Maximizing Efficiency, Quality and Metallurgical Flexibility in Hot Strip Mills With Power Cooling Technology

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ABSTRACT

Primetals Technologies has introduced an innovative strip cooling technology for hot strip mills, known as Power Cooling. This technology leverages increased impact pressure to achieve significantly higher cooling rates, which are essential for producing modern steel grades with enhanced mechanical properties at reduced material costs. The primary cost savings result from the reduced need for expensive alloying elements, made possible by the higher cooling rates.

This paper describes the Power Cooling technology, its application in various positions within a hot strip mill, and the benefits it offers for different production strategies. Key applications include early and late cooling, transfer bar cooling, and immediate cooling, each supporting specific production goals such as increased productivity, improved microstructure, and reduced alloying costs. A significant benefit of transfer bar cooling is the reduction in waiting time for the transfer bar to cool below the recrystallization stop temperature (RST) for rolling in the finishing mill. This can significantly increase productivity of the hot mill, especially for thick thermo-mechanically rolled products.

A notable feature of Power Cooling is its potential capability to produce hot rolled Quenched and Partitioned (Q&P) steels, part of the third generation of AHSS. The high cooling rates, coupled with precise strip temperature control provided by Power Cooling, are crucial for the hot rolling process of Q&P steels. This process facilitates the development of a microstructure that offers an optimal balance of strength, ductility, and toughness.

The Power Cooling system incorporates advanced automation models that ensure precise temperature control and optimal cooling strategies. These models include comprehensive temperature control and a microstructure monitor, which are crucial for maintaining the desired metallurgical properties and achieving consistent product quality.

This technology meets current market demands for high-strength materials and positions steel producers to capitalize on future metallurgical requirements.

Keywords: Strip Cooling, Run-out table Cooling, Power Cooling, Intensive Cooling, Pressurized Cooling, Transfer Bar Cooling, Interstand Cooling, Immediate Cooling, Early Cooling, Late Cooling

INTRODUCTION

The run-out table in a hot strip mill is responsible for cooling the hot rolled strip with water as it moves on a bed of rollers from the finishing mill to the down coiler, ensuring the strip reaches the desired temperature and quality before coiling (see Fig. 1). Laminar Cooling is a fundamental strip cooling technology for hot strip mills, aimed at achieving controlled, uniform cooling with water after finishing rolling to influence phase transformation, microstructure, and adjust the mechanical properties for further processing or the final product. Turbo Laminar Cooling is an advanced technology that enhances traditional laminar cooling by providing intense strip cooling with high-capacity cooling headers.

However, when attempting to improve metallurgical properties in the cooling section, existing cooling equipment in hot strip mills often reaches its limits. To address this, Primetals Technologies has introduced a new strip cooling technology called Power Cooling. This technology employs pressurized cooling with increased impact pressure to break the water/steam layer on the strip surface, achieving higher heat transfer rates for enhanced cooling power. Power Cooling is a superior technology and a further enhancement of turbo laminar cooling, applying the highest cooling rates for the flexible production of advanced high-strength steels (AHSS).

