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CSP FLEX – NEW CSP CONCEPTS FOR FUTURE MARKET REQUIREMENTS[1]

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Abstract

CSP® flex is the further development by SMS Siemag of its successful CSP® technology to satisfy new market demands. Main objectives for this development were the increase of production to 4.0 million tpy in two-strand operation, the increase of final thickness of high-strength, micro-alloyed pipe grades and the economic production of ultra-thin hot strip. CSP® flex also reinforces the typical advantages of CSP® such as low investment and operating costs, high availability and yield, uniform product characteristics and a large product mix. An additional development focus was to increase the energy efficiency. Main features of CSP® flex are its modular configuration with an extended range of casting machines and rolling mills. With the new VLB caster, production per strand can be increased to 2.0 million tpy. The innovative Vario Mill concept was developed as a result of the metallurgical necessities for the rolling of high-strength, micro-alloyed pipe grades and enables the production of these grades in larger thicknesses. CSP® flex also includes highly efficient concepts for the production of ultra-thin strip, which enable endless and batch production. The paper presents the CSP® flex concept as well as the metallurgical research and operational considerations, which were the basis for this new development.

Keywords: CSP® technology; CSP® flex; Pipe grades; Vario Mill; Ultra-thin strip; Energy efficiency.

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1 INTRODUCTION

Since the commissioning of the first CSP®-plant (Compact Strip Production) in 1989 at Nucor in Crawfordsville (USA), SMS Siemag's CSP® technology has further evolved into a standard process for the manufacture of high-quality hot strip. Today there are 28 CSP® plants in operation worldwide, achieving a total annual production of more than 50 million tons of hot strip. This represents around 10% of the hot strip production worldwide.(1)

CSP® is a compact plant concept comprising a casting machine, a roller-hearth furnace and a rolling mill. In the proven CSP® caster with its patented funnel-shaped mold, thin slabs are cast in a thickness between 50 and 90 mm, which are fed directly to the rolling mill after temperature equalization in the roller hearth-furnace and then rolled out to finished-strip gauge (Figure 1).

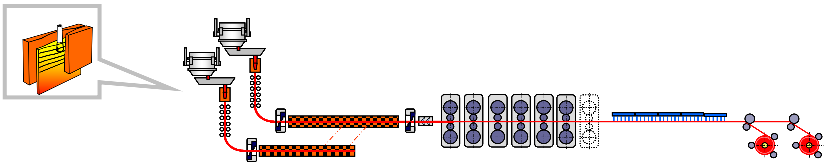

Figure 1: The CSP® concept.

The compact CSP® process makes it possible to produce hot strip with an absolutely homogeneous microstructure and uniform mechanical and physical properties over the entire length and width of the strip. Additional features are close manufacturing tolerances with regard to gauge, width, profile, contour and flatness. This can be achieved thanks to the homogeneous temperature distribution in the thin slab and to the low temperature losses between the roller hearth furnace and the rolling mill. These conditions result in an extremely stable rolling process at constant rolling speeds and temperatures.

In comparison with the production of hot strip in the conventional hot strip mill, the CSP® process is characterized by substantially lower investment and operating costs. This is due to the fact that the roughing mill is no longer needed. In addition, the energy requirement is reduced by the direct rolling of the thin slab without intermediate cooling and reheating.

The introduction of CSP® thin slab technology has enabled the production of thin and ultra-thin hot strip, which is also suitable for the substitution of cold strip.(2) Ternium México (formerly Hylsa) has been producing finished strip in gauges below 1.0 mm already since 1995. Today, some CSP® plants produce 30% of their annual output as thin and ultra-thin hot strip in gauges of 1.2 mm and less.

