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COLD ROLLING TECHNOLOGY FOR ECONOMICAL PRODUCTION OF HIGH STRENGTH STEEL [1]

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Abstract

Increasing energy cost and the necessity to reduce of CO_2 emission, call for more energy efficient cars, trucks, machines and plants. The steel industry has been working for quite a while on these issues by developing new steel grades with higher strength for lighter constructions. SMS Siemag, reknown supplier of rolling technology supports its clients by elaborating mill concepts for economically most efficient production of high strength steel. The general aim of these developments is to find solutions to provide high flexibility in what mills are able to produce. The design should be suitable for rolling soft and ultra high strength steel grades. For an economical mill design, the work roll diameter is the key design factor. Looking at the line load and roll flattening, it becomes obvious that appropriate work roll diameters for 4-high or 6-high stands are too large for an economical production of cold rolled high strength steels. Therefore SMS Siemag took the classic 18-high design and developed it further by the introduction of CVC® plus to improve product flatness and by the HS system to control the horizontal forces on the side support rolls. Together with an optimized lubrication, these measures allow to increase the reduction per pass. In parallel, process stability and product quality are improved. The paper discusses different mill configurations depending on the high strength material to be rolled.
Keywords: High strength steel; Stainless steel; Economical production; Tandem cold mill.

TECNOLOGIA DE LAMINAÇÃO A FRIO PARA A PRODUÇÃO ECONÔMICA DE AÇO DE ALTA RESISTÊNCIA

Resumo

Em face dos crescentes custos de energia e da redução da emissão de CO_2, tornam-se necessários carros e caminhões bem como máquinas e plantas com maior eficiência energética. A indústria do aço já está trabalhando há bastante tempo nestas questões, desenvolvendo, em estreita colaboração com os clientes, novas qualidades de aço com maior resistência para a construção de estruturas mais leves. A SMS Siemag, como um conhecido fornecedor de tecnologia de laminação, presta suporte aos seus clientes elaborando conceitos de laminadores que possibilitam a mais econômica produção de aço de alta resistência. O objetivo geral dos conceitos desenvolvidos é buscar soluções de alta flexibilidade quanto aos produtos que o laminador pode produzir. O projeto deve ser apropriado para a laminação de muitas qualidades de aço, desde o mais doce até o ultra-resistente. Para um projeto de laminador econômico, o diâmetro do cilindro de trabalho é o fator chave do projeto. Observando-se a carga da linha e a laminação de desempeno, torna-se óbvio que os diâmetros apropriados para os cilindros de trabalho numa cadeira de 4 cilindros ou 6 cilindros são muito grandes para uma produção econômica de aços de alta resistência laminados a frio. Por isso a SMS Siemag pegou o clássico projeto de cadeira de 18 rolos e aperfeiçoou-o, introduzindo a tecnologia CVC® plus para melhorar a planicidade do produto e o "sistema HS" no intuito de controlar as forças horizontais nos rolos de suporte laterais. Somadas à lubrificação otimizada, estas medidas permitem aumentar a redução em cada passe. Paralelamente foi melhorada a estabilidade de processo e a qualidade do produto. O trabalho discute diferentes configurações de laminador com relação à operação e à qualidade, dependendo do material de alta resistência a ser laminado.
Palavras-chave: Aço de alta resistência; Aço inoxidável; Produção econômica; Laminador tandem a frio.

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INTRODUCTION

For many decades, the steel industry has been working on the improvement of strength and formability of steel grades in close cooperation with its customers.
Figure 1 gives an overview of the variety of high strength steel grades according to mechanical properties and shows the target area of further developments including stainless steels. The developments are driven by minimizing the amount of material used or by increasing the performance parameters of particular applications.

