REAL-TIME AUTOMATIC PROCESS AND METALLURGY CONTROL FOR FLAT C-STEEL PRODUCTION

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Abstract

Operational constrains of Hot Dip Galvanizing Line – HDGL - management are more and more challenging: competitiveness (quality/yield improvement – productivity increase – OPEX reduction), flexibility (complex product-mix) and environment footprint reduction (lower energy consumption, raw material savings). These challenges can be addressed with the usage of digital tools enhancing the process optimization and automatic control of production lines.

For that purpose, physical-based models have been built and industrially implemented in order to predict microstructural evolutions during annealing and related mechanical properties of flat-C steels at the line exit.

These models rely on the description of the main metallurgical phenomena, i.e. recrystallisation, phase transformation and precipitation during heating, soaking and cooling.

The accurate design of each individual metallurgical brick and sequencing of the models enables the precise description of final microstructural characteristics: phases sizes, fractions and composition. These features are then used for the prediction of mechanical properties thanks to mean-field dislocation-based model.

Finally, these models are implemented in an optimizer (so-called MasterModel in the proposed solution) and coupled with a thermal process control model to manage in the most efficient way HDGL, enabling fine control of coil to coil properties and chemical composition heterogeneities. This digital tool is called SmartLine™.

The proposed approach and model's combination cover large chemical composition and steel grades spectrum from conventional ferrite-based alloys to Advanced High Strength Steels.

Keywords: Hot Dip Galvanizing Line, Digitalization, metallurgical models

1. INTRODUCTION

Steel production quality objectives are defined by standards or customer specifications: mechanical properties, chemical analysis, dimensional tolerance, surface appearance and coating properties. The usual way to achieve these objectives during production on a galvanizing line is to define the metallurgical roadmap per steel grade. These roadmaps contain the chemical composition and all process parameters from slab production to annealing time and temperature, as well as skin-pass elongation. These parameters are defined as validity ranges and/or targets.

The objectives of the manufacturing lines are to assure that the proposed ranges for each process parameter are achievable with a near 100% success rate, and then to drive the lines to meet these rules and deliver the correct product over the entire length and for each coil.

Metallurgical models have been developed over the years to simulate product properties as a function of line parameters, in order to optimize the process path or to verify the feasibility of a specific format. These models cover a wide variety of steel grades, from IF [1] to micro-alloyed [2] and Dual Phase [3].

The Smart line approach is to reverse the above logic by calculating optimized process parameters based on incoming coils and target product properties for each order. The SmartLine™ also considers and verifies the consistency between the equipment to define the optimum in each case. Also, in case of non-uniform incoming coils, the Smart line is able to calculate potential compensations (furnace temperature, line speed, skin-pass elongation) in order to make the final product delivered more uniform.

2. CONCEPT

The objective of the SmartLine™ is to control the production of a continuous galvanizing or annealing line by integrating the various upstream and downstream processes, including annealing, metal coating, and finishing target with skin-pass for each coil. The continuous annealing cycle (time, temperature) is then adapted per line (length, power, etc.) and per coil rather than being defined in tables by quality and dimension. This is made possible thanks to the complete digital integration of industrial processes from control to qualification and delivery in a global Industry 4.0 approach. This approach leads to a homogenization of product properties, optimization of the production process with increased productivity and lower energy consumption. The overall concept is schematized on **Figure 1**.

