ECOTRE VALENTE
TECNOLOGIE D'AVANGUARDIA

9th International & 6th European ROLLING Conference 2013

June 10-12, 2013

Venice, Italy

INTEGRATED FEM CASTING AND ROLLING SIMULATION: PROCESS CHAINING APPROACH

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ABSTRACT

The meaning of this study is to reduce, through FEM analysis, time to reach the final pass schedule and therefore shorter start up time and cost prediction of material behavior and mechanical properties along the mill with return of the key parameters in order to evaluate the rolling feasibility of products. In this article it will be introduced how to chain continuous casting process simulation to rolling simulation.

The FEM simulation software ProCAST® allows to perform complete analysis of continuous casting process including ladle, nozzle, tundish, chills, rolls and spray. On the final shape it will be possible to analyze: thermo-mechanical stresses and deformations, Microstructure (phase, grain size/shape/orientation) and Defects (Porosity, Segregation, Hot tearing).

The FEM simulation software DEFORM® performs rolling analysis using as input data ProCAST® continuous casting simulation results. DEFORM® allows to evaluate final profile shape according to mills geometry and process parameters, provides informations on thermo-mechanical and microstructural properties and gives details for plant dimensioning.

The scope of this paper is to present this novel approach which can be used to help the Continuous Casting and Rolling industry to increase the quality and the productivity of their plants, processes and products.

Keywords: Rolling Simulation, Continuous Casting Simulation, Software, DEFORM®, ProCAST®

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INTRODUCTION

In this paper ProCAST®, FEM simulation software of ESI-Group® dedicated to Casting Processes, is used for simulation of Curve Continuous Casting of a bloom in steel 42CrMo4.
Chemical composition used is reported in table 1; profile cross section is 300 x 400 mm.

Element	C	Si	Mn	V	Cr	Ni	Mo
%	0.38	0.23	0.64	0.01	0.99	0.08	0.16

Table 1. Steel 42CrMo4 chemical composition

Continuous Casting simulation provides results for thermo-mechanical state and microstructure of bloom.
These results are exported from ProCAST® as input data for following operations:

1. Cooling to Ambient Temperature and Heating in Furnace at 1080 °C
2. Shape Rolling

DEFORM®, FEM simulation software of SFTC® dedicated to Forming Simulation, is used for calculation of Cooling, Heating and Shape Rolling.
ProCAST® Casting Simulation has been done both with Tetrahedral and Brick Elements as well as Cooling/Heating and Shape Rolling Simulation with DEFORM®.
These two softwares share the same mesh and results at nodes and elements without any conversion or mapping .
Shape Rolling Simulation has been performed on a Reversible Mill with three grooves, using two different methodologies:

1. Standard Simulation: Bloom with initial homogeneous field for temperature, stress, deformation and microstructure
2. Process Chaining Approach: Initial Conditions for Bloom at Shape Rolling Stage are results of all previous operations of Continuous Casting and Cooling / Heating.

Results of Shape Rolling Simulation obtained with these two methodologies are finally compared in terms of loads on mills, filling of grooves, stresses, strains and microstructure on profile.
Through this novel approach it will be possible to make processes more robust both in terms of process parameters and in terms of geometries, in order to reach in the fastest way the requested quality and productivity for the plant.

CONTINUOUS CASTING SIMULATION

ProCAST® is dedicated to all Continuous Casting and Ingot Processes.
ProCAST® allows to perform complete analysis of continuous casting process including ladle, nozzle, tundish, chills, rolls and spray. On the final shape it will be possible to analyze: thermo-mechanical stresses and deformations, Microstructure (phase, grain size/shape/orientation) and Defects (Porosity, Segregation, Hot tearing).
In this paper a Curve Continuous Casting Plant has been simulated for a bloom profile, with cross section of 300 x 400 mm and chemical composition of a steel grade 42CrMo4.
A copper mold of 1 meter has been used for primary cooling, while secondary cooling is distributed in 3 areas along curve length of casted profile.
Tundish temperature is 1532 °C and casting speed is 650 mm/min.
Finally a linear part is introduced for cooling of profile before cutting.

