VOESTALPINE STAHL GMBH - CC8 CASTER FOR HIGH-QUALITY GRADES AND EXPOSED AUTOMOTIVE STEEL, DANIELI TECHNOLOGY*

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Abstract

At voestalpine Stahl, Linz a new conventional slab caster has been installed to produce mainly automotive and electrical applications grades, implementing the latest design solutions: tight pitch roll geometry, mould and strand stirring and braking devices, SEN water modelling validation, enhanced roll cooling design to allow dry casting conditions, finely defined slab cooling system layout to control slab surface temperature across the width. To control these design solutions the latest generation of technological packages has been implemented like detailed solidification model based on meshless computational algorithm and a fully dynamic application of soft reduction to achieve sound internal quality results.

Keywords: Automotive grades, Silicon grades, Technological packages, Electromagnetic devices.

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1 FOREWORD

As part of the production expansion project the slab caster No. 8 (CC8) at the voestalpine Stahl GmbH - LD3 steelplant in Linz was designed to cast mainly automotive grades for exposed parts to be rolled in coils, focusing on a slab thickness of 225 mm for slab widths ranging between 800 and 1,820 mm.
According to these requirements the roll geometry was finalized as a 9-m radius vertical curved machine with a vertical bender, six bow segments, two unbending segments and six horizontal segments.
An advanced automation features an L1 system based on DCS technology (providing a centralized software maintenance environment) that works in coordination with an innovative L2 system integrating a large set of Technological Packages including: Q-COOL (dedicated to control the secondary cooling in order to maximize the product quality), Q-CORE (dedicated to carefully control the Soft Reduction Practice), Q-MAP (to prevent the BO maximizing the machine performance), Q-MOD (to measure the mold displacement), Q-Level (to reduce the level fluctuations reducing bulging phenomenon by using enhanced control algorithm), Q-MAS (segments measuring and comparing geometry device).
This important project consolidates Danieli technology both in the mechanical and in the Electrics and Automation field.

2 ROLL DIAGRAM

Based on these requirements the main guideline for the roll diagram design was to consider reducing as much as possible the slab bulging between the rolls to avoid mold level fluctuations that could lead to inclusions and mold powder entrapments. This is particularly important for the automotive exposed parts products, in which the subsurface inclusions lead to sliver defects during rolling, worsening the final coil surface quality.
Thus, the values of the roll pitches are defined to be as tight as possible followed by a roll-axis design showing reduced roll diameters to keep enough gap for the sprays to reach the slab surface as necessary. Roll pitch and diameter values are reported together with the caster segment arrangement in Table 1:

Table 1. Roll pitches and roll diameters arrangement

Machine Area	**Roll Pitch range, mm**	**Roll Diameter, mm**
Bender	182 ÷ 185	Ø 150
Bow segment type 1	239 ÷ 248	Ø 200, Ø 220
Bow segment type 2	259	Ø 220
Unbending segments	280 ÷ 290	Ø 240
Horizontal segments	300	Ø 260

3 ELECTROMAGNETIC DEVICES

3.1 Mold Multi-Mode Electro Magnetic Stirrer (MM-EMS)

As is well known from many years of experiments on continuous slab casters, an optimal steel flow pattern in the mold is the starting point for achieving the best surface and sub-surface product quality, reducing defects from inclusions and mold-powder entrapment to the lowest level.

To determine the natural flow associated with different casting conditions of casting speed, slab width, SEN immersion depth and argon flow, different methodologies and models have been developed, including CFD simulations and real-scale water modeling (Figure 1). However, on continuous casters, nailboards and paddle methods are used to capture the steel flow direction and intensity at the meniscus.