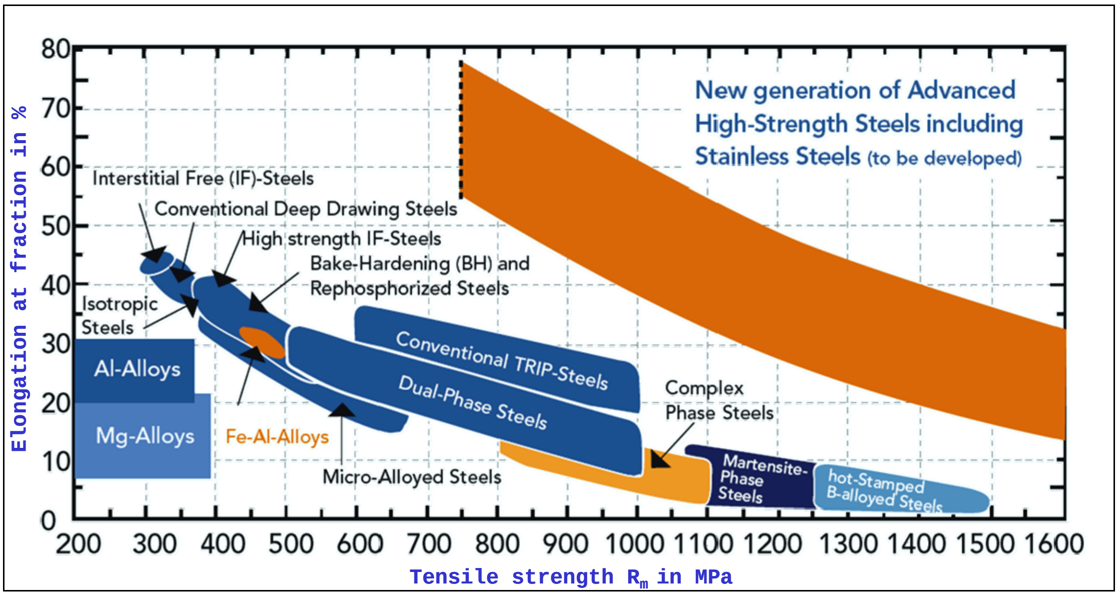

Figure 1 : Variety and mechanical properties of high strength steel.

In the light of the climate change and the reduction of CO_2 emission, the topic has gained a special actuality and importance.
After having had a look at the requirements of the steel market in closer detail regarding cold rolled high strength steels, this paper discusses consequences in dimensioning cold rolling mills as well as appropriate technologies and mill concepts provided by SMS Siemag to ensure product quality and operational flexilibility. Further, references of particular solutions, elaborated and implemented together with our clients, are given.

HIGH STRENGTH STEELS AND THEIR MARKETS

Looking at the variety of high strength steel grades available and cold rolled, first of all it should be distinguished between carbon and stainless steels. For both, the improvement of the strength goes along with the reduction of the formability or ductility.

Carbon steel

The development of carbon steel during the last decades was mainly driven by the car industry. Already in the nineties, steel producer and car manufacturer established joint projects to develop lighter steel car bodies. Well known projects are ULSAB, LTS, ULSAS or the ULSAB AVC project.[1]

[1] Cf. www.worldautosteel.org

Motivated by bringing down the weight of major car parts and consequently reducing fuel consumption, the development projects have shown that, at the same time, stiffness of the car body and safety of the passengers can be increased at a lower price. All this underlines the potential of steel and its competitive strength against other materials.
Today a common classification of steel grades in the car industry is made according to strength. It is distinguished between low strength steels like IF steels and mild carbon steel, high strength steels (HSS) like bake hardening steels and HSLA steels with tensile strength in a range of 270 – 600 MPA, and so called advanced high strength steels (AHSS) like DP, CP, Trip and MS steels with tensile strength up to 1,600 MPA.
In this context, it is important to note that different classification criteria are used by different car manufacturers and steel companies.
Beside upper class vehicles, also for compact and small cars the proportion of high strength steels is rising continuously. For example in 2001 Honda used for its cars approximately 13 % of HSS. Only six years later, in 2007, the portion of HSS steels increased up to 56 %. The tensile strength of these steel grades varies in a wider range from 440 MPA to 1000 MPA.