Today, the product range of CSP® covers all of the steel grades demanded by the market. These include in particular low-carbon IF and mild steel grades, medium- and high-carbon steels, HSLA and pipe steels (e.g. according to API standard), stainless, acid and heat-resistant special steels, as well as Si-alloyed electrical steel grades.(2-4) The consistent process conditions are ideal prerequisites above all for the manufacture of steel grades in which the material properties have to be adjusted in the cooling section by means of defined temperature control following finish-rolling. Thus, hot strips made from micro-alloyed (HSLA) or multi-phase steels (DP, CP and TRIP steels) can be produced much more easily and in closer tolerances.(5,6) Hot strip produced on CSP® facilities for the manufacture of non-grain oriented (NGO) electric sheet results in lower magnetic losses and has better dimensional accuracy.(7)

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2 CHANGING MARKETS DEMANDS WITH CSP® FLEX

The design requirements made on CSP® plants have changed over the last few years. Today, steel producers demand that CSP® plants should be able to operate just as flexibly and productively as conventional hot strip mills without, at the same time, forfeiting their specific strong points relating, for example, to the production of thin strip, of high-strength and Si steels or to energy efficiency. SMS Siemag have therefore further developed its CSP® concept into CSP® flex in order to expand the CSP® technology and to offer the customers additional flexibility.
Below are listed some of the essential tasks in order to explain the most important development objectives of CSP® flex:

- production of high-strength, micro-alloyed pipe steels with thicker finished-strip gauges
- economic manufacture of ultra-thin strips
- increasing of production to 4.0 million tpy in two-strand operation
- further lowering of energy consumption.

The distinguishing feature of CSP® flex is its modular structure with additional components for the casting machine and the rolling mill. This allows tailor-made technological overall solutions to be provided. Figure 2 displays the core components of the concept. Besides the tried and tested modules VSB (Vertical Solid Bending) caster and compact CSP® rolling mill, these components include the VLB (Vertical Liquid Bending) caster and the CSP® Vario mill.

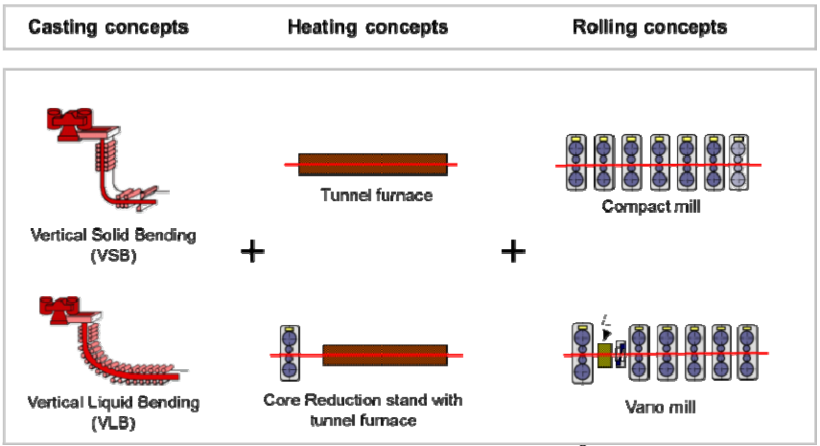

Figure 2: Modular components of the CSP® flex concept.

3 ROLLING MILL CONCEPTS FOR THE PRODUCTION OF API PIPE STEELS

The transport capacity of large-diameter pipes for oil and gas pipelines can be raised by an increased line-pipe diameter and pressure. Both of these require greater wall thicknesses and/or higher-strength materials. Most developments in pipe steels, for example according to the well-known API standard, aim at increasingly thicker hot strip with improved weldability and toughness at sub-zero temperatures.
The toughness properties of the hot strip are closely related to the overall degree of deformation. High-strength pipe-steel grades with excellent toughness properties up to a thickness of more than 12.7 mm (0.5“) can already be manufactured from slabs of thicknesses between 50 and 60 mm on a compact CSP® rolling mill. The optimum combination of strength and toughness demands a very fine-grained hot strip microstructure. In direct rolling, furthermore, the non-homogeneous cast structure must first be reshaped and homogenized. The corresponding hermomechanical (TM)

