Thin slab casting and rolling

Danieli thin slab casting and rolling plants operating in China are demonstrating both high output capability of 3Mtpa, and the ability to produce non-commercial steels such as high silicon, peritectic and microalled grades. Currently a 1.2Mtpa plant is being built in Russia, the first such plant specifically designed to produce pipe grades for arctic application.

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In March 2005 the Russian OMK Group and Danieli signed the order for the supply of the new Casting Rolling Complex (CRC) to be constructed in Vyksa, Nizhny Novgorod Region. The plant will produce 1.2 Mtpy of hot rolled coils (HRC) for pipe production, ranging from 21 to 530mm diameter in the OMK Group plants in Vyksa and Almetyevsk. The plant will be the first thin slab casting and rolling plant installed in Russia and the first in the world specifically conceived for the production of API grades for arctic application using the thin slab process route.

The choice of Danieli as technological suppliers was based on the optimum technological level of the equipment proposed and on the successful production of X70 grades in the Danieli reference plant at Ezz, Egypt. This paper describes the main features of the plant layout and the specific characteristics of the caster in order to cope with production needs.

The paper also describes the latest achivements of the two Danieli Thin Slab Casting and Rolling plants in full operation in China - at the Tanshan Iron & Steel Group Co Ltd (which holds the world production record for production of more than 3Mtpy of coils produced in 2005), and Benxi Iron & Steel Group Co Ltd., the first plant in China to cast and roll silicon steels using the thin slab process route.

THE OMK CASTING ROLLING COMPLEX

The plant includes:

- 174 t/hr AC EAF
- Twin ladle LF
- Twin tank VD
- Single strand flexible Thin Slab Caster (fTSC)
- Tunnel type heating and soaking roller furnace
- Two stand rougher with attached vertical edger
- Intermediate cooling and heating transfer table
- Five finishing stands with vertical edger
- Laminar cooling facilities
- Downcoiler and coil handling facilities
- Electric and automation equipment up to level 3

As well as the production of light gauges the CRC will significantly extend the range of today's mini mill products to include high added value steels such as API 5L, X65 and X70 grades to be used at temperatures down to -60°C and in aggressive atmospheres. A future capability down to 1mm strip thickness is foreseen with the installation of a 6th mill stand. *Figure 1* shows the plant layout.

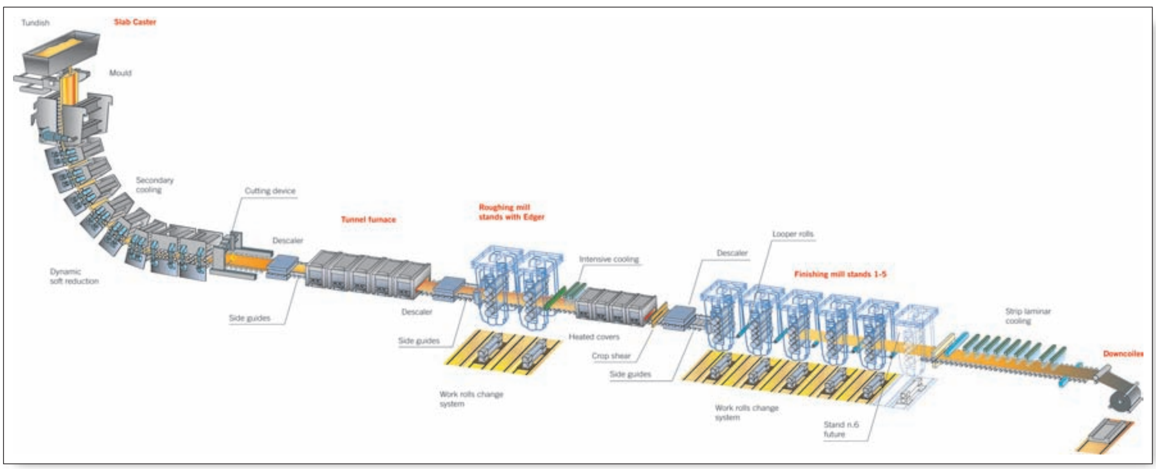

Fig.1 OMK fTSCR plant lay out

CASTING

Special attention has been paid to caster design features such as casting speeds, slab thickness, dynamic soft reduction strategy and secondary cooling design in order to cope with the demanding product mix.