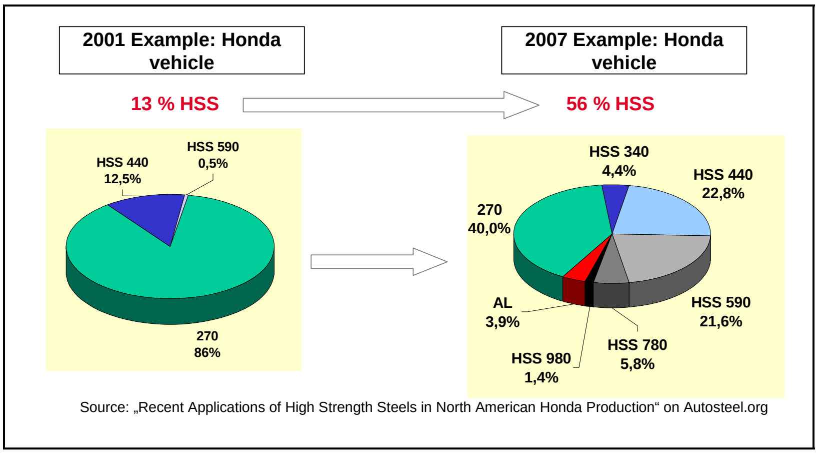

Figure 2: Development of HSS in automotive application.

The high strength steels are used for center pillars or transversal and longitudinal members. The average thickness can be kept at around 1.0 mm by increased torsion stiffness.

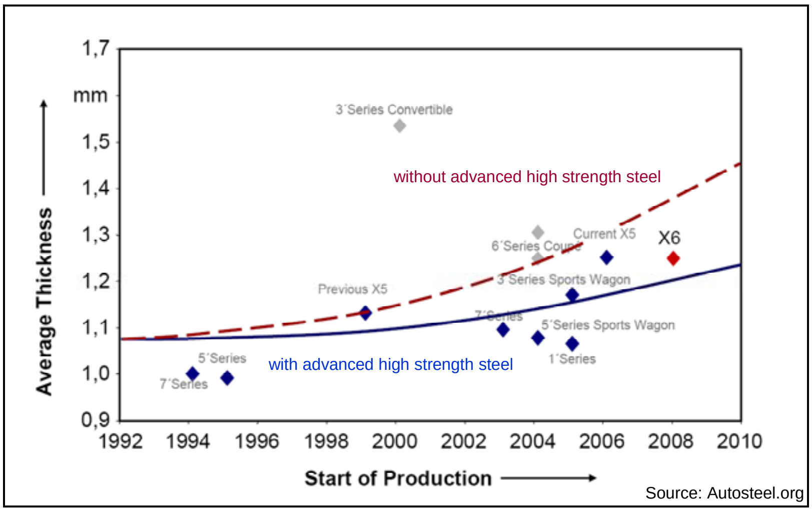

Figure 3: Average thickness of BMW vehicle parts.

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However, beside the car industry, also other industries require lighter structures, want to reduce the amount of steel used, or simply to increase the performance of their applications. To some extent, they make use of the car steel grades. However they also require higher strength for case hardening steels, steels for quenching and tempering or for spring steels which are rolled in a thickness range from less than 0.3 mm up to 3.0 mm.

Stainless steel

The application of stainless steel grades is mainly driven by their corrosion resistance. This property increases the service life significantly and therefore reduces the life cycle cost of the application. However, because of its remarkable ductility, especially of the austenitic grades, these grades are also preferred material for complicated format components.
The further development of the stainless steel grades during the last decades were mainly focused on two aspects:

1. the volatility of alloying element cost and
2. improving the mechanical property especially increasing yield and tensile strength

Consequently alternative alloy concepts are tested resulting in the establishment of the 200 series, an austenitic stainless steel with low nickel content. Regarding the yield and tensile strength, the duplex grades achieve the highest values today.
For cold rolling of stainless steel strips, 20-roller or 18-high mill stands are used. Looking at yield and tensile strength of stainless steel in comparison to carbon steel and high strength steels, this is not obvious. However, the strength of stainless steel increases dramatically during cold rolling, which requires a slender work roll diameter and consequently such sophisticated mill stand types.
The market for stainless steel is growing continuously, not considering the crises of the year 2009. In 2008, worldwide nearly 26 million tones of stainless crude steel were produced. The biggest production is already located in Asia (including China) with approximately 58 % of global production. Despite the economic turbulences big stainless steel producers are looking for mill concepts offering high capacity and reduced operation cost to be better positioned in the future.

