ArcelorMittal

Predicting the metallurgical structure and the mechanical properties along the process: where are we?

SF2M presentation

Summary

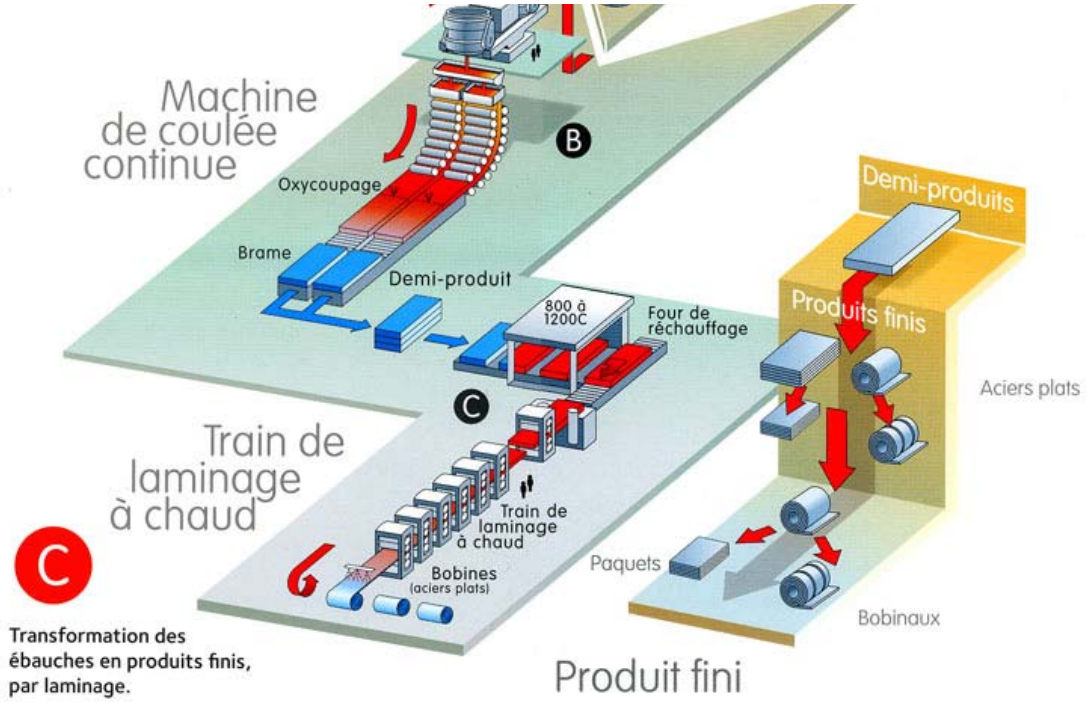
- What are we talking about?
- Model?
- Success:
  - Rolling
  - Phase transformation
  - Water cooling
- Way forward
  - Segregation
  - Austenite structure

What are we talking about?

Prediction of mechanical properties all along the process

- We focus mainly on flat products.
- Which mechanical properties?
  - Those asked by our customers: Yield stress (YS), Utlimate tensile stress (UTS) , total elongation (El%)
  - Next step: other properties: Reduction of area, complete stress-strain curve, ductility???

- From Continuous caster to final forming in our plant (usually skin pass)

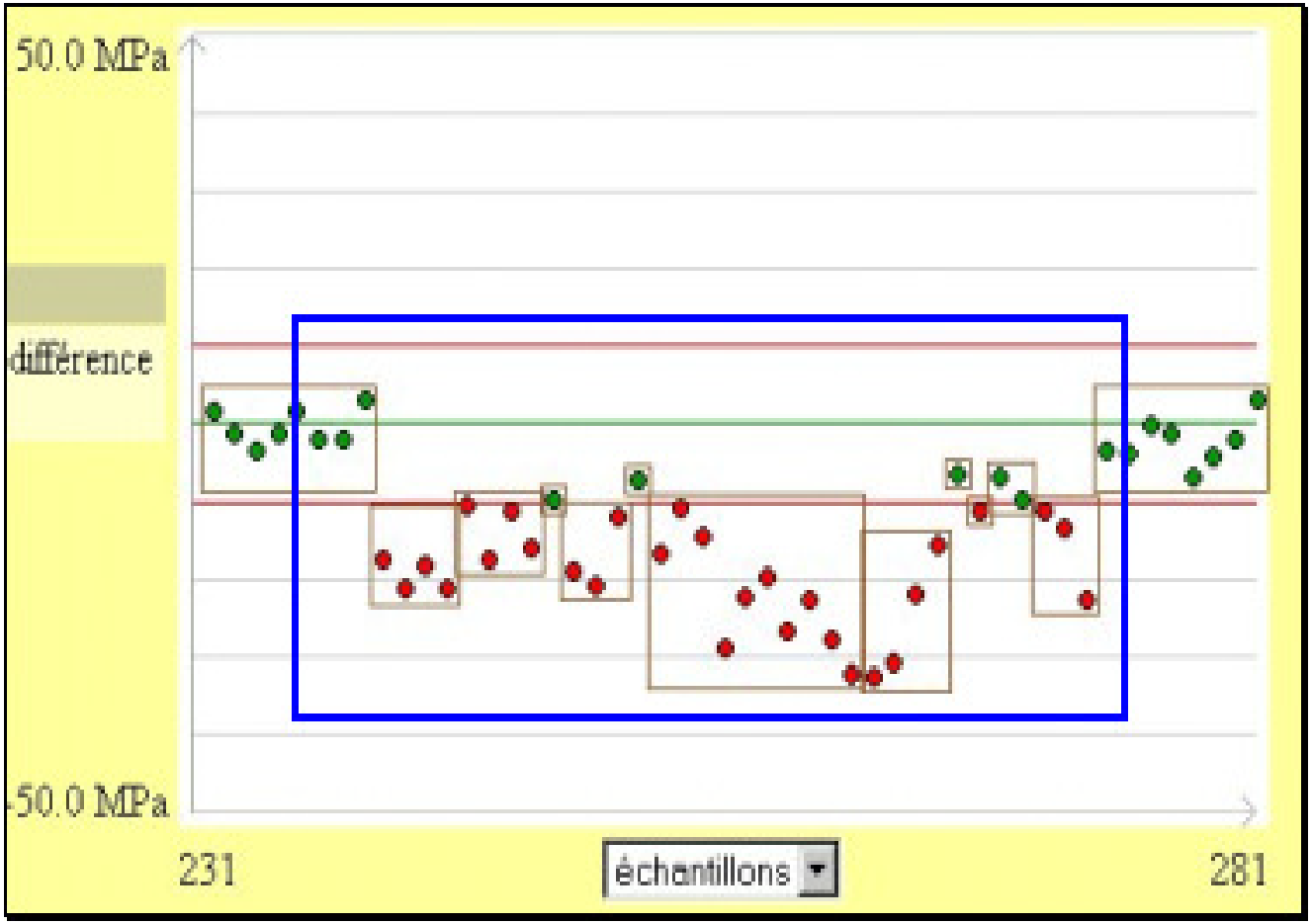


Such predictions are made daily in our plants

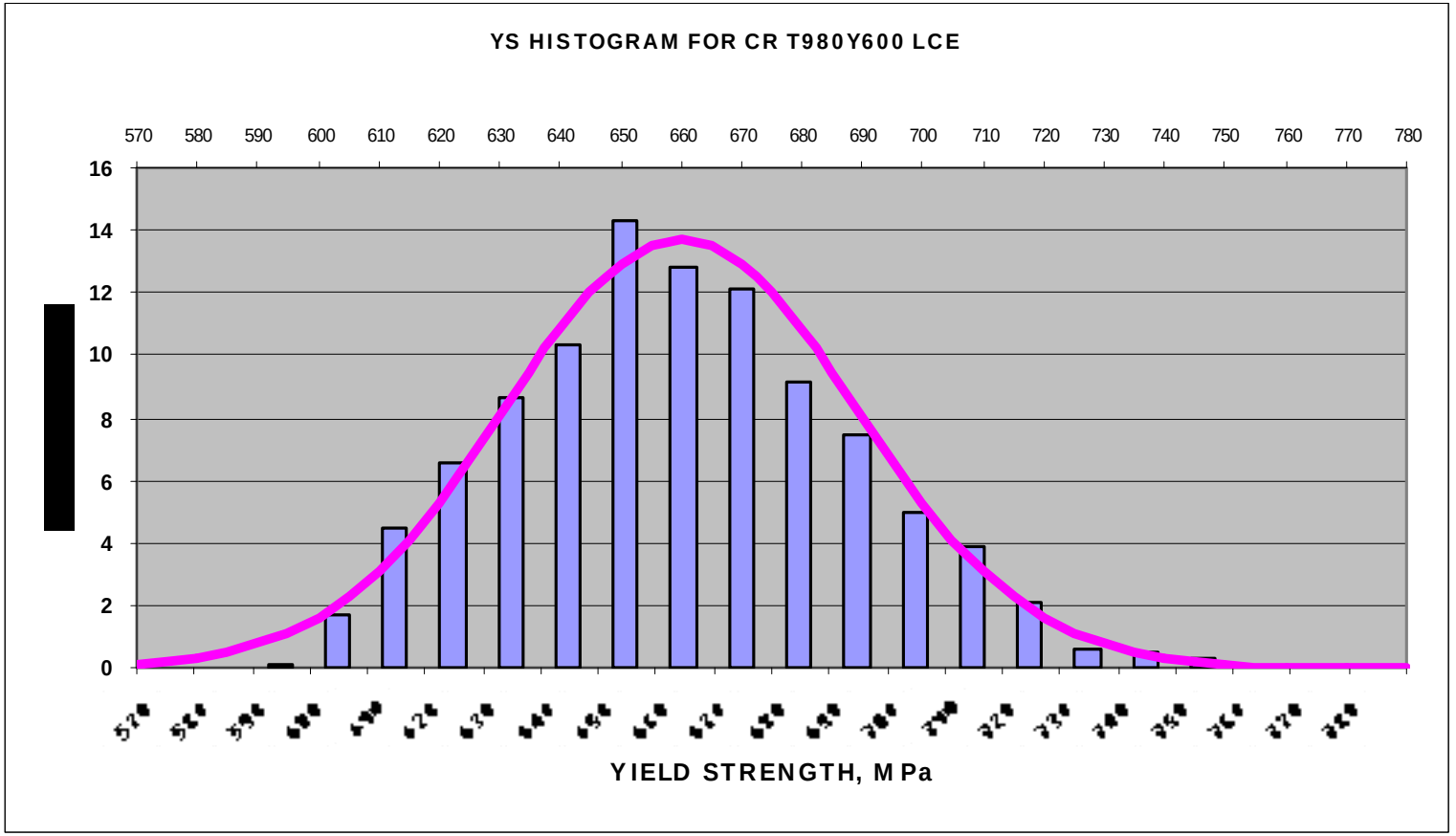
- Objective : Need of a very good precision.
  - deliver coils to customers without testing of mechanical properties
  - Analysis of effect of each process step on final properties: final scatter,
  - React to possible troubles during the production.
- Status:
  - Good prediction for “common” metallurgies: Interstitial free, conventional C-Mn steels, High strength low alloy steels,
  - Focus on Higher resistance steels with more alloyed metallurgy → under development.

