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THE EVOLUTION OF THE THIN SLAB CASTER CONCEPT: LATEST TSC TECHNOLOGY TO PRODUCE OVER 330 T/H PER STRAND[1]

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Abstract
The recent Danieli experience in the thin slab caster proved that it is possible to reach a production of 1.8 Mt/y with a single strand caster utilizing a slab 80x1300 mm. With a more favorable range of thickness and width as per the majority of the operating plants a production of 2.5-3.5 Mt/y it is possible with a single strand. This will be a revolution in the thin slab caster plant layout eliminating definitively the need of installing a second strand.
Key words: Thin slab caster; Latest technology.

Resumo
A experiência recente da Danieli no lingotamento de placas finas provou que é possível chegar a uma produção de 1,8 Mt / ano, com um único veio de lingotamento, utilizando uma placa de 80x1300 mm. Com uma faixa mais favorável de espessura e largura de acordo com a maioria das usinas em operação, uma produção de 2,5-3,5 milhões de toneladas / ano é possível com um único veio. Esta será uma revolução no layout das plantas de placas finas, eliminando definitivamente a necessidade de instalação de um segundo veio.
Palavras-chave: Lingotamento de placas finas; Tecnologia de ponta.

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1 INTRODUCTION

Since the first pioneering applications of thin slab casting in the late 1980s, Danieli has developed its own particular thin slab caster design aimed at overcoming the quality and productivity limitations of the first generation plants.

This approach has materialized into the “flexible Thin Slab Caster“ (fTSC) concept, where “flexibility“ stands for its particular capacity to ensure top-quality slabs in the full operating range of casting conditions in the mill, over an extremely diversified product mix of steel grades and slab thicknesses.

About 20 years after the first pioneering applications, this strategic approach in innovative, consolidated solutions allows Danieli to proudly include among its references some world record-breaking plants, such as Tangshan Iron and Steel in P.R.China, that affirm it was possible to overcome the 3-million tons per year threshold for hot-rolled coils (with two casting strands in operation since 2005). As for product quality, since the first industrial application of its fTSC caster in 1997, Danieli’s EssarAlgoma plant (Canada) has proven consistently that it is possible to cast sensitive grades, such as peritectic, which, as a rule, are still excluded from the product mix of “first generation” thin slab casters.

This process of targeting more demanding grades continued over the years and at present we can practically cover all the steel grades for flat product applications. This includes API X60 and X70 used for Arctic pipe applications, which were first produced successfully in the Danieli Ezz Flat Steel plant in 2005 and put into full production in the OMK plant in Russia in 2009; and the high-silicon grades (Si content exceeding 3.2%) in the Danieli Benxi Iron and Steel plant in China, since 2005.

This paper describes the defining features of the Danieli fTSC, including the most recent developments that target record-breaking casting speeds of 8 meters per minute, allowing Danieli plants to aim for plant capacity ratings of 1.8 / 2 million t per strand, as in the new POSCO plant in Korea.

2 MATERIALS AND METHODS

Since the first developments of the thin slab casting process in the late ’80s, Danieli created its own particular caster design based on extensive R&D. This design was then improved upon thanks to the experience gained in its first industrial-scale pilot plants and confirmed over the last 20 years in close cooperation with our customers, who are an invaluable source of operational feedback, essential for the continuous improvement of the proposed solutions.

Thanks to this partnership, Danieli has been able to develop dedicated solutions to fulfill the specific needs of each application, all including the defining technological packages that identify the Danieli concept of flexible thin slab caster.

Most of the limitations of the early generations of thin slab casting and rolling plants installed in the world were imposed by the casting process, mainly due to the imperfect handling of fluid dynamics in the mold, in the secondary cooling and soft reduction processes.

