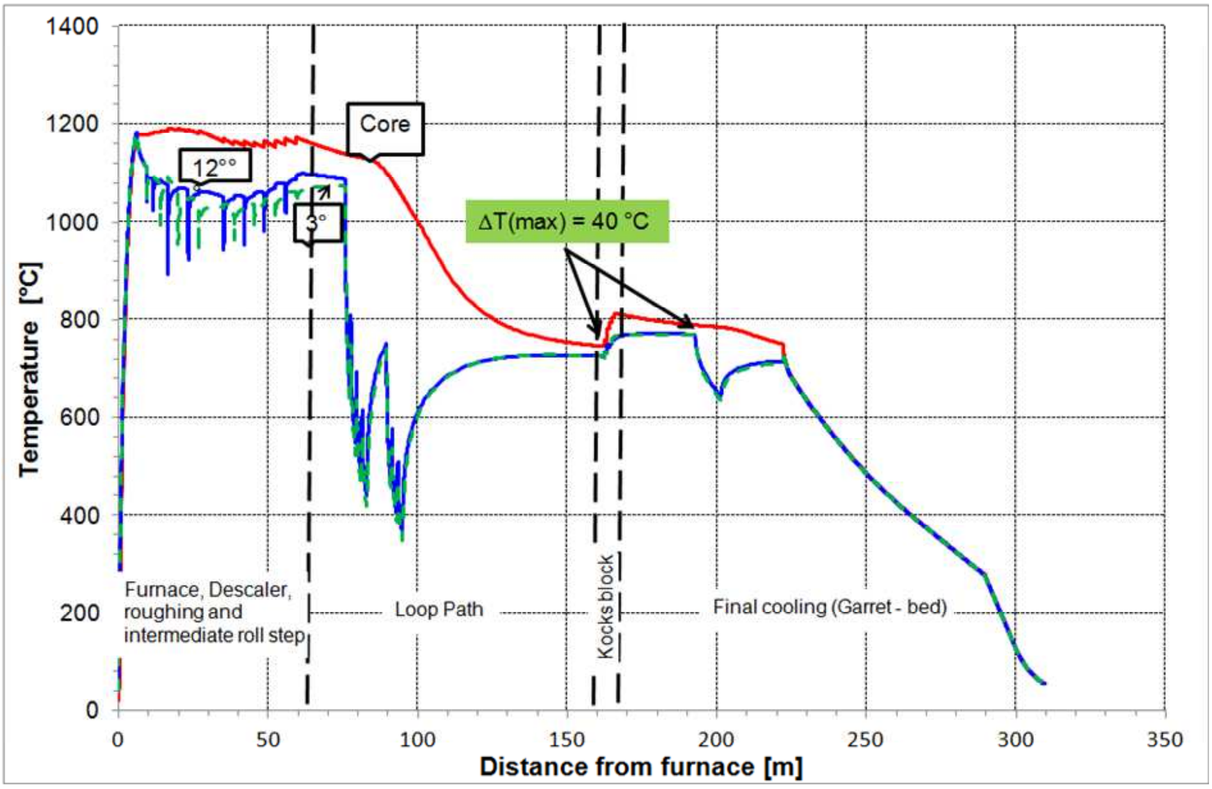


Fig. 7: Temperature development during thermo-mechanical treatment of 21.0 mm wire

