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FLEXIBLE PLANT CONCEPTS AND TECHNOLOGIES FOR HOT STRIP AND PLATE PRODUCTION[1]

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Abstract

In the light of a changing world economy, utmost efforts are being made to improve the competitiveness of plants. Production cost and product quality are of highest importance for steel producers in these times and flexibility is another key to success as it enables quick adaptation to customers' needs and to changing market requirements. To meet these requirements, SMS Siemag offers flexible plant concepts that integrate different hot strip production lines or production lines for plate and strip in one single plant and thus offer a great flexibility with respect to the product spectrum. Furthermore, the paper introduces technologies that are increasing a plant's flexibility, production efficiency and product quality such as the slab sizing press, microstructure modelling, the UNI plus coiler, CVC® plus for hot strip and plate mills or the combined spray and laminar cooling system.
Keywords: Hot strip mill; Plate mill; CSP® plant; Plant concepts.

CONCEITOS E TECNOLOGIAS DE PLANTA FLEXÍVEL PARA A PRODUÇÃO DE TIRAS E CHAPAS LAMINADAS A QUENTE

Resumo

Em face de uma economia mundial em transformação, grandes esforços são feitos para melhorar a competitividade das plantas. Nestes tempos, o custo de produção e a qualidade do produto são fatores da mais alta importância para os produtores de aço. A flexibilidade é outro requisito importante, uma vez que possibilita uma rápida adaptação às necessidades dos clientes e aos requisitos de um mercado em transformação. Para cumprir estes requisitos a SMS Siemag oferece conceitos de planta flexíveis que combinam diferentes linhas de produção de tiras laminadas a quente ou linhas de produção de tiras e de placas numa única planta, proporcionando, assim, uma grande flexibilidade com relação ao leque de produtos. Além disso, o trabalho introduz tecnologias que estão aumentando a flexibilidade da planta, a eficiência da produção e a qualidade dos produtos, tais como a prensa de calibrar placas, a modelagem de microestruturas, a bobinadeira UNI plus, o sistema CVC® plus para laminadores de tiras e placas a quente ou o sistema combinado de resfriamento laminar com spray.
Palavras-chave: Laminador de tiras a quente; Laminador de chapas; Planta CSP®P Conceitos de planta.

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1 INTRODUCTION

In the light of a changing world economy, utmost efforts are being made to improve the competitiveness of plants. Production cost and product quality are of highest importance for steel producers in these times and flexibility is another key to success as it enables quick adaptation to customers' needs and to changing market conditions.
Market requirements for hot rolled products have increased considerably during the last years. One characteristic is the extension of the product spectrum. Today, in addition to customary carbon steels, steel grades with tailor-made mechanical properties are demanded. Exemplary fields of application of these steel grades are the automotive industry or the manufacturing of pipelines. At the same time, steel users demand hot rolled flat products with close geometrical tolerances and excellent surface quality. Together with the continuous improvement of operational efficiency, the environmental compatibility of production is also becoming more and more important.
SMS Siemag offers technologies and plant concepts that enable to fulfil these market demands. The paper presents these new technologies and concepts for the three main types of hot rolling mills, starting with the conventional hot strip mill, followed by the CSP® plant and plate mills.

2 HOT STRIP MILLS

2.1 Plant Concepts

The choice of the plant concept for the production of hot strip depends mainly on the annual capacity and the product mix. In the field of conventional hot strip mills, SMS Siemag established two mill concepts: X-Roll® high-performance hot strip mills with a production of up to 5.5 m t/y and X-Roll® compact hot strip mills with an annual capacity of up to 4.0 m t/y. Since 2000, SMS Siemag has received orders for 12 new conventional hot strip mills, thereof seven high-performance and five compact mills. Both mill types are universal metallurgical tools and are characterized by a very broad product spectrum from low carbon steels to high-strength pipe grades including micro-alloyed and stainless steels in widths up to 2,150 mm and thicknesses between 1.2 mm and 25.4 mm.
With respect to the plant layout the main differences between the two concepts are the slab sizing press that features the high-performance mill and the mandrel-less coilbox which is part of the compact mill.

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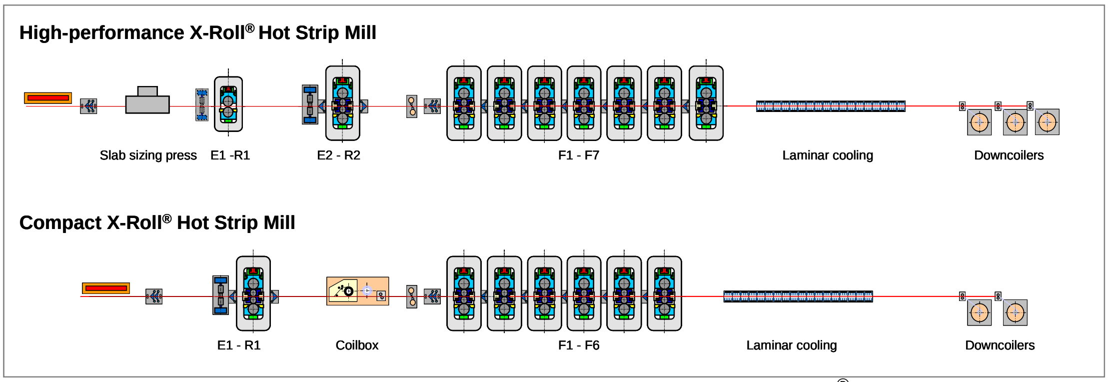