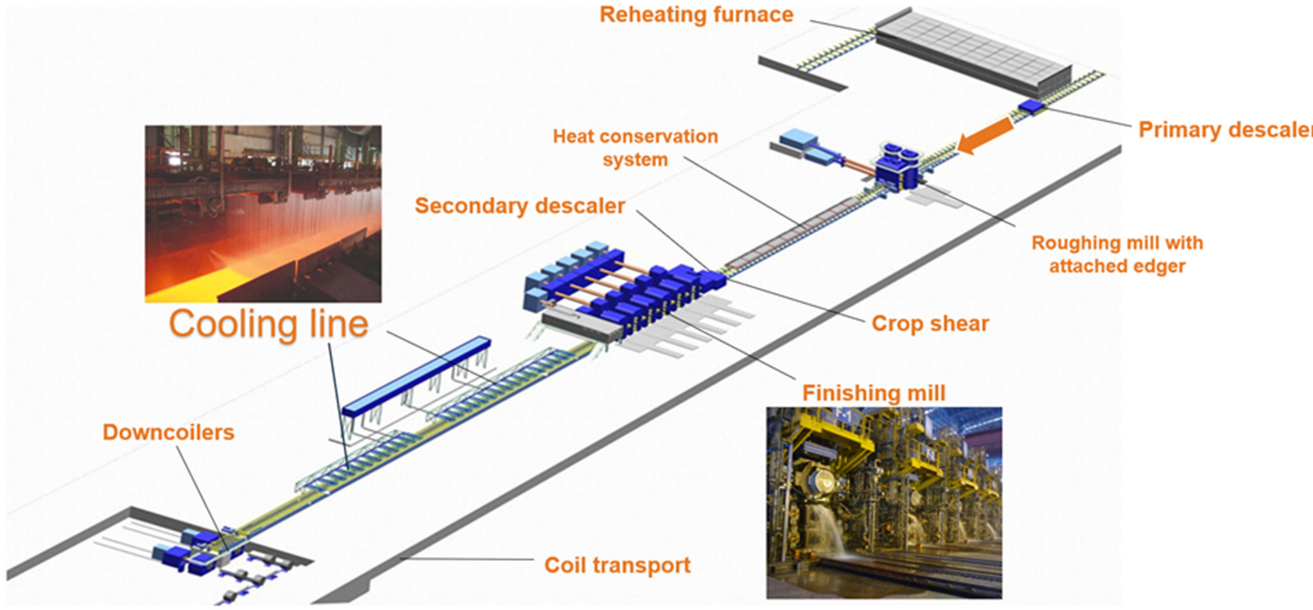

Figure 1: Hot strip mill with run-out table cooling

Steel producers aim to meet the market demand for AHSS (Advanced High Strength Steel) grades, such as Dual Phase (DP), Martensitic steels, and Complex Phase (CP), by delivering high-quality products in the most economical and efficient manner, eliminating the need for further heat treatment after hot rolling. This market trend is primarily driven by the automotive industry, which uses these steels to manufacture car parts with reduced thickness and increased strength, contributing to lightweight car designs. For HSLA (High Strength Low Alloy) steel grades, the demand is driven by the oil and gas industry, which requires higher strength pipe grades (API X80/X100) with thicknesses up to 1 inch.

The microstructure of 3rd generation AHSS consists of martensite and austenite, providing an excellent combination of strength, ductility, and toughness. New research focuses on developing processes to produce Quenched and Partitioned (Q&P) Steels in a hot strip mill, which are part of the 3rd generation AHSS. These grades necessitate advanced cooling technologies, such as Power Cooling, which offer high cooling rates and precise temperature control to achieve a homogeneous microstructure with the desired phase fractions. The process begins with quenching austenite to a temperature between the martensite start (MS) and martensite finish (Mf) temperatures. This is followed by a partitioning treatment, which results in carbon diffusion from carbon-rich martensite into the retained austenite (RA), stabilizing the RA until room temperature.

MARKET DEMAND FOR PRODUCTION OF AHSS AND SAVING OF ALLOYING ELEMENTS

The mechanical properties of hot rolled strips depend strongly on their chemistry and microstructure. The major factors of influence on strength, ductility and toughness of the material are mixed crystal strengthening, grain refinement, content of non-equilibrium phases as well as size and amount of precipitates.

In order to arrive at the desired properties of the final product careful choice of the time-temperature deformation path in the hot strip mill is a must. This includes proper thermomechanical treatment during deformation steps at the roughing and finishing stage as well as the proper cooling strategy at the run-out table.

Fig. 2 depicts schematically the different cooling courses for various types of AHSS grades. It also shows the influence of major alloying elements on the γ->α phase transformation kinetics. Virtually all important alloying elements delay the transformation from austenite to ferrite, pearlite and non-equilibrium phases.

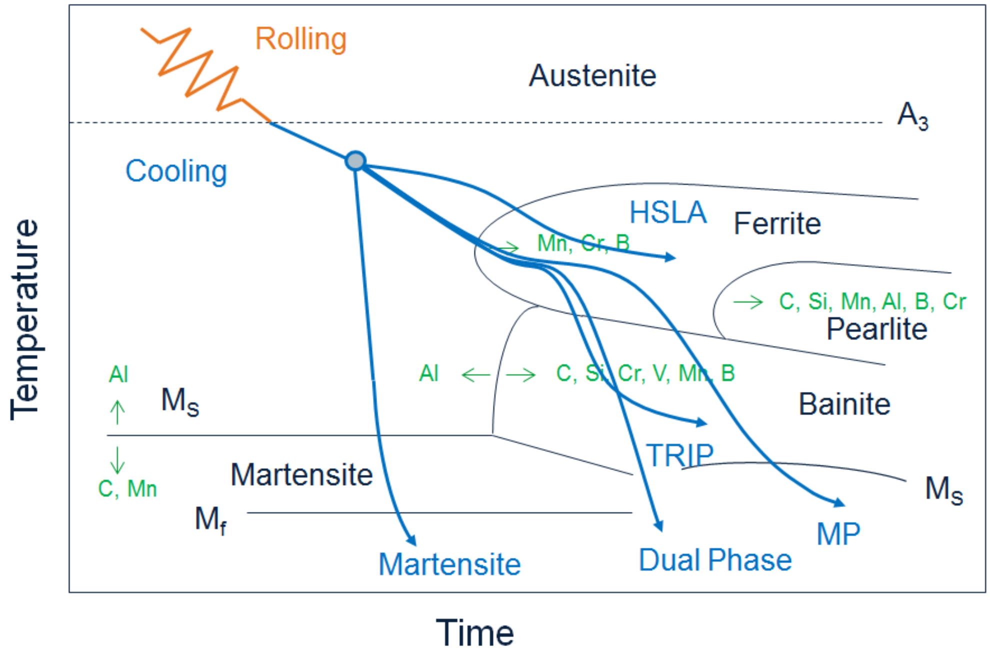

Figure 2. Typical run-out table cooling strategies (source: voestalpine Stahl GmbH). A3: Upper transformation temperature, MS: Martensite starting temperature, Mf: Martensite finishing temperature.

Martensitic steels need a high cooling rate directly after the rolling process for the transformation of austenite to martensite. Dual Phase (DP) steels consist of martensite and ferrite, which need a partial transformation from austenite to ferrite and afterwards rapid cooling to transform the remaining austenite into martensite. The phase transformation must be well controlled, because the influence of the amount of ferrite and martensite on material properties is very strong.

For the production of pipe grades thermo-mechanical rolling with certain process preconditions needs to be applied: (i) the thickness of the transfer bar is approximately three times the thickness of the finished strip, (ii) the average temperature of the transfer bar before entering the first finishing mill stand needs to be between the non-recrystallization temperature and the temperature A3 [1] and (iii) after the rolling process the strip has to be cooled as soon and fast as possible.