These limitations mean that the caster operates “at its best” in a limited operational “window”: this operational rigidity contradicts the needs of a fully integrated plant

(i.e. a single production line made up of the caster, the tunnel furnace and the mill). As a consequence, plant productivity and product mix were limited mainly to

commercial grades. In opposition to this “rigid” operational strategy, Danieli developed the concept of a “flexible” caster with a remarkably wider range of applications.
Since the first applications of this concept Danieli has defined its own approach to solve these limitations successfully, as is widely recognized thanks to the achievements of our reference plants currently in operation.
The main areas of concern were analyzed and solved as follows:

2.1 Roll Diagram Concept

Since the beginning, Danieli promoted its vertical curved design as opposed to a vertical caster design.
The advantage of this design is that it combines the internal cleanliness of the vertical portion with a remarkably lower height of casting platform. This ensures less potential bulging, which benefits internal slab quality.
Moreover, this caster allows the addition of future segments in the future, thus increasing the metallurgical length with no limitations.

2.2. Fluid Dynamics in the Mold

Danieli developed the concept of its long funnel mold that, taking into account the well-known benefits of the funnel design, brilliantly solved the problems of slab surface quality, by an optimized distribution of the geometry along the slab where the shape of the early solidified slab is flattened.
This is the defining feature of the Danieli patented H2 mold (High speed, High quality) and is the key factor in the casting of sensitive grades, including truly peritectic grades.
In the picture 1 and 2 the Danieli H2 long funnel design mold concept.
The increased volume of the liquid steel in the mold as well as the multiple port patented SEN ensures that the correct flow pattern is obtained in the mold, without the risk of meniscus instability, non-uniform temperature distribution and “wash-away effect “ on the just-solidified steel skin.

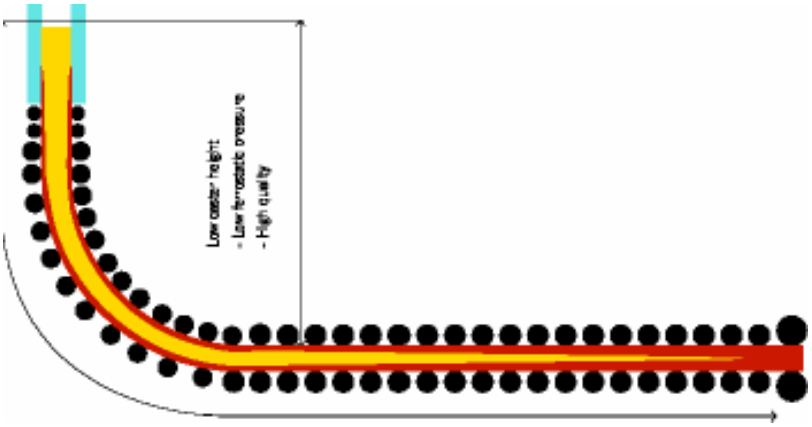

Figure 1. Long containment length for high speed and productivity.

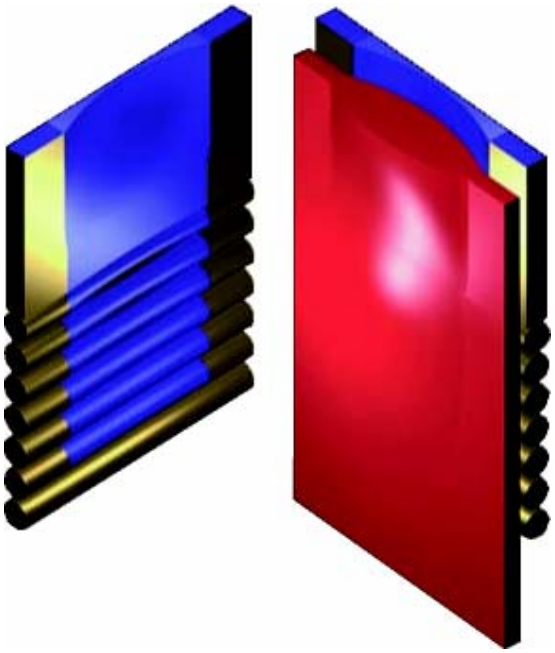

Figure 2. Danieli H2 long funnel design mold concept.