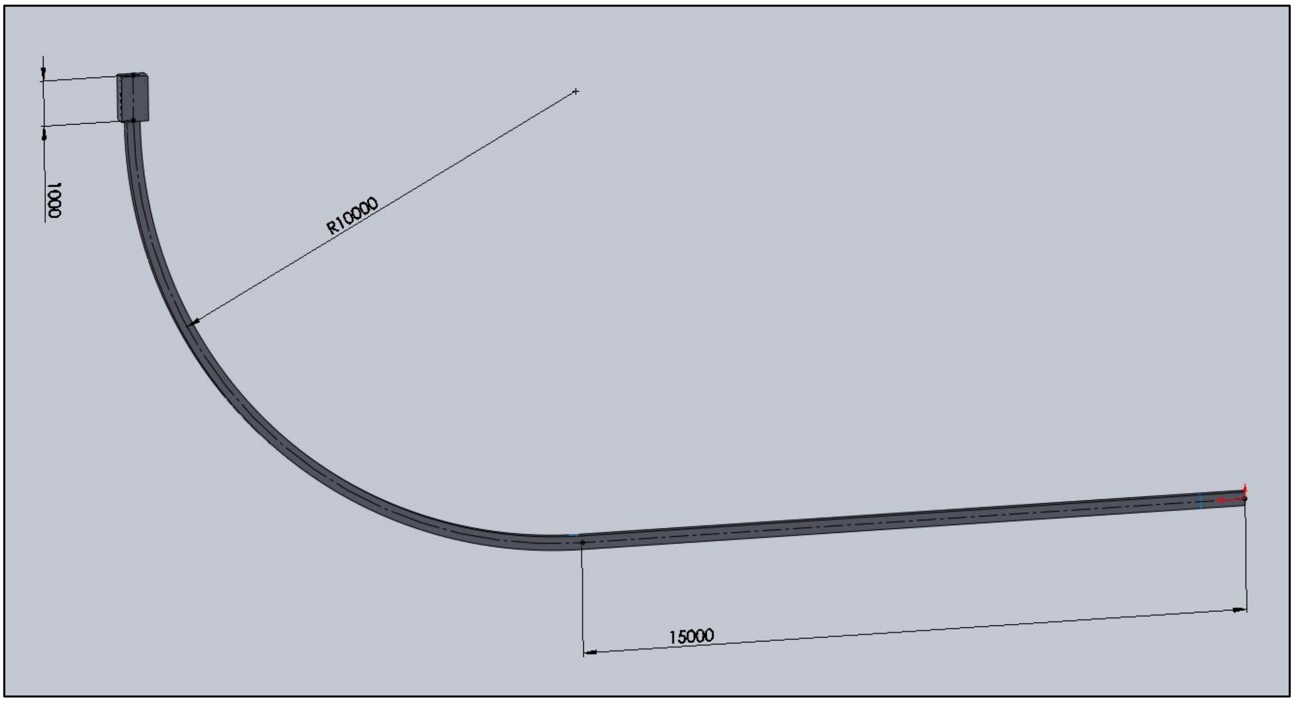

Figure 1. Continuous Casting Plant for Steel 42CrMo4 Bloom 400 x 300 mm

For this simulation both Tetrahedral and Brick meshes have been used.

The goal of this simulation is to model the steady state thermal field of bloom, as a function of the chemical alloy composition, the casting speed and the primary and secondary cooling sequences.

The metallurgical length, the shell thickness evolution, the temperature profiles inside and on the surface of the bloom can be analyzed [1].

Moreover, thermo-mechanical field and microstructural condition can be studied during all the process and used as input data for following operations.

Copper mold is water cooled; thermal profile of copper mold is represented in following figure 2 together with solid shell of bloom growing inside the mold and thermal distribution for both mold and bloom.

Secondary cooling is applied with water spray nozzle in three different areas along curve length of bloom; Wendelstorf model[2] has been applied to evaluate the efficiency of secondary cooling, according to nozzle flow rate and cooling geometry.

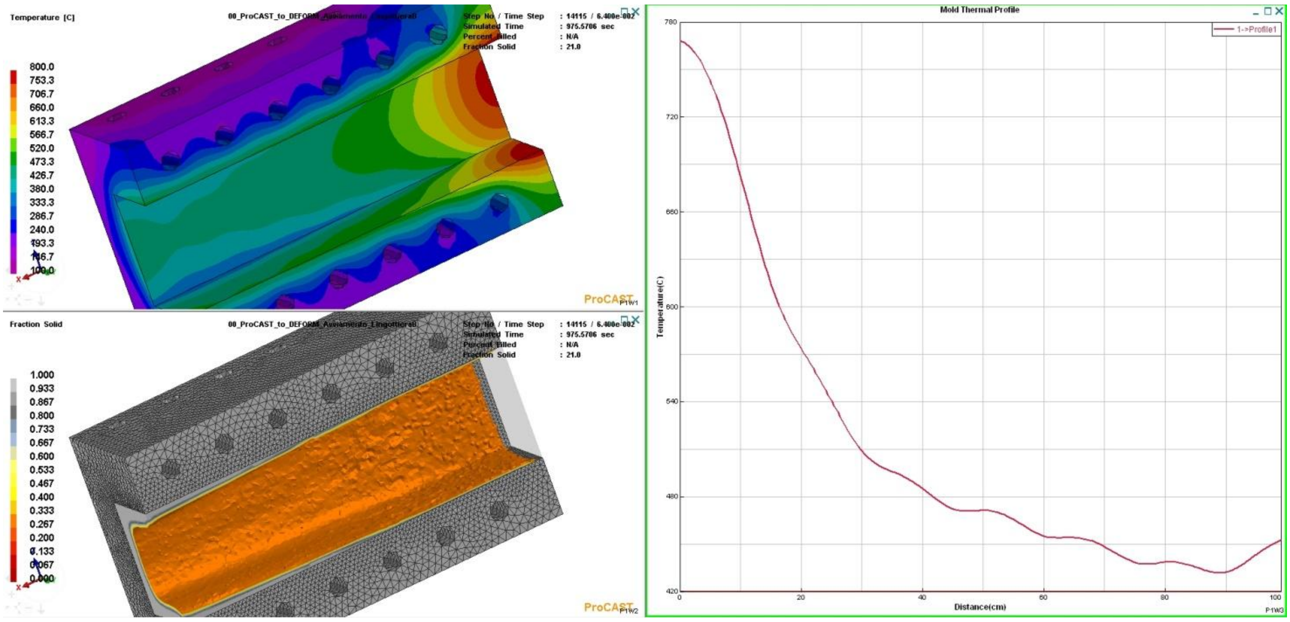

Figure 2. Copper Mold. Top Left: thermal distribution; Bottom Left: solid shell; Right: thermal profile

According to plant geometry and process parameters, resulting thermal distribution on a slice central plane for bloom is shown in Figure 3. Temperature on surface and at mid-section are plotted in graph. Length of mushy zone is represented through Fraction Solid evolution.

