Products quality improvement through numerical simulation in Steel Industry

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ABSTRACT: Increasing requirements concerning the product quality have led ASCOMETAL to build research projects where the relationship between surface quality, internal segregation or porosity, and product quality are studied using numerical simulation. These numerical tools, more and more powerful and accurate, are today a deciding and validating factor used to improve our products. ASCOMETAL is equipped with process simulation software: continuous casting and ingot casting simulation software, rolling and straightening simulation software that can cover the entire manufacturing process of steel bars. They are used to study the effect of process parameters on defect formation or evolution. Applications are the adjustment of continuous casting primary and secondary cooling and the adjustment of roll pass design to improve the billet quality, internal porosity as well as bars surface quality.

Key words: Process Modelling, Rolling, Casting, Damage criterion, Hot tearing

1 INTRODUCTION

Steelmakers are facing an ever increasing demand to improve product quality, not only to minimise scrapping and increase productivity but also to ensure customers satisfaction. Concerning the latter, measures can be taken to ensure final product quality. The most common procedure consists in ensuring absence of unwanted defects through a variety of non-destructive testing methods, repairing defects when possible and scrapping when not. While this allows for defects detection and guarantees the final product conformity, it does not affect defect occurrence and therefore does not help reduce scrapping. Defect formation may happen at different stages along the steel manufacture route (casting, cooling, rolling, etc). To reduce defect occurrence, it is therefore important to understand the mechanisms of formation of the different kinds of defects, and quantify the influence of the processing parameters. Numerical simulation softwares are today of considerable help in these tasks, as they allow for a reasonably accurate modelling of the temperature and stress conditions at any point of the processing route. With the help of a few carefully designed experiments, it is possible to correlate defect occurrence with calculated stress and temperature conditions. An optimised process route can therefore be proposed to reduce the likelihood of occurrence of a given kind of defect. In the following, we provide three such examples. In the first case, calculation of stresses during continuous casting were used together with a damage criterion to reduce hot tearing. In the second, the influence of the rolling schedule of square bars on porosity closure is modelled, and the results used to propose an alternative rolling schedule. In the last example, modelling of surface damage during rolling is used to redefine the geometry of the intermediate passes and minimise the risk of surface cracking, while leading to the same final geometry in the same number of passes.

2 CRACKING DURING THE CONTINUOUS CASTING PROCESS

In continuous casting, both solidification cracks (hot tears) and intergranular cracks can be caused by solid skin deformation. In the secondary cooling zone, these deformations are mainly caused by the bulging of the solid skin between the supporting rolls, by thermal stresses or by the contact with the supporting rolls themselves .

The software THERCAST® [1] is used for the simulation of casting processes. Thermal-mechanical modelling of continuous casting was not possible few years ago because of the high computational time it requires. Numerical and hardware developments allow us today to use 3D FEM modelling of continuous casting in the industrial

framework. The continuous casting process is modelled here using a transient approach [2] (upgraded Lagrangian method). The heat equation, and the mechanical equilibrium equation are solved using 3D finite element methods. Hence, the Cauchy stress tensor, the strain and the temperature fields are outputs.
Due to spray cooling and roll contact (figures 1 and 2), series of compressive and tensile stress areas occur at the surface of the bloom.