Proof of the efficiency of the combination of the long funnel mold and patented multiport SEN lies in the fact that even if almost all the Danieli thin slab casters currently in operation are designed to accommodate an electromagnetic stirrer, none of the Danieli casters needed such an expensive device to control the liquid steel pattern flow, as it was already controlled by the caster itself.

2.3 Secondary Cooling

All Danieli Thin slab casters are equipped with air-mist cooling for fine tuning of the temperature profile, instead of the more traditional water-cooling only strategies.
In the picture 3 Danieli segments with split- roll design and air-mist secondary cooling.

2.4 Soft Reduction Process

The application of Dynamic soft reduction also is a key factor. Danieli's way of application considers the following key principles:

2.4.1. Soft reduction must be applied according to the principles of a dynamic process, hence in a variable position along the strand where, and only where, the optimal metallurgical conditions are found (in terms of correct ratio between solid and liquid fraction) (Figure 4).
These conditions are not set but migrate along the length of the containment area.

Figure 3. Danieli segments with split-roll design and air- mist secondary cooling.

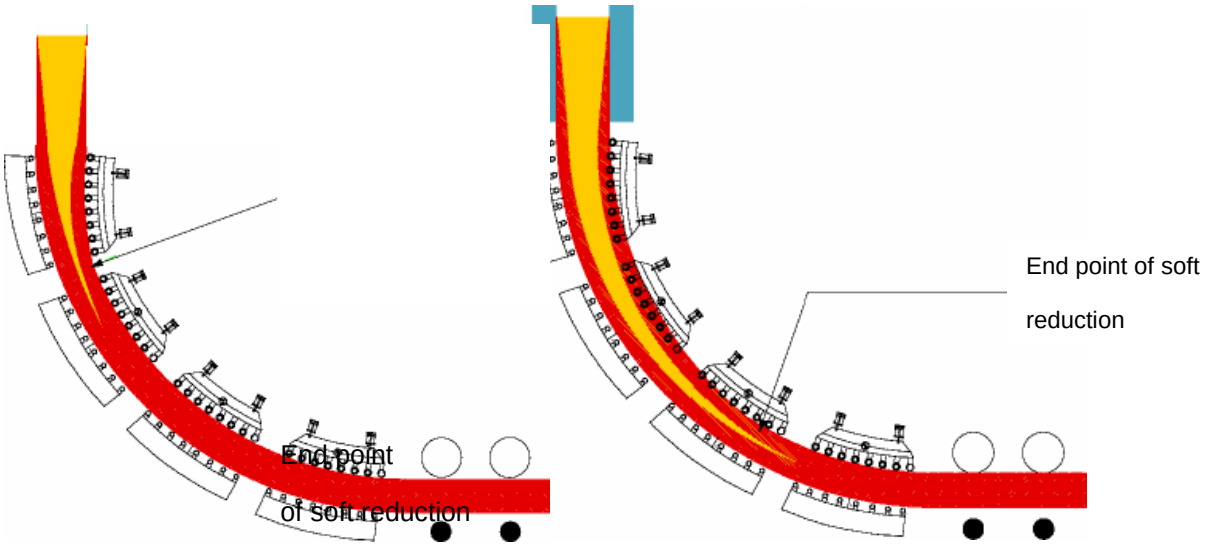

Figure 4. Different Soft Reduction patterns according to low and high casting speed.

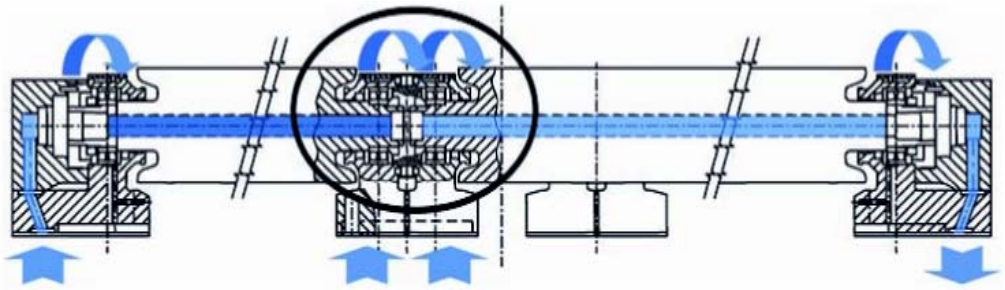

Figure 5. Roll bearing supports and caster rolls internally water cooled.