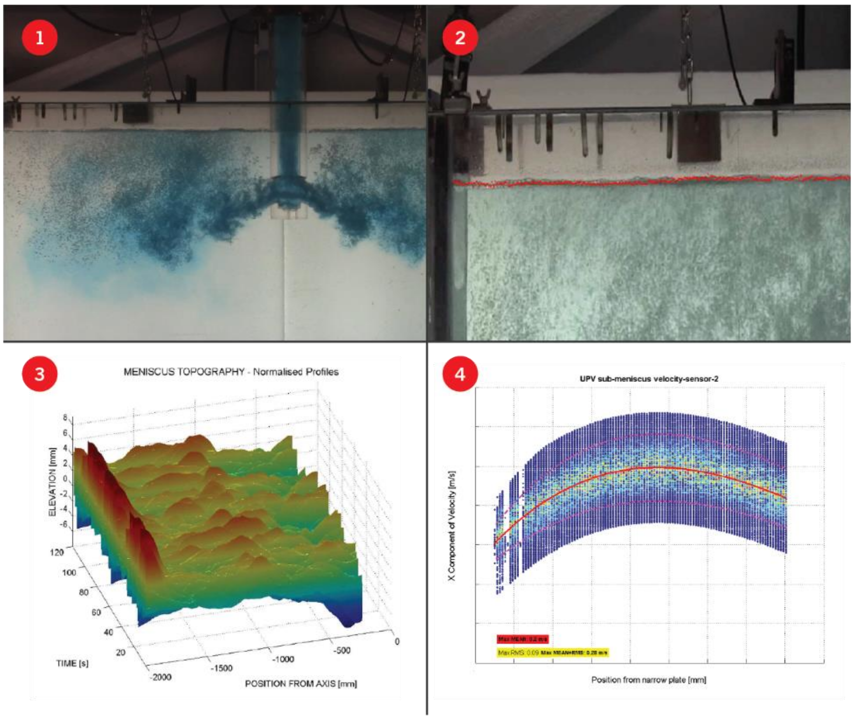

Figure 1. Water model is used to study the natural flow pattern of liquid steel into the mold. Argon injection is modeled thanks to air injection in the stopper rod and the flow is traced with methylene blue (1). Meniscus shape is detected through digital camera level topography (2) and results are analyzed to reconstruct the wave (3). Sub meniscus velocities are measured with an Ultrasonic Velocity Profiler (4), allowing a complete characterization of the flow pattern.

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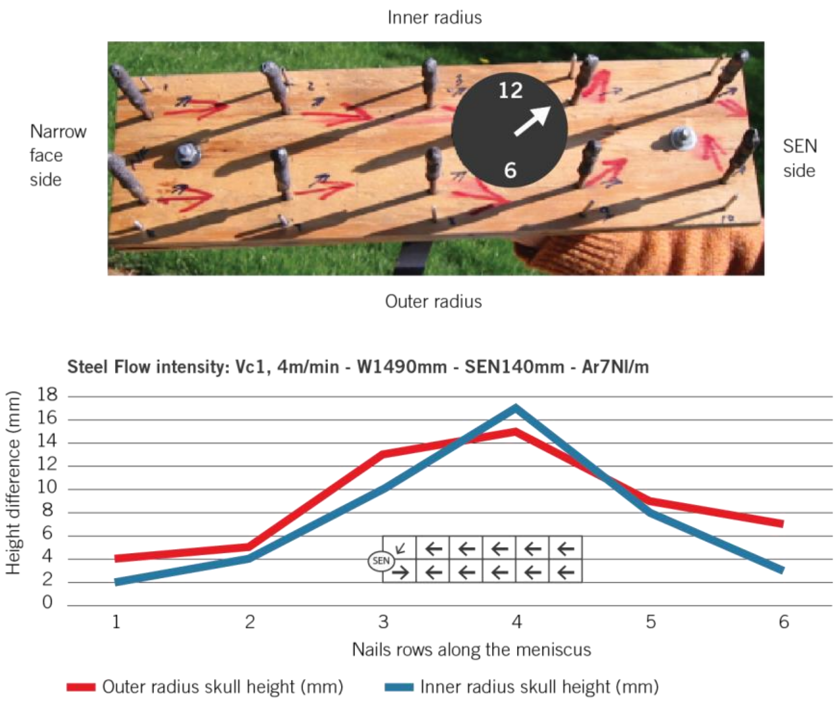

Figure 2. Nailboards.

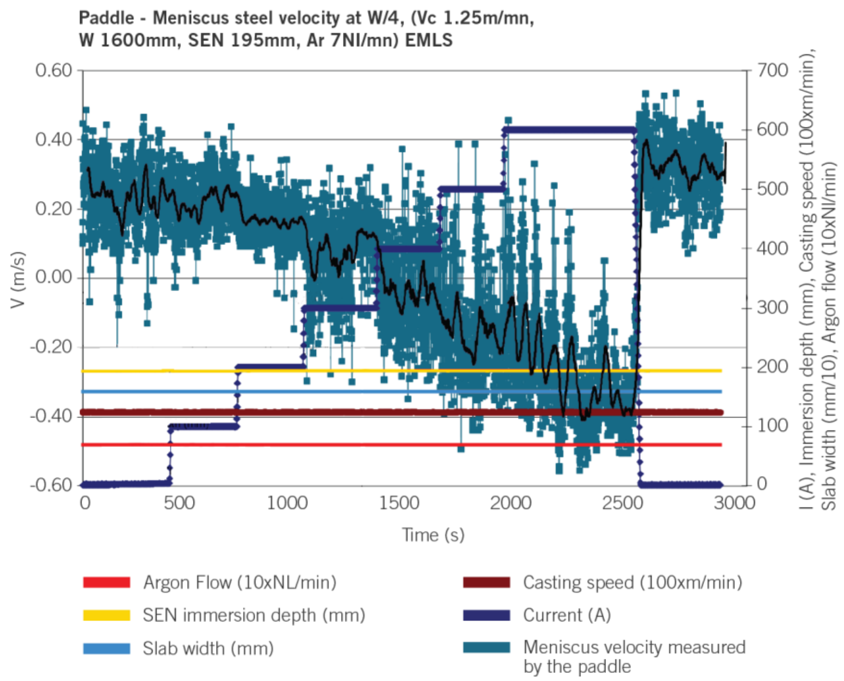

Figure 3. Paddle measurement with EMLS, slowing down function.