The main metallurgical challenges can be summarised as follows:

- Good surface quality is essential because API grades are crack sensitive
- In the thin slab casting process no slab conditioning is allowed. This implies that slab surface cracks or depressions must be avoided in the casting practice otherwise slabs will be downgraded
- No trace of oscillation marks must remain on the surface of the rolled product
- Internal quality must be at the highest level
- Grain size must be minimised for control of toughness
- Centreline segregation must be minimum

The Danieli-patented H2 mould and Dynamic Soft Reduction process are the optimum tools to overcome these quality issues.

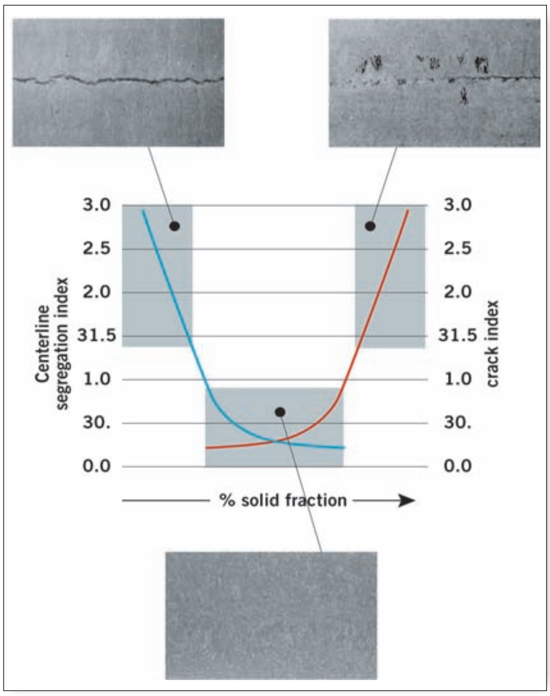

Fig.2 **Relation between slab quality and position of soft reduction application along the strand**

Slab thickness selection The vertical curved caster is designed to produce slabs with a variable final thickness of 70 to 90mm after soft reduction, starting from 90 to 110mm at the mould exit. Slab thickness can be chosen according steel grade and optimum rolling schedule. Although the caster is designed to cast at speeds up to 6m/min, a 90mm final thickness enables a design output of 1.2Mtpa to be reached without the necessity to cast at the extremely high casting speeds required by thinner slabs. Casting at a slightly lower speed reduces the risk of surface cracks and depressions, which are unacceptable for API and peritectic grades.

With reduced casting speeds the heat transfer in the mould can also be easily kept below critical values.

An API grade pipe must not have residual traces of oscillation marks on the surface as even these small defects can initiate cracking at low temperature and in the presence of hydrogen. In traditional casting the oscillation marks are eliminated during rolling, thanks to the high reduction ratio. With a 90mm thick slab it is possible to eliminate oscillation marks during rolling, even for the thickest strip because sufficient reduction is available in the mill. Moreover, hydraulic oscillation allows the best possible control of oscillating process; minimising oscillation marks at source. Provision for a second strand has been made for future expansion.

The Danieli H2 mould The mould section at meniscus level of the H2 mould is significatelly larger than with other designs. This provides high meniscus stability and optimised fluid dynamics, hence it overcomes the risks of transverse and longitudinal cracks. Also, as the distance between SEN and copper plate is greater than other designs the risk of centreline longitudinal cracks is reduced. Mould lubrication is also a key factor in ensuring quality. The wide surface meniscus available with the H2 mould allows use of high basicity, low melting point powder that helps to reduce the heat transfer to less than 2500 kW/m^2. Below this level it is possible to cast microalloyed steel grades and peritectic steel with no cracking.

Dynamic soft reduction Segregation and axial porosity must be completely eliminated as any cavity or defects at the centreline can lead to cracking and reduced hydrogen induced cracking(HIC) resistance. The application of dynamic soft reduction reduces segregation and porosity in any casting condition and any residual porosity can be easily eliminated thanks to the high reduction ratio between slab and strip.