Figure 1: Layout of high-performance and compact X-Roll® Hot Strip Mill.

The slab sizing press in high-performance hot strip mills is installed in front of the first roughing stand. Its main benefit is that it offers more flexibility in mill and caster operation. With a width reduction of up to 350 mm in one pass, the slab width can easily be adapted to the rolling program. This facilitates the increase of the hot and direct charging rate and the number of casting sizes of the continuous caster can be reduced to a few standard widths. Also casting with a width that is considerably higher than the required finished-strip width is possible which boosts the throughput of the continuous caster. In comparison to width reduction in the edger, the slab sizing press achieves a distinctly better through-forming of the slab. Flatter “dogbones” lead to reduced respreading and greater sizing efficiency (Figure 2).

Figure 2: Functional principle of the slab sizing press.

The mandrel-less coilbox in compact hot strip mills is used to coil the transfer bar after the last pass in the roughing mill, and to uncoil it again for finishing rolling. This process features temperature equalization along the transfer bar length and increases process stability in particular for temperature-sensitive steel grades during rolling (Figure 3). Furthermore it allows for achieving a final gauge of 1.2 mm with six finishing stands. The minimized number of stands and the possibility of shortening the roller table between roughing and finishing mill reduces the total length of the plant.

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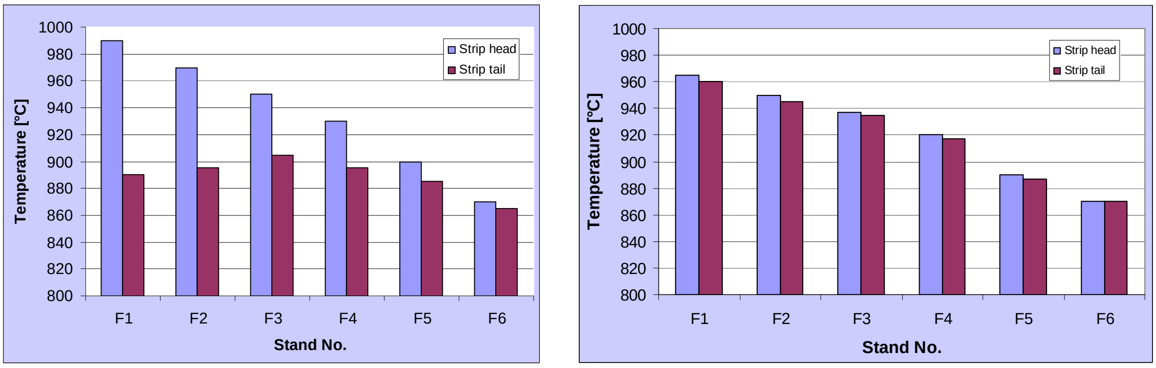

without coilbox　　　　with coilbox

Figure 3: Temperature distribution over transfer bar without and with coilbox.

2.2 Technologies for Hot Strip Mills

2.2.1 Camber-free rolling

Camber-free rolling is a technology that increases the rolling stability and thus contributes to the competitiveness of a plant. Camber in the transfer bar is a main cause for reduced stability of the rolling process in the finishing mill and results from asymmetric heating of slabs or thickness wedges in the slab. The formation of camber is largely avoided by the combination of strong and position controlled side guides and the automated Roll Alignment Control (RAC). The RAC keeps the roll gap perfectly in parallel and thereby, in interaction with the side guides, enforces a mass flow in the stock crosswise to the direction of rolling. In this way, wedge formation is minimized and transfer bar camber is prevented widely (Figure 4).