This, in connection with micro alloying elements, creates a finer grain structure and therefore increase the strength and toughness. The microstructure of a pipe grade X70 for different production ways is shown e.g. in [2] or [3] (see Fig. 3).

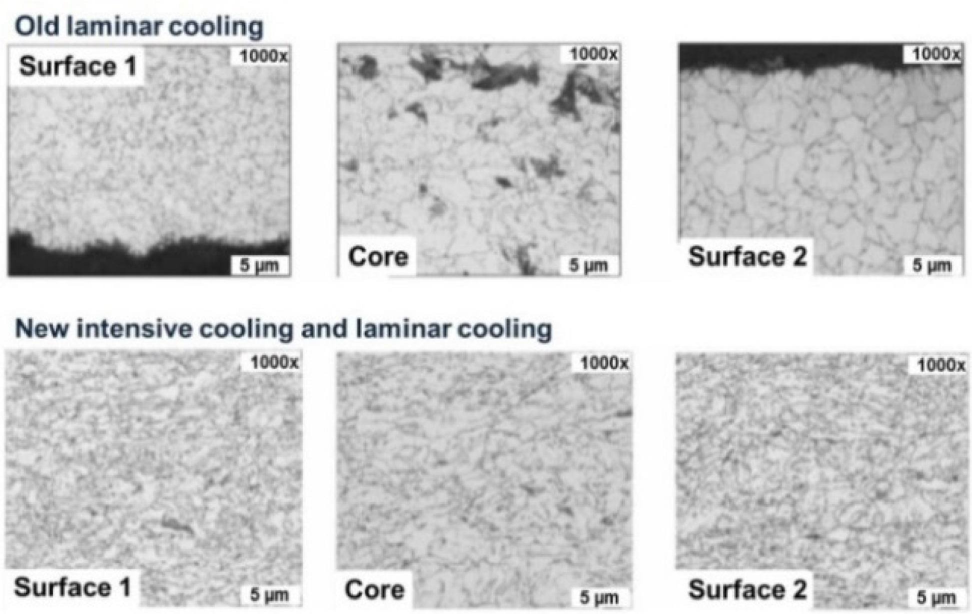

Figure 3. Influence of Power Cooling on X70 (25.4mm) structure (source: TKSE [3]).

Power Cooling opens the opportunity for the reduction of alloying costs by substitution of hardening elements using the strengthening effects of higher cooling rates (see Fig. 4).

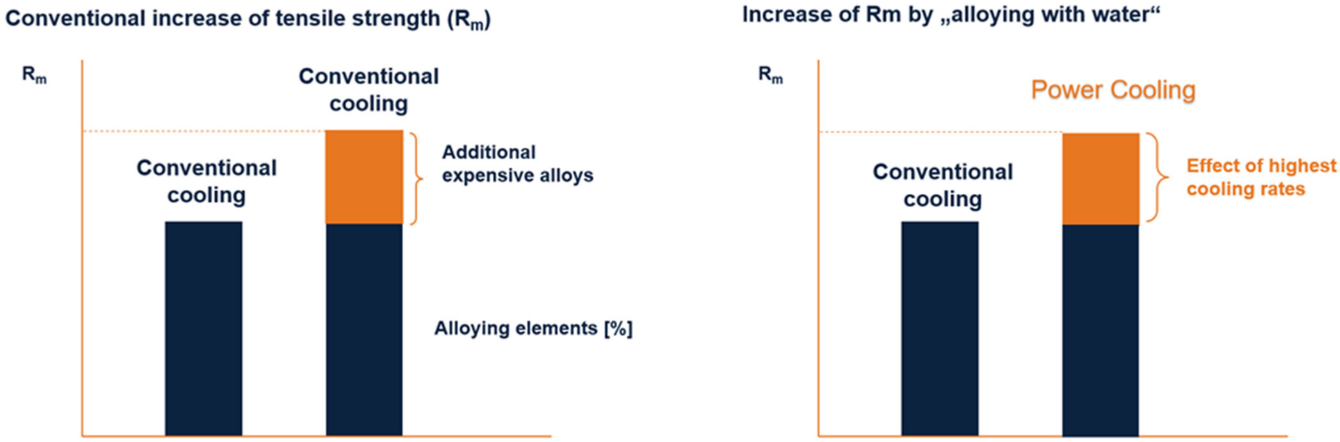

Figure 4. Cost savings potential by using Power Cooling and reducing alloying elements.

The strength increase of the industrial installations has 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.

The experience of the first installations in existing hot strip mills are (i) considerably increased range of steel grades that can be produced, (ii) access to new product niches with higher profit margins, (iii) uniform microstructure and (iv) lower production costs due to reduced quantity of alloying materials required to produce AHSS. These benefits were achieved already at the first industrial installation at TKSE in 2010 ([3]).

POWER COOLING

Rapid cooling of the material ensures better and more uniform metallurgical properties and thus increases the quality of the hot rolled strip. Primetals Technologies developed the Power Cooling technology to reach high cooling rates in hot strip mills and thus fulfill the respective requirement.

The main idea of Power Cooling is to use an increased operation pressure to achieve higher impact pressure. This breaks the insulating water vapor layer which is generated during cooling on the surface of the hot rolled strip – known as Leidenfrost effect – and ensures that further cooling water reaches directly the strip surface for enhanced heat transfer and cooling power. Booster pumps generating the required operation pressure supply the Power Cooling units with pressurized water. Due to its extraordinarily high cooling capacity Power Cooling provides the means to sharply control the microstructural evolution within very short lengths.