Soft reduction is an effective method of minimising segregation in slabs. However, in order to be effective in all casting conditions, the soft reduction process parameters (position of thickness reduction, total ▷

reduction and reduction rate) must be adapted and optimised to the variable casting conditions. For these reasons the process must be dynamically controlled. The Danieli Dynamic Soft Reduction process, based on the Liquid Pool Control System, can optimise the internal quality of the slab throughout the whole casting speed range.

With this mathematical model-based system, soft reduction can always be applied at the position along the strand where the ratio between liquid and solid fraction is optimum. Only in this way can the segregation and the axial porosity be controlled. If soft reduction is applied too early, no improvement in segregation is obtained. If it is applied too late, internal cracks can be generated.

The relation between slab quality and position of soft reduction application along the strand is shown in *figure 2*. Dynamic soft reduction also has a beneficial effect on the grain structure of the slab, which is passed on to the strip, as illustrated schematically in *figure 3*.

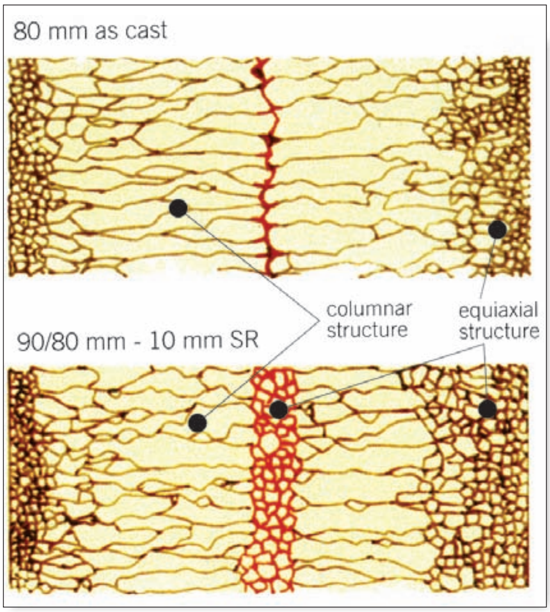

Fig.3 Improvement of slab internal quality thanks to application of Dynamic Soft Reduction.

In-line high pressure descaler Integrated into the withdrawal unit of the caster, this device, consists of a rotary descaler that removes scale using high pressure, low flow rate sprays, before the slab enters the tunnel furnace. Eight nozzles are installed on the rotating arms (4 top and 4 bottom nozzles) which is about 80% fewer than a conventional descaler such as the ones installed in front of stands R1 and F1. Through this design it is possible to achieve a high descaling efficiency with low temperature losses (about 5°C). The slab is then scale-free and then enters the tunnel furnace. This avoids any damage to the furnace rollers and provides the possibility of controlling scale growth and composition in the tunnel furnace.

Tunnel furnace The rolling mill is directly connected with the CCM by means of a roller type tunnel furnace, forming a unit. The slab enters the furnace at a temperature of 900 - 1050°C depending on the speed, width and steel grade.The furnace is 200m long and has the capacity to hold up to five slabs having a maximum length of 37.5m. The resulting buffer capacity makes it possible to continue casting operations even during mill stoppages due to work roll changes or automation default without affecting the CCM operating conditions.

Rolling mill The main features are as follows:
- Header descaler No. 2: A high pressure descaler (conventional header type) is located at the tunnel furnace exit and is designed to keep the slab surface as clean as possible and to remove the scale formed during slab heating
- Vertical edger E1: A vertical edger is located at the inlet of the roughing stand group and is designed to reduce the slab width to within the set tolerances and to improve edge quality
- Two 4-high roughing stands, R1 and R2, followed by the interstand cooling unit, intermediate runout table with units for intermediate cooling and heating of rolled material
- Flying shear for 45mm transfer bar
- Header descaler No. 3
- Vertical edger E2
- Continuous finishing group comprising five 4-high stands, F1 to F5 (F6 for future)
- Runout table with unit for laminar cooling of the strip
- One hydraulic downcoiler (second downcoiler for future)
- Coil handling system, including circumferential and radial strapping machine, marking machine, weighing system and off-line coil inspection
- Storage area for the hot rolled products.