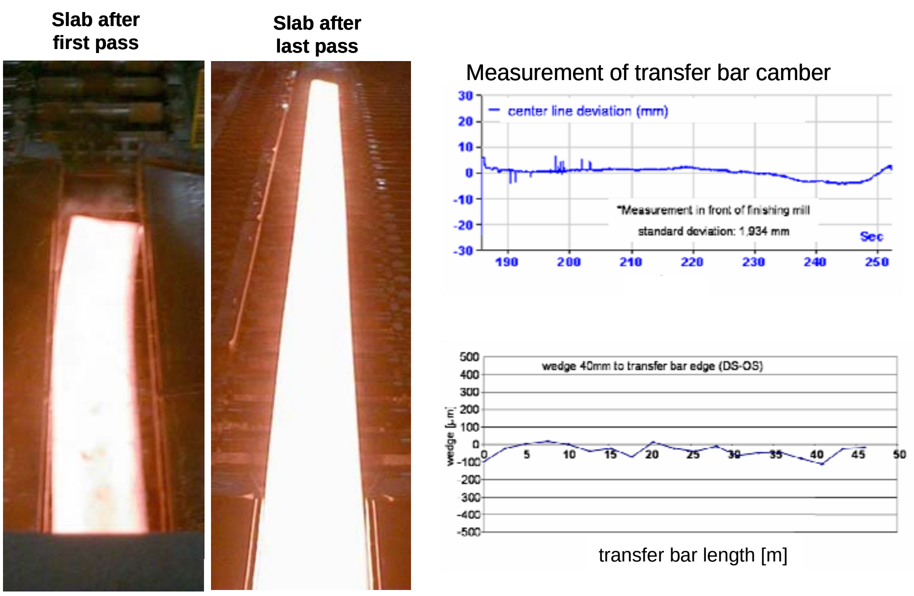

Figure 4: Operating results of camber-free rolling.

2.2.2 Microstructure modeling

The modeling of microstructure characteristics is a feature to increase rolling stability and thus a plant's yield. Furthermore, the microstructure models contribute to the development of new materials. By virtue of the prediction of the hardening and softening behavior, the final grain structure and the metallurgical properties, process

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control can be optimized in a way that the development period for new materials is shortened.

Modern microalloyed materials are often diffcult to roll, because they are characterized by a complex, temperature-dependent recrystallization behavior in longitudinal and cross directions. If the work hardening and softening fronts relocate from the interstand area into the roll gap, the rolling behavior becomes instable, cobbles may be the result. The microstructure model can be used to optimize the reduction distribution and temperature control in such a way that the critical work hardening and softening fronts are always in a well-defined position between the stands.

Figure 5 shows an example of the optimized, stable rolling process of a highly microalloyed, thermomechanically rolled Nb-steel. The critical pass is F2 when a dynamic recrystallization occurs at the tail end while it enters the roll gap. The rolling process remains stable as the reduction is distributed in such a way that the material runs fully recrystallized into stand F3 along the complete strip length. From this stand onwards no more dynamic recrystallization takes place and there is just a small static strain softening in conjunction with a constant increase of the overall strain hardening.

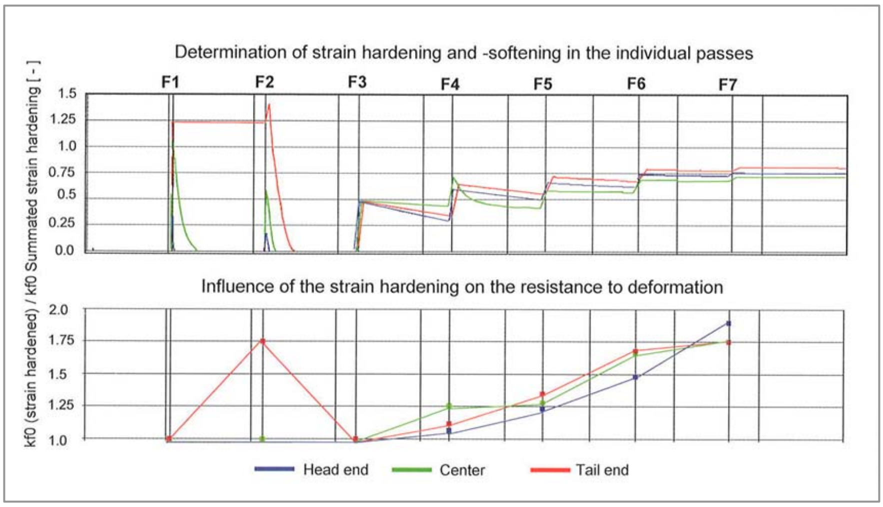

Figure 5: Strain hardening and softening of highly microalloyed Nb-steels, rolled thermomechanically.

2.2.3 CVC® plus for more flexible rolling schedules

CVC® plus is the world-wide proven technology package for the control of profile, contour and flatness. Beyond this, it offers great flexibility in the compilation of rolling schedules.

CVC® plus is based on the combination of the axial shifting of work rolls with the special CVC grinding, the work roll bending and the pertaining technological process model (Profile, Contour and Flatness Control, PCFC). One important recent development in this technology has been the application of the CVC grinding also to the back-up rolls. It allows an enlarged operating field and a homogenous load distribution between work and back-up roll. This leads to a reduction of the work hardening of the back-up rolls and to the extension of the back-up roll campaigns.