MILL DESIGN AND FLEXIBLE SOLUTIONS

Proper dimensioning of cold rolling mills starts with determining the optimal work roll diameter. It depends on the product mix, the hardening behavior of the grades during cold rolling and of course of the final strip thickness which is intended to be produced for the particular grades.
Based on pass schedules considering the most demanding strip, the maximal rolling force is calculated depending on the work roll diameter. Considering the specific line load as a consequence of the rolling force, the most appropriate work roll diameter is to be determined.
For small work roll diameters, the degree of slenderness needs to be considered and it is necessary to check the sensitivity of the work rolls against horizontal deflection. This can be expressed by the so-called critical rolling force which depends on the roll stiffness and roll geometry. Beside the roll diameter also the width of the mill and therefore the length of the various rolls are to be considered. This depends on the desired maximum width to be produced by the mill.

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In Figure 4 all this is shown for a strip with a work hardened strength of 1200 N/mm^2 and a width of 1250 mm, rolled on a mill with a barrel length of 1350 mm and one with 1950 mm. Considering the critical rolling force for the 1950 mm wide mill, even for thicker strip lateral support of the work roll may be required.

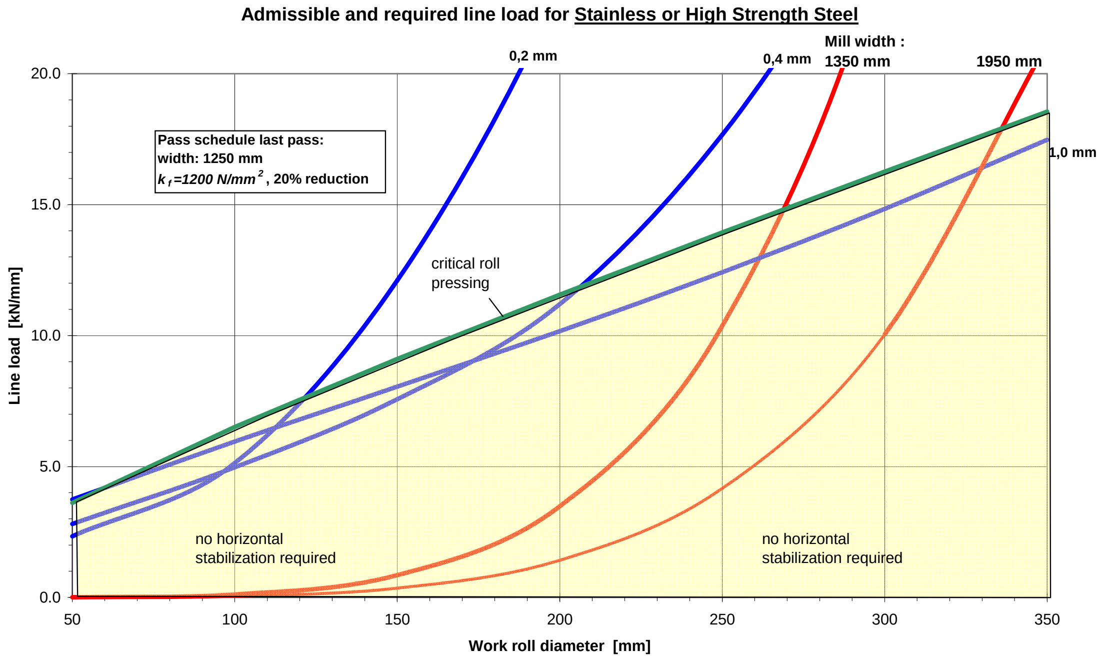

Figure 4: Line load for cold rolling of high-strength steels.