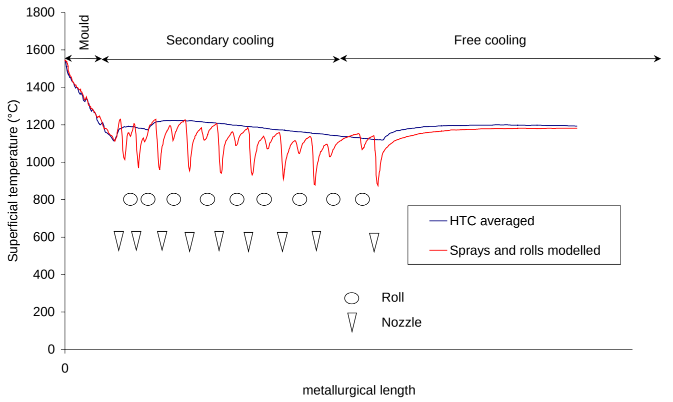

Fig. 1 : Temperature evolution : primary and secondary cooling zones

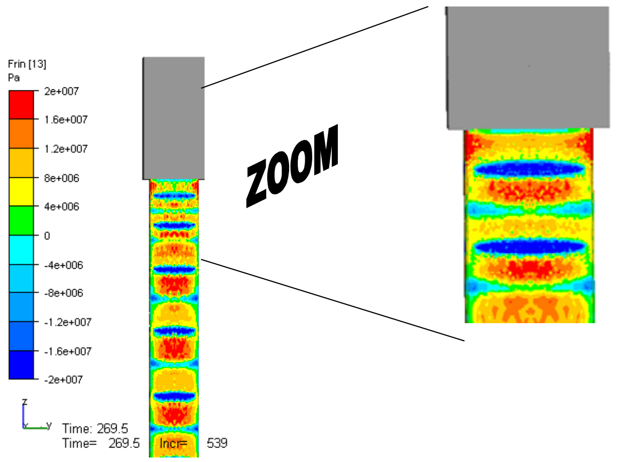

Fig. 2 : Pressure field in the secondary cooling zone

A hot tear criterion (Yamanaka criterion [4]) is used to determine the critical areas in the bloom during casting (figure 3). It is supposed that the material is brittle between 0,9 and 0,99 of solid fraction. Using this criterion, it is then possible to study the impact of process parameters – such as cooling spray patterns for example – on the occurrence of solidification cracks. Results are shown for two different kind of sprays (figure 4).

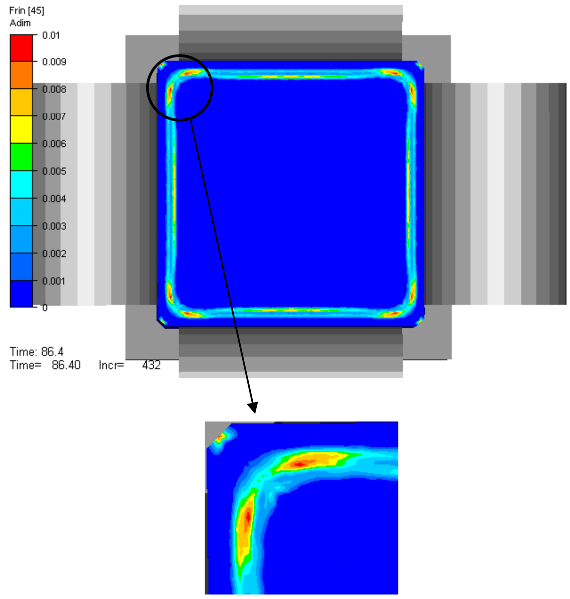

Fig. 3 : Yamanaka et al. [3] criterion at the corner

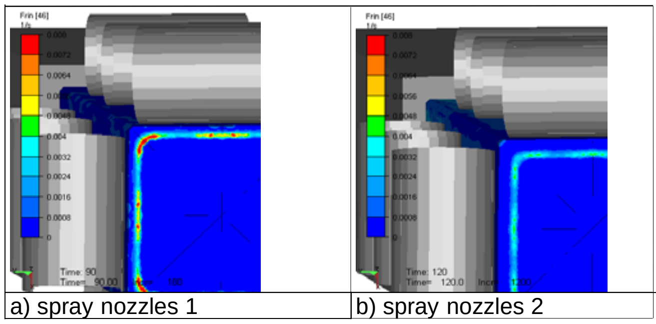

Fig. 4 : Yamanaka et al [3] criterion (cutting plane) for two different cooling patterns

Finally, we concluded that increasing the spray impact surface, decreasing the casting speed or the roll pitch induce significant reduction of the Yamanaka et al. [**3**] criterion. Thermal-mechanical modelling helps to determine the optimal casting parameters for grades sensitive to solidification cracks.

3 POROSITY REDUCTION FOR LARGE DIAMETER PRODUCTS

Solidification shrinkage leads to the creation of porosity into the cast product. Mostly, they are closed during rolling if the rolling reduction is large enough. For large diameter products, it is necessary to optimise the rolling parameters in order to obtain an internal soundness which satisfies the customer's quality requirements. Two different rolling schedules leading to the same final section were investigated. The question is: which one is the most efficient to close the porosity ?
FE software LAM3® [4] and FORGE2005® [5] were used to simulate the rolling schedule. LAM3® is based on a steady state resolution and FORGE2005® is used for transient simulations.