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rolling process is carried out in two steps, with the first step taking place in the recrystallizing temperature range and the second step in the non-recrystallizing range. It is of decisive importance here that a homogeneous recrystallized microstructure is produced during the first step. Any non-homogeneities still remaining, such as single coarse grains, will be "inherited" by the finished hot strip and will have a negative effect on the toughness properties. Figure 3 shows non-homogeneities of this kind resulting from incomplete recrystallization downstream of the second finishing stand of a finishing mill.[8,9] They occur above all in steel grades micro-alloyed with niobium, since this element has a strong effect in delaying recrystallization. For this reason, the amount and the temperature of the deformation in the first two stands of the finishing mill must be as high as possible in order to ensure that the recrystallization occurs at least twice and is complete. In this way, thicker hot strips with higher strength and, at the same time, improved toughness properties can be produced. If additionally the slab thickness is increased, then even thicker finished strip can be produced.

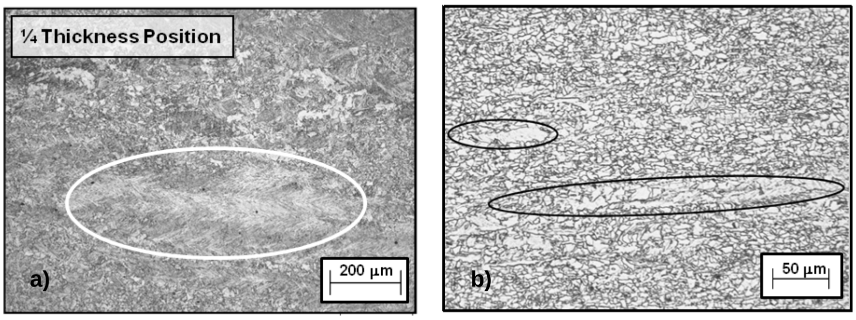

Figure 3: Structural heterogeneities after the second stand of the hot rolling mill (a) and in the finished strip (b).

The CSP® Vario rolling mill was developed on the basis of these metallurgical fundamentals, Figure 4. It possesses a strong medium stand M1 with two single drives, arranged upstream from the first finishing stand F1 at a distance that is ideal for process conditions. In this space of approximately 11 metres between M1 and F1 there is space for a pre-leveller for levelling the intermediate strip head end and for an induction heating system. The temperature and the retention time between M1 and F1 are so adjusted that a complete recrystallisation takes place without micro-alloying elements being precipitated prematurely or excessive grain growth taking place. Such undesired reactions would occur prior to entry into the finishing mill in the case of a combination between one or two disconnected roughing stands in a larger distance to F1.

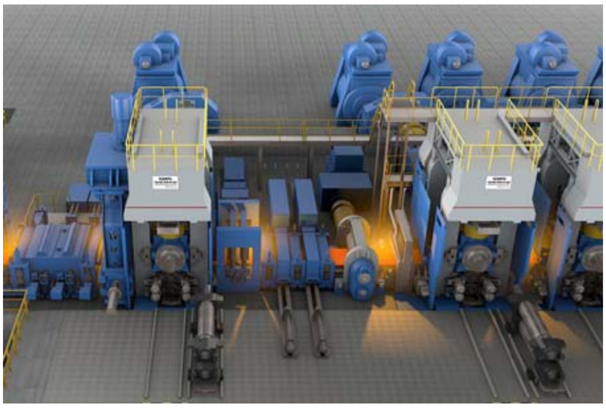

Figure 4: CSP® Vario mill with medium stand M1, pre-leveller and induction heater for the production of thick linepipe steel.

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The Vario mill can be combined with a caster of type VSB or type VLB. Thanks to a larger thin slab thickness, the combination with a VLB caster will enable the finished strip gauge to be considerably increased (Figure 5).

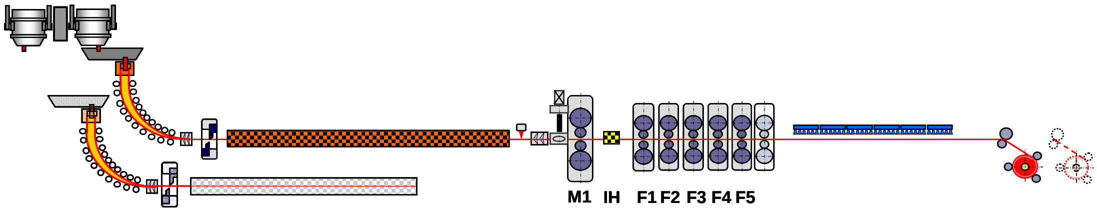

Figure 5: Plant concept for the production of thick linepipe steel with VLB caster and Vario mill.