Use of models in the plant

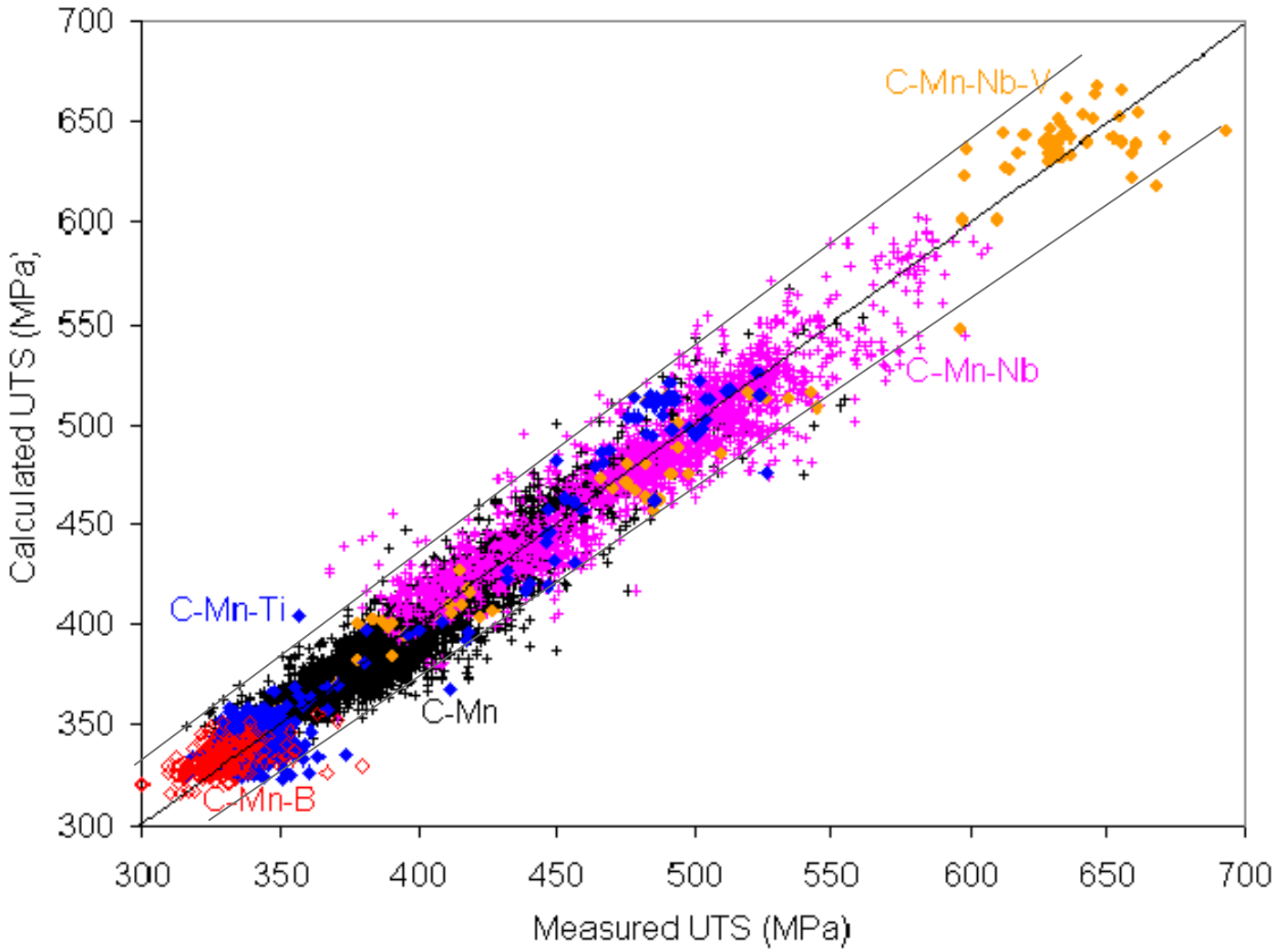
- Example of the outcome of the model showing that some part of the production is beyond allowed scatter band. Correction action has to be taken.



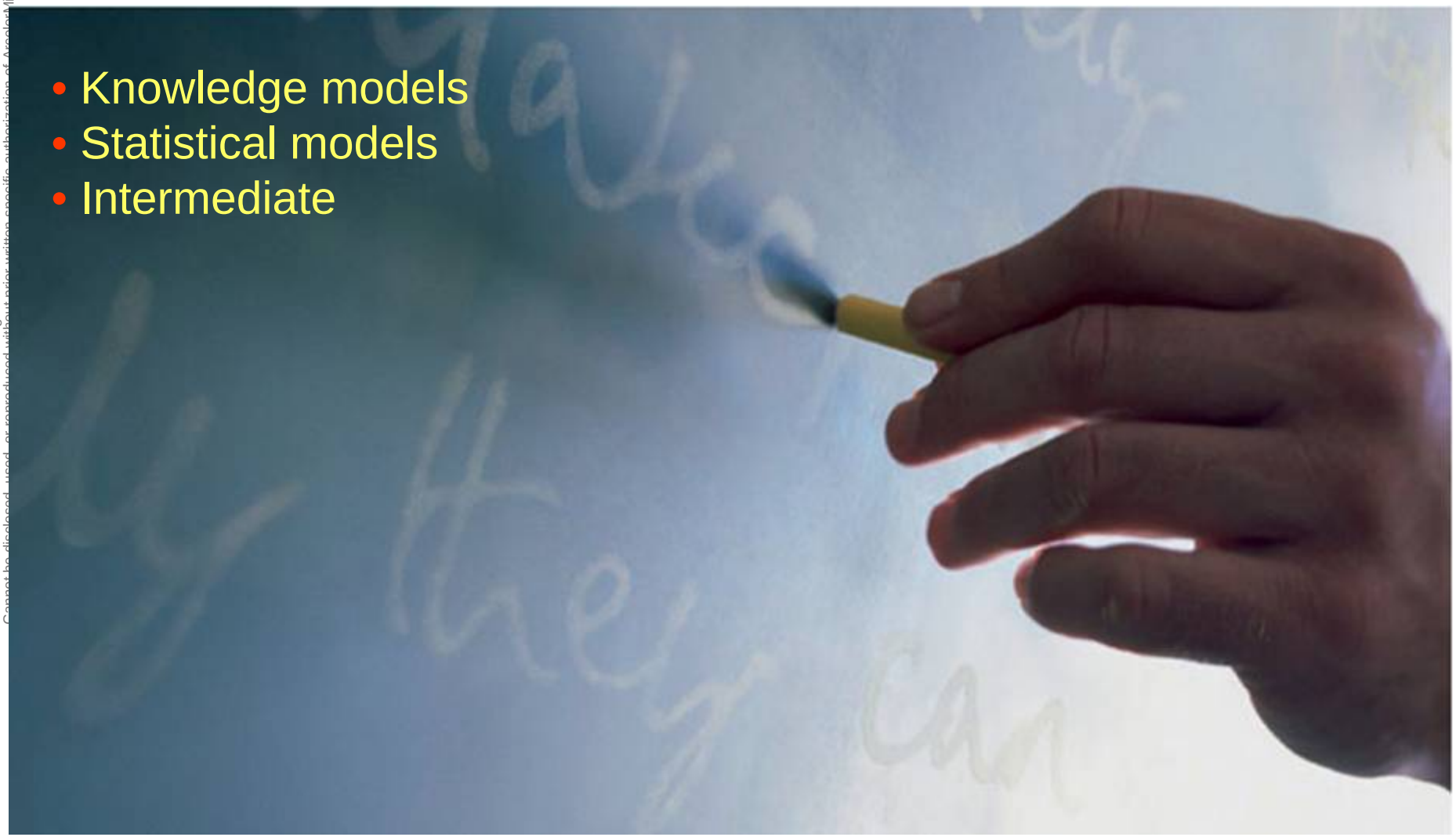
Precision and scatter



Prediction within +/- 8% in different plants, different metallurgies ; +/- 2% in one plant, one metallurgy.