In particular as result of the thermal crown and the work roll wear, hot strip mills are governed by stringent requirements regarding the structure of the rolling program in order to avoid profile anomalies and out-of-flatness. The combination of CVC® plus with intelligent shifting strategies allows to extent the rolling program in general as

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well as in cases of sections of constant width, alternating width or alternation of material classes.

Figure 6 shows a rolling campaign where despite partially extreme boundary conditions satisfactory strip profiles are generated by employing the CVC® plus technology with intelligent shifting strategies. In this case, the finishing mill is equipped with CVC® plus from F2 to F7. In this rolling campaign of a high-carbon steel long passages were rolled with same strip width. With conventional work rolls this would result in early flatness deviations which would necessitate a work roll change. The use of CVC® plus with intelligent shifting strategies facilitates rolling of ca. 60 km of hot strip with the same width and achieving very satisfactory strip profiles.

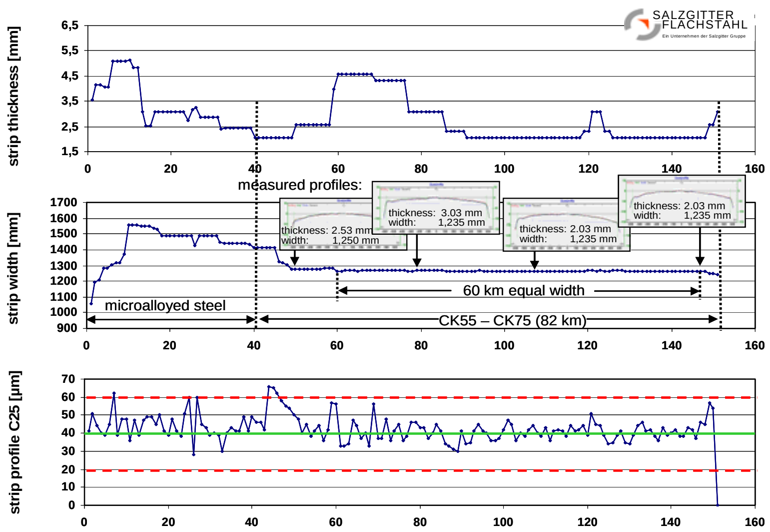

Figure 6: Rolling campaign of high-carbon steel at Salzgitter Flachstahl, Germany.

2.2.4 Modernization of downcoilers systems for extension of product spectrum

The modernization of coiler systems is on the agenda of many hot strip producers. The main driving force is the demand for high-strength pipe grades in large thicknesses and widths from tube manufacturers after spiral-welded tubes have been admitted for the manufacture of long-distance pipelines. A second product group is ultra-high strength steel to be used for highly loaded structures. The production of such steel grades leads to an increase in the mill loads, in particular on the coiler systems. The plastic bending torque for this type of strip is by approx. 250 % higher than the maximum plastic bending torque that has been applied by conventional coiling process.

To meet these demands SMS Siemag developed the UNI plus coiler. It is based on the well proven universal coiler (68 references since 2000). For the development of the UNI plus coiler, the entire coiling process including all movements and the plastic deformation of the strip was analyzed using FEM. In particular, the initial phase of strip winding and the build-up of the first wrap up to coiling round the strip head were thoroughly investigated because this is where the highest forces and torques occur (Figure 7).

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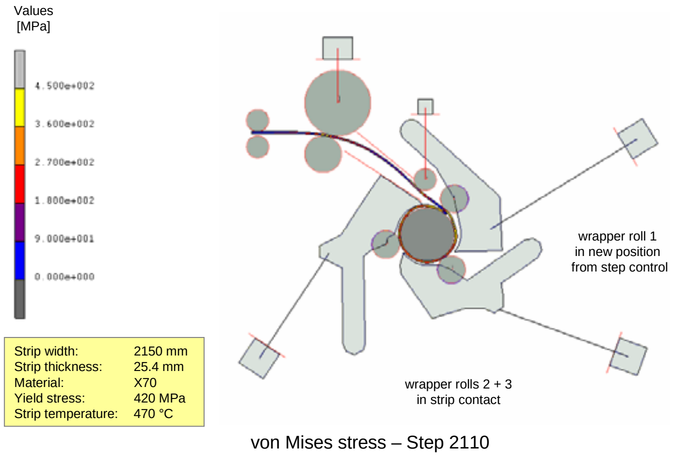

Figure 7: FEM-simulation of the coiling process.

Mechanical components and technological process controls of the UNI plus coiler were adapted to the requirements of the coiling of high-strength, thick materials. With regard to the mechanical design, mention should be made of strong hydraulic side guides, the extended functionality of the chute roll, increased adjustment forces and higher drive torque of the pinch roll unit, reinforced wrapper rolls and a specially designed mandrel. Particularly for the optimization of the winding of initial wraps the Automatic Step Control system was extended.