4 EXPERIMENTAL EVALUATION OF DIFFERENT PLANT CONCEPTS FOR THE PRODUCTION OF PIPE STEELS

4.1 Isothermal Rolling on the CSP® Vario Mill

Figure 6 shows a typical example of the time-temperature curve during the thermomechanical (TM) rolling of an API line-pipe steel on a CSP® Vario mill. The steps designated with numbers 1 to 4 denote the following:

1. High deformation in the recrystallizing temperature range of the austenite to ensure the complete elimination of the non-homogeneous cast structure
2. Cooling down below the austenite recrystallization stop temperature
3. Finish-rolling in the non-recrystallizing temperature range of the austenite
4. Rapid cooling for phase transformation and attainment of a fine-grained ferrite microstructure.

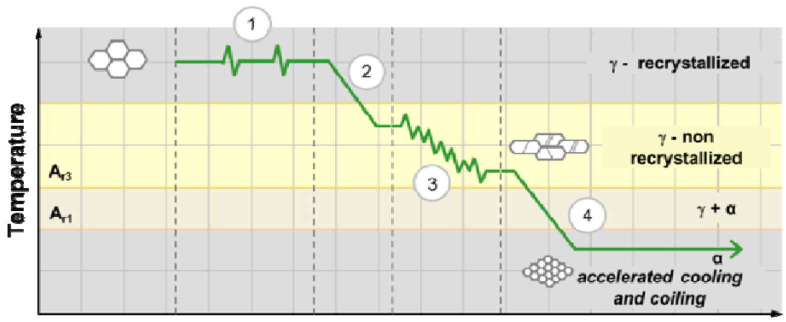

Figure 6: Isothermal rolling in the first stands of the CSP® Vario mill.

As explained above, the complete elimination of the cast structure by means of complete recrystallization in the first stands of the rolling mill is essential for producing hot strip with a combination of high strength and toughness. Therefore, comprehensive experimental research was carried out to analyse the development of the microstructure evolution during the first stage of TM rolling within the recrystallizing temperature range of the austenite. These experiments were performed with the aid of a torsion plastometer. The trial material was obtained from the industrial production of a pipe steel of API grade X70, the chemical composition of which is indicated in Table 1.

Table 1: Chemical composition of the API grade X70 linepipe steel

C	Si	Mn	P	S	Al	N	V	Nb
0.05	0.19	1.36	0.012	0.004	0.032	0.006	0.05	0.06

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First of all, isothermal rolling was examined in the first two stands of the CSP® Vario mill and compared with the common practice. To do this, the samples were cooled down quickly during a simulated entry into the fourth stand of the CSP® Vario mill (F3) and the microstructures were examined. As is customary in operating practice, the finishing stand F2 was inactive (open) and therefore no thickness reduction took place there. The rolling temperature in M1 and F1 was 1,080°C. Figure 7 shows the temperature curve and the sample-taking point upstream of stand F6.