Considering this, beside 20-high, 4-high and 6-high cold rolling mills, SMS Siemag extended its product portfolio by developing the CVC® plus 18 HS stand type. This type can be designed to be used in reversing mills as well as in tandem mills.
The CVC® plus 18 HS, as well as the conventional 18-high mill, is in principle a 6-high mill with driven intermediate rolls which are axially shiftable and equipped with roll bending devices. The small work rolls are laterally supported at entry and exit sides by supports which are fixed in the so-called cluster. The cluster arms are adjustable both for entry and exit sides by movable support bridges which are installed in the mill housing and driven by screws.
The benefit of this millstand type is that it allows application of the CVC® plus technology to adjust the roll gap geometry in a wider range. By the use of the specific CVC® plus roll contour flatness defects of higher order can be corrected in a wider range compared to other approaches available.
By shifting the lateral side support and moving the work rolls in horizontal direction, it becomes possible to minimize the horizontal force and increase the process stability during rolling with such small work roll diameters. In more detail, the work roll offset causes an additional rolling force component to work in opposite direction of the drive force which reduces the horizontal force (F_H) on the side support and thus increases the life time of the backup bearing (Figure 5 b) .

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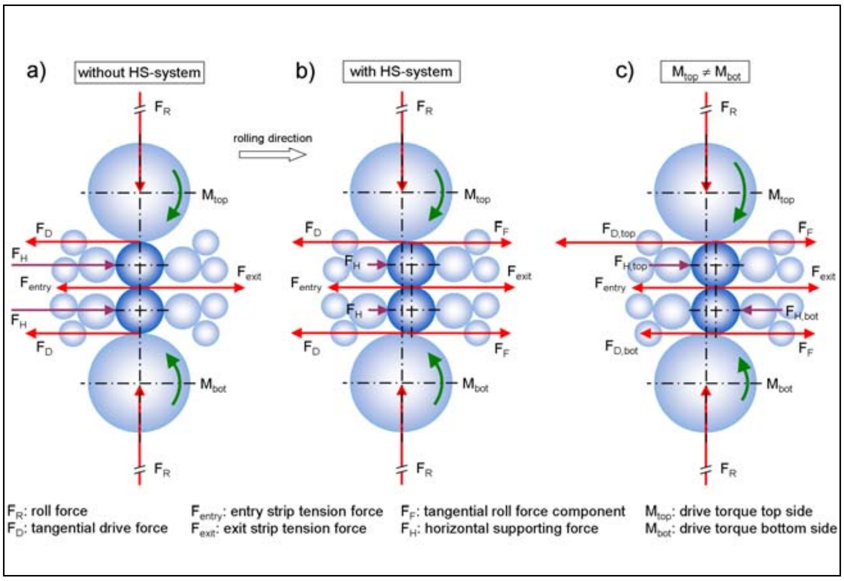

Figure 5: Principle of horizontal stabilization (HS) – horizontal force depending on work roll offset and torque asymmetry.

Considering that the smaller the work roll diameter the higher the sensitivity for asymmetric torque split, a stable support of the cluster arms in the mill housing like in the CVC® plus 18 HS mill is needed.

Consequently changes in amount and direction of horizontal force going along with torque split will not cause any unwanted movement of the work rolls in horizontal direction with interrupting the rolling process.

In view of the particular situation of steel producers and the market demand of high strength steels and stainless steels, for many steel producers the amount of high strength steel does not justify operating a specialized mill for these grades like the CVC® plus 18 HS.

Therefore SMS Siemag developed the multipurpose mill. With this concept it is possible to change between CVC® plus 4-high and CVC® plus 18 HS during regular roll change. This increases the flexibility of our customer and allows to adjust the cold rolling mill according to the material to be rolled and thus to be more economically efficient in producing an even wider range of steel grades.