3 CSP®: COMPACT STRIP PRODUCTION

3.1 CSP® Plant Concept: Economic and Quality Advantages

A very economic plant concept for hot strip production is CSP® (Compact Strip Production). This concept was developed by SMS Siemag and introduced to the market in 1989. It is based on the principle of casting and rolling without intermediate reheating. The caster supplies thin slabs with thicknesses typically between 50 and 70 mm, which are moved into a soaking furnace and then rolled in the finishing mill. The maximum strip width produced so far on CSP® is 1,880 mm, strip thickness ranges from 0.8 to approx. 16 mm. Depending on the product mix, a one-strand CSP® plant has a maximum capacity of up to 1.5 m t/y (Figure 8).

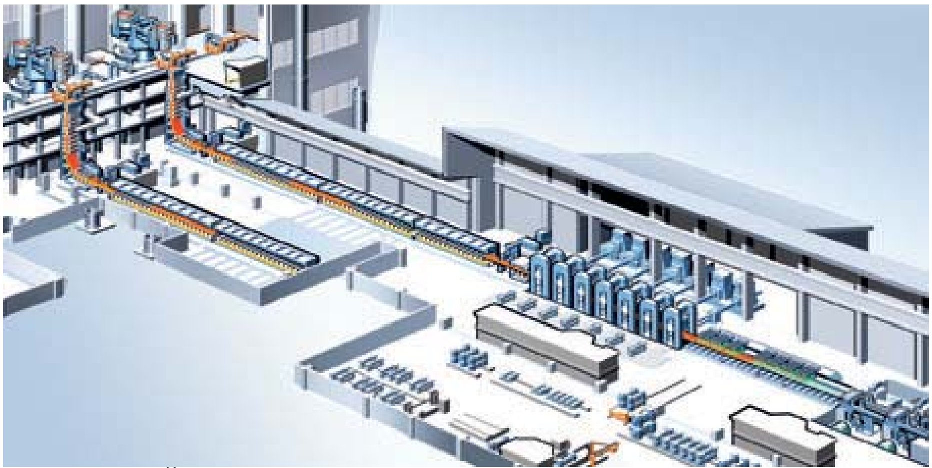

Figure 8: Layout of CSP® plant with 2 thin-slab casters, tunnel furnaces with parallel ferries and 7-stand rolling mill.

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The possibility of the stepwise increase of production capacity by adding one or two casting strands is an important advantage of CSP® technology. This gives CSP® owners the flexibility to start production with one casting strand and to establish themselves as hot strip producers with little investments and then to grow along with the market. Retrofitting a third strand is also basically possible in already existing plants. The first 3-strand CSP® plant will be commissioned at Essar Steel (India) in 2010/2011. The plant is designed for approx. 3.4 m t/y and will thus be in the range of a conventional compact-type hot strip mill.
From the economic point of view the advantages of the CSP® concept are to be found in the largely reduced investment and conversion costs compared to conventional plants. The investment costs are lowered above all by the fact that a roughing train is no longer needed. Production "from a single heat" considerably reduces the energy consumption and thereby the processing costs. This plant concept thus enables profitable operation already with an annual production of less than 1 m t/y.
CSP® plants have both been integrated in mini-mills with electrical steelmaking based on the use of scrap and in conventional integrated steel works with steelmaking in basic oxygen furnaces (BOF). An alternative concept is the combination of CSP® with a Midrex DRI (direct reduced iron) plant and an EAF (electric arc furnace) for steelmaking (Fig. 9). With this concept it is possible to use both iron ore and scrap as raw materials according to the availability and the cost as well as of the requirements of the finished products.

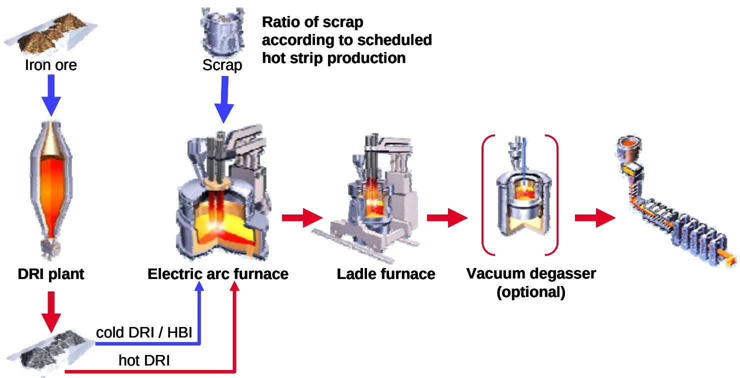

Figure 9: Integrated mini-mill concept.