The rolling mill work roll body length is 1950mm for R1 and R2 and 2250mm for F1 to F5.

All the equipment and its arrangement have been designed to meet the required annual production of the wide range of steel grades:
- Since 30% of the mix is perlitic steel a 90mm thickness slab has been chosen to allow optimum casting conditions

- For a 90mm slab, a two roughing stand solution has been adopted in order to meet productivity requirements and give the finishing stand group the required thickness of transfer bar
- The interstand cooling device installed between roughing stands R1 and R2 provides the required finishing rolling temperature in the roughing stand group. Pyrometers installed on the entry side of the roughing stand R1 and exit side of roughing stand R2 provide the input of data to the control system for interstand cooling.
- Two temperature control devices are provided between the roughing and the finishing stand group.
  - **First**, an intermediate strip cooling system is located close to roughing stand R2 exit in order to achieve the best transfer bar cooling results. This is dedicated to API grades (especially X70 arctic grade) and reduces the temperature at the beginning of deformation in the finishing stand group to about 830-860°C. The intermediate cooling device is about 18m long and is a laminar based system, designed to meet the rolling loads of roughing stand R2 and the maximum heat removal in the interface water/transfer bar.

In this way, quenched areas on transfer bar surface and excessive thermal stresses are avoided. For X70 a maximum cooling rate of 8-10°C/s is required for an incoming transfer bar average speed of 1.0 - 1.5 m/s. A pyrometer at the exit side of the intermediate cooling section provides feedback for optimum regulation of the cooling system.

- **Second**, a 100m long natural gas heated transfer table (HTT) located after intermediate cooling is used to keep the transfer bar temperature constant and minimise the temperature difference between head and tail ends of the bar prior to rolling in the finishing group.

Although the distance between roughing and finishing mills increases considerably with these facilities, this does increase the overall flexibility of the plant because the roughing and finishing stand groups do not roll the same transfer bar at the same time. This means that it is possible to roll at R1 and R2 with a higher speed and without using a hydrostatic unit for oil film bearings. Also faster rolling here prevents local overheating of the work rolls thus reducing their wear. Finally, if a cobble occurs in finishing group the transfer bar can be removed from the line of the heated transfer table without stopping continuous casting.

- The five finishing stands have adequate rolling force and rolling torque to maximise productivity and flexibility. An interstand cooling system produces the required finishing temperature of the strip, followed by laminar cooling at the run out table A set of pyrometers on the entry side and exit side of the finishing stand group checks the material temperature for optimum regulation of the interstand cooling system and consequent regulation of the laminar cooling device at the run-out table.

The chosen equipment for the finishing stands represents the complete Danieli solution to control strip profile and flatness and to enable schedule-free rolling. The proposed system is capable of obtaining top level performance without interference from the rolling mill controls and without any maintenance overload, while considering all the effects which influencing the final dimensional tolerances of the strip as shown in *table 1*.

- At the run-out table, the laminar cooling system provides cooling in the required temperature range needed to achieve metallurgical and mechanical properties and safe winding of thin strip at the down coiler. It consists of 20 main waterwall type headers plus other three similar ones dedicated to the fine tuning of coiling strip temperature.

TANGSHAN IRON & STEEL GROUP CO. LTD.

The first Danieli fTSC Flexible Thin Slab Caster in China started operating at the beginning of October 2002,

Variable	Method of control
Strip thickness control	Long stroke hydraulic automatic thickness regulation (AGC) in all stands
Strip crown and flatness control	Work roll heavy bending in all stands (both positive and negative bending)
Roll bite lubrication system	To lubricate the work roll bite on stands F1, F2 and F3 to reduce the friction coefficient and therefore to reduce separating force and limit roll wear
Work roll wear control	Work roll axial shifting in all stands
Work roll thermal crown control	RTC system on stands F1 to F4 and selective cooling on stand F5