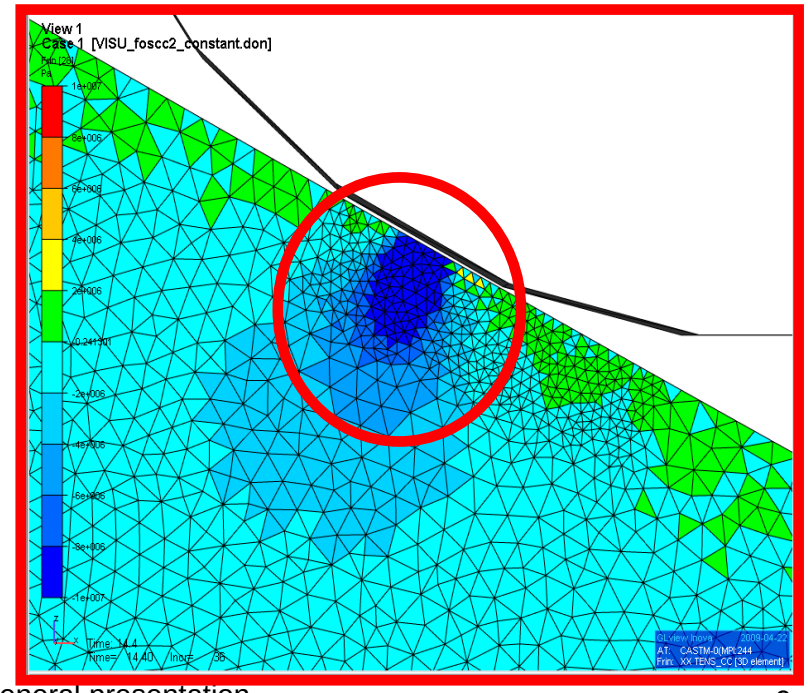


Models



Knowledge models

- heavy models , long calculation times.
- Example, a model of continuous caster with all details of the rolls and of the secondary cooling
- Solving partial derivative equations and including a variety of physical effects. Finite element or similar (finite volume…)
- Allow validation of simplified approach
- fine understanding of some local difficulties leading to defects that appear during the process and are not fully understood

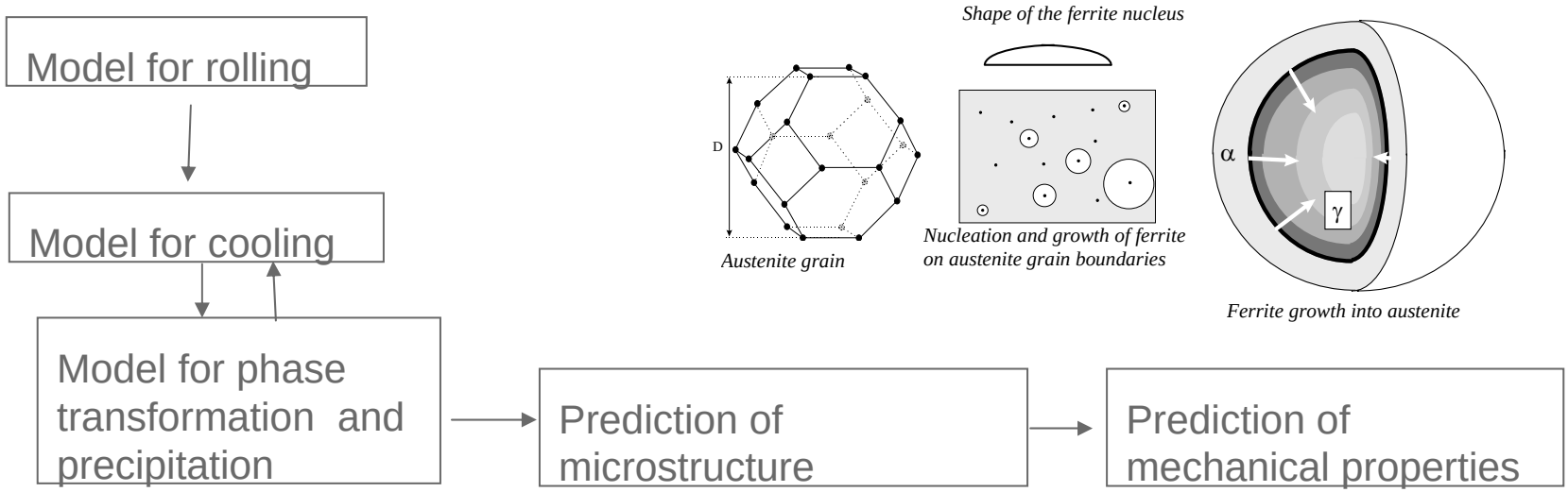


Statistical models

- Huge database in the plants:
  - Process parameters in each process step
  - Number of physical measurements in each of them : temperature, force, etc…
  - Final measurement of mechanical properties
  - Data mining techniques: extraction of main parameters
  - Correlations predicting the mechanical properties.
- Good result in a given plant for a given metallurgy. Poor transferability from Plant to Plant

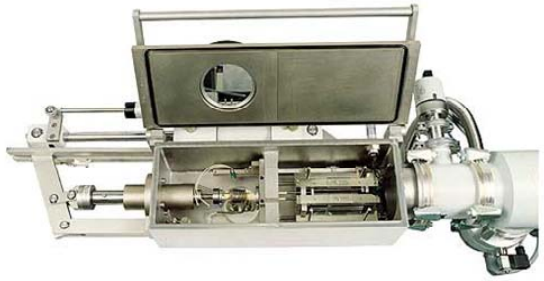
Intermediate models

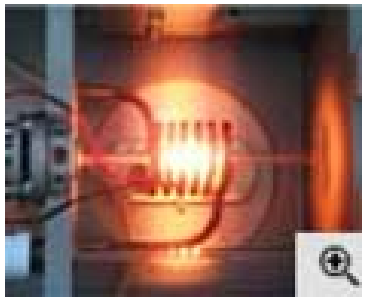
- Simplified description of the evolution of metallurgy using physical models: Just enough complexity, good enough results.
- Plant parameters gathered in meaningful process parameters: e.g. « finishing temperature of the hot rolling mill », « soaking temperature » , etc…
- All internal parameters have a physical meaning. However the precise value is not well known: fitting using plant data.

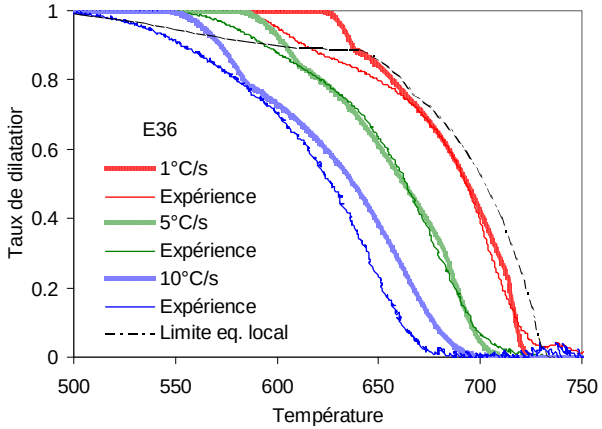


Validation of each sub-model

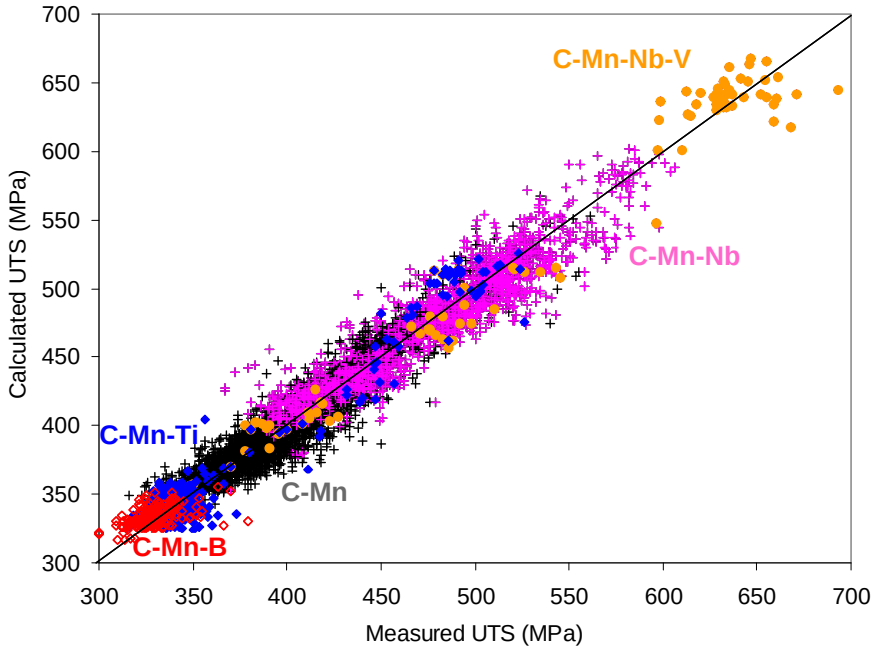
- **On laboratory data**
  - For example by dilatometer experiments for the phase transformation model (effect of composition and thermal cycle)





