THE IMPLEMENTATION OF HIGH PERFORMANCE SOLUTIONS FOR THE PRODUCTION OF ADVANCED HIGH-STRENGTH STEEL GRADES HOT-STRIP*

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Abstract
For the production of advanced high strength steel grades (AHSS) like API X80/X100, dual-phase, martensitic and complex-phase grades a number of hot strip mills need to extend their limits in terms of power and flexibility. Especially for cooling and coiling of these new materials, Primetals Technologies developed the “Power Cooling” and “Power Coiling” technologies. Power Cooling combines the advantages of conventional laminar cooling or “low pressure cooling” with the newly developed “high pressure cooling” with highest cooling rates for flexible operation. The Power Coiler which is needed to coil those high strength grades especially at thicker gauges ensures reliable strip-coiling for a most economical production. To enhance the reliable production of high-strength steel grades for a wide range of strip dimensions, the automation system with its advanced models is an integral part to the mechanical design. In this context the paper presents examples for the installation of power cooling and power coiling in new and modernized HSM.
Keywords: Power cooling; Power coiler; AHSS; Advanced high-strength steel; Cooling rates.

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1 INTRODUCTION

Steel producer seek to cover the market demand on AHSS (Advanced High Strength Steel) grades with high quality and in the most economic and efficient way that needs no further treatment after hot rolling. Typical driver for this market trend is the application of car parts with reduced thickness and increased strength for weight material cost savings. But also the production of even higher strength pipe grades with increased thickness on HSM is a trend which can be observed for many investment projects. Examples for such steel grades are:

- Highest strength pipe grades (API X80/X100)
- DP (Dual Phase)
- Martensitic steels
- CP (Complex Phase)

To meet those demands technologically related equipment has to be adapted or new equipment needs to be installed. This paper gives an overview in two areas of a hot strip mill, the cooling line and the downcoiler) whereas other equipment also needs to be considered and reviewed when the production is to be extended to those steel grades, for sure the capability of the crop shear, the finishing mill and the coil strapper has to be checked and also be modified.

2 MARKET – DEMAND PRODUCTION OF AHSS

The properties of produced hot rolled steels depend mainly on chemistry, rolling parameters and the cooling strategy.

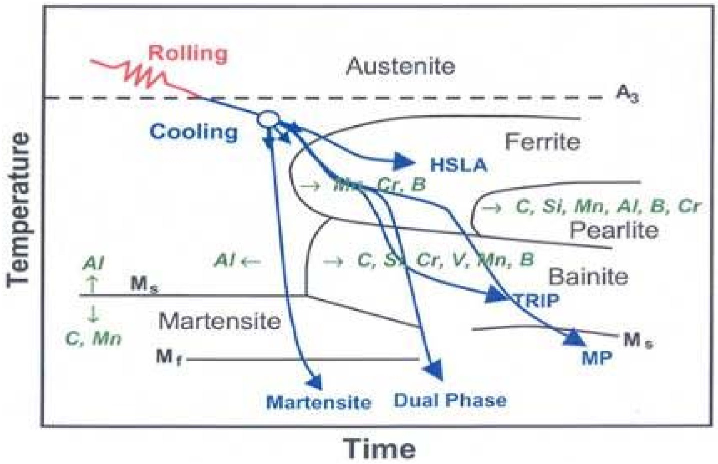

Fig. 1: Different cooling strategies (source: voestalpine Stahl GmbH)

Figure 1 shows cooling strategies for different AHSS grades. The green arrows indicate the different alloying elements and how they influence the beginning of the phase transformation. Blue arrows schematically show the cooling paths of different AHSS steel grades.

- A3: Upper transformation temperature.
- MS: Martensite starting temperature.
- Mf: Martensite finishing temperature.

Martensitic steels need a high cooling rate directly after the rolling process for the transformation of austenite to martensite [1].

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DP steels consist of martensite and ferrite, which need a transformation from austenite to ferrite and afterwards a rapid cooling to transform the remaining austenite into martensite.

For the production of pipe grades thermo-mechanical rolling needs to be applied. Preconditions for this process are:

- The thickness of the transfer bar is equal to three times the thickness of the finished strip
- The average temperature of the transfer bar before entering the first finishing mill stand needs to be between the recrystallization temperature and the temperature A_{R3}. [2]
- After the rolling process the strip has to be cooled as soon and fast as possible.