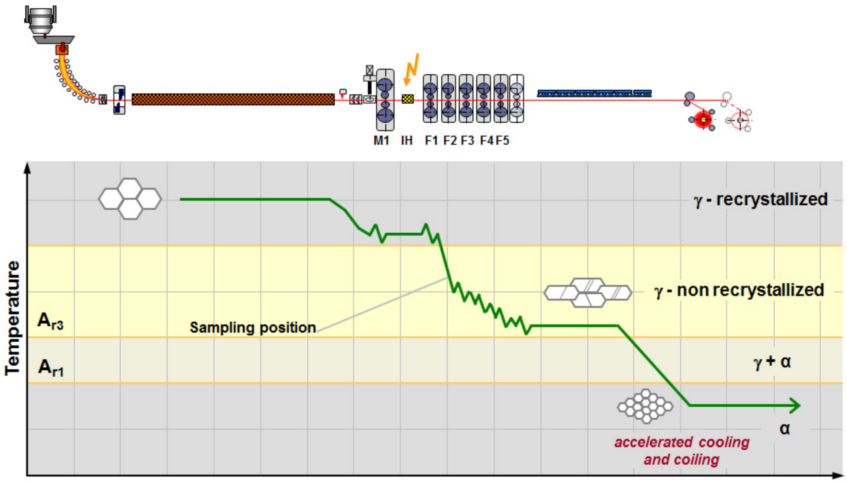

Figure 7: Temperature control during isothermal rolling in a CSP® Vario mill and sampling position.

Figure 8 displays a representation of the austenitic microstructure and the grain size distribution. The microstructure consists of uniformly recrystallized grains and is free from non-homogeneous constituents. The grain size distribution shows a scatter band closely grouped around the mean grain size.

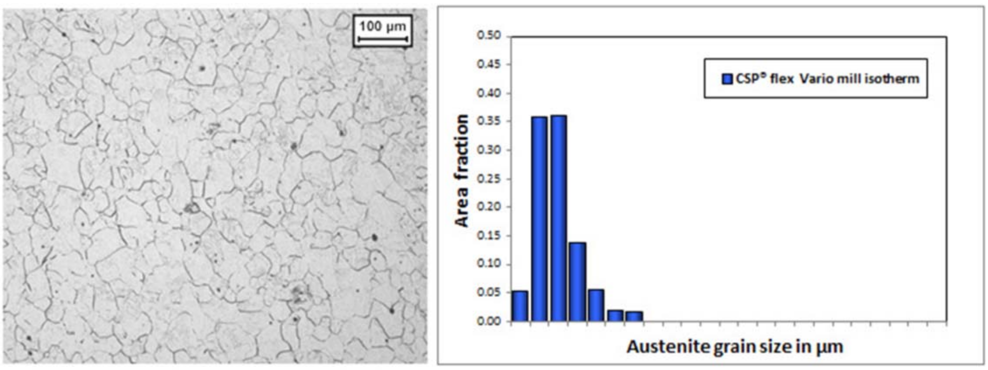

Figure 8: Austenitic microstructure and grain size distribution after isothermal rolling in M1 and F1 on a CSP® Vario mill according to Figure 7.

4.2 Comparison with Plant Concepts with Roughing Stands

As part of the investigations, concepts were also examined for thin slab casters with one or two roughing stands as they were implemented by SMS Siemag at Handan Iron & Steel in China and Saldanha in South Africa. Similar concepts are also suggested by other suppliers.
The austenite structure at the end of recrystallization rolling in the austenite (first stage of TM rolling) was examined by means of experiments conducted in the same manner as the trials on the CSP® Vario mill. The respective temperature controls and sampling-points are indicated in the graphs in Figure 9 and Figure 10.

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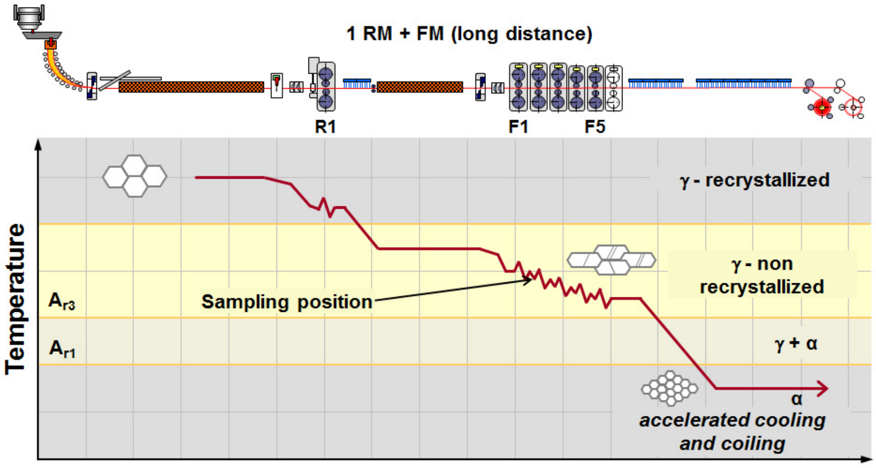


Figure 9: Temperature control for rolling with one roughing stand and sampling position.