Power Cooling can be applied at different locations in a hot strip mill supporting different production strategies and benefits (see Fig. 5). "Early Cooling" represents a Power Cooling application in the early part of the cooling area just after the finishing mill supporting a rapid first stage cooling for the production of AHSS. In order to increase mill productivity or to support ferritic rolling, Power Cooling can also be applied between the roughing mill and the finishing mill. This "Transfer Bar Cooling" unit can be equipped with water crown control on both sides of the transfer bar to compensate a non-uniform temperature distribution or a temperature wedge. "Interstand Cooling" also supports an increase of mill productivity and is applied between the finishing mill stands which elongates the cooling line towards the finishing mill for example for the production of thick pipe grades. "Immediate Cooling Power Cooling" directly after the last finishing stand facilitates up to 50ºC temperature drop with the benefit to reduce the time between last rolling stand and first cooling header and thus to produce a very fine grained structure, e.g. for thermo-mechanical rolled products (HSLA / API) and AHSS (CP / MP). "Late Cooling" becomes more and more important for producing new steel grades, particularly multi–phase steel, which requires an interrupted cooling strategy combined with sufficiently high cooling rates during the final cooling stage. The main benefit of Late Cooling is to achieve smaller tolerances of the coiling temperature (< 550°C) for grades such as, e.g., hot-rolled DP steel.

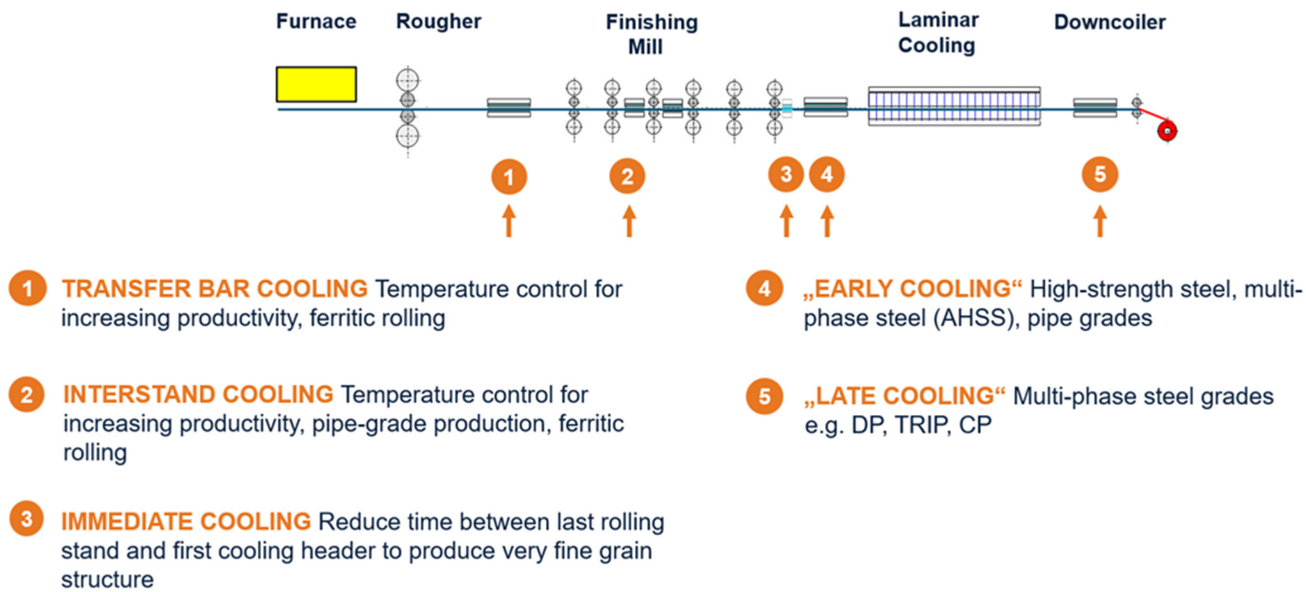

Figure 5. Layout of a hot strip mill with different applications of the Power Cooling Technology.

Compared to laminar / Turbo laminar cooling installations Power Cooling shows significantly higher specific water flows resulting in heat fluxes up to 5 MW/m² and cooling rates close to the theoretical limit given by strip dimension, heat capacity and heat conductivity of the steel (see Fig. 6), while maintaining a wide control range for applicable flow rates to account for maximum metallurgical flexibility. The difference between laminar cooling and Turbo laminar cooling is characterized by an increased cooling capacity of about 50%. This is achieved by using 4 rows of U-tubes for Turbo laminar cooling and associated higher cooling rates as compared to 2 rows of U-tubes for standard laminar cooling (see Fig. 6).

	Laminar Cooling	Turbo Laminar Cooling	Power Cooling
Adjustment Range	On / Off or 25 – 100%	25 - 100%	**10 - 100%**
Typical Spec. Flow Rate [l/(min*m²)]	860	1450	**2900**
Cooling Rates Structural Steel; h = 6 mm; 900°C → 600°C	45 °C/s	64°C/s	**140 °C/s**
Cooling Rates Structural Steel; h = 12.2 mm; 900°C → 600°C	24 °C/s	34 °C/s	**74 °C/s**
Cooling Rates Structural Steel; h = 25.4 mm; 900°C → 600°C	11.5 °C/s	17 °C/s	**40 °C/s**

Figure 6. Comparison of cooling rates for different cooling technologies.