This in connection with micro alloying elements, create a finer grain structure and therefore increase the yield strength and toughness. Fig. 2 illustrates the microstructure of the pipe grade X70 at different production ways. [3]

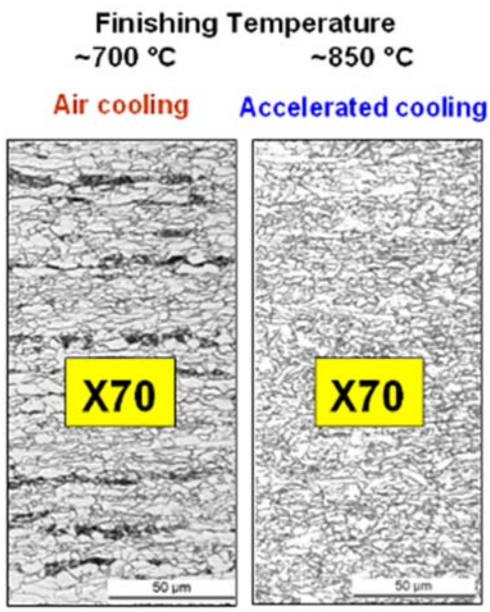

Fig. 2: Grain structure at different cooling strategies (source: Primetals)

3 IMPORTANT TECHNOLOGICAL EQUIPMENT FOR THE PRODUCTION OF AHSS

3.1 Power Cooling

To reach high cooling rates in hot strip mills and therefore fulfill the requirement of higher cooling rates Primetals Technologies developed the Power Cooling technology. Power coolingcan be applied in the early part of the cooling area of the mill as mentioned before but also between the roughing mill and the finishing mill, between the finishing mill stands and in the late part of the cooling area. This is necessary to make different production strategies possible as they are shown in Fig. 3:

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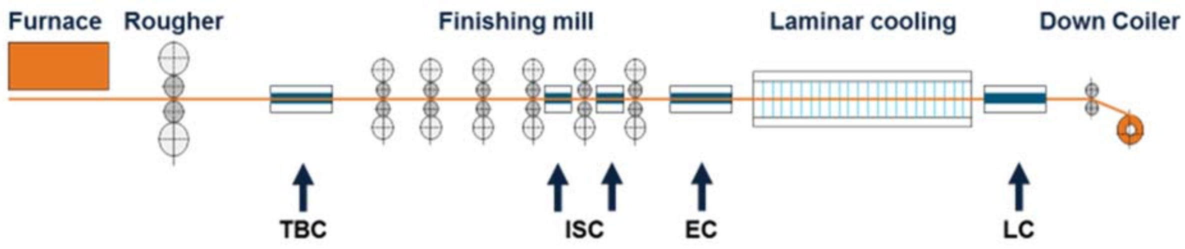

Fig. 3: Layout of a hot strip mill with different application of the Power Cooling Technology

EC – "Early cooling" is applied for API X70/X80/X100 grades with strip thickness up to 25,4 mm, 2 step cooling can be applied
LC – "Late cooling" is applied for e.g. DP, Multiphase steel grades as well in a 2 step cooling approach
The same technology can be applied to increase the productivity if installed as **TBC** – Transfer bar cooling, and/or **ISC** – Interstand cooling.

3.1.1 Implementation in new or existing plants

The power cooling unit can be implemented even into existing plants using the existing water treatment plant, tank and piping infrastructure. The power cooling units are supplied with water via a booster pump generating the required operation pressure. Additionally the pump can be by-passed. The power cooling headers are then supplied directly from the overhead tank for operation in laminar cooling mode. Thus the full operation spectrum which requires laminar cooling on the total cooling length can be kept after installation of power cooling.