This mini-mill concept is furthermore characterized by reduced production costs and a high quality of the final product. The production of DRI in a Midrex plant is very energy-efficient due to a low specific energy consumption and heat recovery. Direct feeding of hot DRI with temperatures of 600°C to 700°C to the EAF offers the possibility for an up to 25% reduction of energy. After secondary metallurgical treatment, the hot material is directly delivered to the CSP® plant and processed into hot strip.
With respect to quality this process route offers ideal conditions. The DRI features a high metallic iron content, but also no non-ferrous metal impurities. In combination with SMS Siemag's clean steel technology, it is possible to achieve ambitious metallurgical results and to reliably produce sophisticated steel grades.
Due to its specific process conditions, CSP® offers also optimum pre-conditions for high-quality products. The hot strips are characterized by a greater degree of uniformity with regard to the microstructure and to the mechanical and geometrical

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properties of the hot strip. This is particularly advantageous for high-quality steel grades such as microalloyed steels or Si grades.

The very homogenous temperature of the thin slab discharged from the soaking furnace results in excellent preconditions for a stable rolling process. On leaving the furnace, the thin slabs exhibit a constant temperature over their width, thickness and length. There is also no longer the problem of "cold edges" which arises in conventional plants, nor the related coarse grain formation in this area. As a result, uniform mechanical properties are obtained over the whole width and length of the strip. The constant conditions also provide an extremely stable, trouble-free rolling process, thus enabling the strip gauges and widths to be within close tolerances (Figure 10).

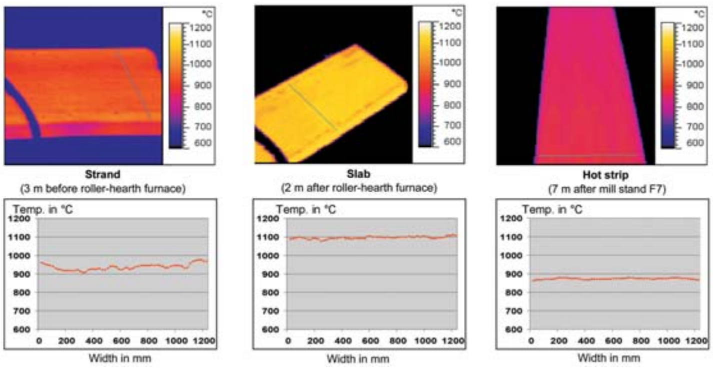

Figure 10: Homogenous temperature conditions in all steps of CSP® process.

3.2 Extension of the CSP® Concept

An extension of the CSP® concept for more flexibility is the combination of a single-strand CSP® facility with a conventional roughing train. In the single-stand reversing roughing train thick slabs are reduced down to the typical thin-slab gauges of 50 to 70 mm and are then fed to the CSP® line via a ferry and rolled down in the finishing mill. The extension makes it possible to produce steel grades and final dimensions which, due to process considerations, can be produced on CSP® facilities only to a limited extent. The combination of a thin-slab and a thick-slab line is a concept for those users who wish to cover the entire hot-strip product spectrum with all grades and dimensions by means of one single plant without having to forego the advantages of CSP® technology at the same time (Figure 11).

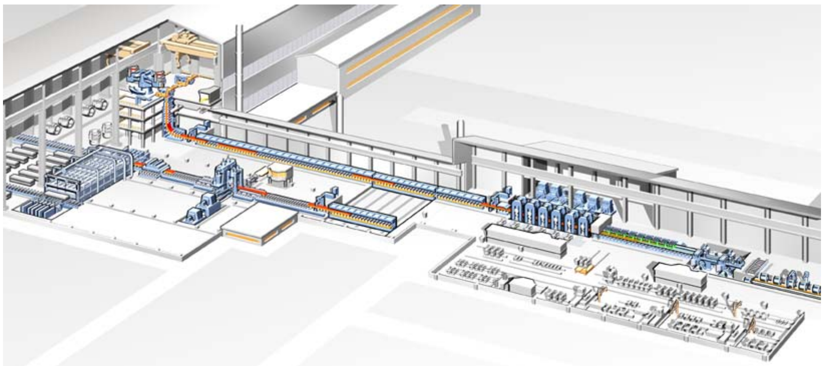

Figure 11: Layout of combined CSP®/thick slab plant.

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For the first time, we are implementing such a concept at G Steel in Thailand. Here, an existing casting-rolling plant is being extended by means of a single-stand reversing roughing mill.