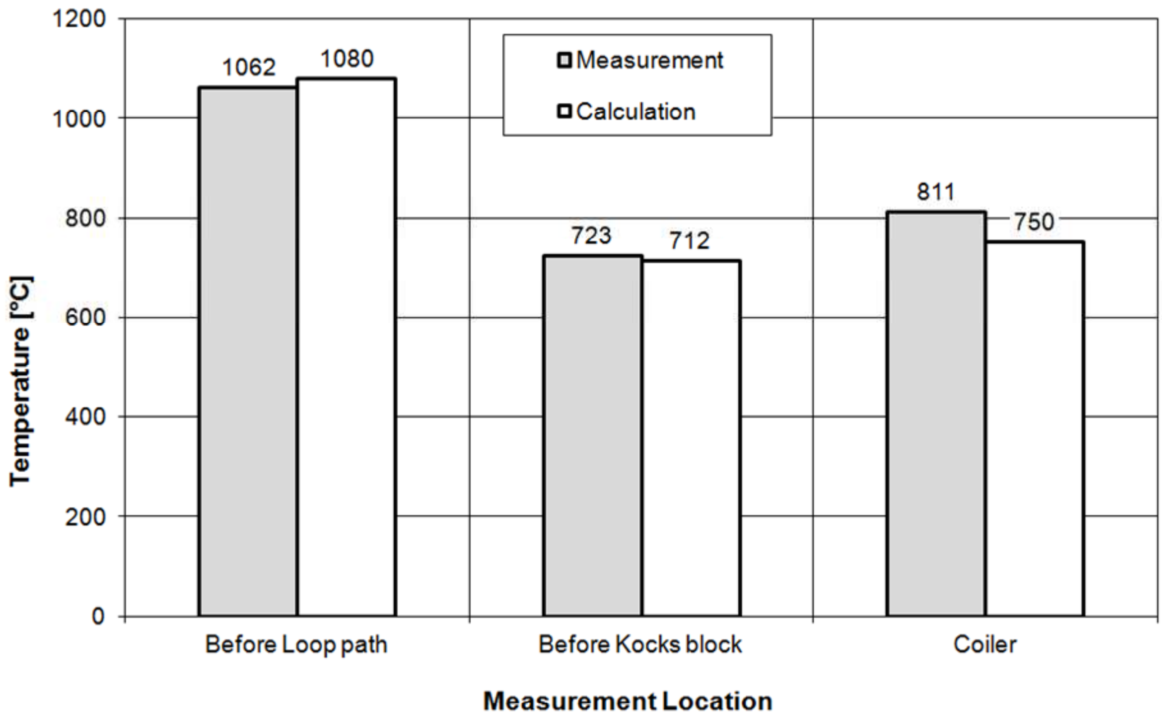


Fig. 8: Comparison between the calculated and measured temperature profile

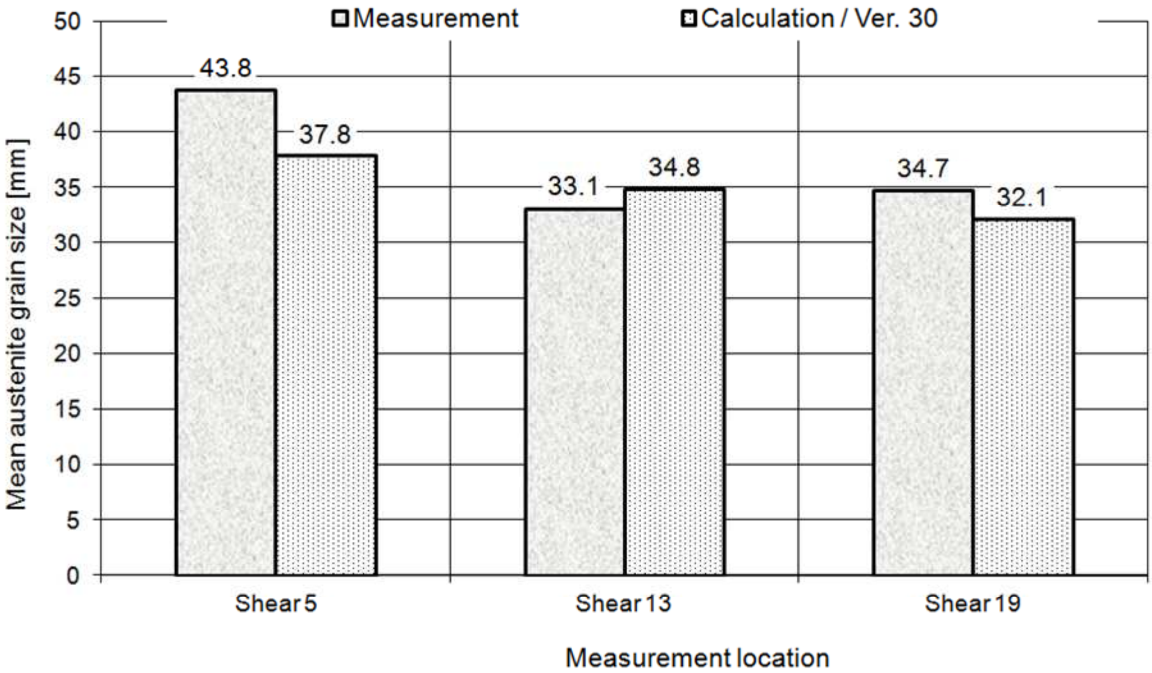
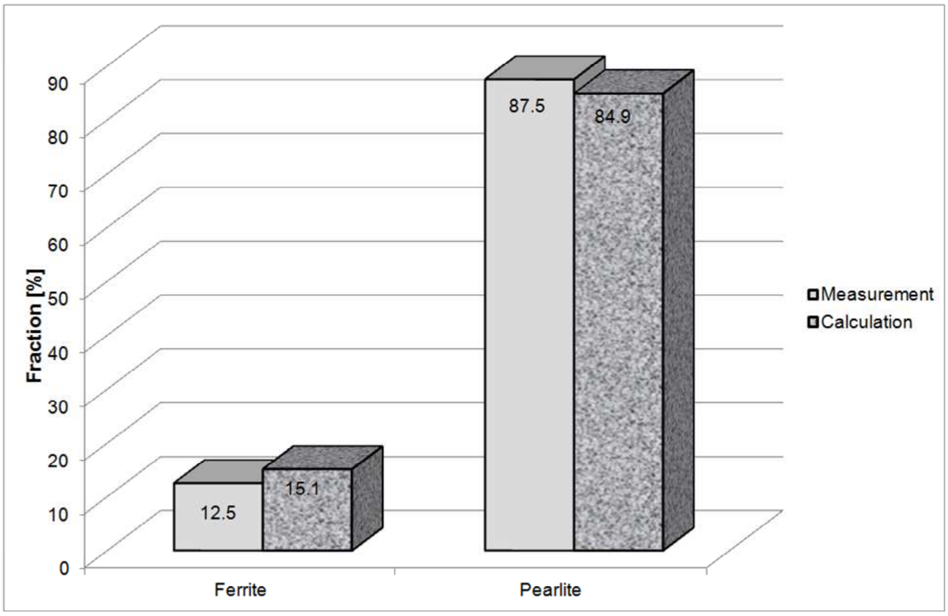