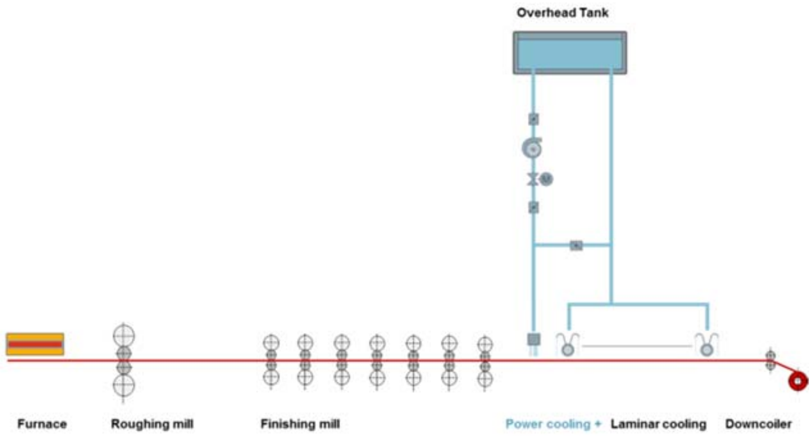

Fig. 4: Power Cooling water supply system

3.1.2 Application

The working area of the Power Cooling is not only dedicated to thick strips (> 18mm) with high cooling rates. Due to the extended control of water flow and therefor control of heat flux it is also used for strips with a critical combination of thickness-speed ratio and required cooling rates and for standard steel grades, e.g. using the power cooling in laminar mode.
The combination of Power Cooling with laminar cooling or the advanced turbo laminar cooling is a perfect solution of cooling lines which require a wide range of applications as well as for optimizing of the current or future product mix and metallurgical requirements.

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Physical characteristics of Power Cooling:

- Significantly increased cooling rates compared to laminar / turbo laminar cooling
- High heat flux rates up to 5 MW/m²
- Wide flow-rate control range for maximum metallurgical flexibility.

Table 1: Comparison of different cooling technologies

	Laminar Cooling	**Turbo – Laminar Cooling**	**Power Cooling**
Adjustment range	On/Off	25–100%	10–100%
Cooling rate Structural Steel h=6mm	~45°C/s	~64°C/s	~140°C/s
Cooling rate Structural Steel h=12.2mm	~24°C/s	~34°C/s	~74°C/s
Cooling rate Structural Steel h=25.4mm	~11.5°C/s	~17°C/s	~37°C/s

Fig. 5: Power Cooling at Wuhan Iron and Steel

Fig. 5 shows installed top cooling headers and the corresponding supply piping of the power cooling installation at Wuhan Iron and Steel in China.

3.1.3 Alloying

Power cooling opens the opportunity for the reduction of alloying costs by substitution of hardening elements using the hardening effects of higher cooling rates (Figure 6).

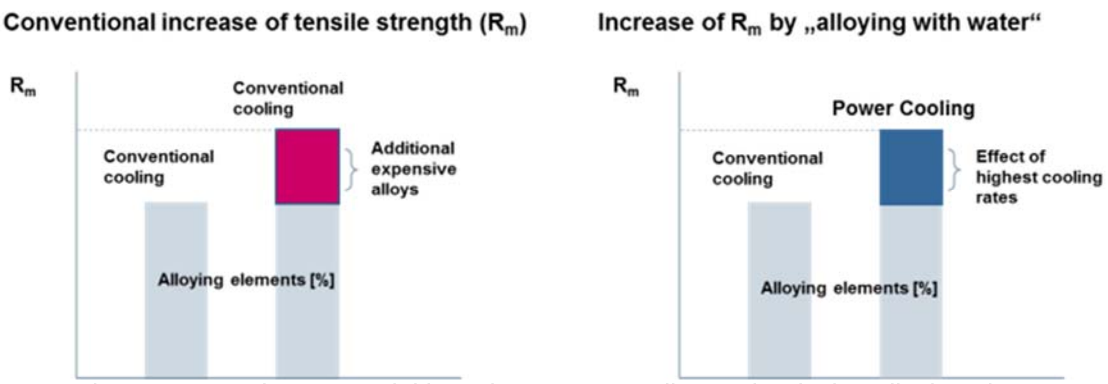

Fig. 6: Cost savings potential by using Power Cooling and reducing alloying elements

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The strength increase of the industrial installations have proven the first results based on dilatometer tests. A set of variations of alloys has been tested with different cooling rates and the grain size and hardness (HV10) have been compared.
The results for Ferro-Mn show a potential of savings of alloying costs by 66%, for Nb and Ti the potential is even up to 90%.
Using the full capability of the Power Cooling system to adjust mechanical properties can also be used for the reduction of the number of internal steel grades in the melt shop.