Power Cooling is not only designed to be applied to thick strips (> 12 mm) with high cooling rates. Due to the extended control of water flow and therefore 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 Turbo laminar cooling is a perfect solution for cooling lines which require a wide range of applications as well as for optimization of the current or future product mix and metallurgical requirements.

Applied to steel grade development Power Cooling technology gives the opportunity to use leaner chemistries and thus significantly contributes to higher profit margins.

Customized Cooling Line Solution - Implementation Into New or Existing Plants

Power Cooling can be implemented into new plants or existing plants using the existing water treatment plant, tank and piping infrastructure. If switched to Power Cooling mode, for each strip the desired pressure is derived from the cooling rate needed just a few seconds before the strip enters the cooling line. This is possible because pumps are frequency controlled.

As depicted in Fig. 5, Power Cooling headers can be installed at various positions within the hot strip mill. In addition, also the selection of electric and mechanic equipment will be highly customized to the customer's needs. For instance, application of the so-called "Power Cooling light" concept means that the intensive cooling system is operated without booster pumps by direct feeding from the overhead tank (see Fig. 7). The solution is characterized by comparable flow rates as conventional Power Cooling due to larger nozzle size. However, the proven conventional Power Cooling header design is used as well as accurate flow control valves. Cooling rates of about 80% of the conventional Power Cooling are achievable and the system can later be upgraded to a conventional Power Cooling system by installing a booster pump station and the required interconnecting piping and by exchanging the spray nozzles.

Alternatively, especially for transfer bar cooling installations, a novel concept using decentralized booster pumps is offered. The advantages are on the one hand the lower investment costs for smaller booster pumps compared to larger ones and on the other hand faster response and improved accuracy due to the individual booster pump solution for each valve.

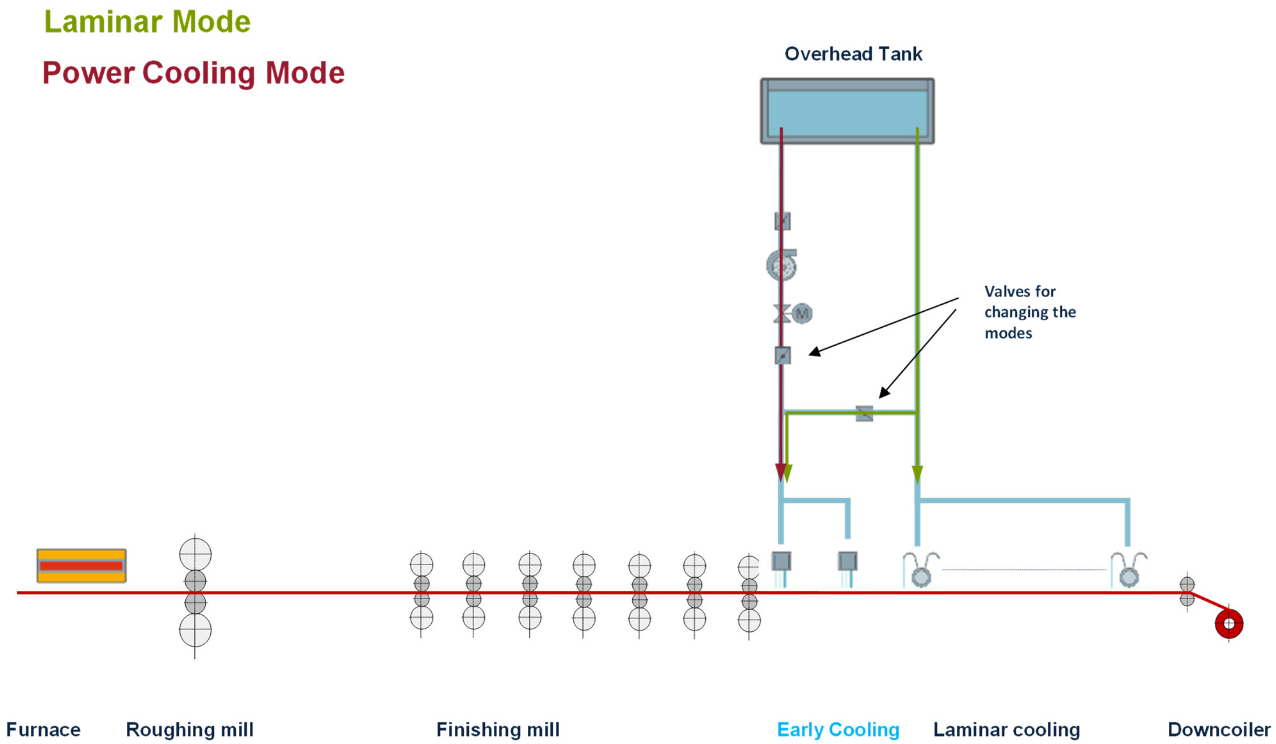

Figure 7. Power Cooling water supply system (strip cooling from bottom side is not shown).