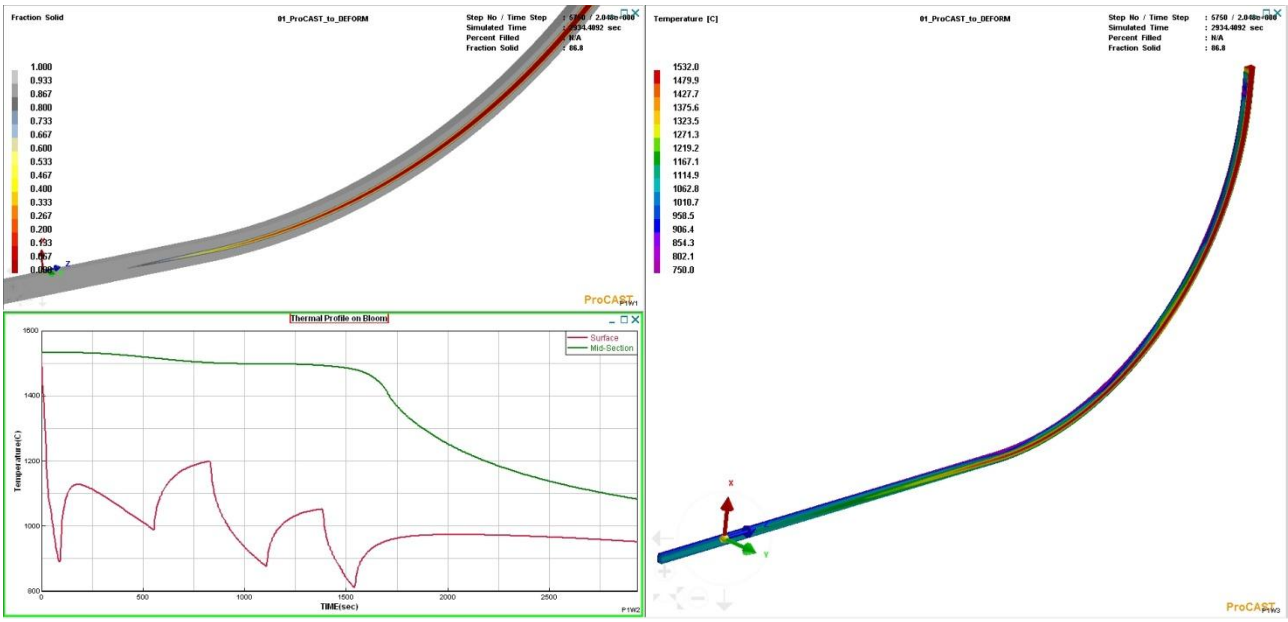

Figure 3. Temperature Field. Top Left: Solid Fraction: end of mushy-zone ; Bottom Left: temperature profile at surface and mid-section of bloom; Right: thermal distribution on a slice plane along central axis of bloom

After Continuous Casting Process a bar is cut from the line and transferred to following operation, that will be simulated in DEFORM®.

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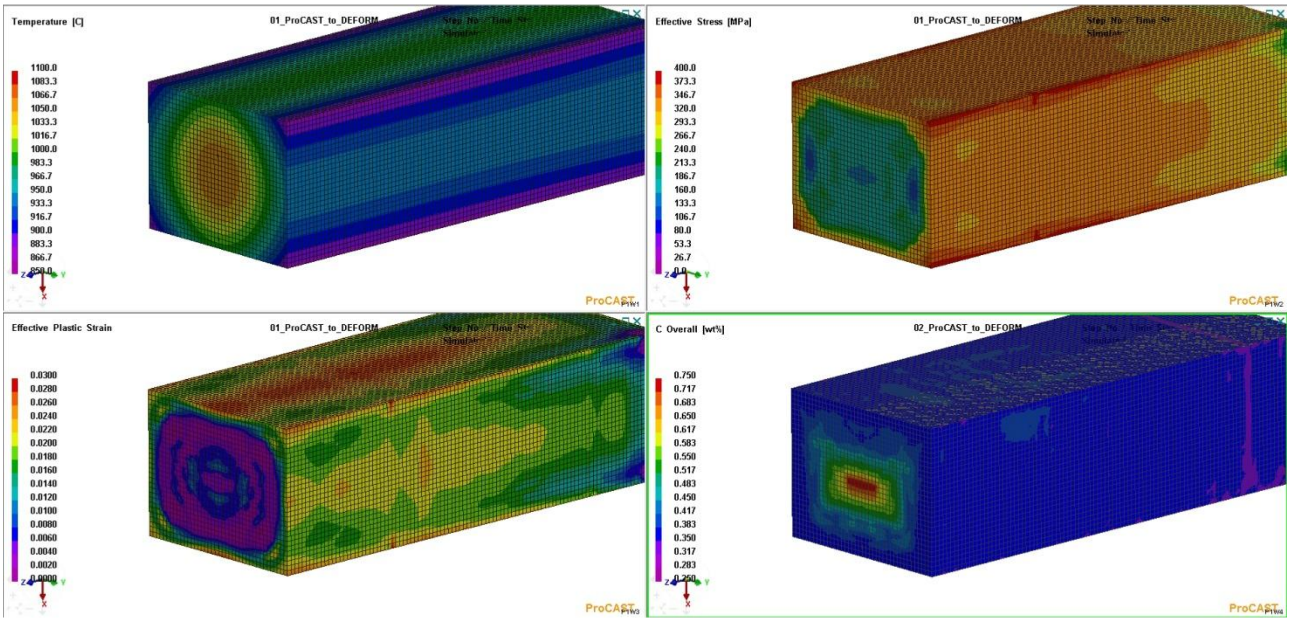

