Rolling process and material properties modelling

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ABSTRACT

Purpose: This paper deals with rolling mill process control and optimizations using mathematical model.

Design/methodology/approach: The rolling process is very complex with high demand for energy, material and equipment. Furthermore, rolling mill requires precise setup to be able to roll specific material. Therefore, rolling mill model system is required in most production, research and development facilities.

Findings: A set of different kind of models coupled to one solution was shown. Usage of the described solution, like on-line process control and offline rolling conditions simulation, was demonstrated in test case for grain size modeling.

Practical implications: To development or test new production practices or new materials takes long time and requires relatively high costs for preparing large number of test cases and requires expensive physical equipment. These costs and longtime for getting the results could be reduced or even canceled in some cases at all by using computer modeling.

Originality/value: There is commonly used process models predicting and simulating the rolling process used for mill setup during the rolling. Additionally, to this functionality it was assumed to use such system as tool for studying new materials and its behaviour during the rolling as well as tool for analysing the specific mill problems or designing new mill depending on the required product mix.

Keywords: Rolling mill; Rolling model; Material properties; Adaptation; Simulation

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ANALYSIS AND MODELLING

1. Introduction

Rolling is very complex process when many effects influencing final product quality. It is mainly material composition, temperature and deformation. Material composition can't be modified during the rolling process nevertheless it is one of the key actuator for final mechanical properties of the material. Actuators for controlling temperature and deformation are many and it needs to be acting synchronously in order to reach desired quality results.

It is not possible to react and consider physics calculation during the rolling by the operator as well as try and fail method is nowadays not applicable. Furthermore due to lack of measurement and complexity of the process

we need to predict behaviour in the mill and do not react on the feedback, which usually comes too late.

Therefore, there is commonly used process models predicting and simulating the rolling process used for mill setup during the rolling. Additionally, to this functionality

2. Mathematical models

There is full set of mathematical models for rolling process. The main set of models consists of:

- Yield stress model
- Friction model
- Roll force and torque model
- Gap – screw down model
- Material temperature model
- Roll wear and temperature model
- Profile and flatness model
- Shape control model – PVPC
- Grain size and mechanical properties model
  Thermo-mechanical rolling

3. Yield stress model

The material deformation resistance is mainly defined by chemical composition, temperature, deformation, speed of deformation, aspect and also residual stress from previous deformation.
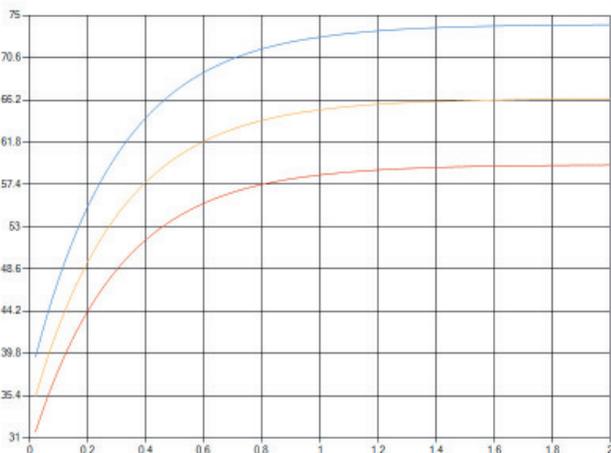

Fig. 1. Deformation resistance example

In Fig. 1 is example of deformation resistance [MPa] depending on strain for 3 different temperatures. Before first use of the system it needs to be filled from literature

it was assumed to use such system as tool for studying new materials and its behaviour during the rolling as well as tool for analysing the specific mill problems or designing new mill depending on the required product mix.
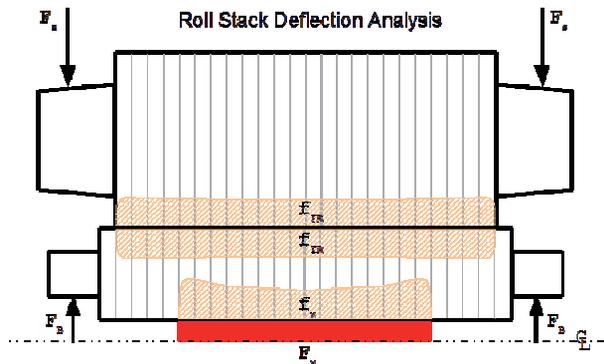
for known materials or set start-up definitions. After the material is rolled, the material properties are automatically adapted.

4. Roll force and torque model

For roll force and torque prediction is used stripe model simulating conditions on the roll gap over the contact length between material and the roll. It allows us consider variable condition in the roll gap caused by material hardening, friction, temperature etc.