Reference Installations

- ThyssenKrupp AG, Beeckerwerth, Germany (2010, 2014)
- ThyssenKrupp AG, Bruckhausen, Germany (2013)
- Wuhan Iron and Steel Co., Ltd., China (2014)
- TATA Steel Port Talbot, UK (2018)
- Severstal Cherepovets, Russia (2019)
- ArcelorMittal Dofasco, Canada (2020)
- Rizhao Steel Holding Group Co., Ltd., Arvedi ESP Line No. 5, China (2021)
- ArcelorMittal Lázaro Cárdenas, Mexico (2021)
- United States Steel Corporation, Arvedi ESP Line, Osceola, AR, USA (2024)
- Undisclosed Customer, Arvedi ESP Line, Middle East (2025)
- United States Steel Corporation, Gary, IN, USA, 2026

Power Cooling Installation at WISCO's HSM No. 2 in Wuhan, China
With the installation of "Early Cooling" – Power Cooling immediately after the finishing mill, the Chinese steel producer WISCO entered the AHSS market successfully.

Technical description of the equipment: The Power Cooling unit behind the finishing mill consists of 36 top and 36 bottom headers with a maximum total water flow of about 14,000 m^3/h and an installation length of ~16m. Each top header corresponds to one bottom header. The Power Cooling headers are equipped with solid jet nozzles to ensure maximum possible impact pressure. In Power Cooling mode a pressure of 3 bar is achieved at the nozzle compared to 0.8 bar (and 7200m^3/h flow) otherwise.

Each pair of two top or two bottom Power Cooling headers features a pneumatically actuated on/off valve, an electro- pneumatic flow control valve, a manually operated valve and a pressure transducer. For ventilation every top header is equipped with an automatic air venting valve. To calibrate each flow control valve, a flow measurement is integrated in a by-pass piping system. As mentioned above two headers are controlled by one pneumatic flow-control valve, which enables a wide control range of the flow rate. Because of the special design of the equipment, it is possible to reduce the flow rate for the Power Cooling headers to as low as 7 % of the nominal flow.

The cooling section modernization included the installation of a new overhead tank. When extremely high cooling rates are required for some of the most critical products, it might happen that the overall flow rate required for cooling temporarily exceeds the supply to the tank. Since the tank is used as a buffer in this case, the total flow rate of the cooling water from the well to the tank could remain unchanged. The water tank level is measured, and the automation model is provided in real time with this measurement. Due to infinitely adjustable valves, the process model fully compensates for supply pressure fluctuations without any visible changes of water flow rates.

As for measurement a water-free strip surface is needed, specially designed cross sprays are arranged between the gauge house and the first cooling header of the cooling section. Additional air sprays are installed at the same position to blow off the rest of the water and dry the surface.

Fig. 8 and Fig. 9 show the installed top cooling headers and the corresponding supply piping of the Power Cooling installation at Wuhan Iron and Steel in China.

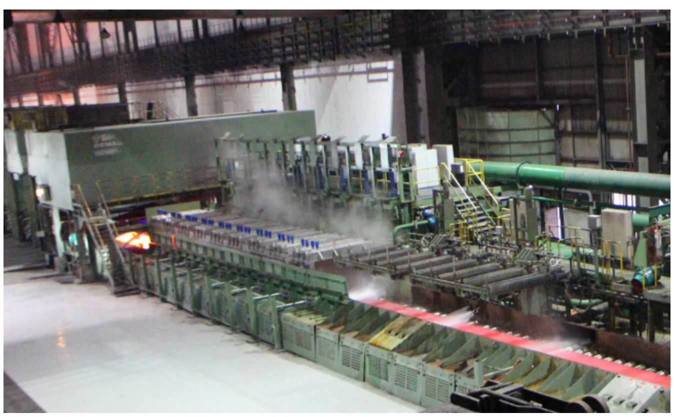

Figure 8. Power Cooling at Wuhan Iron and Steel.

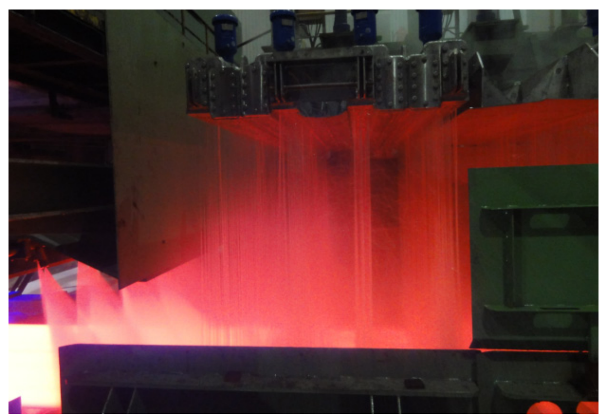

Figure 9. Power Cooling headers and sweep sprays in operation

Comprehensive Model with Power Cooling
Power Cooling of enhanced material cannot be controlled with a process model as described in [5] anymore without major loss of accuracy and production capability. The following challenges need to be solved:

- Water needs to be provided with huge acceleration rates, as shown by the following example: A 4mm thick strip passing the 16 m long Power Cooling unit with 11 m/s head speed shall be cooled with maximum possible water quantity at full pressure. Assume that a desired uncooled strip head with a certain length does not allow to switch any water in advance. Then 16,200 m^3/h water need to be switched on within 1.54 s with high precision, resulting in an acceleration of 2.9 m^3/s^2.
- A conventional cooling model starting computations at the pyrometer installed behind the finishing mill would not work properly. Booster pumps and valves of the Power Cooling unit would be activated too late.

- Phase transformation is crucial for material properties, especially when power cooling is applied. The pass schedule of the finishing mill has a major influence on phase transformation speed in the cooling section and thus needs to be considered as well.
- A lot of strips are cooled using mainly the Power Cooling device. Any material that has already passed Power Cooling cannot be corrected afterwards if the finishing mill changes speed to correct deviations of the finishing mill temperature from its target. Many steel grades are affected here. As an example, pipe grades cooled with high cooling rates to some low target temperature do not allow further cooling with laminar valves to trim the coiling temperature. Therefore, a model predictive controller of the cooling section needs an accurate speed diagram of the finishing mill train up to 60 s in advance.