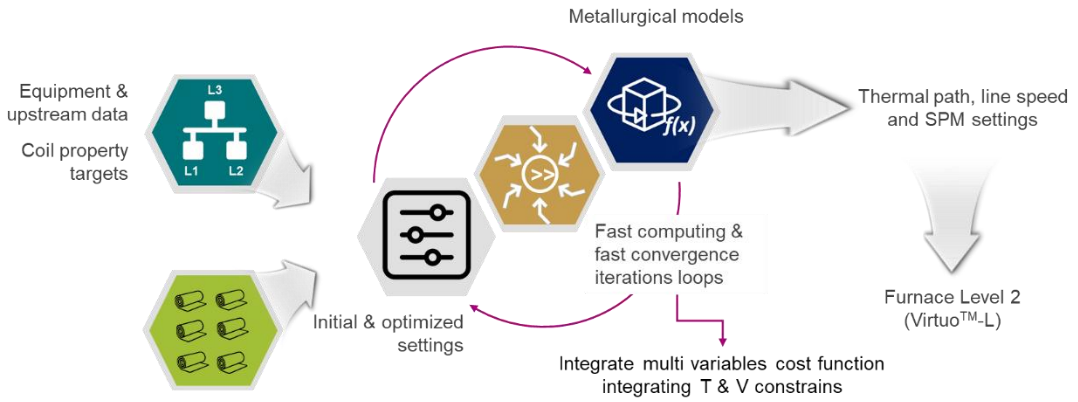

Figure 1 Schematic concept of SmartLine™ and associated process control

The prediction of the strip microstructure evlution along the process and associated mechanical properties, rely on several key modeling bricks as highlited on **Figure 2**:

- Prediction of the incoming coil properties, based on mechanical models describing cold rolling process,
- Prediction of the outcoming coil microstructure, based on the description of metalllurgical phenomena occuring during annealing (recovery, recrystallization, precipitation, phase transformation),
- Prediction of the outcoming coil tensile properties, based on mean field mechanical models.

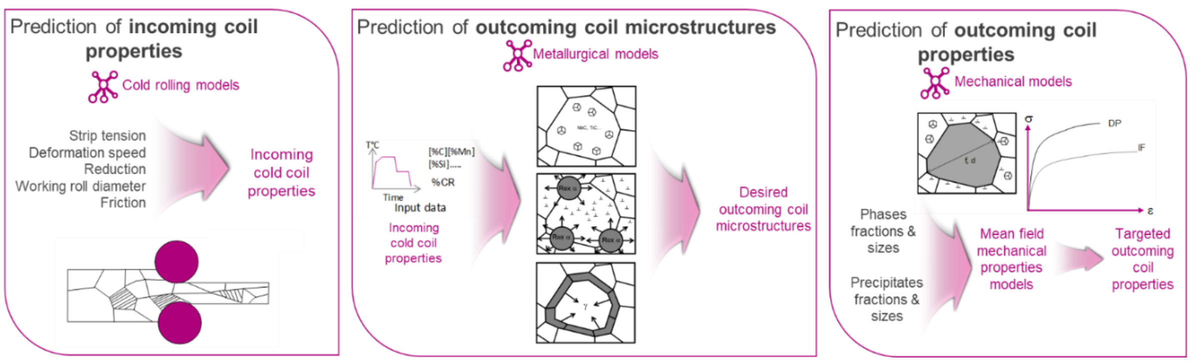

Figure 2 Key modeling bricks

The cold rolling and phase transformation models will be further discussed.

3. COLD ROLLING MODELS

To evaluate the tensile properties and associated microstructure of the incoming strip, mathematical models describing cold-rolling process have been developed.

Geometrical description of cold rolling process enables to correlate de rolling force to sheet mechanical properties. Based on the measured vertical rolling force applied on the strip between the 2 working rolls, it is possible to determine strip properties (**Figure 3**).

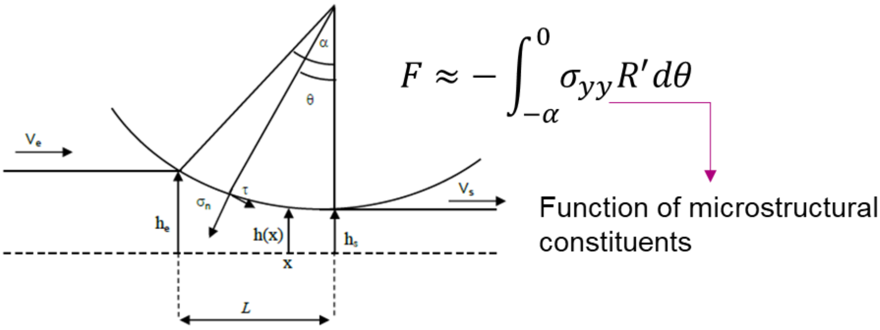

Figure 3 Geometrical description of rolling

Several models are well documented in the literature as Bland & Ford (no deformation of the rolls) and Sims (elastic deformation of the rolls) approaches. Both are built on different assumption (rolls deformation) and friction criteria (Coulomb & Tresca).

Different models and related hypothesis can be used and applied, depending on several factors related to steel producer product mix, scheduling, lubrification regime management…The final choice of the most suitable approach is based above mention parameters and measurement on the strip (tensile properties and grain size) that are being compared to predicted ones.