Figure 4. ProCAST® results after cutting operation: Temperature, Effective Stress, Effective Plastic Strain and Carbon concentration.

COOLING AT AMBIENT TEMPERATURE AND HEATING AT 1080 °C IN FURNACE

ProCAST® Continuous Casting Simulation mesh and results are imported into DEFORM® software to calculate on this 3D model the transformation to temperature, stress, deformation and carbon distribution.

DEFORM® is a FEM commercial software produced by SFTC® which is dedicated to rolling, forging and heat treatment.

DEFORM-3D® has been used to simulate complete model, both with tetrahedral and brick mesh, during cooling at ambient temperature and heating in furnace at 1080°C before beginning of shape rolling operation.

These two softwares share the same mesh and results at nodes and elements without any conversion or mapping.

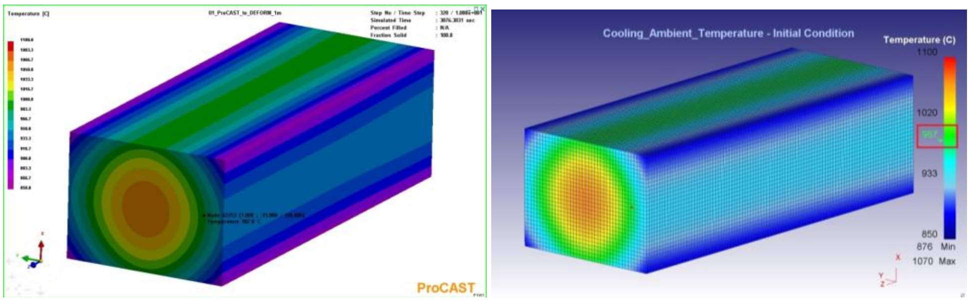

Figure 5. ProCAST® final Temperature Map (left) and DEFORM® Initial Temperature Map (right).

Bloom has been cooled down to ambient temperature in calm air and has been heated in a furnace with set point of 1100 °C until all nodes of profile reached 1080 °C, selected as initial temperature for shape rolling operation.

Model is Elastic-Plastic, in order to consider stress relief as well as carbon diffusion during both operations and elastic spring-back effects.

In following picture a slice in mid-section show final state of bloom that will be transferred to shape rolling initial step.

