voestalpine Stahl GmbH – CC8 caster for high quality grades and exposed automotive steel

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Fig 1 CC8 product mix

**BASIC DESIGN**
The single-strand caster is a 9m radius vertical curved machine with a vertical bender, six bow segments, two unbending segments and six horizontal segments. It is designed to produce slabs with a nominal thickness of 225mm and widths from 740mm up to 1,820mm and, considering the specific product mix, has a design capacity of 1,200,000t/yr of slabs.

**TECHNOLOGY PACKAGES**
CC8 is equipped with a full suite of the latest Danieli technology packages, including mould displacement and level fluctuation control, electromagnetic stirring, dynamic secondary cooling, dynamic soft reduction and segment dimension measurement and control; all of which were successfully hot commissioned. Some of these are described below.

**ELECTROMAGNETIC STIRRING**
There are two stirring systems: mould and strand.

**Mould Multi Mode Electro Magnetic Stirrer (MM-EMS)**
Many years of experiments and steel production on continuous slab casters have established that an optimal steel flow pattern in the mould is mandatory to achieve the best surface and sub-surface product quality, and to minimise the defects resulting from non-metallic inclusions and mould powder entrapment. MM-EMS provides intelligent control of three functions for slowing down, accelerating and rotating the liquid steel in the mould to reduce the steelmaking defects.

CFD simulations and true-scale water modelling were used to determine the fluid flow associated with different casting conditions, ie, casting speed, slab width, SEN immersion depth and argon flow, as well as an extensive campaign of nail board tests to capture the steel flow direction and intensity at the meniscus. Some examples are shown in Figure 2.

Water models are used to study the natural flow pattern of liquid steel into the mould. Argon injection is modelled by air injection into 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 analysed to reconstruct the wave (3). Sub-meniscus velocities are measured with an ultrasonic velocity profiler (4), allowing a complete characterisation of the flow pattern.

According to these measurements, the control functions of the MM-EMS have been fine-tuned and, based on product quality results from the downstream process lines, all contractual surface quality performance guarantees for the caster were fulfilled.
Strand Electro Magnetic Stirrer (Strand-EMS)
Moving from the mould down along the strand, the focus shifts from surface and sub-surface to internal slab quality. In order to improve the equiaxed zone, a box-type strand stirrer has been installed. Strand-EMS is used to improve the internal solidification structure in terms of increased equiaxed zone.

The main reason for adopting the strand stirrer on CCB is the silicon steel grades, which have a Si content of about 2.3%. Figure 3 shows examples of grain structure taken from three slab positions, as shown in Figure 4. The equiaxed zone size ranges from 50.5% to 56% of slab thickness – an excellent result.

Q-COOL: DYNAMIC SECONDARY COOLING SYSTEM
To reach the required quality levels in terms of internal and surface quality for all the different slab sections, the cooling system for CCB has been designed to control the water distribution across the entire slab width in the smoothest way possible. To achieve this, the common arrangement in sprayed cooling sections across the width has been enhanced by adding the ability to control them independently by means of dedicated control loops with separate valves for air and water flow control. This is shown schematically in Figure 6 with a specific example in Figure 7 from the bender zone exit. The spray nozzles have been carefully designed to compensate for 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.

Based on actual measurements performed by the nozzle supplier, each individual nozzle feature has been implemented within the detailed model so 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 entire caster strand. An example is shown in Figure 8.

DRY CASTING
Crack-sensitive and some 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.

To avoid the formation of cracks in these areas it is important to control the deformation stress and the slab temperature. Temperature is a critical factor in the ductility trough area, where even relatively low values of stress can induce crack formation. This may not be a significant problem in the bending part of a vertical curved caster where the slab temperature is still high, but can be very significant in the unbending area.

The concept of ‘dry casting’ can be applied to this phenomenon. The idea is very ‘simple’ and involves switching off slab secondary cooling water to reduce the heat extraction from the slab and achieve a slab temperature above 900°C. There are, however, considerable drawbacks:

- Exposing the equipment to higher temperatures which could significantly compromise the life of rolls and bearings
- Losing control of the solidification process and...
so introducing internal defects such as centerline segregation and cracks.

The key factors to enable dry casting are:
- The design of the equipment in terms of roll and bearing cooling to protect parts
- Introduce minimum required contact cooling effect on the slab
- Use a tight roll pitch to ensure proper containment to control bulging and segregation
- Use tuned application of soft reduction to achieve an even centerline quality
- Limit conditions resulting from the significant removal of spray cooling.

An internally cooled peripherally drilled rolls (PDR) 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 achieved is in line with expectations and comparable to other less critical steel grades.

CC8 is equipped with PDR from segment 3 to segment 8. Some trials were necessary to evaluate the influence on the slab temperature and the effect on the roll cooling during dry casting condition. The driven rolls from segment 3 to 8 on the inner bow were equipped with additional thermocouples to measure the influence on the cooling water temperatures of the PDR rolls over the width. The output of these trials was an optimised cooling flow for the PDR rolls to be sure that dry casting will not lead to any roll damage. Additionally, some software changes relating to machine safety were incorporated in the control models.

An example of slab temperature across the width with dry and conventional casting is shown in Figure 9.

**Q-CORE: DYNAMIC SOFT REDUCTION**

An important role is played by the solidification model and dynamic soft reduction control model, which have been merged into a unique advanced model that controls spray cooling flows and segment position dynamically, according to the different casting conditions, steady or unsteady.

The development of a meshless algorithm to compute the heat exchange equations makes it possible to reduce the computational time enough to allow handling of a full two-dimensional slice model in real time.

It is thus possible to simulate the behaviour of each individual nozzle across each sprayed row to attain a full map of the cooling behaviour 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 fine-tuned control of the temperature distribution to reduce differences across the width.

Coupled with slab cooling control, the model integrates the functions for applying Q-CORE so that, according to the different steel compositions, different thickness reduction profiles can be dynamically applied on the three main areas of liquid core, mushy core and solid core. Examples at two
casting speeds are given in Figure 10 showing segment gap (blue) and solid fraction (grey) during soft-reduction.

OPERATIONAL RESULTS
Following an extensive period of cold commissioning, hot start-up began in January 2018, working up to full shift operations within five weeks. Production has been steadily increased as shown in Figure 11, with 103,000t produced in October 2018, exceeding the design capacity of the plant. A total of 95% of the product cast was of high quality vacuum-treated steel, of which more than 80% was interstitial-free (IF) grades for the automotive industry. Since October, machine design and process reliability has been demonstrated by casting 101 heats in a sequence with 16 fly tundish changes.

CONCLUDING REMARKS
Thanks to the quality and reliability of the Danieli mechanical equipment and technology packages, in synergy with the experience and knowledge of voestalpine stahl, the new CC8 continuous slab caster has exceeded all expectations both in terms of productivity and product quality during a highly successfully work-up period, and has been accepted for full production.

These impressive results are only possible due to the extremely strong teamwork between the voestalpine and Danieli project teams and are a testament to the hard work and detailed planning undertaken by all involved. MS

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