Table 1 Strip variables and control system

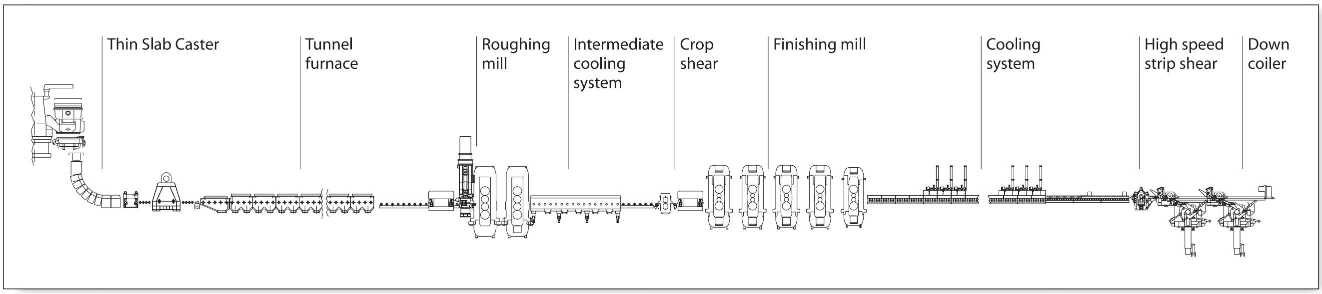

Fig.4 **Layout of the Tangshan plant**

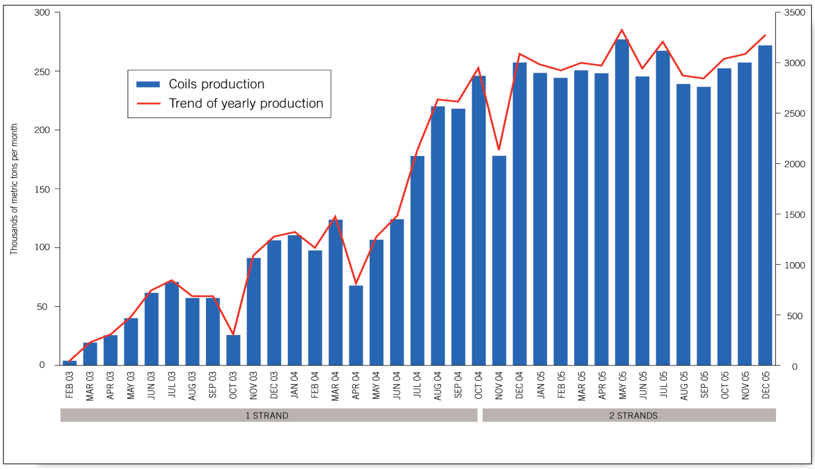

Fig.5 **Tangshan production ramp up and production records**

two months ahead of the contract schedule. It is part of the installation of the UTSP Ultra thin strip production plant at the Tangshan Iron and Steel Group. *Figure 4* shows the layout of the plant.

This was the first of the two casting lines foreseen in the project. The early startup of the caster ensured a three month tuning period before the hot strip rolling mill started. Thanks to the high plant reliability and technological quality it was possible to increase the final slab thickness from 70mm to 85 mm, ramping up to 61,000 t of rolled coils by June 2003 (5 months from start), 106,000 t of rolled coils by December 2003 and 123,000 t by March 2003.

In June 2004 the second thin slab caster came into operation using an 85mm slab thickness - increasing production to 220,000 t by August 2004 and setting a world record in May 2005 with 277,000 t of rolled coils. Thanks to these records, the plant reached a yearly production in excess of 3mt, a world first, Output is shown in *figure 5*. This level of output continued in 2006, confirming plant and process reliability.

Wt%	C	Si	Mn	P	S	Al	Sb
Ladle wt.	0.0050	0.64	0.53	0.018	0.007	0.27	0.022
100t	0.0043	0.63	0.55	0.019	0.008	0.25	0.023
70t	0.0050	0.61	0.56	0.019	0.008	0.23	0.023
40t	0.0043	0.61	0.58	0.019	0.008	0.24	0.023

Table 2 **Steel analysis of first Si steel trial**

BENXI IRON & STEEL GROUP CO LTD.