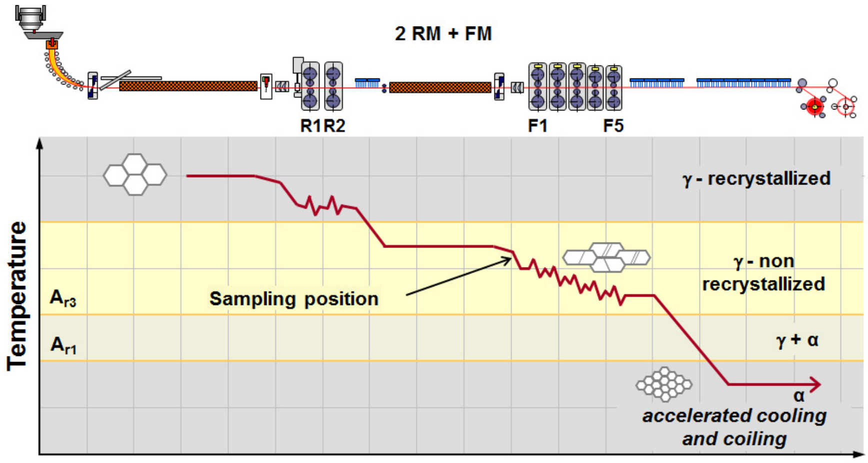
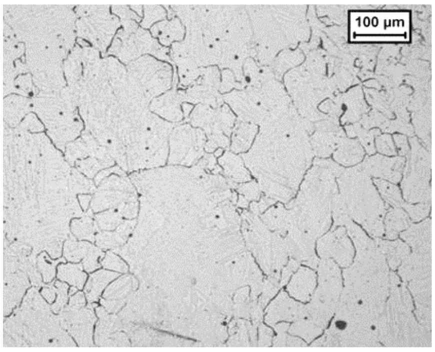


Figure 10: Temperature control for rolling with two roughing stands and sampling position.

The corresponding austenite microstructure is summarized in Figure 11. The microstructure produced by utilizing one roughing stand contains a large number of coarse grains and displays a correspondingly wide scatter band for the grain size distribution. The temperatures were 1,080°C in the roughing stand and 1,045°C in F1. Better results are achieved with two roughing stands, provided that thickness reductions of 50% are achieved on each of the two stands. The corresponding temperatures here were 1,130 - 1,116 - 950°C.



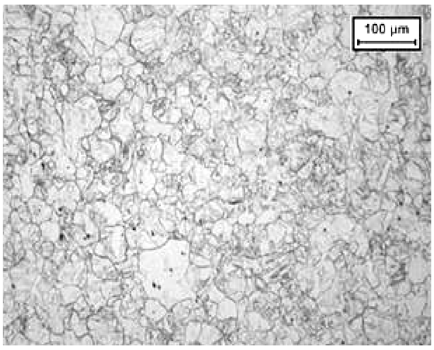


Figure 11: Austenitic microstructure at the end of recrystallizing rolling with one (left) and two (right) roughing stands.

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Examining only the austenite grain size, the results achieved with two roughing stands appear to approximate very closely to the results attained from isothermal rolling on the CSP® Vario rolling mill. However, when using roughing stands further aspects must also be taken into consideration. Owing to the different entry speeds of roughing stands and of the finishing mill, the head and tail ends of the transfer slab have differing transfer times between the two rolling groups. Typically, these are around 70 seconds for the head end and 270 seconds for the tail end. If the slab is maintained further at high temperature following the roughing stands in order to avoid premature precipitation of alloying elements, different grain sizes and distributions will develop in the slab head and tail ends. If the slab is cooled down after the roughing stands, premature precipitation of alloying elements will occur. This particularly affects the expensive micro-alloying elements, especially niobium whose the effectiveness becomes greatly diminished.
Since these problems do not arise during isothermal rolling on the CSP® Vario rolling mill, higher micro-alloy contents can be attained, thus enabling hot strips of higher strength classes to be produced. Thanks to the complete elimination of non-homogeneities originating from the cast structure, thicker finished strips can be obtained from slabs of a given thickness, which satisfy the most stringent demands relating to strength and toughness.