According to these measurements (Figure 2 and Figure 3) the proper control functions, like slowing down, accelerating or stirring, are applied by the Multi-Mode Electromagnetic Stirrer at the correct intensity.
The system controls automatically the steel flow inside the mold to maintain as much as possible the optimal steel flow with the appropriate magnetic forces generated by the stirrers in all the different casting conditions.
The general procedure for MM-EMS automatic control can be summarized as follows:

A meniscus steel velocity is issued according to the casting conditions, the nailboards mapping and four parameters (casting speed, slab width, SEN immersion depth and argon flow). Then, from this velocity and through the master files, the stirring function and the current intensity are calculated and applied (Figure 4).

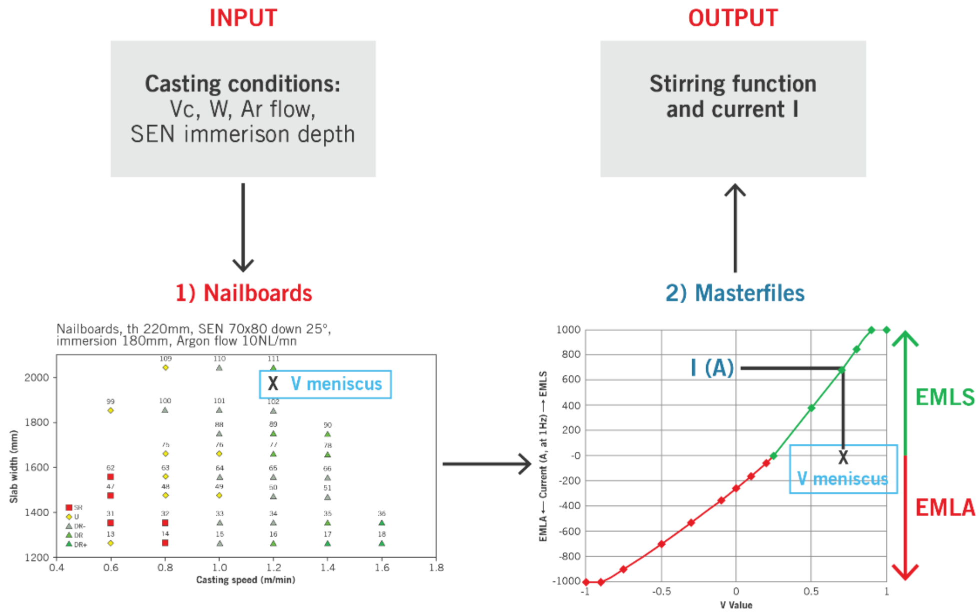

Figure 4. Control of stirring function based on meniscus steel velocity measurements

Based on first quality results, the adoption of the MM-EMS shows an improvement in the quality results in terms of sliver occurrences. At present, Multi-Mode tests are still on-going on the CC8 caster in collaboration with voestalpine stahl and the quality data are collected from the downstream process lines to consolidate the results and fine-tune the process further.

3.2 Strand Electro Magnetic Stirrer (Strand-EMS)

Moving from the mold down along the strand, the focus moves as well from surface and sub-surface to internal slab quality. In order to improve the equiaxial zone extension a strand stirrer has been installed in voestalpine Stahl GmbH-CC8 slab caster.

Internal distribution of equiaxed grains is a crucial parameter for the final quality of steels used for electrical applications. For voestalpine Stahl GmbH - CC8 product mix the main targets are the silicon steel grades with a Si content of about 2.32 %. In this case the EZ is enlarged by more than 50% (Figure 5, Figure 6).

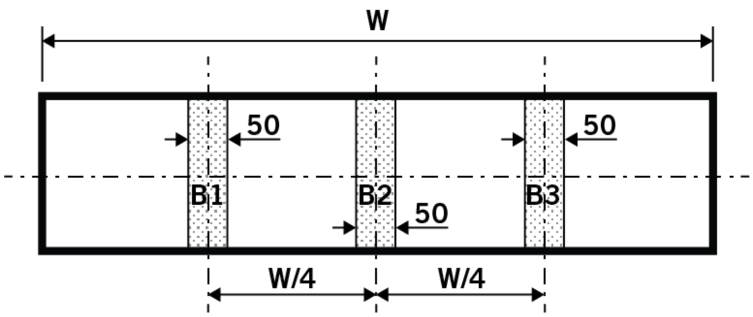

Figure 5. Internal slab quality samples sketch.