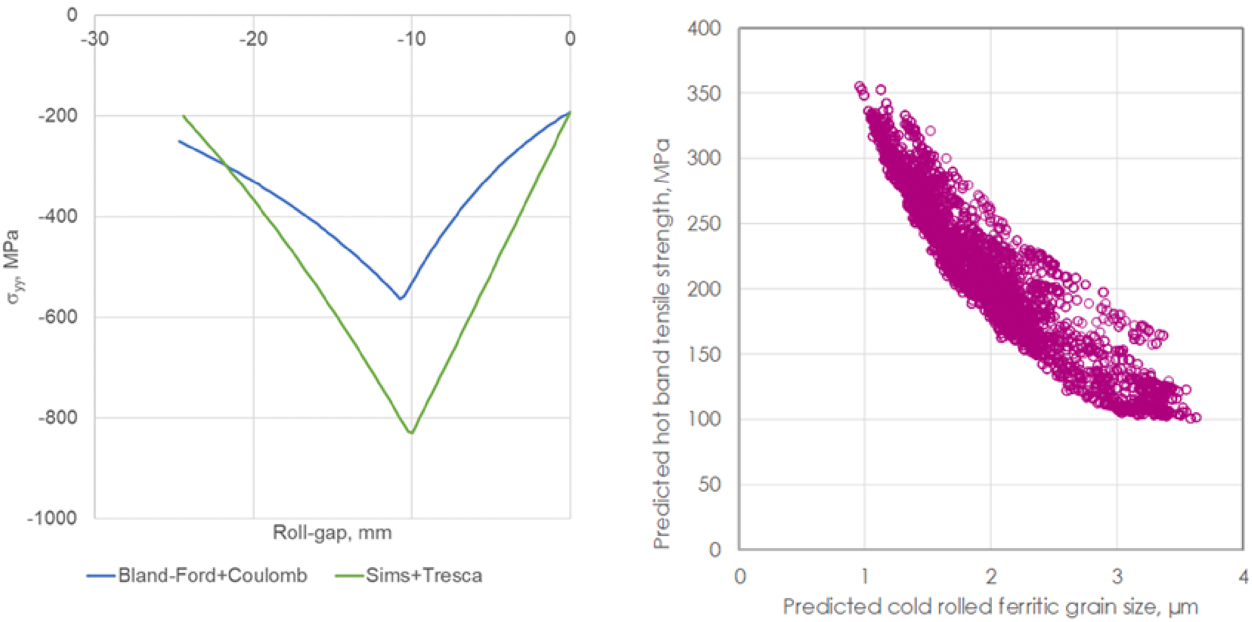

Figure 4 Comparison of cold roll model results, and predicted strip properties for various IF steel grades.

4. PHASE TRANSFORMATION MODELS

Several models have been developed and adapted to describe phase evolution during annealing. In particular, austenite formation during heating and soaking is particular importance in regard to final microstructure. Depending on the steel, chemical composition and line type, different approach can be used:

- For conventional ferrite-based steel grades (IF, BH, Al-k, HSLA) or low DP grades (DP600 with ~1.6%Mn maximum), clean chemistry (Blast Furnace based) or long CGL furnace, determination of phase fraction through equilibrium approach is accurate enough,
- On the contrary, for more advanced steel grades (DP>600, CP, 3rd GEN…), chemistry with large amount of tramp elements (Electric Arc Furnace based) or short CGL furnace, thermo-kinetic approach is required.