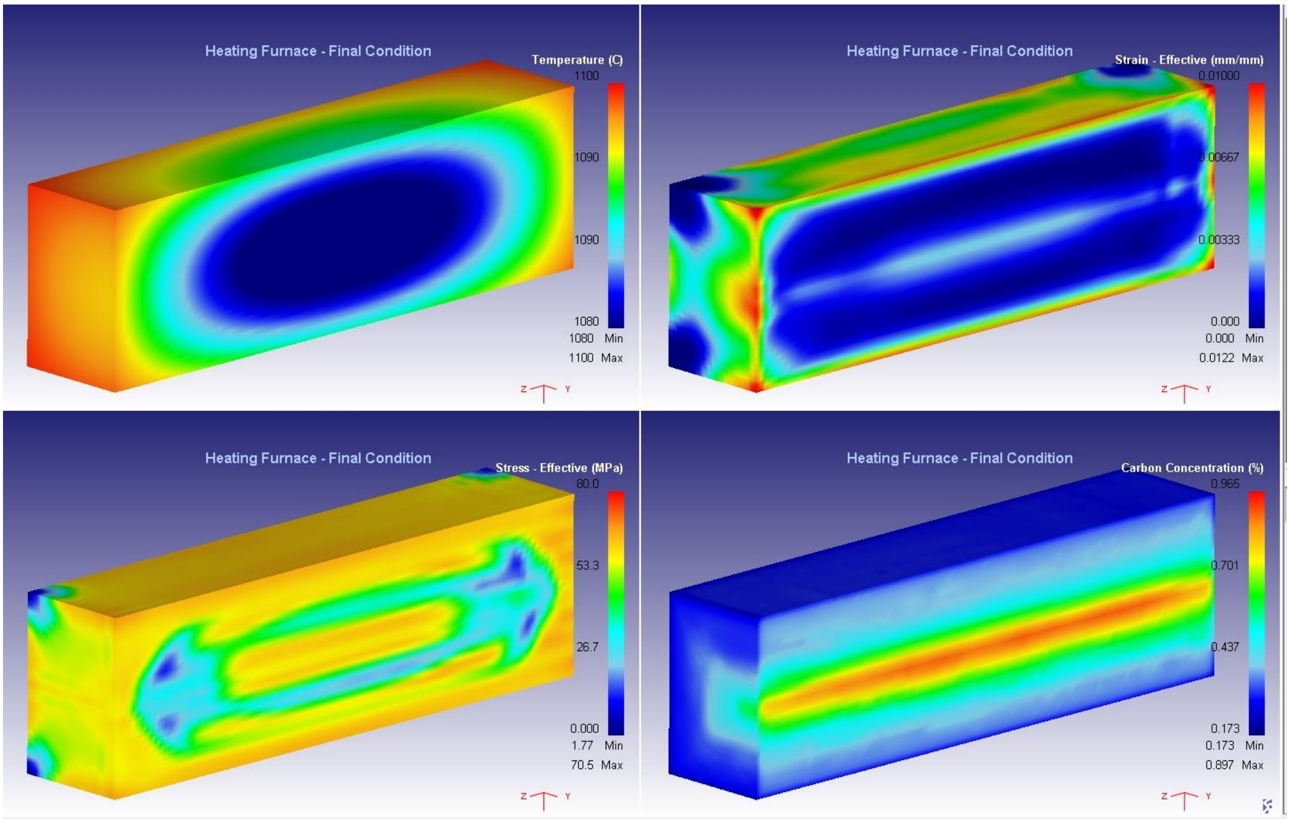

Figure 6. DEFORM® results on bloom before rolling operation (slice at mid-plane): Temperature, Effective Strain, Effective Stress and Carbon Concentration.

SHAPE ROLLING SIMULATION: COMPARISON BETWEEN STANDARD APPROACH AND "PROCESS CHAINING APPROACH"

In this application a reversible mill with 3 grooves is simulated; 5 passes are scheduled for this stage. Transfer between passes is simulated too.
Shape Rolling simulation has been done with DEFORM–3D® [4], [5].
ProCAST® Continuous Casting Simulation mesh and results was imported into DEFORM® for cooling at ambient temperature and heating in furnace at 1080°C.
After these operations, profile has been rolled with the "Process Chaining Approach".
It has been used a Lagrangian approach to fully consider all transitorily phenomena that technique like Arbitrary Lagrangian Eulerian (ALE) couldn’t detect.
ALE method is in fact working on a steady state condition of rolled profile and information about distorsion or temperature-time dependant information, like microstructure, are neglected.
Simulation is non-isothermal both for Shape Rolling with chaining to Continuos Casting Results and for simulation without.
In following images are represented mill geometry and a detail of groove geometry.

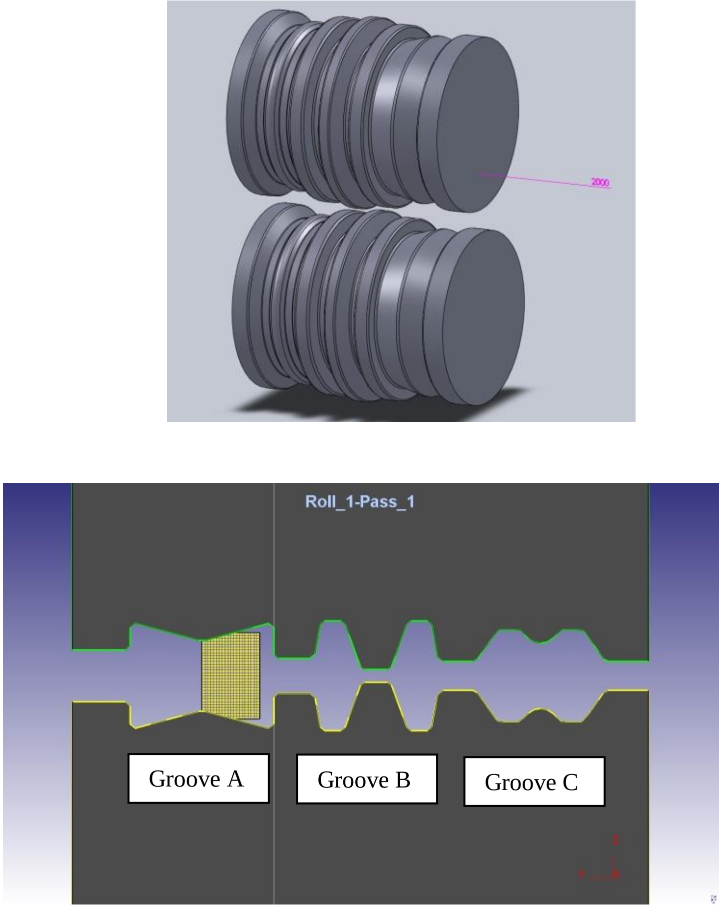

Figure 7. Reversible mill geometry: 3D view and 2D slice.

PASS	GROOVE	ROLL GAP [mm]	SPEED [rpm]	INTERVAL TIME [s]
1	A	100	45	7
2	C	100	48	5
3	B	130	47	5
4	C	110	49	5
5	B	110	55	10

Table 2. Shape Rolling operation parameters for Reversible Mill 1

Process Parameters are the same for both Shape Rolling simulations, with Standard approach and "Process Chaining approach"; only initial conditions of bloom are different.
Initial temperature for bloom with standard approach is 1080 °C and no stress or deformation are present at the beginning of rolling operation; initial situation for bloom with "Process chaining approach" are shown in following image.