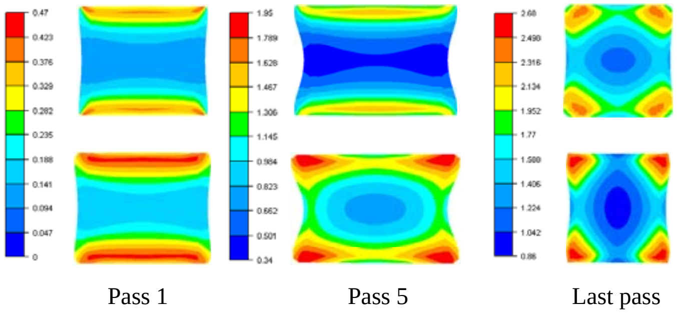

Fig. 5 : Cumulated strain evolution during rolling for two roll pass design leading to the same final section (LAM3®)

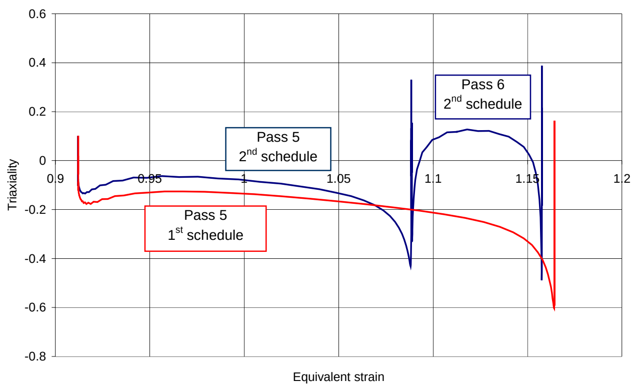

Fig. 6 : Triaxiality versus strain for both rolling schedules at the billet centre and during one (two) pass(es)

A simple analysis of the cumulated plastic strain at the bloom centre is not sufficient to select the best rolling schedule (Fig. 5). An explanation is given on figure 6: passes 5 and 6 of the second rolling schedule are equivalent in term of cumulated strain to the 5th pass of the 1st rolling schedule but, for the first one the stresses remain compressive, whereas the second one is submitted to a tensile stress. This tensile stress may reopen the porosity.

To simulate the porosity evolution, a 10 mm hole was introduced in the FE mesh at the billet centre (figure 7). The effect of different parameters such as the rolling schedule itself, the roll diameter or the thermal gradient on the pore volume evolution during rolling were analysed.

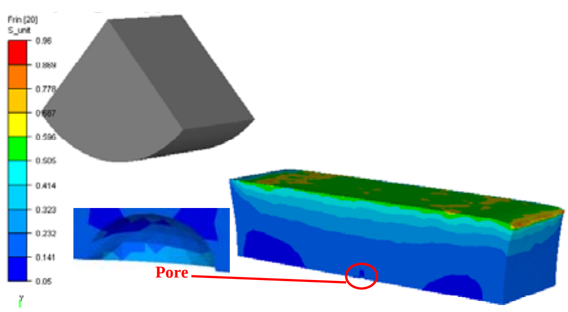

Fig. 7 : Forge2005® simulation of porosity evolution using an actual hole in the mesh (transient simulation)

The main results are given in table 1. The efficiency is measured using the evolution of the cavity volume (V/V_0).

Table1. Results on pore closing efficiency

	V/V_0
RPD 1 (isothermal, mean roll radius)	74%
RPD 2 (at the same elongation)	90%
RPD 1 with thermal gradient (core hotter than skin)	60%
RPD 1 with thermal gradient (core colder than skin)	83%
RPD 1, roll diameter + 15%	72%
RPD 1, roll diameter - 15%	80%

These results allow to classify the effect of parameters on pore closing. The roll pass design and the thermal gradient are of primary importance, the diameter roll evolution (successive remanufacturing) lead also to a loss of efficiency of the roll pass design on pore closing.

4 PRODUCT SURFACE QUALITY

Other unwanted defects are the skin defects that can have effects on cracking risks during forging or on fatigue life. Some of the defects are mechanical defects due to shocks, stripes or scale incrustation. In this study we focussed on intergranular cracking caused by the nucleation, growth and connection of voids. The FE software LAM3® and a damage criterion (Cocks model [6,7]) were used to simulate the rolling schedule in order to detect the critical areas for each stand of the wire rolling mill.