4.3 Wide Range of Products

The Vario mill is not only designed for the production of thick, high-strength strips, but also makes it possible to manufacture the wide product range typical of CSP®, including thin gauge strip of 1.0 mm. By installation of a drum shear in the area between M1 and F1 an optimum strip end shape is obtained, which guarantees a reliable and stable rolling process particularly when rolling thin final gauges.

5 CSP® FLEX FOR THE PRODUCTION OF THIN STRIP

Today some CSP® plants are already producing 30% of their annual production as thin and ultra-thin hot strip in gauges of 1.2 mm and less. For those customers who are aiming to achieve an even higher proportion of hot strip below a gauge of 1.0 mm, the endless mode can be recommended. Since threading-in and tailing-out are no longer required, faulty rolling of the strip head and tail ends can be avoided for thin strip gauges and the risk of cobbles reduced. Further advantages are a uniform quality over the entire strip length and a compact plant layout.
An endless rolling facility can only be operated economically when the costs for ensuring the endless operation do not outweigh the advantages and savings thereby achieved. In the endless process the rolling speeds are approx. 30% lower than for batch operation due to the coupling with the casting process. To achieve acceptable final rolling temperatures, inductive reheating is therefore required in the rolling mill. Consequently, for energy-related reasons, batch operation is always preferable to endless mode due to the reduced overall energy requirements in the conversion of liquid steel into hot strip. For high-quality steel grades the batch mode is generally required for metallurgical and economic reasons. In view of these considerations, our CSP® flex concept always allows the batch mode in addition to endless operation. This offers the customer the necessary flexibility in his operation as well as a wide range of products.

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The configuration in Figure 12 makes it possible to produce ultra-thin hot strip by endless rolling and, at the same time, to manufacture high-strength pipe grades in final thicknesses up to 18 mm.

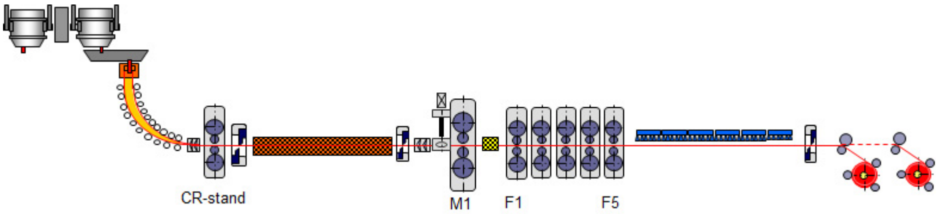

Figure 12: Plant concept with Vario mill for the production of thin strip in batch mode and endless mode.

For endless operation, the caster is normally of type VLB so as to achieve a high mass flow. Directly after it leaves the caster, the slab is rolled in a CR (Core Reduction) stand before moving through a short roller-hearth furnace. This furnace is designed to make batch operation and work-roll changing possible. Upstream of the coilers, our tried-and-tested high-speed shear cuts the endless strip into single coil lengths.
Independent of the plant concept, our development objective is to substantially increase the casting speed in continuous operation in order to also reduce the temperature losses and, as a result, the required reheating energy.