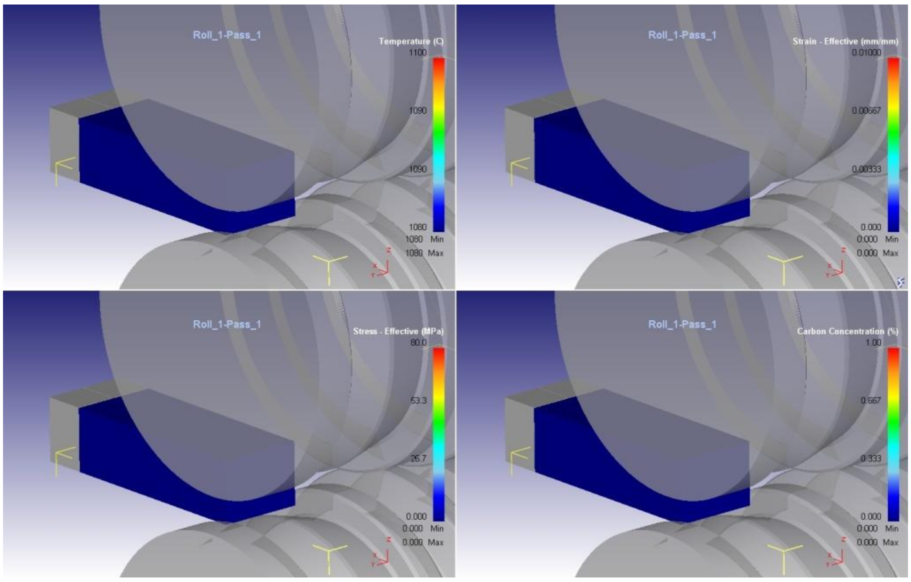

Figure 8a. Initial Condition for bloom at the beginning of Rolling.
Simulation with Standard approach. No stress, no deformation, no carbon distribution

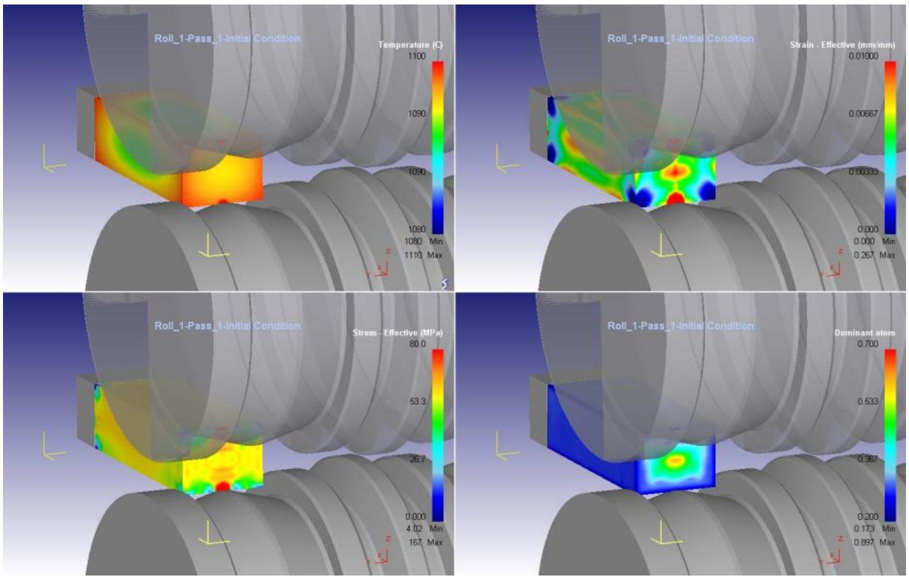

Figure 8b. Initial Condition for bloom at the beginning of Rolling.
Simulation with "Process Chaining Approach".
Temperature, Effective Strain, Effective Stress and Carbon Concentration.

Differences in temperature and strain fields at the beginning of second pass are shown in following images. Simulation with "Process Chaining Approach", according to more complete thermo-mechanical and microstructural history, shows a completely different distribution, less homogeneous and with a reduced strain respect to Standard Approach.