Hence, a completely new comprehensive automation strategy was developed to ensure high accuracy of the temperature control. Details and first results are described in [6]. This newly developed process automation allows for excellent performance figures for both finishing mill and coiling temperature, respectively, by controlling the cooling section and the rolling speed in the finishing mill simultaneously.

In this paper, we focus on the also necessary control of water management.

The cooling model is supplied with the valve characteristics of all participating valves as well as with the characteristics of the booster pumps and supply pumps. Beside the temperature also pump speed and water pressure must be controlled precisely in real time. Fig. 10 and Fig. 11 show results from booster pump control.

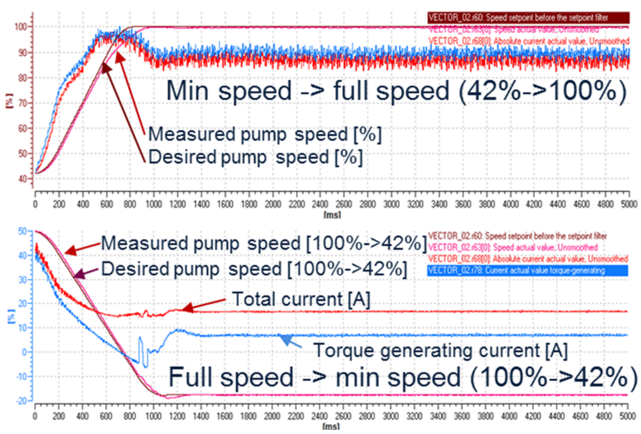

Figure 10. Converter step response results.

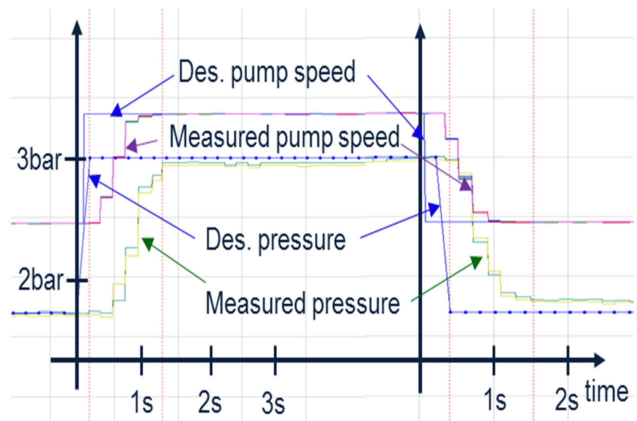

Figure 11. Step response of pressure control.

Fig. 10 shows the step response on desired pump speed, recorded using STARTER on the SINAMICS converter. Vector control has been applied to control the speed of the asynchronous pump motors to ensure high dynamics and accuracy of speed control. The pumps follow a ramp with a delay of less than 0.1 s. Acceleration from minimum speed to full speed or deceleration from full speed towards minimum speed are realized within 1 s.

Figure 11 shows pressure control results of the entire process automation system. All 36 Power Cooling valves are fully opened in this example. The step response for desired pressure from minimum pressure of 1.6 bar to almost maximum pressure of 3 bar is shown. The figure shows that the entire pressure control is as fast as valves of a laminar cooling section can open; measured pressure reaches the target value within less than 1.2 s and stays there with an accuracy better than 0.1 bar.

Comprehensive control of water management and cooling temperature works as described below. The process model predicts future temporal trajectories for enthalpies, temperatures and phase fractions for respective strip points of the passing material every 200 ms. In a second step, the amount of water is determined that needs to be switched for every valve. Thus, the necessary amount of water to be applied to the strip is known, depending on time, for every valve. In a series connection of pumps and valves, water flowing through the valves needs to be pumped by the water management system at the same time. The model balances the entire water that is needed, valve amplitudes and derives the actual pump speed. The underlying computation considers limits of the water management system (such as minimum and maximum amount of water per pump) and determines a solution with optimum energy consumption of the pumps. Then set-points for pump speed and valve amplitudes are sent to the basic automation with a single set-point telegram. This procedure is repeated every 200ms, forming a real time control.

This real time approach allows for highest possible dynamics of water management control. There is no loss of speed and performance even if strips are cooled that enter the Power Cooling with 11m/s strip speed and need to be cooled with full power.

Hereafter, production of an 18mm-thick strip of grade X100 is described exemplarily.

The target value for the coiling temperature was 350°C, cooling rate and amount of water was almost at full power. A snapshot of the strip leaving the Power Cooling is shown in Fig. 12. The computed strip temperatures at this time are depicted in Fig. 13.

Figure 12. Power Cooling machine with cross sprays.

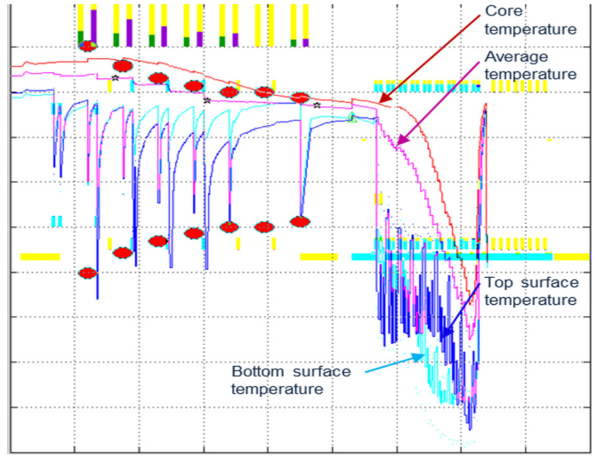

Figure 13. Computed temperatures for X100.