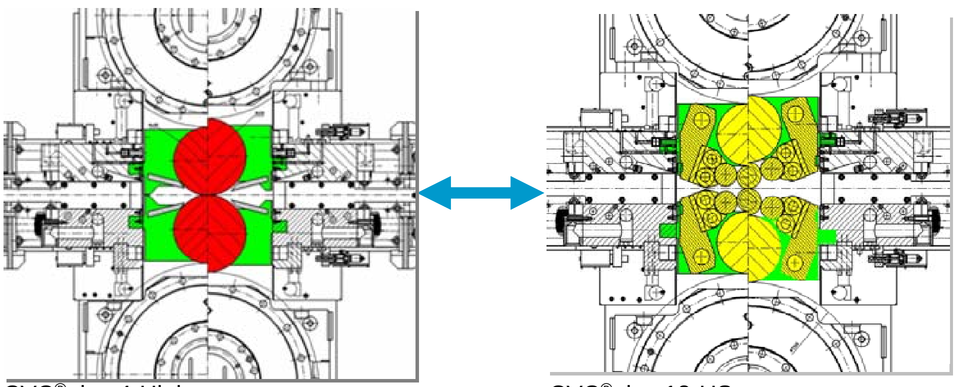

Figure 6: Changeable mill stand configuration

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REFERENCES

Over the last decade, SMS Siemag received orders for 14 tandem cold mills. 12 of them are coupled to pickling lines and are referred to as X-Roll® PLTCMs. From China SMS Siemag received 8 orders for tandem mills, all requiring CVC® plus 6-high technology.
Looking at the product mix to be rolled, already for 10 of the 14 mills high strength steels are required. In general these are HSLA steels. But for some mills also DP, multiphase steels, or Trip steels are demanded.
One of the latest references is the five stands CVC® plus 4-high tandem cold mill for the new cold mill complex of MMK in Russia. Beside low carbon grades like IF steel for exposed parts, the mill is designed to roll a wide range of high strength steels for the car industry down to the required thicknesses (0.9 mm – 1.2 mm). With its high drive power rating and rolling force of 35 MN per stand, it is one of the most powerful tandem cold mills in the world. Equipped with all advanced technologies, it ensures the economic production of up to 2.1 m t/a of high quality products and will be started up in 2011.

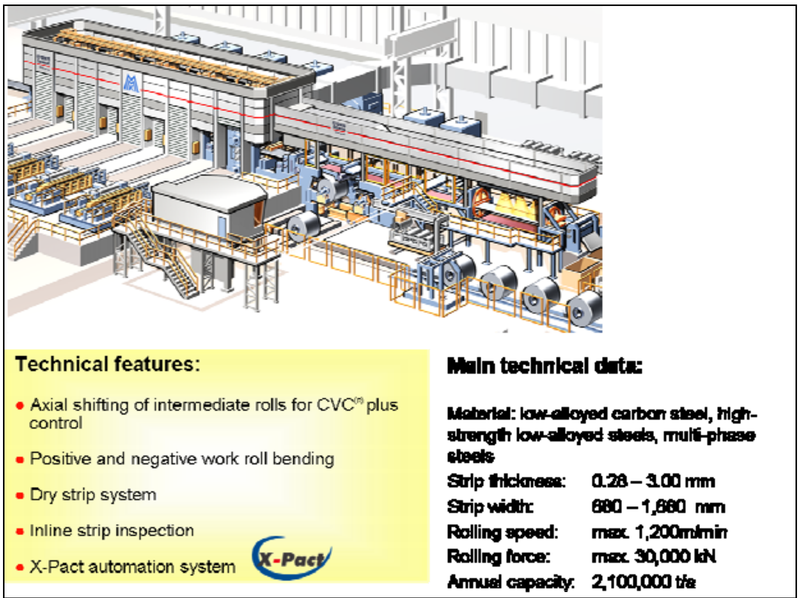

Figure 7: Five-stand CVC® plus PLTCM for MMK, Russia.

The following references describe concepts to produce both high strength carbon and stainless steel or only stainless steel in a thickness range down to 0.3 mm.

Friedrich Gustav Theis Kaltwalzwerke GmbH, Germany: CVC® plus technology in an 18-high mill

At Theis Cold Rolling Plants in Germany, a producer of cold rolled quality and stainless steel of widths up to 650 mm, the CVC® plus technology was successfully installed in 18-high mills for the first time, figure 8.
The Theis cold rolling mill is a 4-stand CVC 4-high tandem mill. Stands 3 and 4 can be changed between CVC® plus 4-high and CVC® plus 18-high. This allows the use of different work roll diameters like D_{WR}=100 mm in multi-roll operation and D_{WR}=310 mm in 4-high operation to expand the range of rollable final gauges especially for higher strength steel.