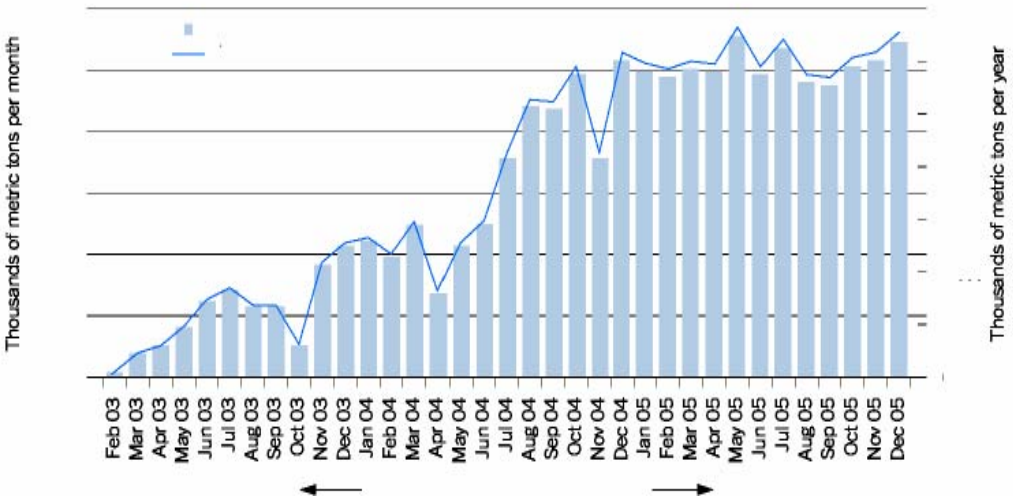

Figure 6. Tangshan Iron and Steel Co.Thin Slab Caster production ramp-up.

According to the specific casting conditions considered (i.e. casting speed, superheat, secondary cooling flows ...).
As a consequence, the position of the Soft Reduction Must be variable.
Only in this way can we obtain the well known benefits to internal quality: if the process is not applied in the correct position, the results could be either null or could worsen the internal quality of the slab.

2.4.2. The application of slab thickness control from mold to caster exit imposed by soft reduction is not only limited to the few millimeters required by the soft reduction itself, but is also used to significantly increase slab thickness in the mold area, hence creating casting conditions similar to the ones experienced in traditional plants. Because of this concept, a typical Danieli solution is to adopt about 20 mm of soft reduction.
A visible result is the dramatic reduction in breakout rates - the same as those of a traditional caster - even if the casting speeds are remarkably higher.
These concepts, together with more specific maintenance-related issues such as the internal cooling of caster rolls to ensure proper cooling of rolls and bearings under all load conditions, in recent years has allowed the users of Danieli casters to achieve world records in terms of diversification of steel grades produced and productivity levels.
In the Figure 5: roll bearing supports and caster rolls internally water-cooled.