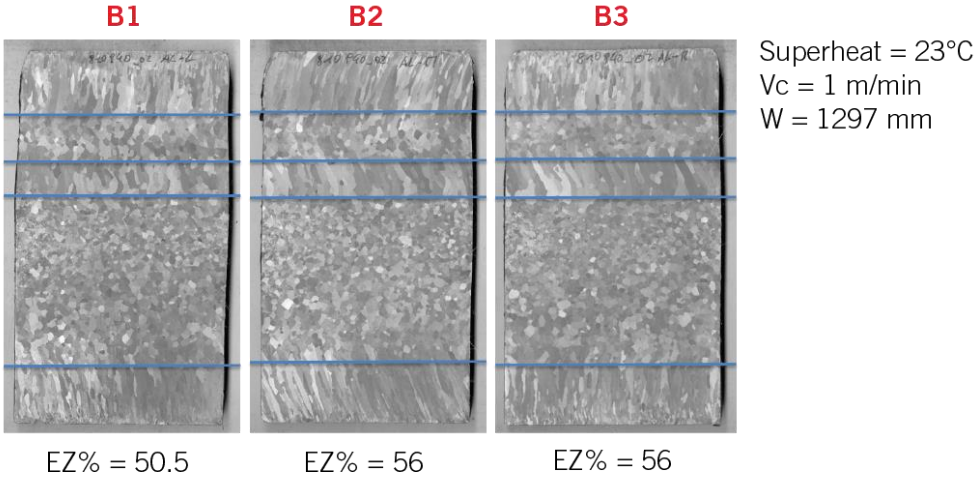

Figure 6. Equiaxial zone percentages.

4 SECONDARY COOLING DESIGN

To reach the required quality levels in terms of internal and surface quality for all the different slab sections, the cooling system has been designed with the ability to control in the smoothest possible way the water distribution across the width. For this purpose, the common arrangement in spray-cooling sections across the width has been enhanced by adding the ability to control the spray nozzles independently by means of dedicated control loops, with separate valves for both air- and water-flow control (Figure 7).

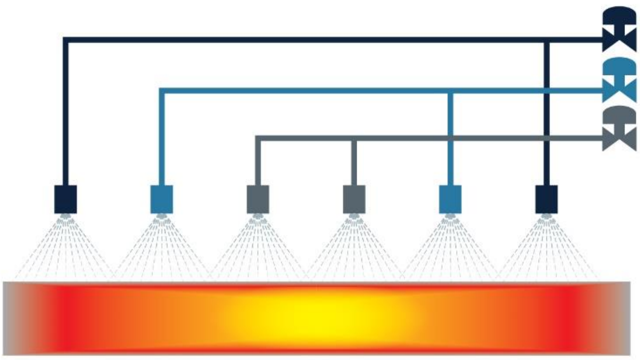

Figure 7. Independent control of spray-cooling sections across the slab width.

To get a controlled situation the spray nozzles have been carefully designed to compensate both the overlap effect across a single row and the total water density at the end of the spray cooling zone given by the overlapping of all the nozzles along the length of the caster (Figure 8, Figure 9).

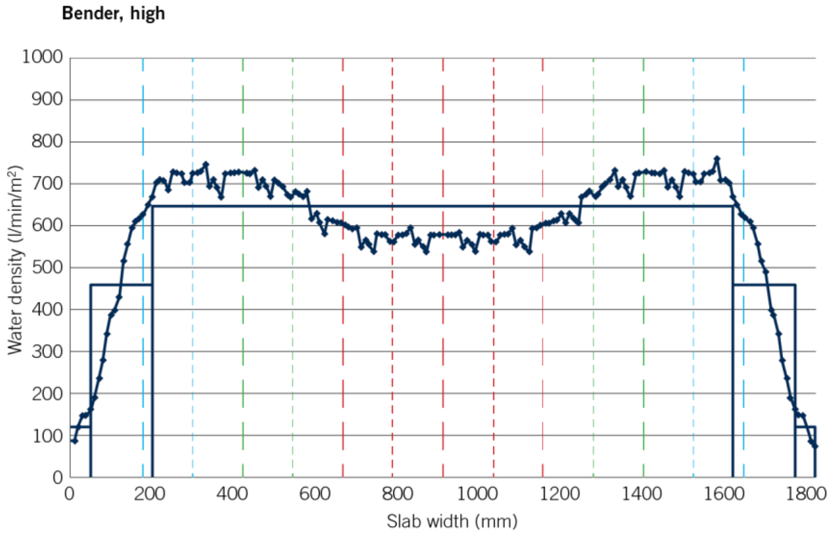

Figure 8. Total water density across the width at bender zone exit.