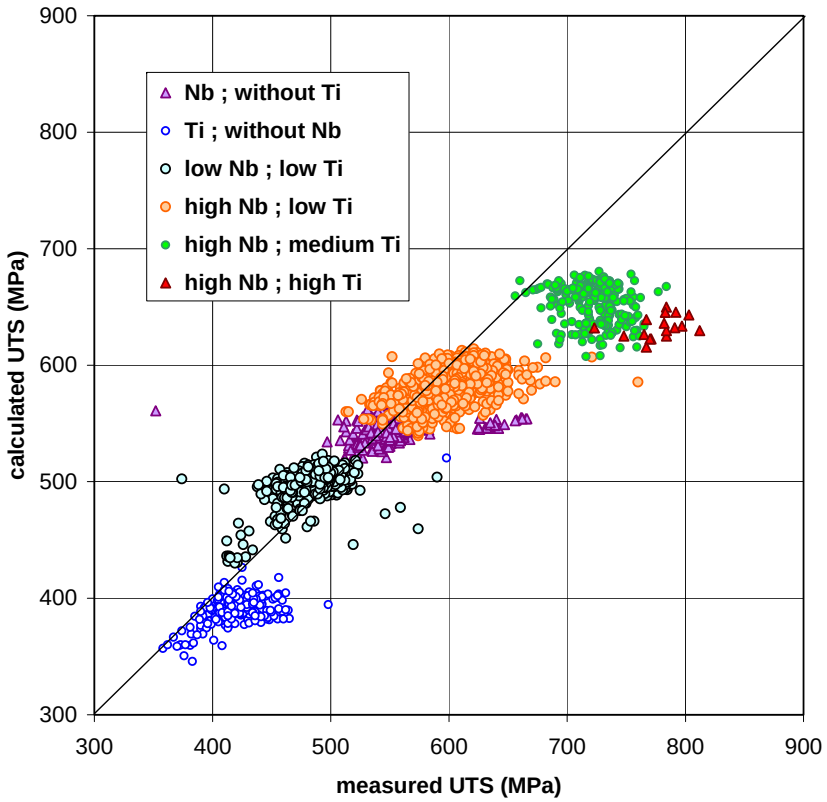


- **and on industrial data-bases**
  - model is applicable to any hot strip mill (Carlam, Fos, Dunkirk, Bremen) without dedicated fitting parameters… for a wide range of products

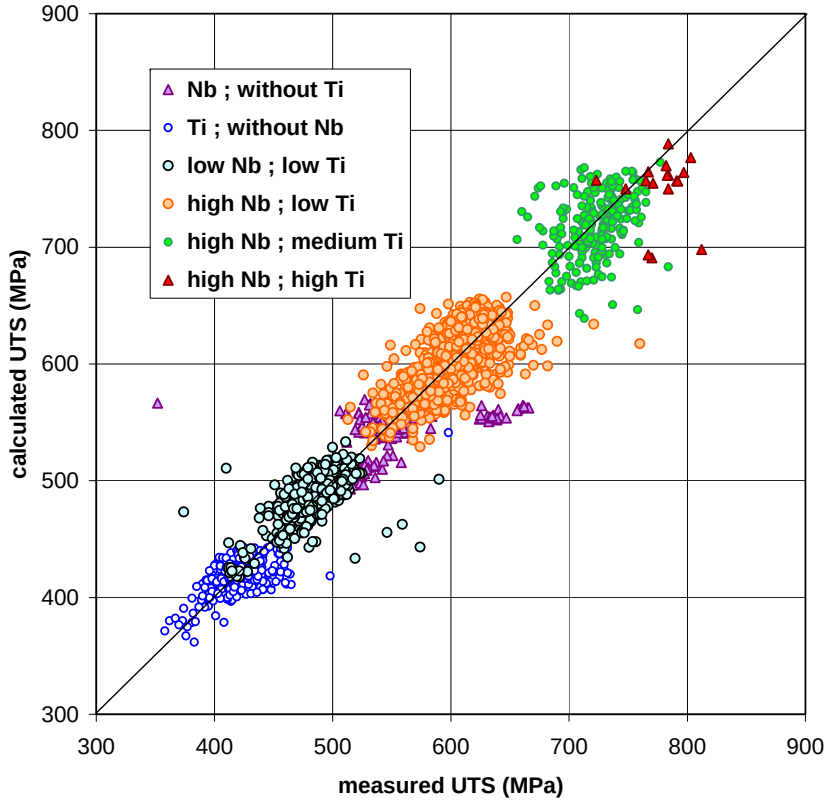


Precipitation model not precise enough for Nb-Ti higher strength steels: improvement of model

previous



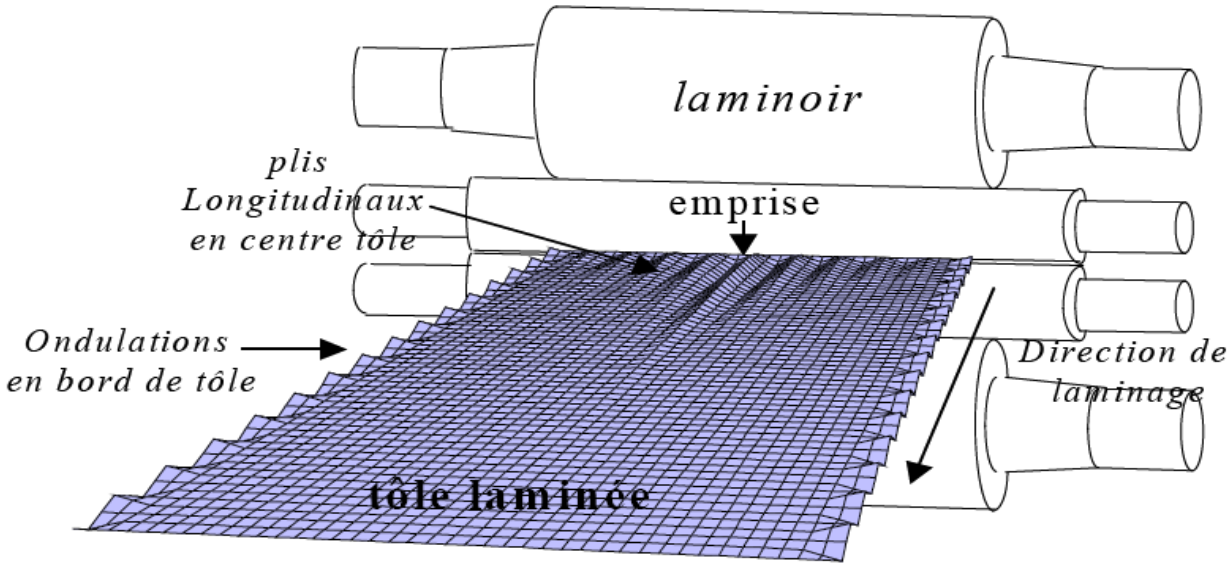
new



Some successes

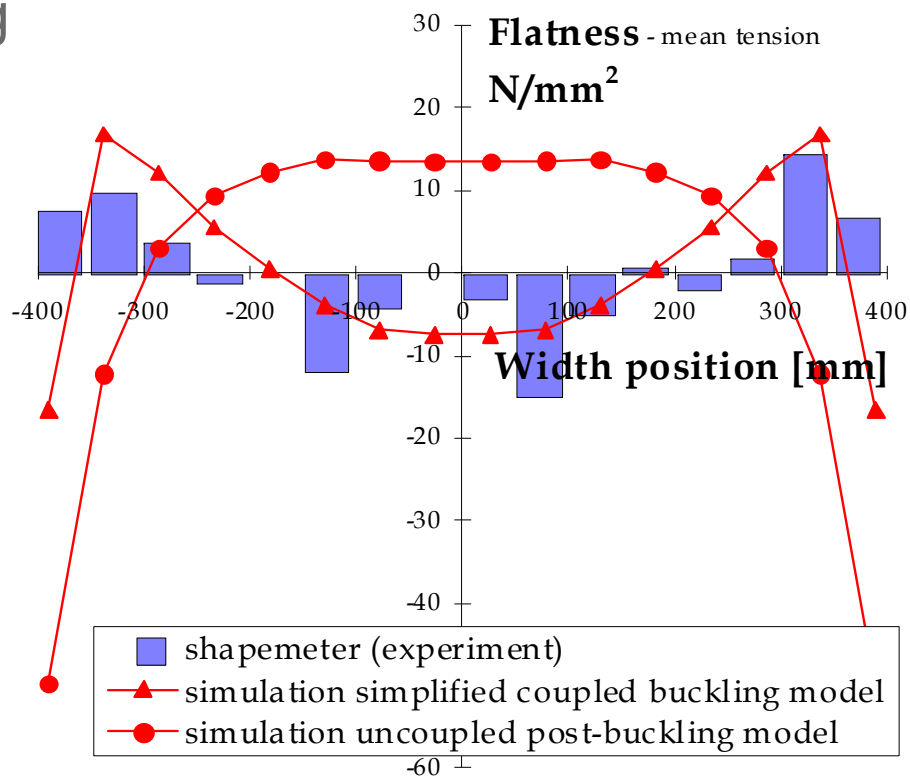
Rolling

- Finite element models known since a long time dedicated to flat products.
- Take into account:
  - Hot rolling: effect of oxidation layer on heat transfer, rheology as a function of strain, strain rate and temperature, camber and flattening of rolls
  - Cold rolling: effect of lubricant on tribology, flatness prediction after roll bite exit.