Curves of triaxiality rate versus strain were plotted at a point, along a streamline on the free surface, where the damage criterion is maximum. On figure 8 the triaxiality rate evolution on 4 stands of the wire rolling mill is plotted versus cumulated strain. It can be seen on this graph that, obviously, at stand 4 the product surface is submitted to a high triaxility rate.

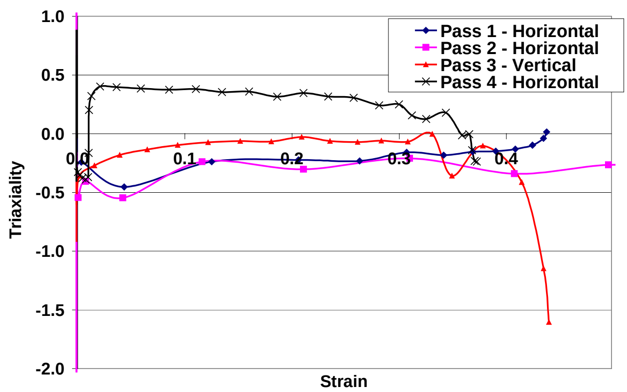

Fig. 8 : Triaxiality rate versus strain evolution during rolling on the free surface

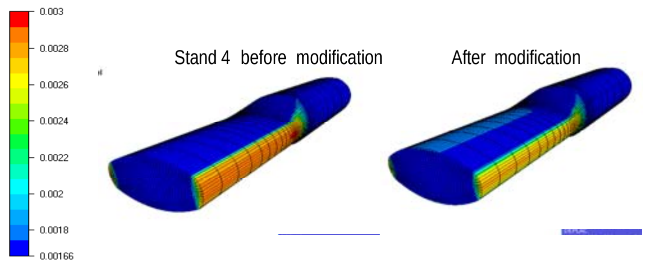

Fig. 9 : Damage contours on stand 4 before and after groove radius modification.

The groove radius of stand 4 was then modified to reduce the damage criterion value (figure 9). It can be seen on figure 10 that, at stand 6, the shape of the product remain the same. It was not necessary to modify the following stands. The related changes on the rolling force are :

- stand 4 : -0.6%
- stand 5 : -3%
- stand 6 : +3.8 %

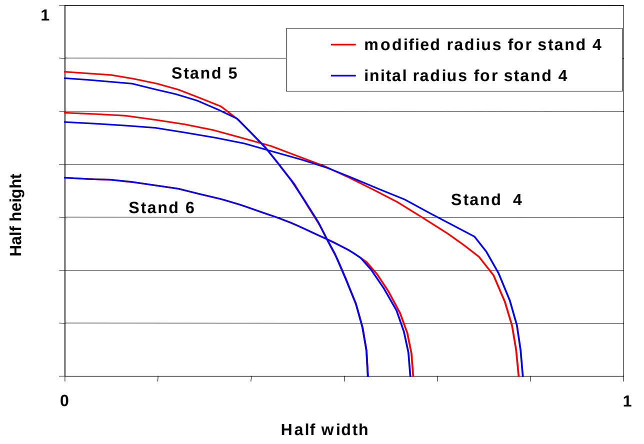

Fig. 10 : Groove radius modification for stand 4, effect on stands 5 and 6

This modification has been scheduled on ASCOMETAL plant. The actual impact of this modification is of course difficult to measure on the final product because the wire is the result of a wide number of operations. As the mechanical solicitation of the product surface during rolling is reduced on stand 4 (lower strain and lower triaxiality), the occurrence of defects is reduced.

5 CONCLUSIONS

This paper gives an overview of how numerical simulation is nowadays used in the industrial framework to study and optimise process parameters. Today, most of the industrial processes involved in steelmaking companies can be modelled. Using such models, expensive and time consuming industrial trials are avoided. They permit to understand how and when some defects may occur all along the process stages.

Thermal-mechanical modelling of continuous casting is applied to understand how defects such as hot tearing occur in the product. In order to avoid them, parametric analysis can then be applied to understand the impact of process parameters on the defect formation. The example of spray cooling pattern is given herein.

Rolling process is also widely studied using numerical models. Damage criteria are used to study surface defect formation. The study of the closure of internal porosity is also presented here. It is shown that the influence of process parameters such as the groove radius, the roll pass design or the reheating conditions on the internal and on the surface quality.

ASCOMETAL takes part in several French and Europeen research projects like Simulforge, Osc, Pacrolp, Improsound, Cracracks.

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