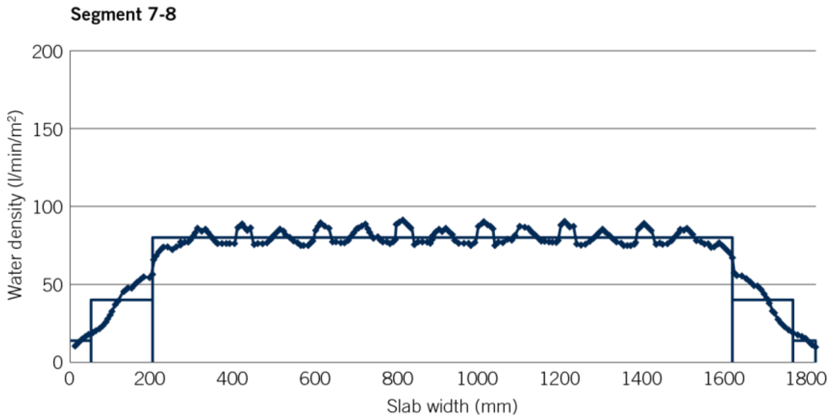

Figure 9. Total water density across the width at Segment 7-8 zone exit.

To measure and check the surface temperature distribution across the slab width in the different casting conditions, a special design pyrometers system is installed between two straightening segments to collect the temperatures in a dense distribution of points across the slab width.

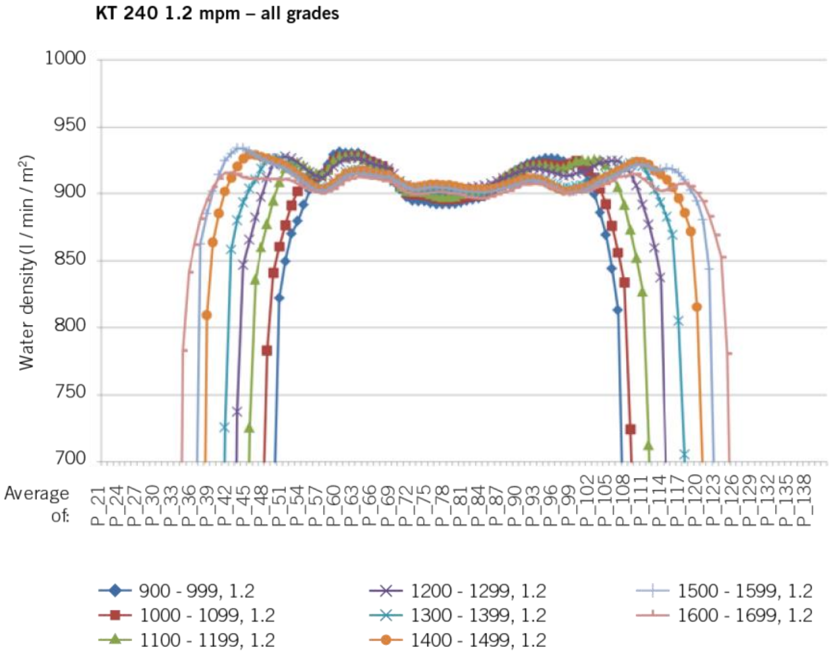

Figure 10. Surface temperature measurements middle Seg 7-8 zone.

This measurement, coupled with the ability to control the flow rates separately at the different sprayed width zones, allows levelling of the peaks and valleys of the temperature profile measured so that internal quality control improves as well (Figure 10).
This control capability coupled with the secondary cooling solidification model makes it possible to tune the solidification end-shape along the casting direction to avoid side elongations that lead to uneven centerline across the width, with higher segregation near the narrow sides (Figure 11, Figure 12).

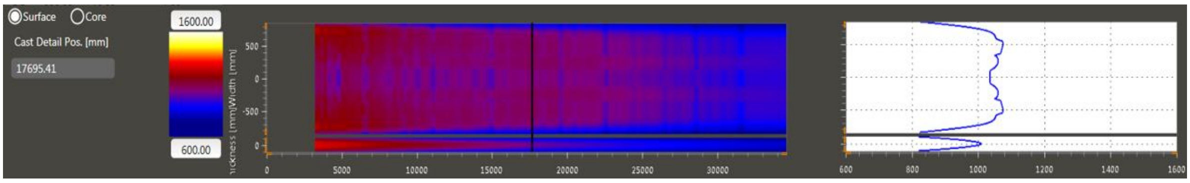

Figure 11. Model computed surface temperature.

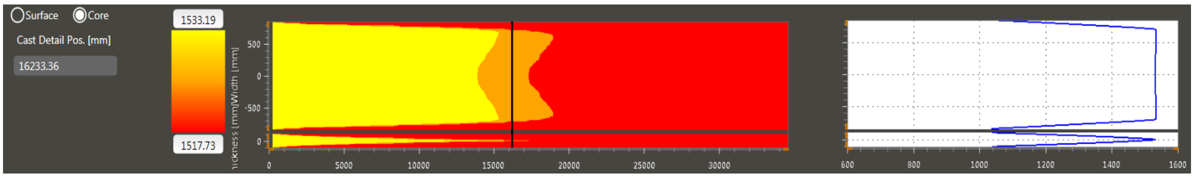

Figure 12. Model computed centerline solidification.