3 THE "STATE-OF-THE-ART"

To date, Tangshan Iron and Steel in P.R. China is the first and only plant in the world to have positively demonstrated that it is possible to exceed the threshold productivity of 3 million tons per year of hot-rolled coils, with two Danieli thin casting strands in operation since 2005. See Figure 6.
As for quality, since the first industrial application of its fTSC caster in 1997, Danieli's Essar Algoma plant (Canada), consistently proved that it was possible
to cast sensitive grades, such as peritectic, which, as a rule continue to be excluded from the product mix of "first generation" thin slab casters.
This process of targeting more demanding grades continued over the years and at present we can cover practically all steel grades for flat product applications. This includes API X60 and X70 used for Arctic pipe applications, which were first produced successfully in the Danieli Ezz Flat Steel plant in 2005; and the high-silicon grades (Si content exceeding 3.2 %) in the Danieli plant at Benxi Iron and Steel in China, since 2005. Outstanding new standards for quality were reached in 2008 thanks to the start-up of the OMK plant in Russia, the first thin slab casting plant in the world specifically conceived for the production of API grades for Arctic applications (representing more than 50% of the product mix of the plant).
At present more than 20 steel grades for pipe applications are already in production.

4 THE "NEXT BEST THING"

In order to expand the boundaries of the application of the thin slab process, Danieli is further developing its design concepts, and thanks to the cooperation of our customers, has set the ambitious target of proposing new solutions. For these, the target rate of production is already about 2 million tons per year per strand, characterized by the latest pioneering experiences at Ultra High Casting speeds, approaching normal cruising speeds of 8 meters per minute, as in the new revolutionary thin slab caster at POSCO, recently commissioned in May 2009.
Overall layout solutions previously adopted in thin slab casters, as well as the design of every single component of the machine, needs to be re-considered to determine whether or not it is capable of withstanding a productivity increase of approximately 50% over the combined rates of previous generations of casters.
The POSCO CEM Project
On September 20, 2007, POSCO and Danieli reached an agreement to jointly develop a new generation of plant for the production of flat products, to be installed at POSCO's Gwangyang site, in Korea.
As is common knowledge, in 1996 POSCO installed an ISP minimill in Gwangyang with thin slab casting and rolling.

After many years of trials and development, POSCO finally decided to completely revamp the existing casting and rolling facilities in order both to overcome the limitations of the original plant and to develop a revolutionary new technology in flat product production.

In order to reach this ambitious goal, POSCO selected Danieli as its technology partner because of its recognized experience in designing high-speed thin slab casters and hot strip mill facilities, as well as in process automation.
The original plant was composed of two single-strand thin slab casters originally supplied by SMS Demag.

Due to the process limitations of the original plant, in terms of both insufficient quality and limited plant productivity, POSCO was not satisfied with the results and decided to completely change the plant layout.

Following the revamp, the target of the new plant is to produce 1.8 Mt/y of quality coils in a single-strand caster, concentrating all the production in narrow and medium widths (approx. 1.3 meters max.).

In place of the two original thin slab casters, a single “new generation high-speed Danieli thin slab caster” was installed, designed to cast 80-mm-thick slabs at speeds of up to 8 meters per min.

5 ULTRA HIGH-SPEED CASTING CHALLENGES

The new Danieli Ultra High-Speed Thin Slab Caster at POSCO in Figure 7.
The key points for success are the enhanced solutions considered to prevent the most harmful phenomena occurring at high speed such as:

a) Unsteady bulging
b) Mold level fluctuation
c) insufficient efficiency in spray cooling
d) Higher wearing of consumable components - Tighter automation control needed for the faster production process
e) Advanced caster layout solutions for efficient maintenance.

In order to deal with these new challenges, which are not simply an enhancement of previous performances but a real “quantum leap” in technology, a comprehensive review of the entire design was carried out.
Below are the areas of concern and the new solutions that were adopted:

5.1 Issue: Mastering Liquid Steel Fluid Dynamics in the Mold

The following solutions are considered:

a) Advanced H2 “high-quality high-speed” Danieli mould, with patented long funnel concept. The Danieli funnel mold is proven to be the only one capable of guaranteeing the production and quality required for HSLA steel grades. Now, a new long funnel mold geometry has been specially designed for high casting speed;
b) New design SEN for high-speed casting. It is worth pointing out that the mold and SEN are designed to handle extremely high flow for rates liquid steel, approaching 7 tons per minute; Figure 7.
c) New concept of the Mold Breakout Prevention System (MBPS) with advanced features for high casting speed. New algorithms were developed for faster detection of the possible abnormalities that could lead to breakouts and for complete thermal mapping. In addition to the complete thermal mapping of the mold, the system also incorporates monitoring of heat flux extraction;
d) Advanced mold level control system in order to master and stabilize liquid steel level in the mold;