Benxi Iron & Steel Group Co., P.R.China awarded Danieli

Wt % or (ppm)	C	Si	Mn	P	S	Al sol	Al tot	N (ppm)	O (ppm)
Tundish 1 (100 t in ladle)	0.0070	1.70	0.17	0.032	0.007	0.23		26	45
Tundish 2 (70 t in ladle)	0.0072	1.70	0.17	0.033	0.0065	0.244	0.249		
Tundish 3 (40 t in ladle)	0.0073	1.70	0.17	0.032	0.007	0.22	0.23		
Tundish 3 (ladle finished)	0.0065	1.69	0.17	0.032	0.007	0.244		13	36

Table 3 **Steel analysis of second Si steel trial**

the order for its new 2.8 Mtpy Thin Slab casting plant in 2003. The two fTSC casting lines, installed in two phases, were successfully put into operation on November 2004 (after only 20 months from contract signing), and in June 2005 respectively.

The plant embodies innovative Danieli design concepts allowing expansion of the original application of thin slab technology, confined to mainly commercial grades, to more sophisticated and demanding steels (such as peritectic, stainless and silicon steels) and, at the same time, to significantly increase caster output. Thanks to these features, Benxi has been the first plant in China to cast Si steels using a thin slab process route.

Having now fulfilled this goal, the full advantages of low transformation costs of Thin Slab Casting & Rolling can be applied to a wider range of steels and markets.

Casting of Si steel The results of the cast trials of Si steels are shown in tables 2, 3 and 4. On June 14th, 2005 the first heat of Si Steel, ZJ214 grade, was successfully cast.

This first trial was performed at a casting speed of 3.2m/min with a hot thickness of 72mm. 2, 2.3 2.5 and 3mm thick coils were produced by the in-line rolling mill; the customer has reported no surface defects.

On July 6th 2005, the first trials of casting high silicon 1.7% grade 50BW600 were successfully performed *(see Table 3)*.

During this test, slabs of 70mm were produced starting from 90 mm thickness in the mould (20mm of dynamic soft reduction). A casting speed of 3.7m/min. was consistently maintained without any perturbation of the casting process. The customer has reported no surface defects on the coils produced by the mill.

On 2nd December 2005 successful production of a 3% Si, 50BW3300 grade was successfully carried out, achieving the guaranteed casting speed of 4.1m/min. The liquid steel analysis is shown in *table 4.*

Other qualifying grades succesfully tested Several other demanding grades were cast during the commissioning period which are representative of the

Fig.6 **Peritectic grade slab cast in Benxi plant**

Benxi envisaged product mix. They included:

- Ultra Low carbon grades (St 16, cast on June 28 2005)
- Micro alloyed, low carbon (X46 and X52, cast on July 5 2005)
- Micro alloyed, medium carbon (J55, cast on July 7 2005)
- High carbon (C 45, cast on July 8 2005)
- Microalloyed (Corten grades) with high phosphorus and high copper

With specific reference to peritectic grades which are difficult to cast with good suface quality *figure 6* illustrates a sample of grade SS400 P whose surface is clearly defect free. This slab was produced during a campaign on June 29th 2005 at a casting speed of 3.4m/min.

CONCLUSIONS

The OMK order - awarded to Danieli after positive proof of the capability of Danieli equipment to successfully produce API grades in agreement with the tough specifications imposed by arctic applications - demonstrated the possibility to further extend the range of steels, and hence cost benefits, that can be produced with a thin slab process route.

The performances demonstrated by the Tangshan and Benxi plants which are in full operation, demonstrate the outstanding level of reliability of Danieli solutions, leading to world production records and product quality achievements in high added value markets.

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Heat		Al	Si	S
1 No. 38204	LF	0.39	3.19	0.006
	Tundish	0.37	3.12	0.005

Table 4 **3% Si steel composition**

Wt% or (ppm)	C	Si	Mn	P	S	Al sol	Al tot	Ca (ppm)
Ladle furnace	0.124	0.09	0.48	0.009	0.006	0.025	0.027	0.07
Tundish 1, 100 t in ladle	0.141	0.10	0.47	0.010	0.007	0.019	0.021	0.0016

Table 5 **SS400P Steel chemical analysis**