Based on real measurements performed by the nozzle supplier (Figure 13) each single nozzle feature has been implemented within the detailed model (Figure 14) so that a full picture of the secondary cooling system is completely considered by the solidification model, providing a complete 3D map of the solidification conditions of the slab along the caster strand (Figure 15).

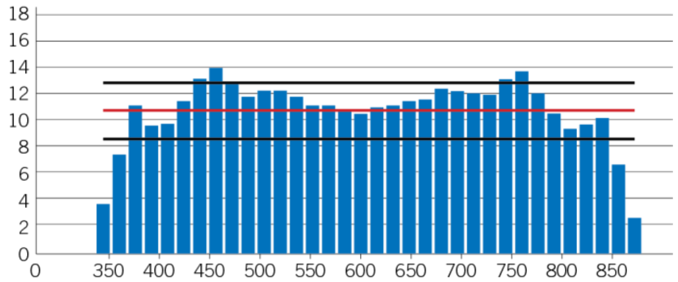

Figure 13. Real nozzle cooling density distribution.

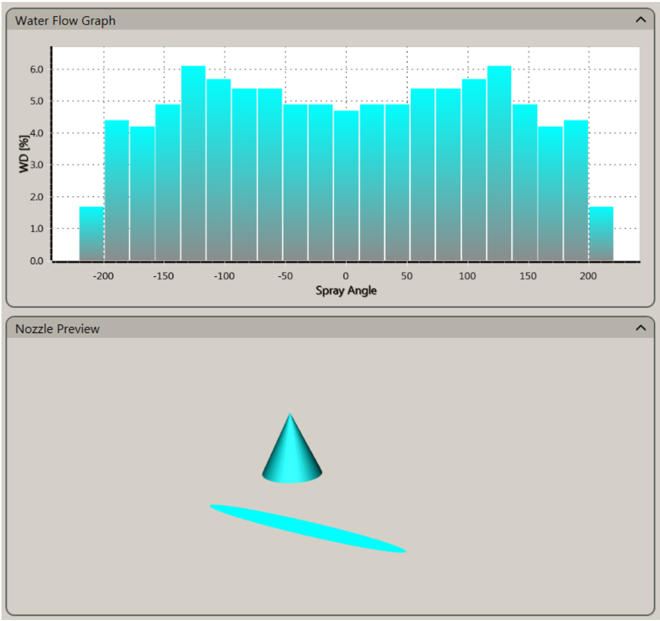

Figure 14. Modelling the nozzle cooling density distribution.

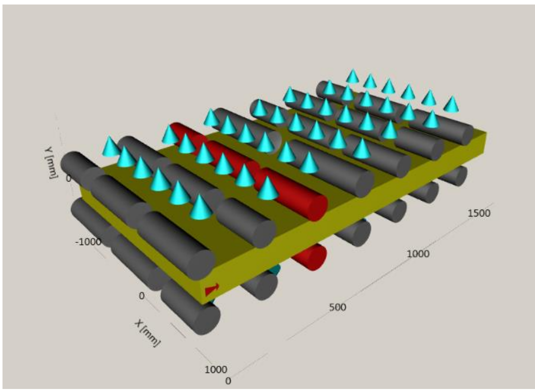

Figure 15. Modelling segment nozzles and rolls arrangement.

Together with the spray cooling, roll cooling is considered in detail and implemented in the model to get full control of its influence on solidification.
To reduce to the minimum any unevenness resulting from a systematic overlapping of spray cooling concentration, a staggering of the sprays has been considered, alternating even and odd numbers of nozzles across the width for the subsequent rows of nozzles along the length of the caster.
Finally, to simplify the design and reduce investment and operational costs, no slab spray-cooling has been considered in the horizontal part of the slab caster, only internally cooled rolls.

5 DRY CASTING

Crack sensitive and high-quality steel grades slabs are prone to develop cracks when they pass through two critical areas of a vertical curved design machine: the bending zone and the unbending zone (Figure 16).
To avoid the formation of cracks in this area it is important to control the stress created by deformation together with the slab temperature.
Temperature is a critical factor whenever it drops down in the ductility drought area, where even relatively low values of stress can induce the formation of cracks.
If the bending part of a vertical curved caster the slab is still not too far from the meniscus to have issues with the temperature, for the unbending area, especially for the higher radius machines, the distance from the mold (meniscus) becomes significantly more important and the control of temperature drop more difficult. To withstand this issue, the concept of dry casting can be applied. The idea is very "simple" and involves switching off slab secondary cooling to reduce as much as possible the heat extraction from the slab. This "simple" action brings considerable drawbacks, like:

- Exposing the machine equipment to higher temperatures, which in principle could significantly compromise the life of rolls and bearings; and,
- Losing control of the solidification process, introducing internal defects like centerline segregation and cracks.