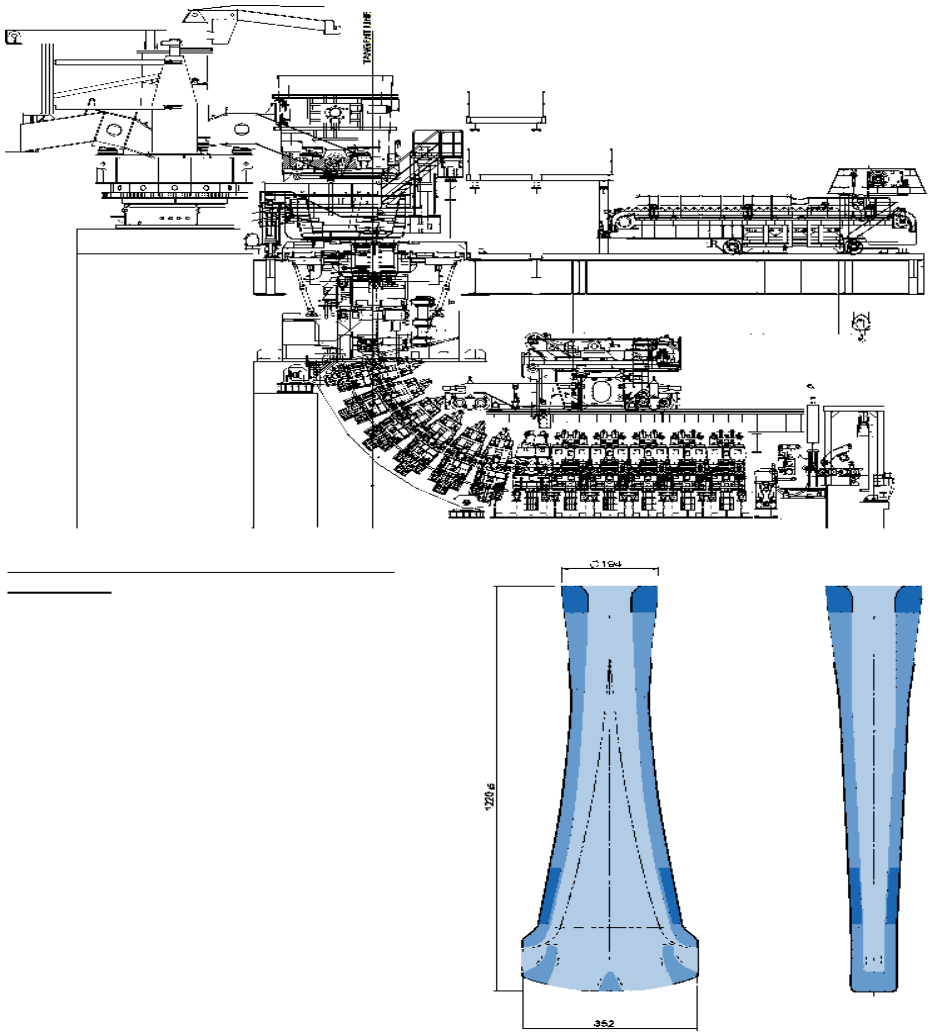

Figure 7. The new Danieli Ultra high-speed thin slab caster at POSCO and Submerged entry nozzle Danieli

Based on LQG control principles instead of traditional PID systems, these algorithms are specifically conceived to identify recurring phenomena, such as dynamic bulging instability and properly counteract them. On line mold level Fourier analyzer (Real time FFT) functions are carried out for these purposes.
Instead of traditional eddy current sensors that “read” a limited area of the meniscus, a dedicated scanning device is used to identify the disturbances (steady and unstable Weaving) that could be generated on the meniscus surface.
Moreover, dedicated sensors were installed along the length of the caster to monitor the slab solidification process closely and to populate the caster technology database, in order to properly investigate the occurrence of dynamic bulging.