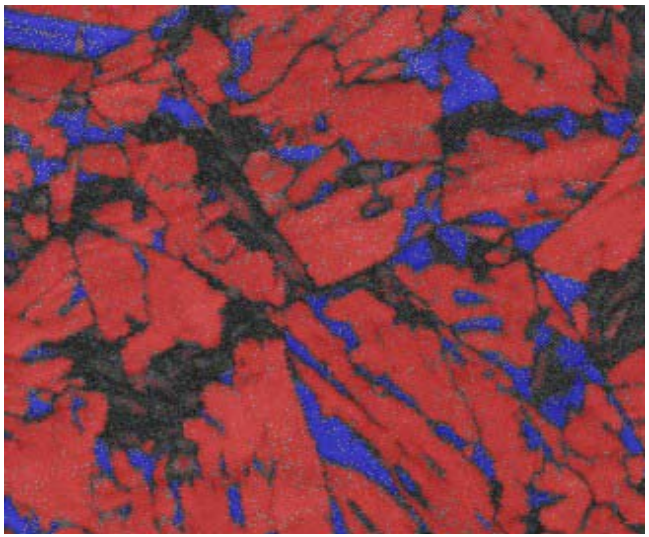
Prediction of flatness

- Need of adequate coupling of rolling with specific buckling module
- Strain hardening of the strip is well predicted
- Ability to predict final residual stresses and final shape after cutting of foil.



Phase transformation

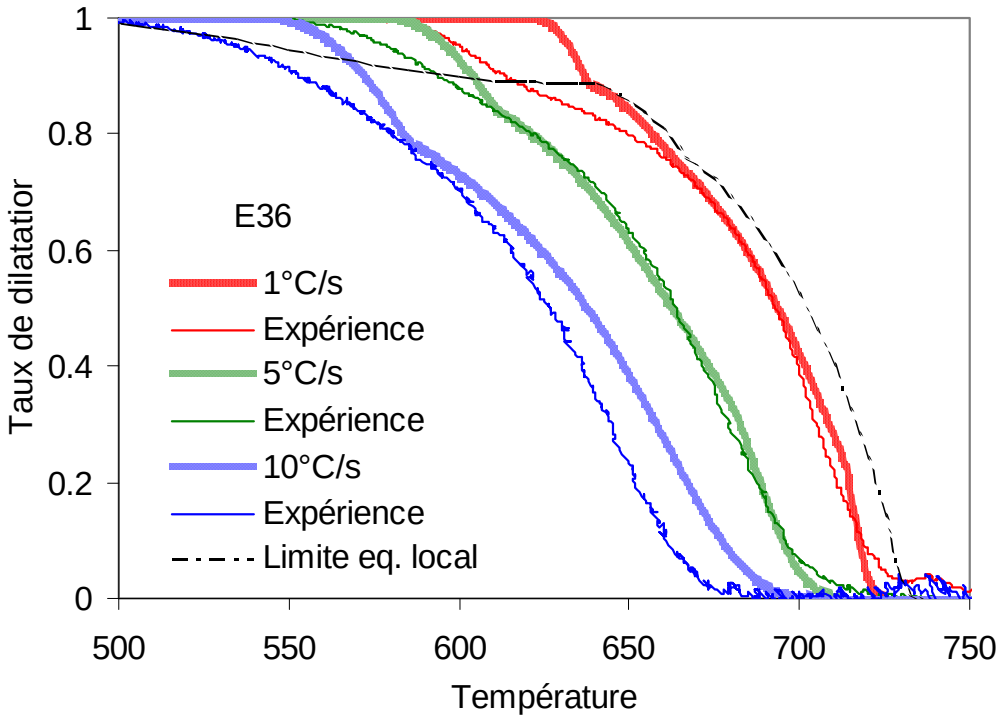
- Long history of « good enough » models for:
  - Transformation from austenite to ferrite
  - Reverse transformation from ferrite to austenite in annealing: in particular intercritical annealing
  - Prediction of perlite and martensite;
  - Still a hard point on Bainite



Phase analysis

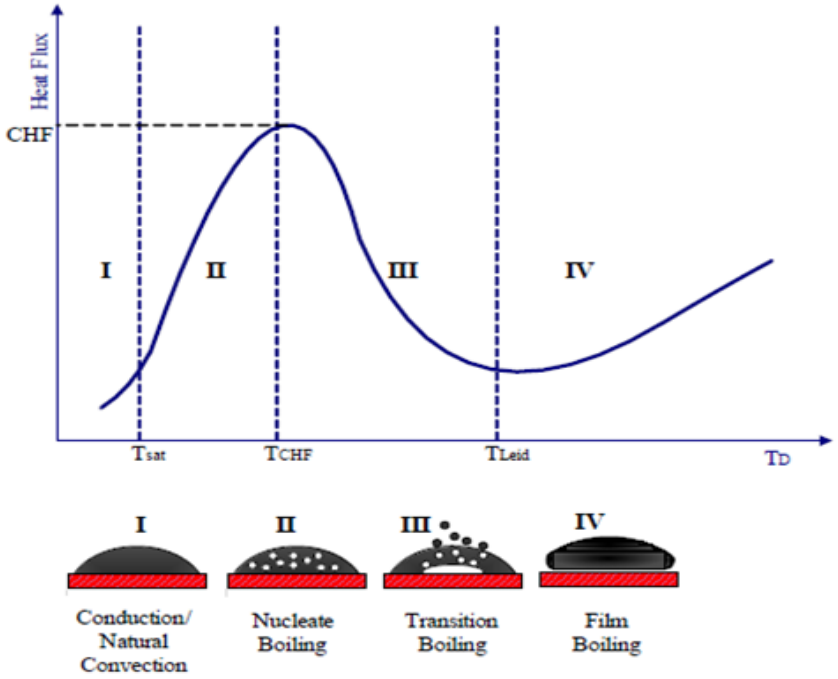
Fcc Bcc

Austenite -> ferrite



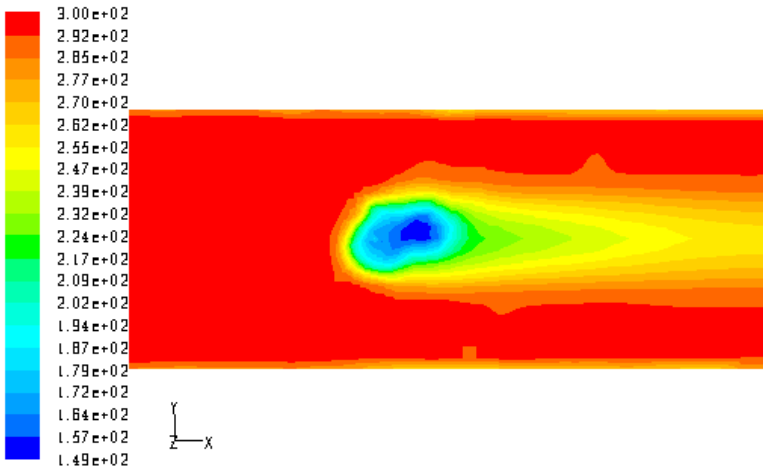
Water cooling

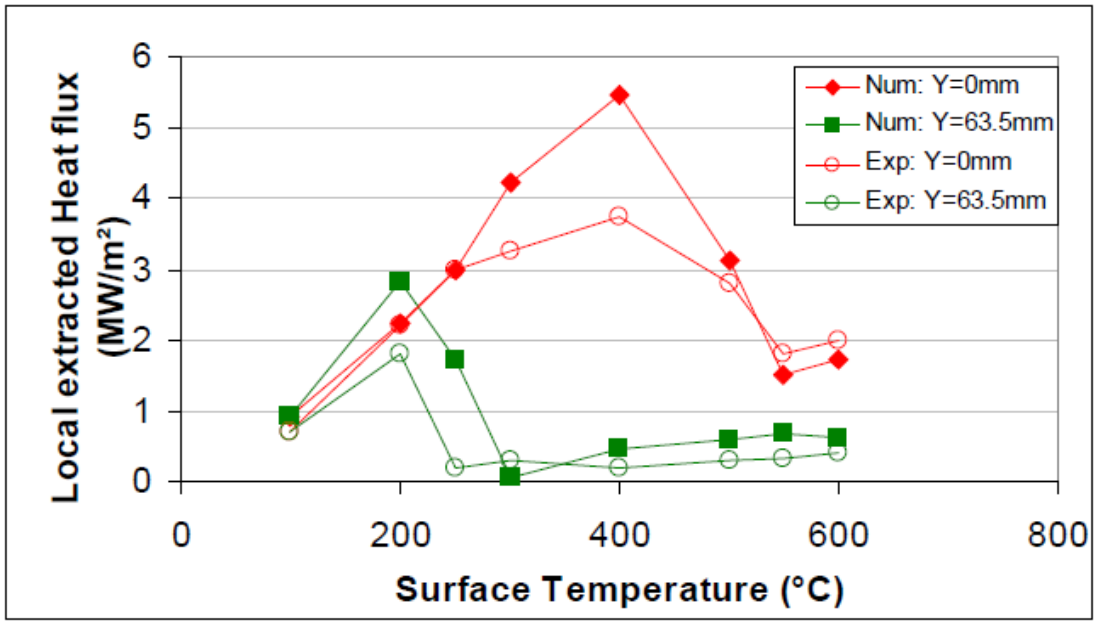
- Cooling in annealing furnaces: Well known but need to develop new technologies to reach higher cooling rates in a flexible way (stop cooling at the requested temperature)
- Cooling in the roll out table is difficult to predict because of the « de-wetting » phenomenon. Heat flux may change by one or two order of magnitude



understanding of de-wetting phenomena when cooling hot steel with water

- Understanding of nucleated ebullition in thin film: experiments and models with universities. Experimental device with a hot cylinder in front of a water jet..
- Numerical simulation of the nucleation of vapor, transition from bubbles to film. Good prediction of global heat transfer.