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For each of the two operating modes, a CVC® plus roll contour was determined covering the entire roll crown range for the respective mode. While in 4-high operation the work roll is used as a CVC® plus roll, this function is assumed by the driven intermediate roll in the 18-high mode. When using this proven technology in combination with roll bending, all flatness requirements can now be satisfied reproducibly. This applies to soft IF grades as well as to austenitic stainless steels.

Figure 8: 4-stand tandem mill with changeable CVC® plus 4-high / CVC ® plus 18-high insert in stands 3 and 4.

AK Steel, USA: high-performance tandem cold mill for fine strip of carbon steel and stainless steel grades

AK Steel as leading steel producer for the car industry as well as for the electric, food, chemical and petrol industries, is known for its silicon, carbon and stainless steels.

In the mid 1990, when discussing the new cold rolling facility for the works in Rockport, USA, the major requirement was to find a solution which allows producing carbon as well as stainless steel in an economical way and at large quantities. The stainless steel production was considered for automotive exhaust systems as well as for industrial applications. Consequently the requirements regarding the appearance of the stainless steel surface were low, and emulsion could be used as lubricant.

After evaluation of different concepts, SMS Siemag won the order to supply a five stand CVC continuous tandem cold mill (CTCM) to produce both carbon and stainless steels. The mill went into operation in 1999.

Figure 9: Production facilities of AK Steel at Rockport, USA.

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The CTCM makes use of two different mill stand types. The first 3 mill stands are designed as CVC 4-high stands, which is preferable with regard to thickness control because of higher stiffness. The last two mill stands are CVC 6-high stands, offering more actuators to influence the strip flatness. Through the CVC control on the intermediate roll (IMR) as well as positive / negative bending of intermediate and work rolls it provides a wider range to adjust strip flatness. In addition, especially during flying product change, bending of the IMR allows to react fast to compensate the required adjustment of the shifting position.
As a continuous tandem cold mill, it is not limited by the process speed of the pickling line and is able to produce up to 3.6 m t/a.
This high capacity allows AK Steel to produce more than 500,000 tonnes of stainless steel per year on the mill without limitation for the required carbon steel production. It has to be considered in this context that the total reduction of stainless steel by passing the mill once is limited by the big work roll diameters. Consequently, a big portion of the stainless steel production needs to pass the mill two or three times.

Technical features:

- 5-stand tandem mill in combined CVC 4-high (stands 1–3) and CVC 6-high (stands 4-5) design
- Positive and negative work- and intermediate roll bending
- Work-roll shifting (stands 1-3)
- Intermediate-roll shifting (stands 4-5)
- DS (Dry Strip) system for a dry strip surface
- Special inline strip inspection for strips of carbon and stainless steel

Main technical data:

Material:	low carbon steel, stainless steel	Strip thickness stainless steel :	0.63 – 4.57 mm (entry)
Strip thickness carbon:	1.77 – 6.35 mm (entry)		0.30 – 2.29 mm (exit)
	0.30 – 4.04 mm (exit)	Rolling speed:	max. 1,600 m/min.
Strip width carbon:	609 – 2,057 mm	Rolling force:	max. 30,000 kN
Strip width stainless:	609 – 1,676 mm	Annual capacity carbon:	3,6 m t

Figure 10: Main technical data and features of the CTCM at AK Steel.

At the time when the mill was started up, it was one of the facilities with the highest stainless steel rolling capacity in the world.