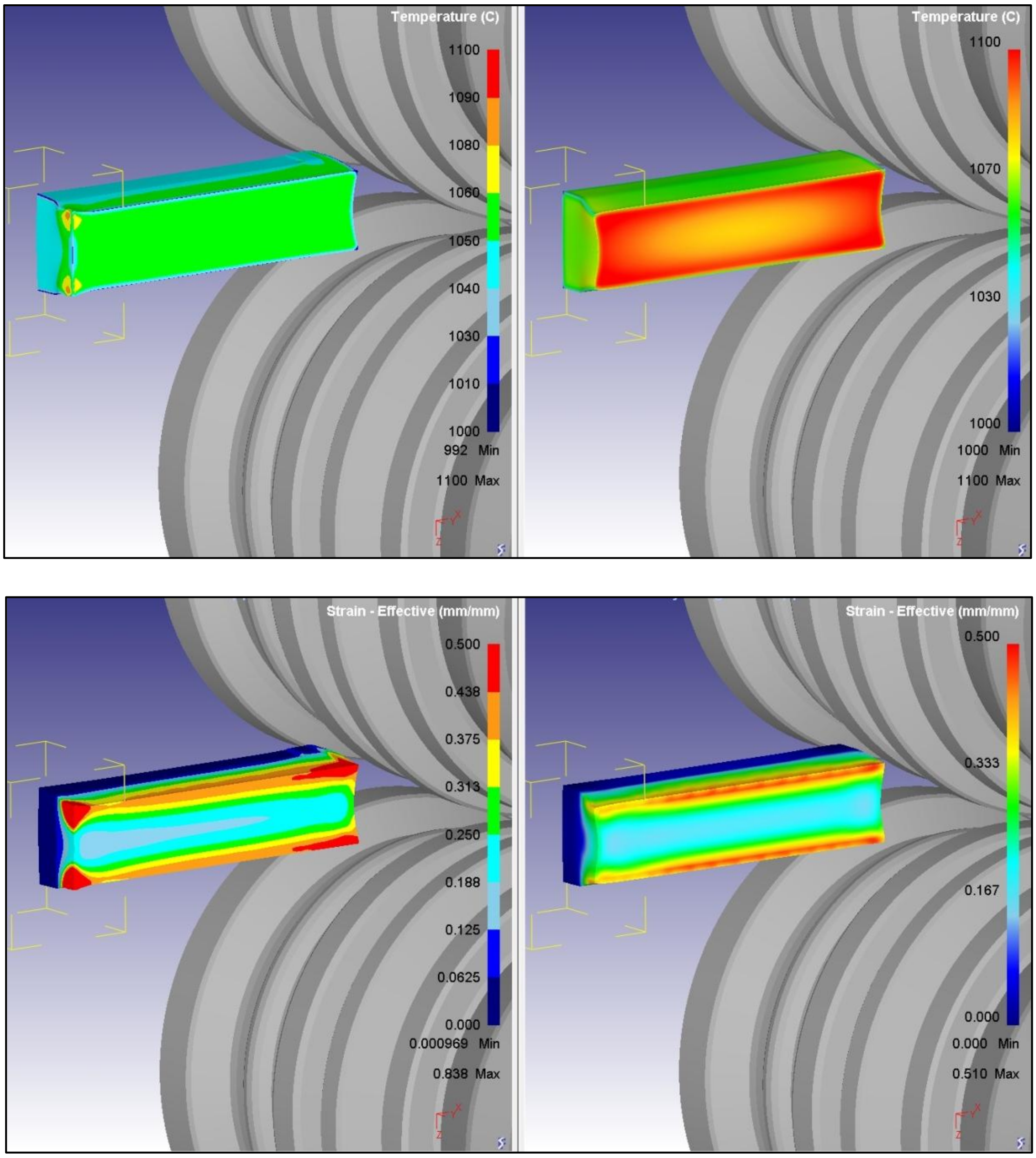

Figure 9. Temperature and Effective Strain at the beginning of second pass Comparison between Standard approach (left) and "Process Chaining Approach"(right).

Graphic Plot of Load on Rolls during operations shows value more variable with Standard Approach and in general lower respect to "Process Chaining Approach", even if stress and deformation on bloom are lower and temperature value are higher.

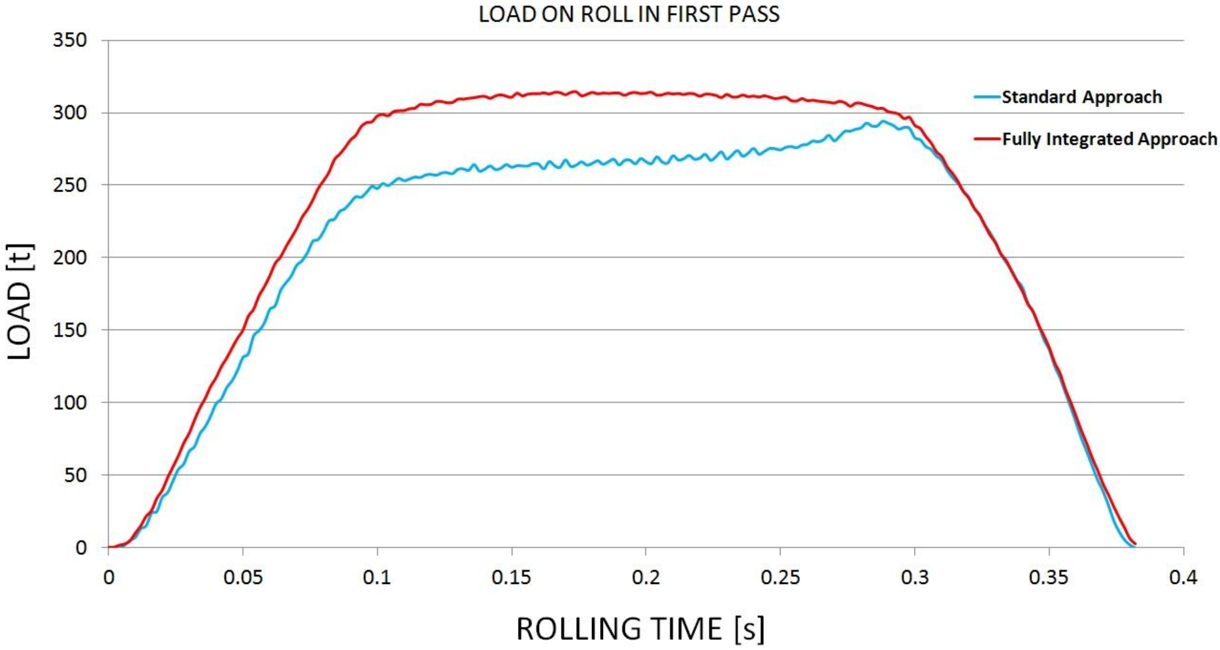

Figure 10. Graph Load vs Time during First Pass
Comparison between Standard approach and "Process Chaining Approach"

Filling of groove cavities is also different: flow-stress curves, according their properties temperature-strain-strain rate dependence, allow a different flow of material. Moreover, different carbon concentration, is an extra variable in this behaviour, as it's variable through section during rolling operations.