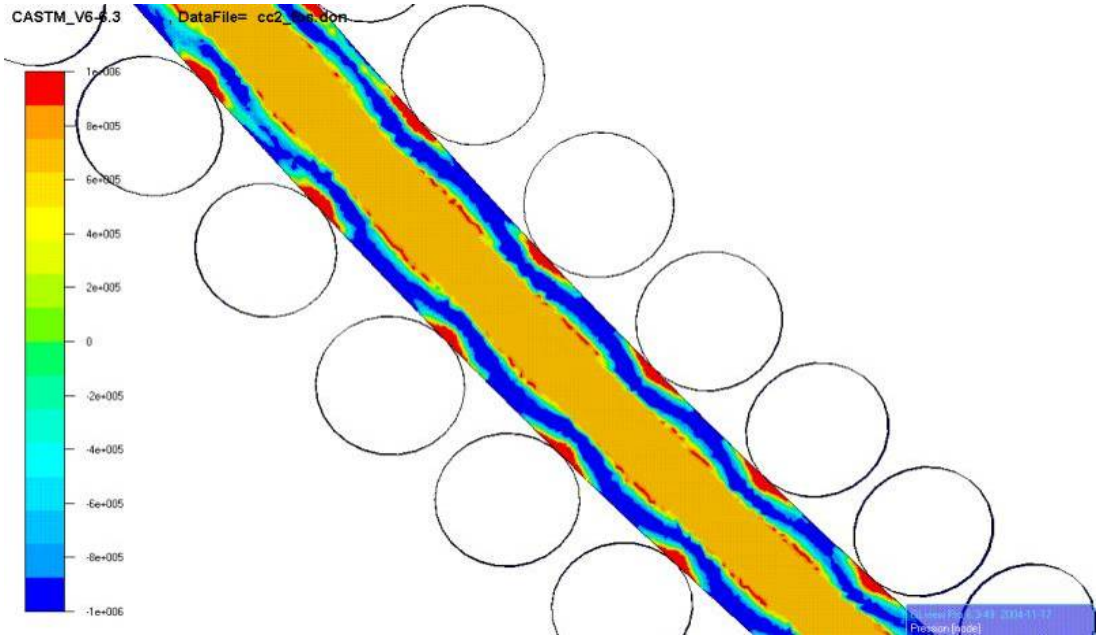


Way forward

- Segregation
- Austenite structure

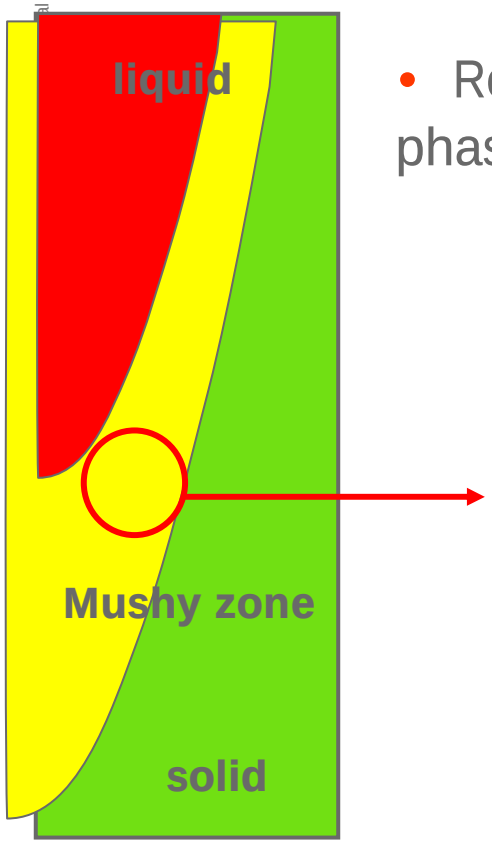
Segregation

- Segregation is a very important phenomenon. Models for the prediction of MICRO-segregation is rather well known. However prediction of MACRO-Segregation is still an issue
- Unfortunately, this is very important for final homogeneity and ductility

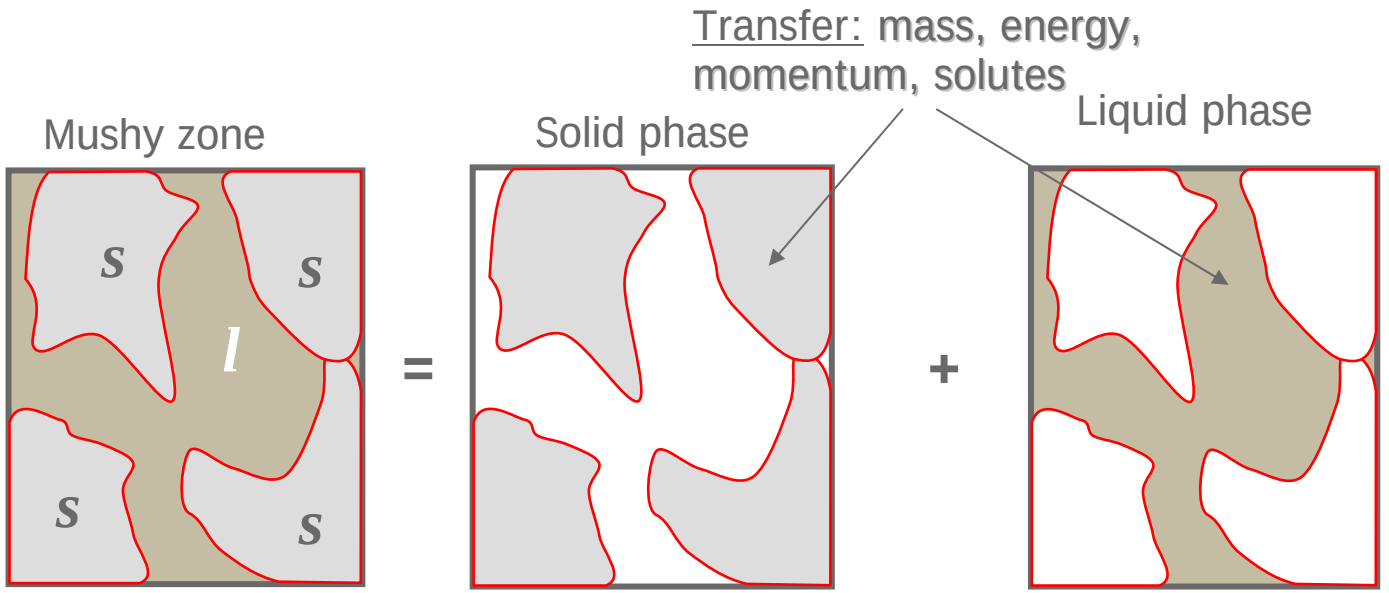


Two-phase modelling

- A two phase model is developed to assess the axial macrosegregation ratio according to the slab bulging.