6 CASTERS CONCEPTS FOR A WIDE CAPACITY RANGE

The key for increasing annual production is the caster. With CSP® VSB casters (vertical solid bending, i.e. vertical bending with a solid core in the bending zone) plant operators achieve annual production of more than 1.5 million t per strand. The CSP® VSB caster with its vertical strand guide and absolutely symmetrical solidification has the metallurgical advantage that it makes bending and unbending of a unsolidified strand unnecessary. Specific features are the short mold and segment change times and ease of maintenance.
A larger slab thickness is required for higher production volumes. As already mentioned, the production of pipe grades with thicker gauges will also require a larger slab thickness. The only economically viable way to provide the necessary longer metallurgical length of the caster is by the use of a CSP® VLB caster (vertical liquid bending, i.e. vertical bending with a liquid core in the bending and unbending area), reaching a production volume per strand of 2.0 million t/year or more (Fig. 13).

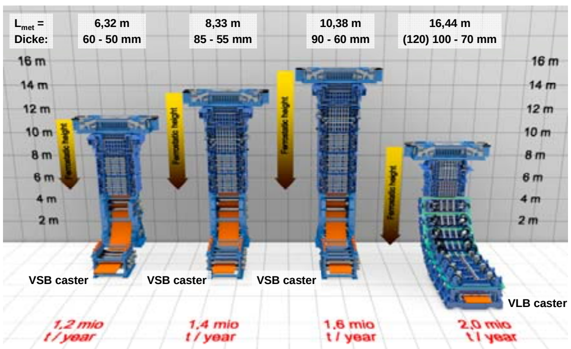

Figure 13: Range of CSP® casters.

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A common feature of both CSP® VSB and VLB casters is the integration of latest caster technology ensuring highest product quality:

- Unique, funnel-type mold with parallel mold outlet for maximum stability at start casting
- MMS plus (Mold Monitoring System) with Longitudinal Facial Crack (LFC) detection
- Hydraulic oscillators with high precision movement
- Hydraulic Segment Adjustment (HSA) with position and force control in the complete strand guide system
- LCR or LCR plus (Liquid Core Reduction) for infinite, dynamic slab thickness reduction by maximum of 35 mm
- DTS (Dynamic Taper Setting) for optimal strand support, irrespective of the casting speed and strand shrinkage
- Active Segment Protection (ASP) against damage due to excessive loading

A feature of the CSP® VLB caster is the patented STEC roll, which enables for the first time a combination of internal roller cooling and small bearing window in rolls with very small diameters. A small bearing window as well as a small and uneven roller pitch is a precondition for optimal strand support with low bulging and low strain. The CSP® VLB casting machine also integrates proven features of conventional caster technology such as Cyberlink segments, air-mist cooling, tunnel-type cooling chamber and top-feeding dummy bar system (Figure 14).

Figure 14: The CSP® caster of VLB type combines the well-known thin slab technology with proven and new technologies

7 SUMMARY AND OUTLOOK

With the modular CSP® flex concept, SMS Siemag provides its customers with individual plant solutions that are tailored towards their specific requirements. During the development work great emphasis was stressed upon reinforcing the advantages typical of CSP® such as low investment and operating costs, high availability and yield, absolutely uniform product characteristics and a large variety of steel grades.
Under the CSP® flex concept a VSB caster and a VLB caster are available. With two VSB casting strands, an annual production of over 4.0 million tons can be achieved. The innovative CSP® Vario mill makes it possible to produce thick, high-strength pipe steel grades. This mill was developed as a result of the metallurgical necessities regarding the rolling of these steel grades. CSP® flex also includes highly efficient endless concepts for the production of ultra-thin strip, which enable the batch mode in addition to endless operation and thus offer the customer a high degree of flexibility.

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In addition to the developments presented so far, also innovations for the further reduction of energy consumption are ready to be introduced into the market. Here, inductive heaters are used to save energy. By installation of induction heating systems on the exit end of the tunnel furnace, the thin slab temperature can be flexibly adjusted according to the needs of the rolling process. Thus, the furnaces can be operated at lower temperatures which leads to a significant reduction in energy consumption. This solution will be realized for the first time in an existing CSP® plant in the USA.

All plant concepts and components are based on the proven technology incorporated in the 28 CSP® facilities currently in operation worldwide. Together with the CSP® configuration which has been well known for now more than 20 years, CSP® flex represents a technology that satisfies the requirements both of the present and the future.

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