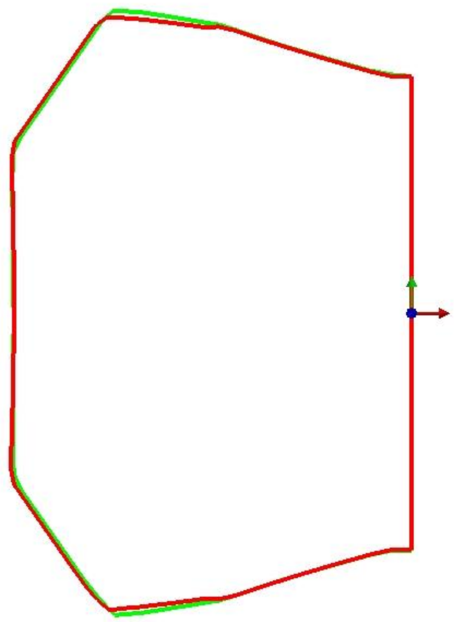

Figure 11. Filling of groove - Slice
Comparison between Standard approach (red) and "Process Chaining Approach" (green).

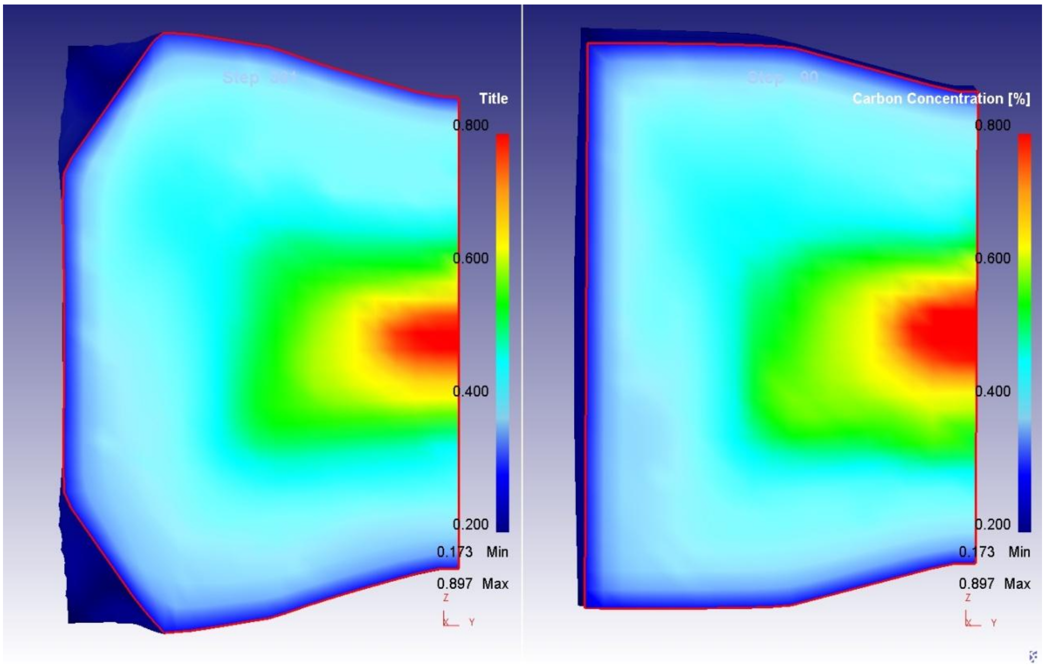

Figure 12. Carbon distribution evolution between different rolling passes, slice in correspondence of minimum rolling section.

CONCLUSION

This paper summarizes the evolution in Shape Rolling Simulation from a Standard Approach that consider Shape Rolling as a stand-alone operation to a "Process Chaining Approach" that consider also the production phase of profile to be rolled, taking into account both Continuous Casting and Cooling / Heating operations before Rolling.
Even if the same geometry and process parameters have been used, differences between two simulations are present, both for load on rolls and for filling of mill's groove.
Temperature, stress and strain in bloom are also different as well.
It's been found that Plastic Strain coming from Continuous Casting, as well as Carbon distribution and Plastic Stresses, play an important role in obtainment of a finished rolled product that satisfy drawing requests and working parameters of rolling plant.
No correlation have been detected to identify a trend for these differences which are consequences of a different way in management of production process.
In this paper it's shown chaining between two different commercial FEM software: ProCAST® of ESI-Group® and DEFORM® of SFTC®
These two softwares share the same mesh and results at nodes and elements without any conversion or mapping.
Computation time is similar for both approaches and this justify the choose of Fully Integrated Approach, to reduce approximation and achieve requested quality and productivity of the Rolling Process in the fastest way.

ACKNOWLEDGMENTS

Authors want to thank Marco Aloe of ESI-Group® for creation of native link in ProCAST® for export .key file to DEFORM®.
Authors want to thank Chris Fischer and Mike Foster of SFTC® for support provided in realization of this work and information given to allow creation of direct data transfer between Continuous Casting and Shape Rolling operation.

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