Roll force and toque model is main part of the Pass Schedule Calculation which finds optimum pass schedule. Example of the pass schedule 2 stand roughing mill and 5 stand finishing mill is in Fig. 2. The graph displays material stress in the roll gap for each pass.

5. Temperature model

Material temperature model plays key role in rolling process, since accuracy of this model influencing all other models as well. The resulting mechanical properties and material deformation resistance, used for roll force prediction, are depended on the material temperature. Therefore, accurate modelling of the strip temperature is required.
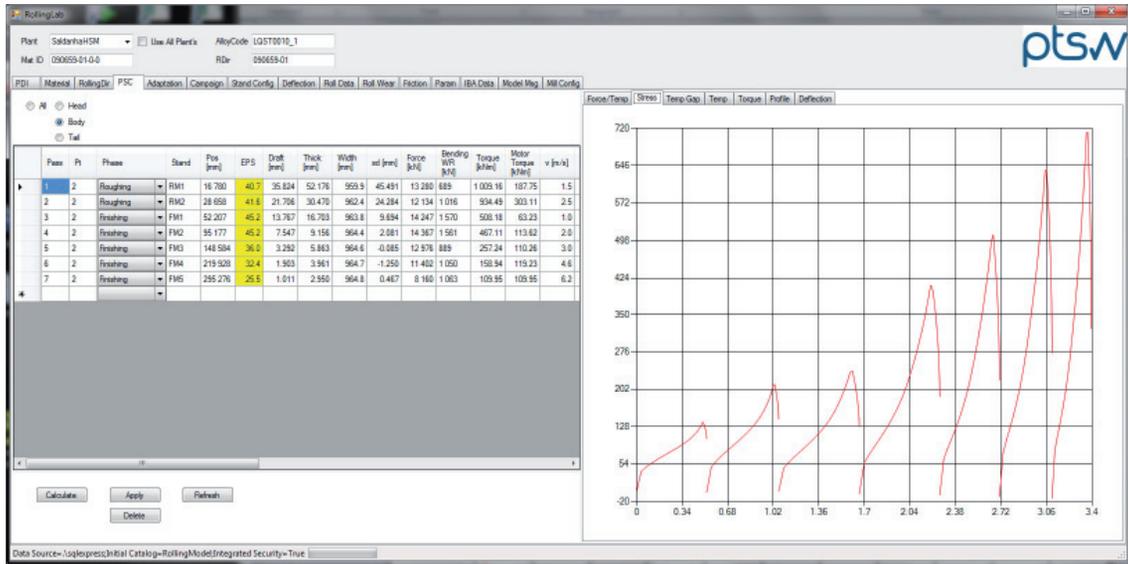
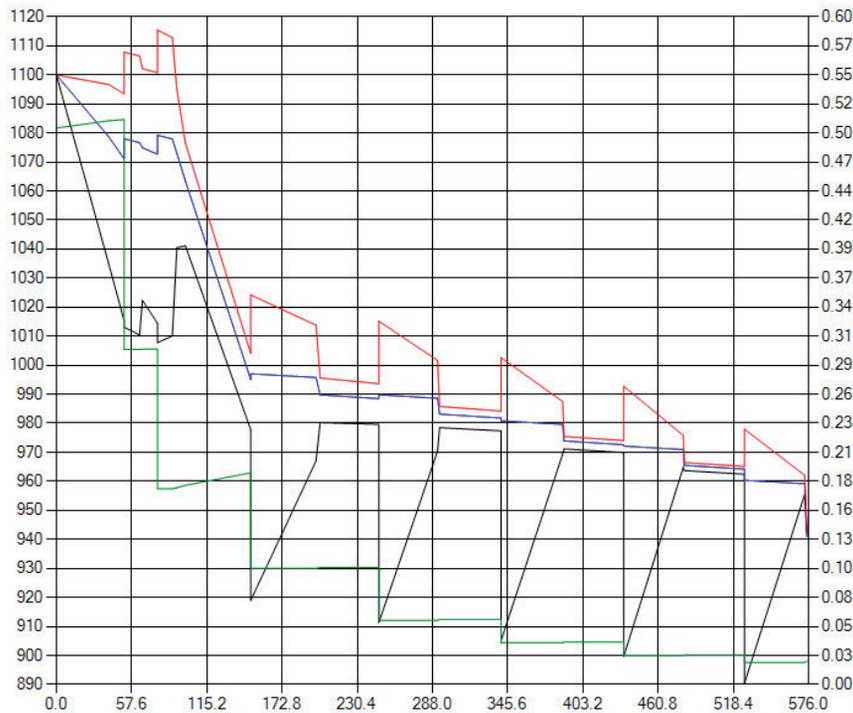Fig. 2. Pass schedule example, with stress distribution in the roll gap

Fig. 3. Temperature model result

Temperature model result in Fig. 3 displays temperatures on material surface (black), average temperature (blue) and in the strip centre (red). There is clearly visible area where material is cooled down on the air between RM and FM as well as where is the impact with stand roll when surface is cooled down and strip centre is heated by the deformation.