4 HEAVY-PLATE MILLS

Heavy plates with a width up to 5.5 m and a thickness between 5 and 100 mm and more are used e.g. for shipbuilding, pipelines and construction. Depending on the product mix, the capacity of an X-Roll® plate mill reaches up to 2 m t/y. The plant layout mainly depends on the production specifications of the customer and the site premises which is why the arrangement of the various plant sections often differs greatly.
In recent years, customer requirements have changed considerably. The market is demanding plates with ever higher strengths along with good ductility. In addition, good flatness and weldability must be ensured. To fulfill these requirements, up-to-date heavy-plate mills are equipped with latest plant technology in all process stages from rolling to the adjustment line.
Modern heavy plate mills are designed for all production techniques, among which thermomechanical rolling gains more and more importance. Here, the temperatures during shaping especially in the finishing mill and during subsequent cooling are exactly controlled. By means of thermomechanical rolling heat treatment is no longer necessary for most steel grades. At the same time, the share of expensive alloying materials can be reduced.
Multi-plate rolling is an important prerequisite for a high capacity when applying thermomechanical rolling. To be able to process up to eight plates simultaneously in their individual rhythm of rolling and pause times the mill pacing from the reheating furnaces to the cooling beds has to be optimized. The SMS Siemag mill pacing model considers the production times with rolling, pause and transfer times that are calculated by the pass schedule model and hence defines the ideal moment for discharging the next slab from the reheating furnaces.

4.1 Technologies

4.1.1 CVC® plus for plate mills

The introduction of CVC® plus technology has certainly been the most important development for plate mills in recent years. With CVC® plus profile and flatness can be controlled exactly. Furthermore, CVC® plus allows higher drafts during the finishing rolling stage. As a consequence, a smaller number of passes is required and therefore productivity is higher, especially in the thermo-mechanical rolling process when finish-rolling is taking place inside the non-recrystallizing temperature range. In addition, CVC® plus supports flexible production scheduling.
A prerequisite for the utilization of CVC® plus is the length compensation of the drive spindle. Due to its high torque transmitting capacity, the slipper type spindle has been the dominant spindle type for decades. To combine a high torque transmission capacity and a modern profile and flatness control with CVC® plus, SMS Siemag has developed a slipper type spindle with length compensation by means of a multiple spline toothing.

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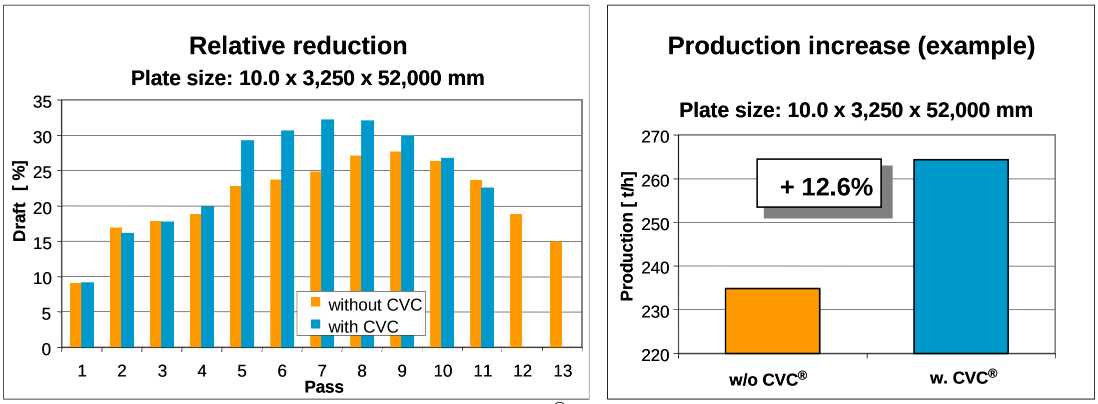

Figure 12: Benefits of CVC® plus for heavy plate mills.

4.1.2 Plate cooling systems

The plate cooling section is the main metallurgical tool for the production of high-strength heavy plate. Here, mechanical properties and the fine-grain microstructure are set by means of targeted cooling strategies. Basically, there are two cooling modes: accelerated cooling (ACC) and direct quenching (DQ).

SMS Siemag has developed two types of cooling systems which can be used for both cooling modes. The laminar cooling is characterized by its simple design, low energy consumption and low maintenance costs. Here, water is supplied by a large number of U-tubes. The spray cooling system is particularly used to cool ultra-thick and ultra-thin plates at high cooling rates, while at the same time maintaining good flatness. The spray cooling system is based on the combination of higher water pressure (up to 5 bar) and pinch rolls between the cooling headers. Pinch rolls control the water flow on the plate, thereby improving the temperature distribution and cooling efficiency. Plate guidance between the pinch rolls also contributes to uniform heat distribution over the plate surface and to improved flatness (Figure 13).

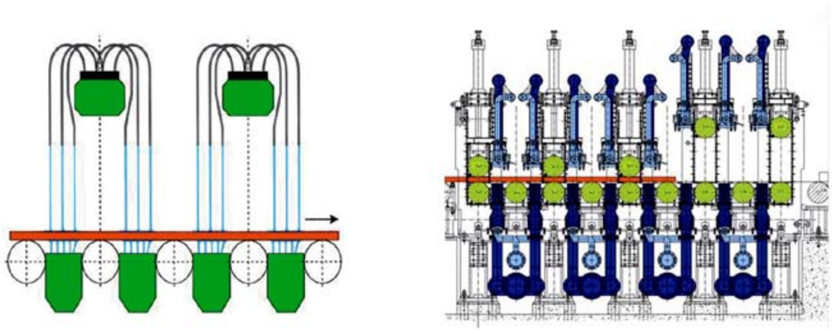
Figure 13: Principle of laminar cooling system (left) and spray cooling system (right).