Therefore, the key factors are the design of the equipment in terms of roll and bearing cooling, to contemporaneously protect the parts and introduce the minimum required contact cooling effect on the slab; tight roll pitch, to ensure proper containment to control bulging and segregation; tuned application of soft reduction to achieve an even centerline quality, as well as to limit conditions resulting from the significant removal of spray cooling.
Internally cooled PDR rolls design together with a controlled and tuned internal cooling-water flow have proven to be successful in reaching higher temperature values at the unbending area, with an acceptable distribution across the slab width. The slab internal quality that is achieve is in line with expectations and comparable to other less critical steel grades.

6 DRY CASTING CONDITION

The CC8 is equipped with special PDR-rolls from segment 3 to segment 8. This allows in this area dry casting conditions without negative effects on the roll life time. Some trials where necessary to evaluate the influence on the slab temperature and the effect on the roll cooling during dry casting condition. Several tests with different conditions were tested.
For this reason, the driven rolls from segment 3 to 8 on the inner bow where equipped with additional thermocouples to measure the influence on the cooling water temperatures of the PDR rolls. During dry casting the 3 scanners shown a full temperature profile over the width and also some hand pyrometer measurements were made. The output of these trials was an optimized cooling flow for the PDR-rolls (machinery cooling) to be sure that dry casting will not lead to any roll damages. Additional some software changes related to machine safety rounded up the final set up for dry casting.

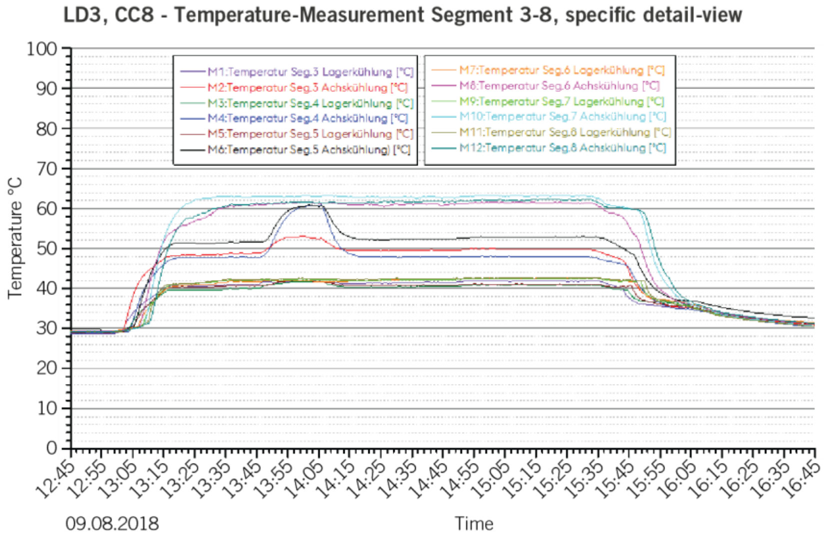

Figure 16. Temperature change on machinery cooling during dry casting (segment 3 to 8).

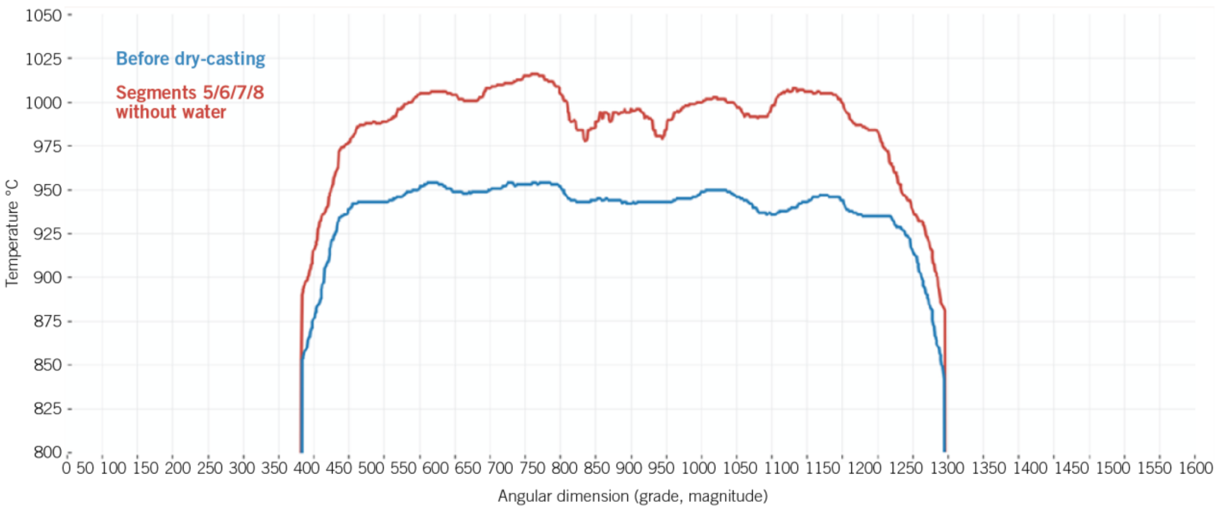

Figure 17. Slab surface Temperature change during dry casting (pyrometer measurement between segment 7 and 8).