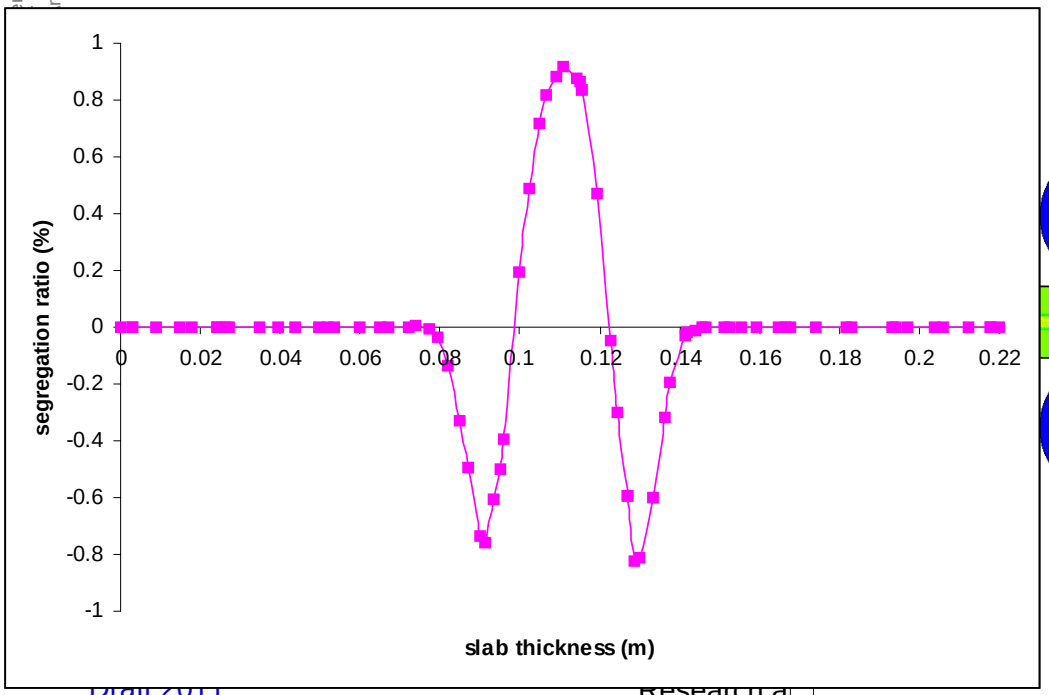


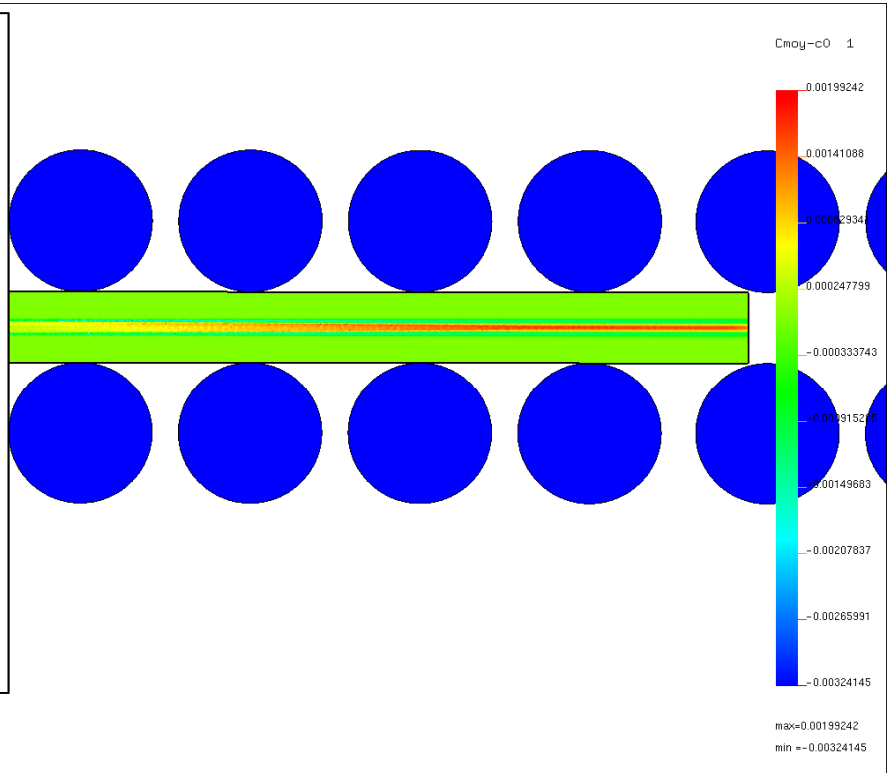
- Relative motion of the liquid phase with respect to the solid phase in the mushy zone due to the movement of liquid.



- Numerical simulation much more difficult. 3D?

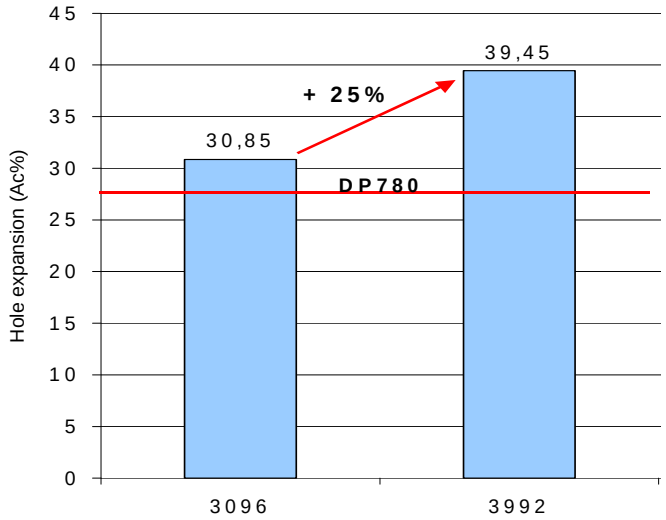
- Segregation profile is in good agreement qualitatively, but it needs to improve modeling because were are still diffrent between prediction of the model and the measurement





Link between segregation in as-cast product and banded structure in hot/cold sheet

- Objective: Develop a generic off-line predictive model to describe the segregation and microstructure evolution from as-cast product to cold rolled strip.



Continuous casting	Reheating furnace	Hot rolling	Cooling table and coiling	Cold rolling and annealing
µ-segregation and Macrosegregation models	Diffusion model for µ-segregation	Diffusion model for µ-segregation	Phase transf. Model taking into account local composition variation	Phase transf. Model taking into account local composition variation

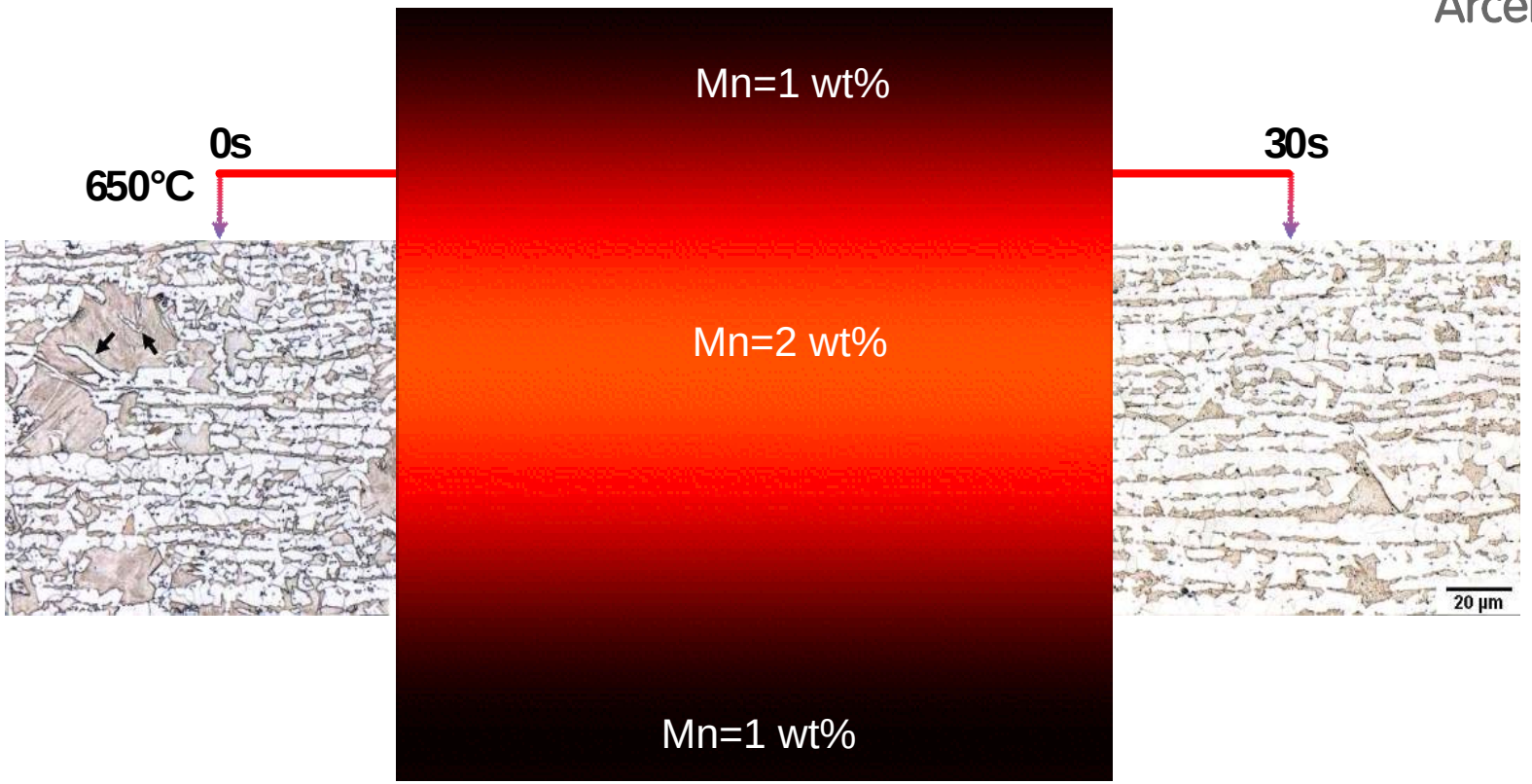
Input: C0, Casting parameters

Macro and microsegregation evolution connected with process parameters

Microstructures formation in the thickness of the sheet (heredity of segregation → banded structures formation...)