6. Profile and flatness

Profile and flatness modelling is one of the most difficult tasks since precise profile and flatness depends on many factors requiring 3D calculations. The equilibrium between material deformation distribution and roll deflection needs to be founded. Additionally to the roll deflection the roll gap profile is influenced by roll wear and thermal growth, which we are unable to measure on-line and needs to be modelled as well. Example of the roll wear after the 38 pieces with strip width 1038 mm is shown in

Figure 4. Similarly roll thermal growth is simulated for each pass.

The output of Profile and flatness model is considered also in Pass schedule calculation in order to consider bending force and CVC roll shifting constrains for each stand in order to reach target profile and flatness after last stand.

The Figure 5 shows example of the roll force distribution (green line) over the strip width in stand F3, roll centre line deflection (blue line) and roll gap profile (red line).
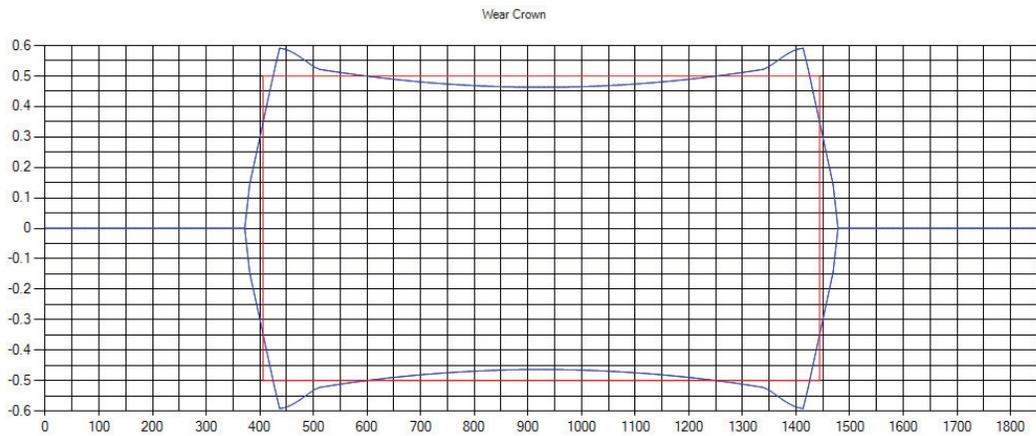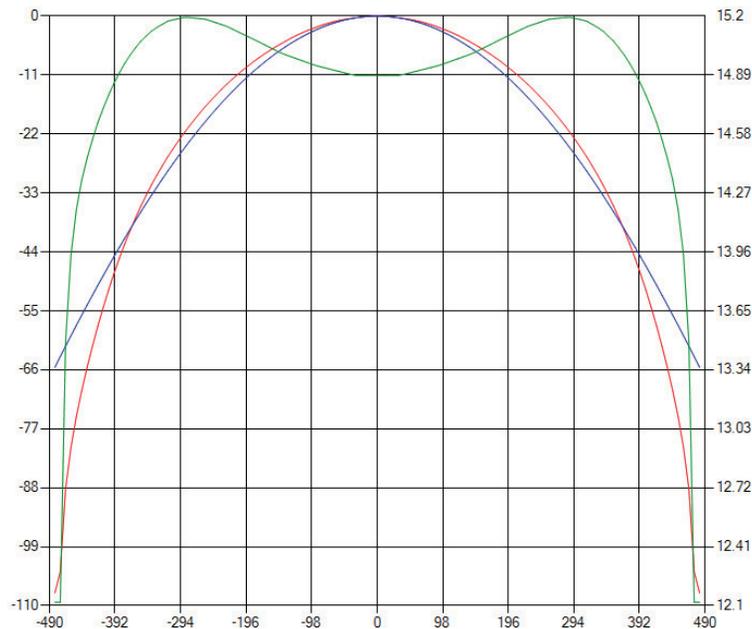

Fig. 4. Roll wear example

Fig. 5. Deflection of the roll gap

7. Grain size model

The previous models were focused on reaching dimensional and temperature properties of the material. The grain size model is focusing on mechanical properties. The result of roll force and temperature model, in case measurement is not available, together with laminar cooling model is used to predict grain size and mechanical properties.