Fig. 9: Microstructure development on the rolling mill – 16MnCrS5 - 27.0 mm Wire

As would be expected, the good correlation between measurements and calculations in the calculation of the material flow, temperature and microstructure development had a positive impact on the prediction of the final microstructure and the mechanical properties (Figure 10). The anticipated results were confirmed in numerous other examples.



	$Rp_{0.2}$ [MPa]	Rm [MPa]	A5 [%]	Z [%]
Measurement	432	760	16.9	33.9
Calculation	445	786	17.4	36.6

Fig. 10: Structure and mechanical properties – Cf53 – 18.0 mm - cooling bed

Literature

[1] Hensel. A., Lehnert, W.: Neue Hütte 18 (1973) No. 11, pp. 654 – 662

[2] Chabbi, L.: Freiberger Forschungsheft, B 315; 2001, ISBN 3-86012-149-9

[3] Chabbi, L., Stüber, A., Urlau, U., van Hüllen, P.: MEFORM 2003, Freiberg, Tagungsband, pp. 232 – 246, ISBN 3-86012-193-6

[4] Braun-Angott, P.; Rohloff, H.: Steel Research, 64 (1993), No. 7, 350-355

[5] Bhatti, M. A.: Fundamental Finite Element Analysis and Applications; John Wiley & Sons, Inc.; 2005

[6] Kawalla, R.; Krause, G.; Bubek, F.: Freiberger Forschungsheft B 306; 2000

[7] Chabbi, L., Urlau, U., Stüber, A., van Hüllen, P., Krause, G, Kawalla, R.: MEFORM 2007, Freiberg, Tagungsband, pp. 33 – 44, ISBN 978-3-86012-300-3

[8] Krause, G., Kawalla, R., Chabbi, L., Urlau, U, Stüber, A., , Diederichs, R., van Hüllen, P.: Steel Research, 78 (2007), No. 10 – 11, pp. 745 – 750

[9] O. Lötscher, G. Nussbaum, G. Bittner, W. Krämer, F. Clement: 3rd Int. Conference on Thermomechanical Processing of Steels, 2008, Padua, Italy