Hot rolling, coiling parameters, annealing + cooling

Banded structure

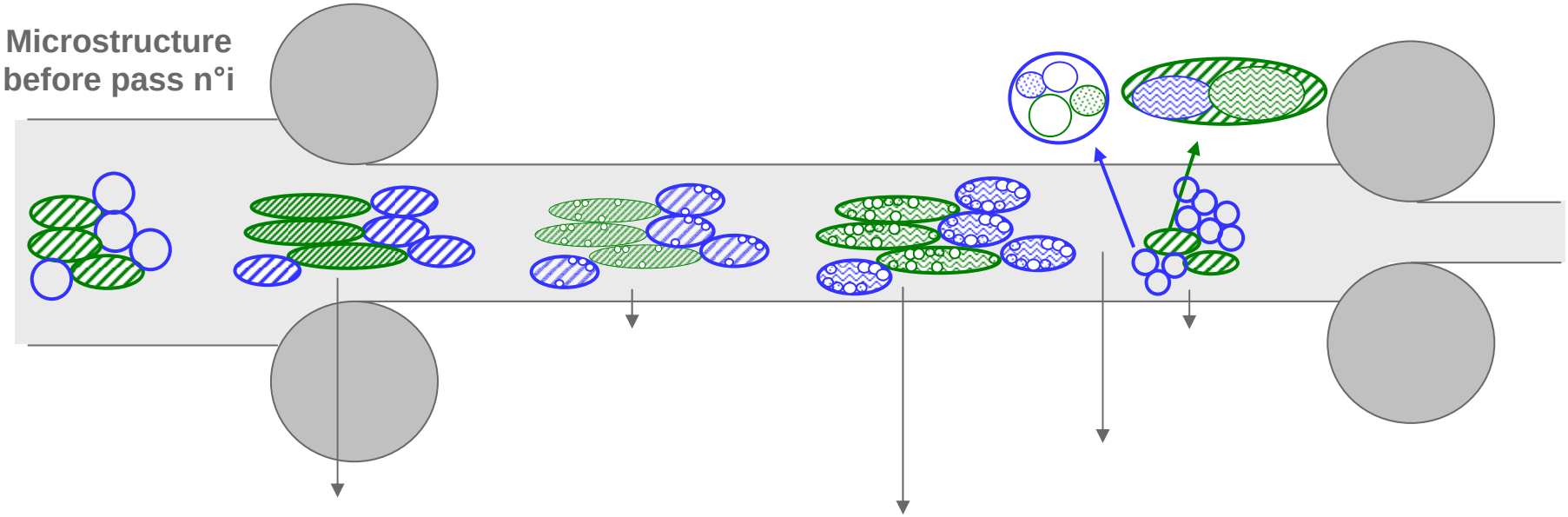


- Ferrite growth in poor Mn regions
  - The growth is rapid (Paraequilibrium mode)
- The ferrite growth very slowly in rich Mn regions
  - since C and Mn is higher (Local Equilibrium mode)

The transition from Paraequilibrium to Local Equilibrium is a key factor in banded structures formation

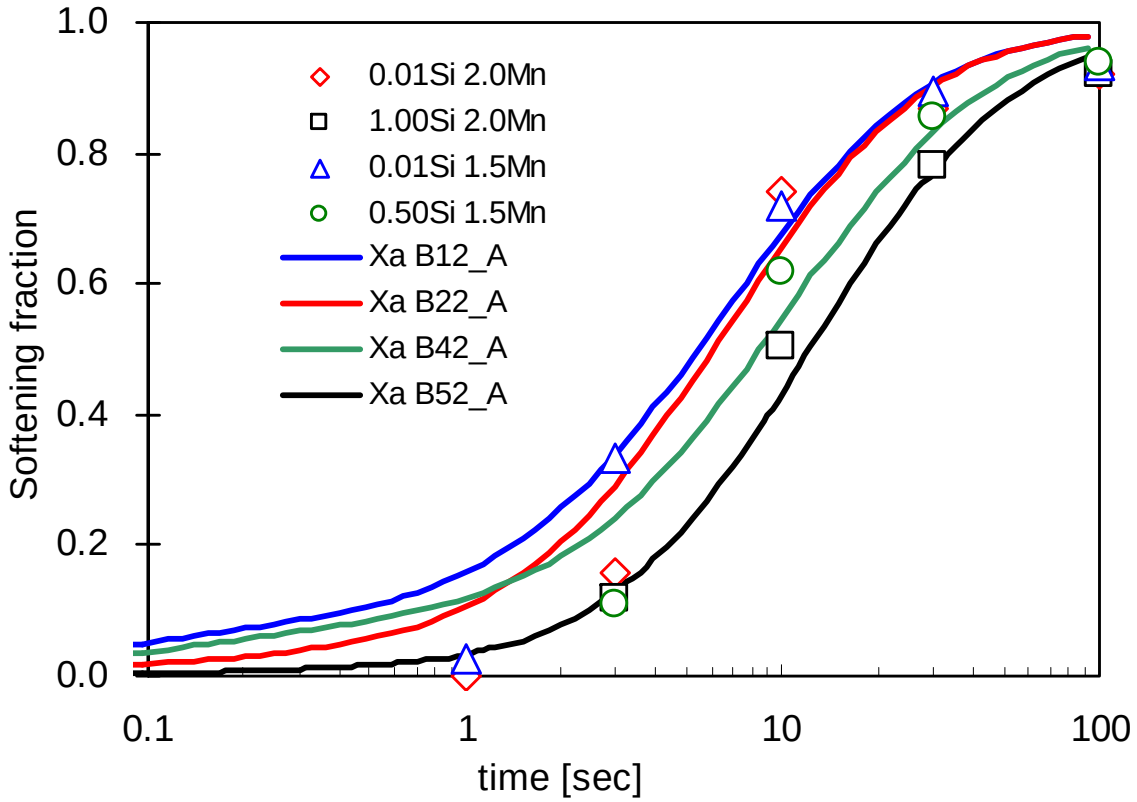
Austenite structure

- Prediction of the austenite structure is becoming more important:
  - effect on transformation (% phases) . Understood for ferrite. Not completely clear for Bainite
  - Effect on the final structure, leading to different properties.

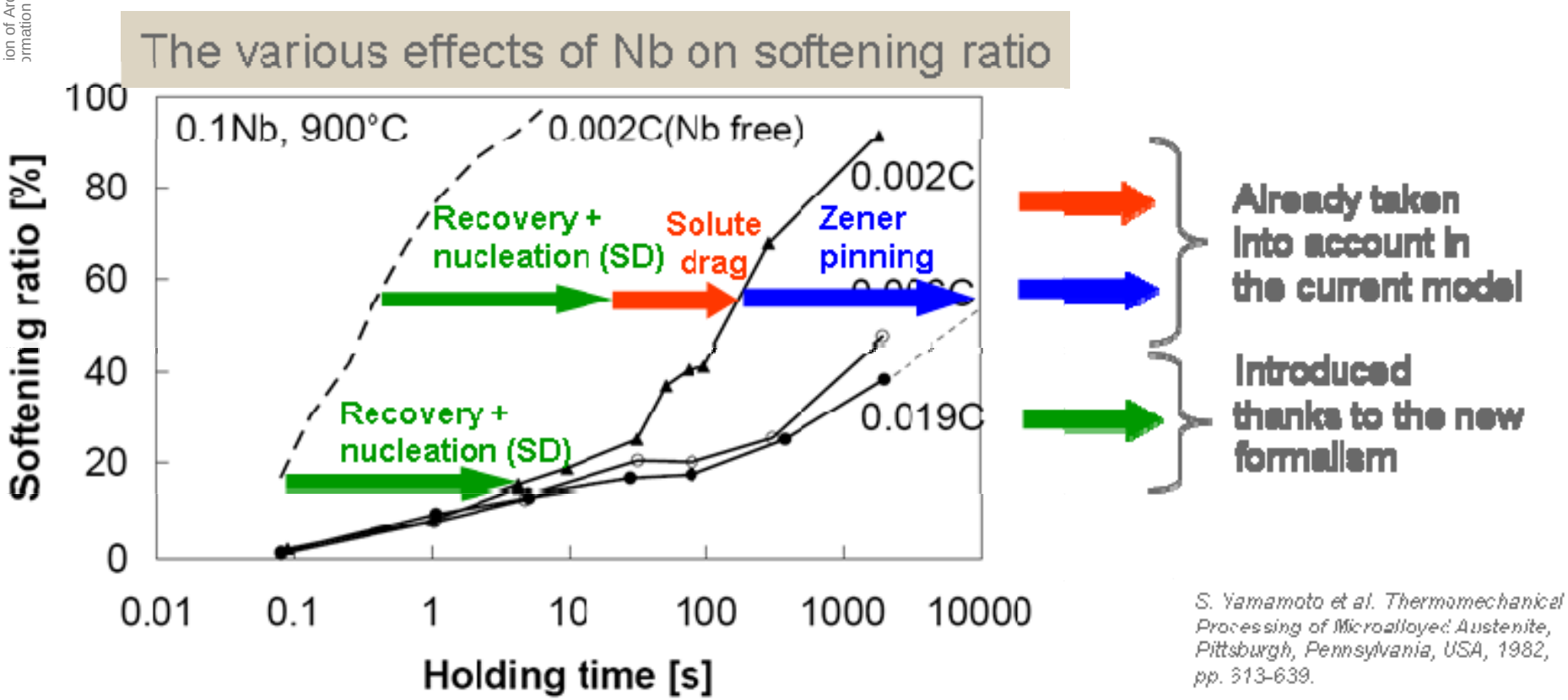


Without heavy precipitation, Models are efficient

- Classical models are efficient in « simple » metallurgy (no micro-alloying).



Interaction of re-crystallization and precipitation



S. Yamamoto et al. Thermomechanical Processing of Microalloyed Austenite, Pittsburgh, Pennsylvania, USA, 1982, pp. 313-639.

Conclusion

- Prediction of mechanical properties in plants is operational for a number of metallurgies
- However, for new metallurgies of high strength steels, models have to be improved, incorporating more detailed descriptions of some physical aspects
- This is achieved for some of them : rolling, heat transfer coefficient and partially for phase transformation
- Further work required for effect of segregation , austenite processing and bainitic transformation.