8. Configuration

Important role in consideration of usability of any SW tool plays user friendliness and easy to get required results. The mill configuration is one of such task and it example is shown in Figure 6.

9. Model tuning and adaptation

Since no model can consider all factors good adaptation is needed for key actuators of roll force, torque, temperature, profile and flatness. The initial set of material and model parameters could be tuned when measured data are available. This adaptation is so called long term adaptation and is looking for statistically best matching parameters. Example of the long term adaption is visible in Figure 7. The residual error is than further adapted in short term inheritance or also so called strip to strip adaptation.

The adaptation tool can be also useful to observe and analyse material properties like deformation resistance, residual strain, material hardening, grain size development etc.

9.1. Test case

In order to test the applicability of the model, sample pass schedules were determined by the pass schedule generator, with a slab thickness of 200 mm reducing to a final plate thickness of 20 mm and plate width 2500 mm. These generated pass schedules were taken from a representative plate mill currently operating in China. The chemical composition of the sample product is representative of a typical low carbon steel grade. The furnace discharge temperature (referred to as reheat temperature) is considered to be 1180°C.
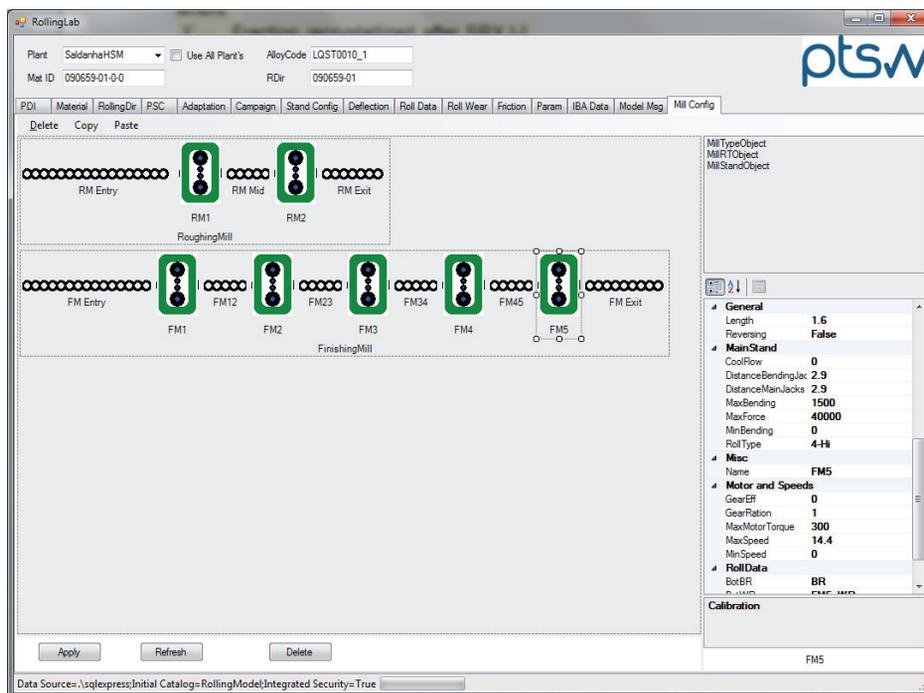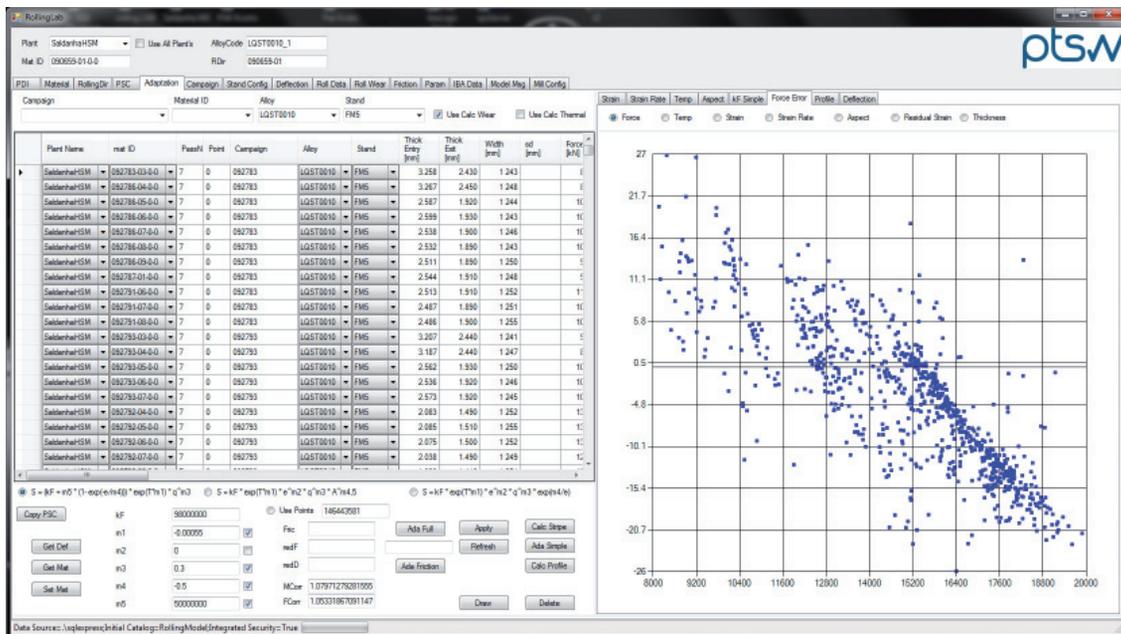