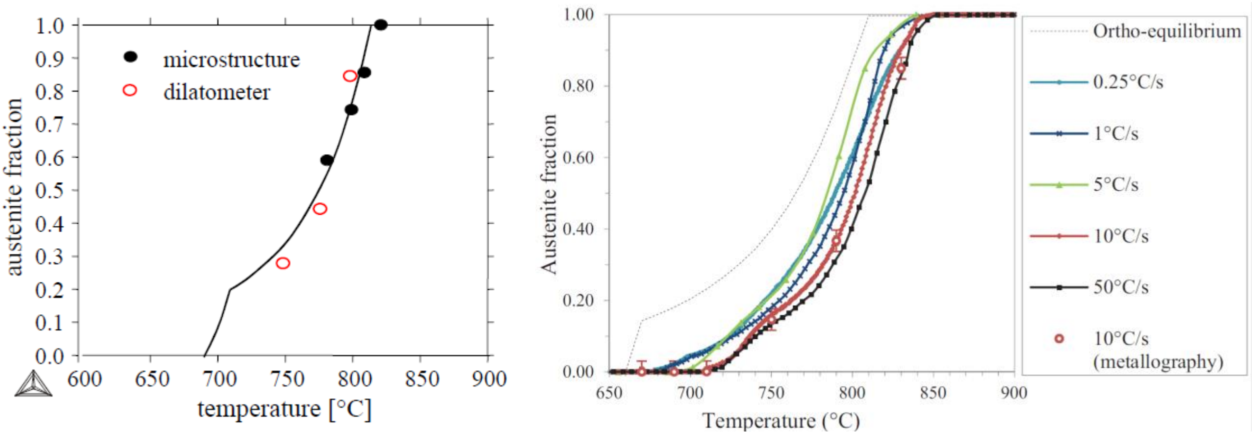

Figure 5 Calculation of austenite fraction during heating based on equilibrium condition for (left) DP600 with 0,1%C-0,1%Si-1,5%Mn-0,8%(Cr+Mo) [4] and for (right) DP980 with 0,075%C-0,3%Si-2,5%Mn-0,3%Cr [5].

Alternative approach has been developed in order to describe austenite formation in more advanced alloyed steel grades, based on a modified Fick equation to model diffusion profiles within mobile interfaces with chemical potential gradients [6][7]. This approach enables successful description of austenite formation in more advanced strength steel with higher alloying content as depicted on **Figure 6**.

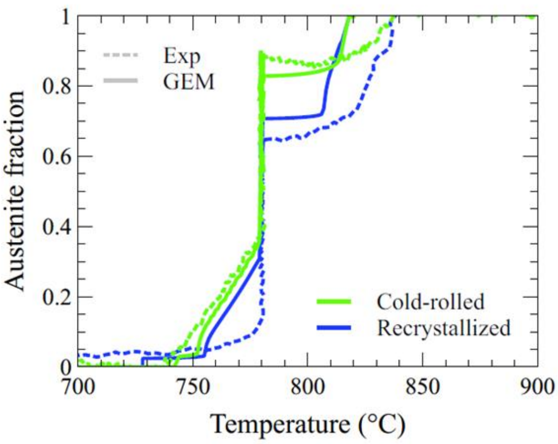

Figure 6 Calculation of austenite fraction during heating based on new model development and applied to DP1000 with 0,17%C-0,3%Si-1,7%Mn-0,43%Cr [8].

5. REAL CASE INDUSTRIAL APPLICATION

These mechanical and metallurgical models are integrated in a digital software solution (SmartLine™) and combined with process model in order to enables process optimization.

It has been implemented on 4 CGLs at an Italian steel producer, having a large coil supplied diversity and product mix (AlK, IF, HSLA and DP steel grades). The implementation of these process control models enables product quality improvement, quality increase and energy savings thanks to optimized process conditions.

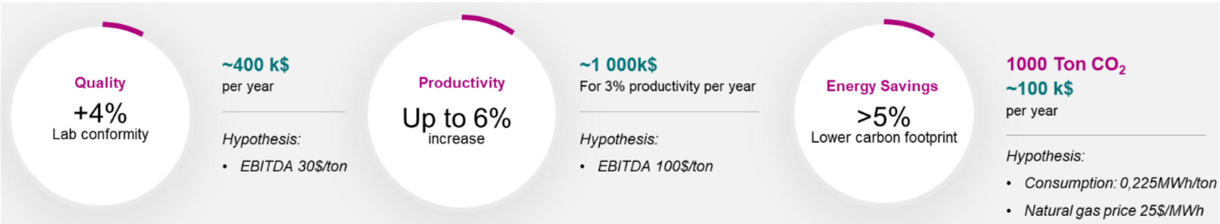

Figure 7 Benefits achieved after model implementation.

6. CONCLUSION

In order to optimize flat-C coil processing on hot dip galvanizing lines, different models were adapted and combined. Depending on the specificities of the operating lines or the product mix, different approach can be used and implemented.

The proposed approach has been successfully implemented on 4 different galvanizing lines achieving strong benefits in terms of quality, productivity and energy savings.

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