5.2 Issue: Monitoring Oscillation Process at High Casting Frequencies and Ensuring Slab Surface Quality

The innovative INMO design for the hydraulic oscillator is applied.
The INMO technology is used for the very first time in Thin Slab Casting.
The defining feature of this patented technology, originally developed by Danieli and POSCO for tight guidance of vertical oscillation in thick slab casters, is the stability of

the oscillation parameters, as well as the absence of parasite movements that could be detrimental at the highest frequencies and with asymmetric-sinusoidal curves.
After benchmarking by POSCO to compare the accuracy during the oscillation motion of the INMO oscillator installed on the CAM caster and any other slab casting machine in operation within the POSCO group (including all the units supplied by all major European and Japanese suppliers) the IMNO mold showed the best accuracy for both vertical movement and lateral displacement.

5.3 Issue: Minimizing Internal Inclusions and Mastering Slab Stress/Strain

While maintaining the defining Danieli vertical curved design concept, the vertical length was increased by about 65% to ensure flotation of inclusions even at ultra high casting speeds. The caster main radius also was increased.
New concept for multiple split-roll diagram with specific features to avoid dynamic bulging, and gradually variable diameter on the vertical portion and bow.
In order to distribute the withdrawal force evenly, driven rolls were placed along the segments, starting from segment 1, while in traditional solutions driven rolls are only used at caster exit.

5.4 Secondary Cooling

New generation, high-efficiency air-mist secondary cooling, including new secondary cooling design and innovative cooling strategies for edge temperature control.
High-efficiency spray nozzles with high wet footprint to cope with hard cooling practice on the top part of the caster, due to the amount of heat to be extracted.
Edge temperature control is very critical for high-speed casting and possible direct rolling. Spray width control with proportional valves is used to adjust slab surface cooling, which differs in intensity from the centre to the corner of the slab according to metallurgical requirements, to prevent corner cracking.

6 RESULTS AND DISCUSSION

Back in January 2010 (only six months from start of industrial operation) the plant had already reached all the expected quality and casting speed performances, establishing a casting speed of 7 meters per minute during sequence operations.
The quality of the final coil is in full compliance with POSCO's market requirements and, considering the reduced transformation costs, POSCO already shifted a significant amount of their "oiled and pickled" production from their conventional mills to the new CEM plant.
The order that POSCO placed with Danieli for the new generation thin slab caster reaffirms Danieli's already established technological leadership in this field, proven by the outstanding quality and productivity performances of our reference plants.
The plant, which is currently being commissioned, has already confirmed the requirement of exceeding, right from the first heat, the maximum casting speed ever reached with the old casters.
Right from the first heats, the plant's production and quality performances were in line with expectations: casting speeds exceeding 7 m/min have already been achieved, as shown in the picture 16.
The results in terms of slab quality are satisfactory since both the internal and surface quality of the slab is top-notch for the steel grades that have been cast up to

now (low carbon with 0.035 % C, medium carbon with 0.170 % C), better than the best achievement for similar plants.

Table 1. Some results

casting speed	7 m / min										
Slab thickness	110 mm										
Operating time	7200 hour / year										
Slab width mm	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800
t/min	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6	10.2	10.8
t/h	288	324	360	396	432	468	505	541	577	613	649
Mt/y	2.08	2.34	2.59	2.85	3.11	3.37	3.63	3.89	4.15	4.41	4.67

7 CONCLUSIONS

1. Casting an 80 mm thick slab at 7.0 m/min is the state-of-the art.
2. Casting speed of 7.0 m/min speed also can be used with a 110 mm thick slab.
3. No special requirements are necessary thanks to the existing technology.
4. The only main modification is the extension of the containment length.
5. Depending on slab width, productivity can be in the range of 300-600 t/h.