The CVC® plus 18-HS tandem cold mill: most effective production concept for large annual production of stainless steel with excellent surface properties

Another concept to produce a large amount of stainless steel at low production cost is a tandem cold mill using the CVC® plus 18 HS mill stand type. As the work roll diameter is less than 180 mm, such a mill allows a total reduction of more than 70% per pass. As lubricant, rolling oil is used which, together with the high reduction, ensures an excellent surface quality.
In 2009, the world's first four-stand continuous 18 HS tandem cold mill (CTCM), supplied by SMS Siemag was put into operation in Asia.
The tandem mill is designed to roll strips of AISI 300 and 400 grades with a width of up to 1,350 mm and a maximum thickness of 5.0 mm down to a minimum final gauge of 0.4 mm.
Due to the slender work rolls of diameter 140/120 mm it is possible to attain extremely high reductions per pass on this mill, which in turn guarantees economical production of the annual output of 500,000t stainless steel strip. Nevertheless, for

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quality reasons, approximately a quarter of the rolling stock has to be annealed in between until being reduced to the final thickness.

The slim work rolls are supported laterally in order to absorb the strong horizontal forces. The mill is driven by the axially shiftable intermediate rolls which have a diameter of 355/330 mm. The fifth mill stand is designed as a two-high for skin-passed strip finish and adjustment of the surface quality, which is identical with the results of the route using conventional single stand reversing mills in 20-high design.

With the aid of our T-roll® process model, the plant was designed and the optimum temperature control of the rolling stock was determined. In this way, for example, it had been possible to determine suitable cooling and lubrication strategies so as to attain maximum reductions per pass under stable roll gap conditions. After the final rolling pass, the strip is cooled again in order to set a wrapping temperature of max. 100°C.

The entry section of the continuous tandem cold mill consists of the payoff reel, welding machine and horizontal strip accumulator. For the exit section, we supplied two tension reels with continuous paper feed, a drum shear and our patented and integrated "Rotary Inspect" strip inspection line. Continuous paper feed is ensured by the carrousel paper winder, including automatic paper coil change.

Rotary Inspect is a new type of inspection line which makes it possible to inspect the rolled strips in line. Compared with traditional inspection devices, Rotary Inspect has several advantages. Strip samples can be taken during a rolling speed of 100m/min. The inline inspection convinces through its ergonomic design and safety concept for reliable inspection of both strip surfaces and the high inspection frequency achieved.

Technical features:

- 4-stand tandem mill in 18 HS-design
- Axially shift able intermediate rolls (prepared for CVC® plus control)
- Positive and negative intermediate roll bending
- Extended strip cooling device
- AIO (All-in-One) modular design
- Two tension reel with carousel paper winder
- Inline inspection line

Main technical data:

Material:	Ferritic and austenitic Stainless Steel
Strip thickness:	1.80 - 5.5 mm (entry)
	0.40 - 2.0 mm (exit)
Strip width:	600 – 1,350 mm
Rolling speed:	max. 400 m/min.
Rolling force:	max. 14,000 kN
Annual capacity:	500,000 t

Figure 11: Main technical data and features of the CTCM in 18 HS design

The mill has completed an exemplary starting phase. All production specifications had been attained within the tolerances required. The daily record until now has been 1,500 tones of rolled stainless steel strip. Some requirements, e.g. the scheduled work roll changing time of 2 minutes "per set" have in fact been surpassed.

CONCLUSION

The paper describes the requirements of the steel market regarding cold-rolled high strength steel and the consequences for appropriate mill design. The portion of high strength steels on the world market, meaning both, high strength carbon steels and stainless steels, is increasing steadily.

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Considering this, beside 20-roller, 4-high and 6-high cold rolling mills, SMS Siemag extended its product portfolio by developing the CVC® plus 18 HS stand type which can be applied in reversing mills as well as in tandem cold mills. Further, as changeable insert in the multipurpose mill concept, the change between the CVC® plus 4-high mill stand type and the CVC® plus 18 HS one becomes possible during regular work roll change. This increases the flexibility of our customer and allows to adjust the cold rolling mill according to the material to be rolled and thus to be more economically efficient in producing an even wider range of steel grades.
As manifold as the market of high strength steels is, as manifold are the tailored solutions elaborated by SMS Siemag. Depending on the individual product mix and capacity, which often includes carbon as well as stainless steel to be rolled within the same mill, several interesting plant solutions are discussed in this paper.