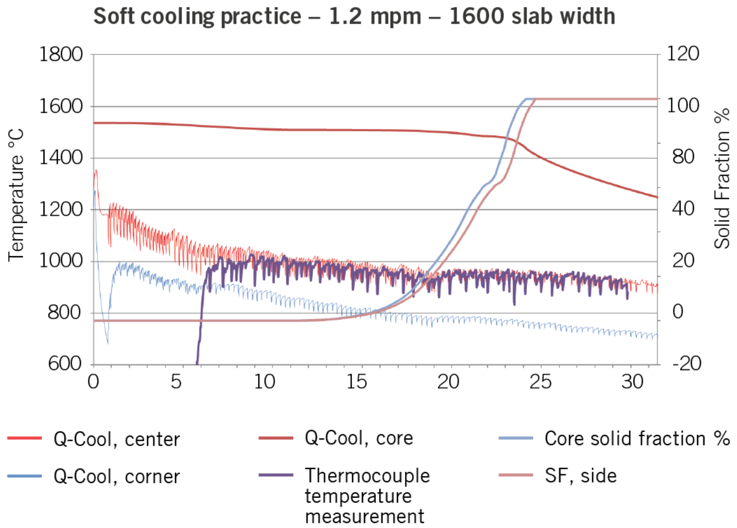

Figure 18. Surface temperature profiles, predicted and measured.

7 TECHNOLOGICAL PACKAGES

To fully control the machine equipment and the casting process the latest-generation technological packages have been fully implemented. An important role is played by the solidification model and the dynamic soft reduction control model, merged together in a unique advanced model that controls both spray-cooling flows and segment positioning dynamically, according to the different casting conditions, either steady and unsteady.
The development of a meshless algorithm for the computation of the heat exchange equations makes it possible to reduce the computational time enough to allow the handling of a full two-dimension slice model in real-time conditions.
Therefore, it has been possible to implement within the model the behavior of each individual nozzle across each individually sprayed row, providing a full map of the cooling behavior over the entire slab surface and a full picture of the solidification progress within a slab section at any distance from the meniscus.
Coupled with a flow-control split across the sprayed width, the model allows a fine-tuned control of the temperature distribution to reduce the differences across the width.
Detailed curves with the metallurgical properties for different steel grade compositions have been generated to cover the full range of product mix. Each curve is properly selected according to the steel-grade target composition. Therefore, the spray-cooling practices are defined directly by Level 2 based on the production schedule.
Coupled with the slab-cooling control the model integrates the functionality for applying dynamic soft reduction. According to the different compositions, different thickness reduction profiles can be assigned on the three main areas of liquid core, mushy core, and solid core.
Again, based on the steel target composition, the proper thickness reduction curves are dynamically applied according to each roll position, to achieve the correct application.
The specific possible positions of the segments are considered by applying several quality protection limitations that adapt the desired thickness reduction application to the real-time casting conditions, reconfiguring the segment position if necessary.

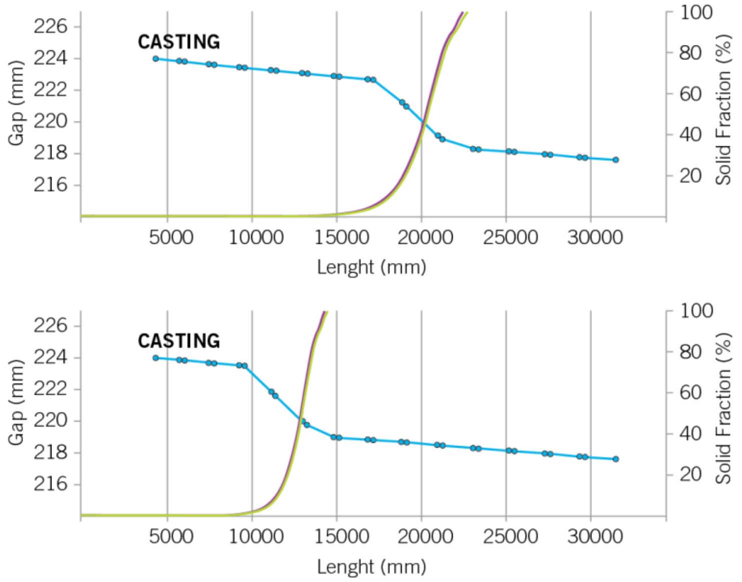

Figure 19. Top, segment gap in casting condition applying soft-reduction; Top, 1.3 m/min; Bottom, 0.8 m/min.