In practical operation, the spray and the laminar cooling sections are combined into one system giving the users a great flexibility with respect to the cooling strategies. In both sections the cooling ramps can be flexibly adjusted and controlled so that the cooling curves may be set exactly.

For excellent cooling results, the precise interaction of mechanical equipment and automation is indispensable. A cooling model developed by SMS Siemag and meanwhile applied more than 30 times in plate mills, controls the process and makes sure that the desired microstructure and mechanical properties are reached. This requires exact knowledge of the transformation kinetics as the steel changes its

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microstructure during cooling. This unstable time-temperature behaviour is considered by the cooling model which calculates the ideal cooling process based on the chemical composition of the plate, the parameters of the pass schedule, the plate dimensions and the plate temperature.

4.1.3 Cold plate leveller

The 9/5 cold plate leveller is a very flexible machine because it can be operated both with 9 and 5 levelling rolls. Thereby it can process thick and thin plates with one set of levelling rolls and has practically the capacity of two machines.
The cold plate leveller can be operated with 9 or 5 levelling rolls because each levelling roll has a separate hydraulic adjustment in addition to the main hydraulic adjustment system as well as an individual drive, so that rolls can be taken out of the process. In conjunction with latest-state levelling models, the individual adjustment and individual drive for each roll makes it also possible to set the ideal curve for all plates. Thus, only plates with perfect flatness and minimized residual stresses leave the cold plate leveller.
The trend towards ever higher cold strengths and larger plate thicknesses and widths has consequences for the dimensioning of the cold plate leveller. The machine for the new 5.5-m plate mill of Posco (Korea) will feature a total levelling force of 54,000 kN and therefore be able to level high-strength plates with yield strengths up to 1,200 N/mm² in one pass.

4.2 Plant Concept for Plate and Strip Production

To increase the flexibility of a plate mill with respect to the product spectrum, it can be combined with a Steckel mill. For maximum flexibility, the reversing plate mill stand can also act as a roughing mill for the Steckel mill. This concept allows the production of heavy plate and hot strip according to changing market demands. Such a mill is supplied to Maghreb Steel in Morocco. The Steckel mill went in production in March 2010; the plate mill will follow in 2011 (Figure 14).

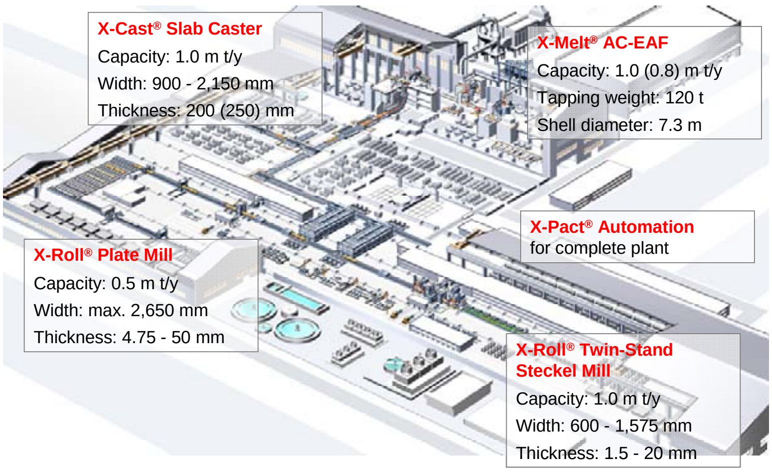

Figure 14: Layout of combined plate/Steckel mill at Maghreb Steel, Morocco.

In the strip production line an innovative mill concept was realized: the twin-stand Steckel mill. It combines the advantages of Steckel technology and tandem rolling. A twin-stand Steckel mill consists of two identical four-high tandem rolling stands, in which the material is rolled out in reversing operation from slab to the final

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dimensions. Due to the compact plant layout, twin-stand Steckel mills are characterized by reduced investment costs. The high quality of the hot strips is guaranteed by equipment such as CVC® plus, hydraulic adjustment systems, work roll bending and an interstand edger.

5 CONCLUSION

The technologies presented can not only be introduced into greenfield plants but can also be applied to existing rolling mills. Today, roughly half of the plate and hot strip mills have been in service for 20 years or more, and about a quarter have been producing for more than 40 years. SMS Siemag has developed and implemented modernization projects to upgrade existing mills such that they meet today's market requirements in exactly the same way as latest-generation mills.