3.1.4 Benefits of the power cooling solution

The experience of the first installations in existing HSM can be summarized as follows:

- Considerably increased range of steel grades that can be produced

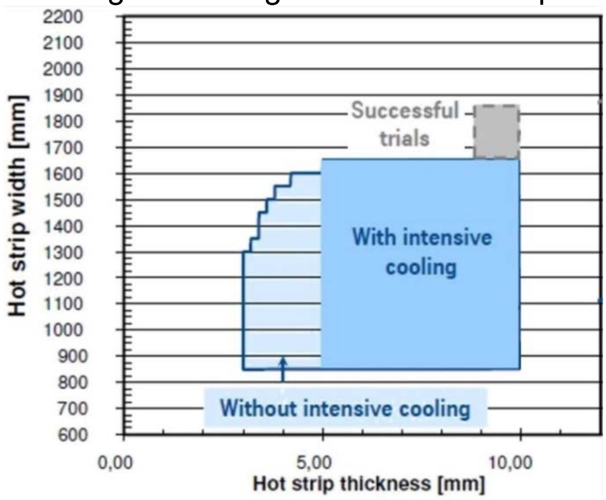

Fig. 7: Perform®700 - Dimensional spread without further heat treatment for hot strip 3,0 to 10,0 mm x 2.000 mm (source: TKSE [5])

- Access to new product niches with higher profit margins

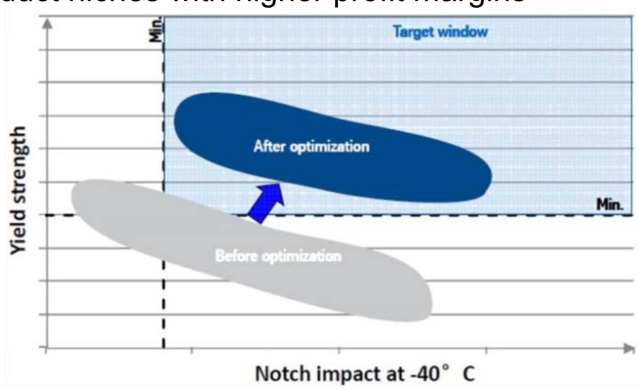

Fig. 8: Optimization of hot-strip properties for S700MC (source: TKSE [5])

- Uniform microstructure

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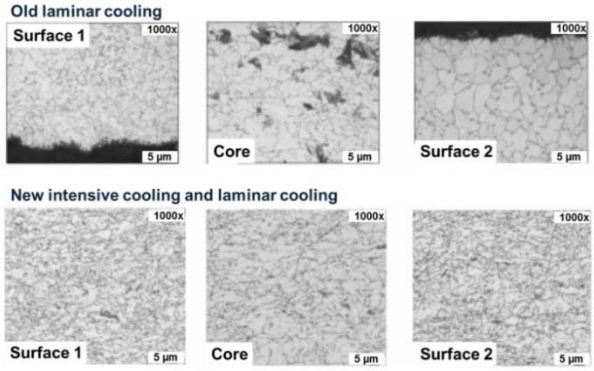

Fig. 9: Influence of Power Cooling on X70 (25,4mm) structure (source: TKSE [5])

- Lower production costs due to of reduced quantity of alloying materials required to produce AHSS

3.1.5 Comprehensive Cooling Automation with Power Cooling

A major challenge for application of Power cooling in a hot strip mill is to keep the accuracy of temperature control although the supplying water management system has to apply rise rates of water up to 10 times faster than for plants with standard laminar cooling only. This has been solved by a completely new automation strategy. The process automation computes temperatures, phase fractions and microstructure along the entire line using a comprehensive model and drives valves of transfer bar cooling, interstand cooling and cooling section, booster pump speed of water management and lead speed of finishing mill with a single comprehensive control. This results in settling times less than 2s for the entire water management system and excellent performance figures for finishing mill exit and coiling temperatures. [4]

3.1.6 Reference installations

- 16 Power Cooling headers at TKSE Beeckerwerth, Germany (2010)
- 16 Power Cooling headers at TKSE Bruckhausen, Germany (2011)
- 36 Power Cooling headers at WISCO, China (2013)
- Further upgrade to 32 Power Cooling headers at TKSE Beeckerwerth, Germany (2014).

3.2 Power Coiler

Further down the cooling line acoiling technology needs to be applied which can handle the high strenghth grades which additionally come now on thicker gauges. The main characteristics of the Power Coiler (Fig. 10) are that the coiler is capable of rolling strips with yield strengths in a range from 355 to 1300 N/mm² and thicknesses from 0.8 to 25.4 mm.