Fig. 6. Example of mill configuration

Fig. 7. Adaptation screen example

Table 1.
Overview of test cases from pass schedule generator

Test case	Passes	Reheat temperature, °C	Slab thickness, mm	Plate thickness, mm	Exit temperature, °C	Delay time, s
1	12	1180	200	20	950	0
2	12	1180	200	20	870	177

In both test cases, a total of 12 rolling passes are taken. After rolling, a cooling rate of 10 K/s is considered, corresponding to what is typically observed in an Accelerated Cooling Setup (ACC). However, in the second case, a cooling pause in air is taken after the 7th pass of approximately 180 s. The effect of the cooling pause on the formation of the ferritic grain size is then considered. The pass schedules of both test cases are tabulated in Table 1.

The chemical composition of both test cases is identical and is tabulated below in Table 2.

Table 2.
Chemical composition of test cases

C, %wt	Mn, %wt	Si, %wt	P, %wt	S, %wt
0.16	0.55	0.21	0.04	0.04

An initial austenitic grain size of 200 mu is assumed, which has shown to be a good approximation for low carbon steels reheated to 1180°C. The austenitic grain size development of both test cases is shown below in Figure 8.

The effect of the cooling pause on the final ferritic grain size can be clearly seen from the Figure 8. It is clearly evident that the pass schedule calculated with a cooling pause (177 s) has a considerably finer ferritic grain structure than the case with no cooling pause. A rapid decrease of the austenitic grain size is observed in the first passes. During the cooling pause however, grain growth occurs and strain induced precipitation occurs. This, coupled with DRX in the finishing passes promotes a fine ferritic grain size.

10. Conclusion

Complex approach to the rolling process was presented in this paper. A set of different kind of models coupled to one solution was shown. Usage of the described solution, like on-line process control and offline rolling conditions simulation, was demonstrated in test case for grain size modeling.
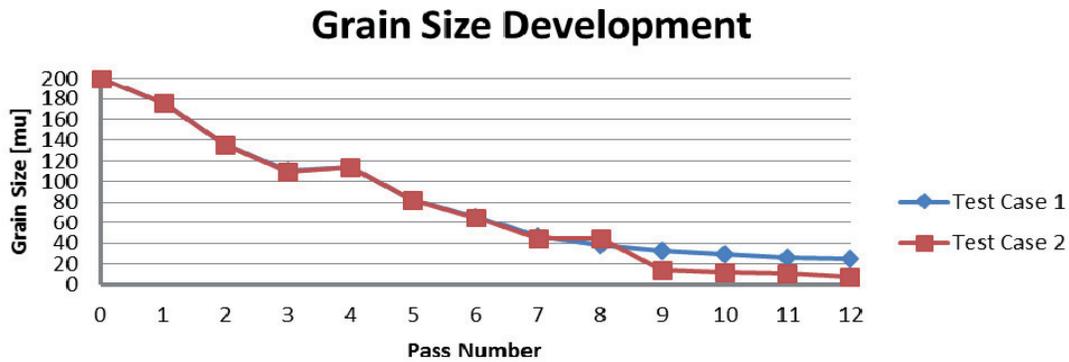
Grain Size Development

Fig. 8. Grain size development

Today when economical competition together with increased quality demands pushing producers to improve technological practices, test new materials and on the other hand minimize the costs, the computer modeling is playing important role. To development or test new production practices or new materials takes long time and requires relatively high costs for preparing large number of test cases and requires expensive physical equipment. These costs and longtime for getting the results could be reduced or even canceled in some cases at all by using computer modeling. Powerful rolling model control system including tools was demonstrated.

Acknowledgements