Fig. 10: Power Coiler (source: Primetals)

Three main features characterize this new coiler type:

- The use of four wrapper rolls instead of the commonly used three (Fig. 12) reduces the friction between the incoming strip and the coiler aprons because of shorter distances between the wrapper rolls.
- The initial wrapper roll is designed as a twin-type unit. This serves the purpose of bending and pushing the strip around the mandrel.
- Pre-bending of the strip at the pinch roll unit is applied before the necessary tension between the pinch roll and the mandrel is built up (see Fig. 11). The reason behind is to make it easier to wrap the incoming strip around the mandrel without considerably increasing the power of the downcoiler drives. Further the controlled hold down roll improves the coiling behaviour at the head and tail end of the strip. The pre-bended tail end creates a kind of shell counteracting the spring back phenomena.

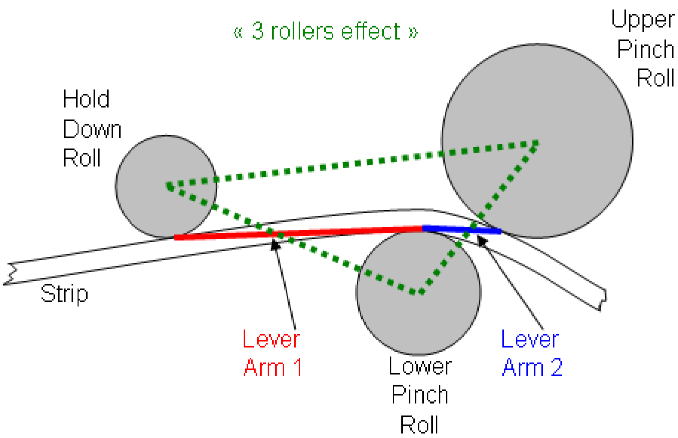

Fig. 11: Pre-bending and pinch roll unit (source: Primetals)

These features and difference in the design compared to the conventional three wrapper roll downcoiler create process conditions at the coiling start that make it possible to have a cooled head and tail end to ensure uniform strip conditions in the sense of mechanical properties also for high strength / high thickness steel grades.

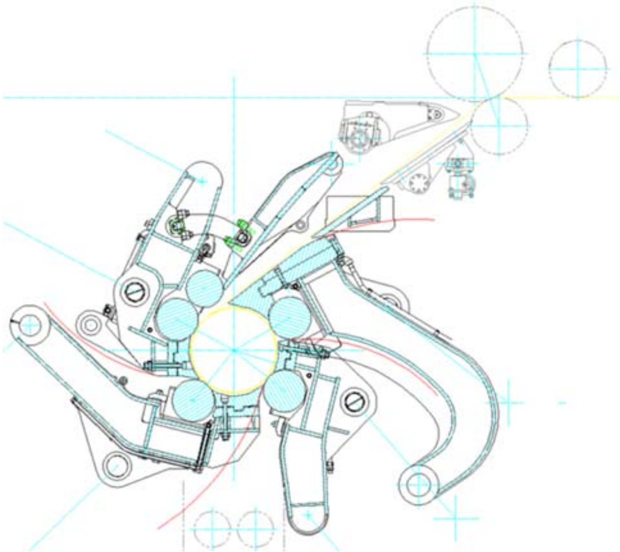

Fig. 12: Schematic design of the Power Coiler

Selected reference installations out of 27 in total

- 1 Power Coiler @ ArcelorMittal Fos-sur-Mer, France (2006)
- 2 Power Coiler @ ArcelorMittel, Poland (2007)
- 1 Power Coiler @ Welspun, India (2009)
- 2 Power Coiler @ Severstal, Russia (2011)
- 1 Power Coiler @ ArcelorMittal Indiana Harbor, U.S.A. (2011)
- 2 Power Coiler @ ATI Allegheny Ludlum, U.S.A. (2013)

4 CONCLUSION

To produce advanced high strength steel grades two technologies are of main importance.

1. Intensive Cooling is necessary for highest cooling rates and cooling accuracy, to reach the required microstructure, yield strength and toughness.
2. Power Coiler: This technology is necessary to coil high strength / high thickness materials

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