At WISCO hot strip mill no. 2, the new L2 cooling process automation system has been integrated into the existing system, and a new L2 process computer together with a Simatic basic automation was installed. Before shutdown, the new L2 model has been configured with the existing laminar cooling mechanics and has been tested in so-called shadow mode. During the shutdown period, the configuration was changed to fit the new mechanical layout. New sensors were installed and connected. Two days before startup, valve characteristics and characteristic curves of pumps were measured, and valve flow was calibrated.

On the day of startup, the production started with conventional laminar cooling. For this first step, the Power Cooling unit was used in laminar mode, and the Power Cooling unit was operated in a way that the cooling rate was the same as with the old laminar valves which had been removed. This way, the entire production could be continued without changes on material properties. Performance and number of produced strips with the new system were similar to the period before from the very beginning.

Two weeks after startup, the Power Cooling unit was used in pressure mode for the first time, and the first strips were produced with high cooling rates.

Today, WISCO is using pressure mode for their entire production with great success. All strips previously cooled in laminar mode are meanwhile cooled with booster pumps in quasi-laminar mode, i.e. in pressure mode with lowest possible desired pressure. This procedure makes sense for modernizations, where some production shall remain practically unchanged. Pure laminar mode is not used anymore. Higher cooling rates can be easily adjusted where needed just by selecting the appropriate primary data (before the strip enters). In other words, there is no restriction regarding production schedule even though 40 s would be required for changing from laminar mode to power mode and vice versa. Handling is as easy as with the laminar cooling device before.

Power Cooling as Transfer Bar Cooling - Installation at TATA Port Talbot, UK

With the installation of "Transfer bar cooling" – Power Cooling behind the roughing mill, TATA steel has achieved a considerable increase of productivity in its Port Talbot hot strip mill [4].

The transfer bar cooling system was commissioned and brought into industrial operation until June 2018 (see Fig. 14 and Fig. 15). Initial commissioning took place using scrap slabs. This was to assess the functionality and control of the transfer bar cooling system, without risking compromises to the product (albeit with a necessary production interruption). The next phase was characterized by formal product trials on slabs of specific chemical compositions. These were non-production slabs cast specifically for this purpose. These product trials confirmed no unintended consequences (to final properties, or other) associated with transfer bar cooling, prior to production use. Then there was a further stage: small 'test' batches of live production orders (with transfer bar cooling in use) destined for further processing at other Tata production facilities before delivery to the final customer. This facilitated further testing and analysis at downstream units.

Figure 14. Transfer bar cooling in industrial operation.

Figure 15. Homogeneous and effective water application of transfer bar cooling system.

All the above was done on a step-by-step basis for each category of product in the portfolio, prior to approval to use transfer bar cooling as a 'business-as-usual' production tool. This was time-consuming, but safe for the customer. The first product approved by metallurgists and technical managers for routine use of transfer bar cooling in production was in week 19, 2018. In March 2019, some 94% of the product mix makes use of transfer bar cooling.

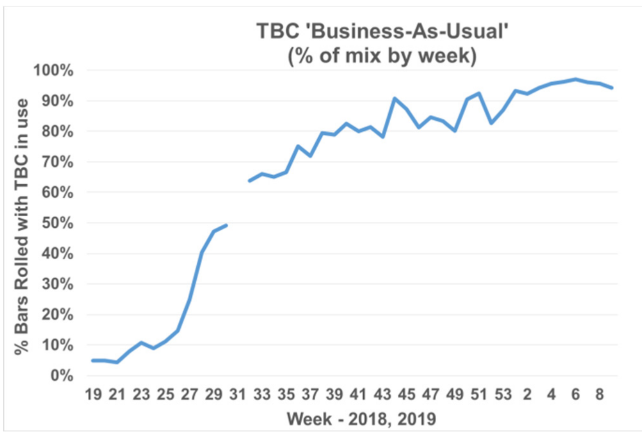

Figure 16. Transfer bar cooling is used for 94 % (March 2019) of the total production at Tata Steel Port Talbot.

Future Improvements on Water Management Control

With the approach described above, 1-2 s settling time can be achieved as a typical speed of water management control. In other words, settling of water management control is possible within the typical delay time of switching valves (also in a laminar cooling device). Nevertheless, especially for transfer bar cooling, even lower settling times would be beneficial. This becomes obvious when looking at a typical mass flow of the transfer bar. Skid marks can be compensated by the Power Cooling device behind the finishing mill train, where a typical material flow is 40 mm·m/s. This is hard with a settling time of 1-2 s in the transfer bar cooling device, where typical material flows are up to 200 mm·m/s or even higher. In this situation, a faster control, e.g. with settling times of 0.5 s or even less would be advantageous.

This can be achieved by reducing the size of the booster pumps. Using many small pumps, e.g. pumps driven with 20 kW power, each pump driving a single cooling header, the settling time of pressure control can be significantly below one second. The electrical motor driving the pump will receive a set-point every 200 ms, and due to smaller masses to be accelerated, it will easily settle to that set-point within the sampling time. Pressure control will result in an individual entry pressure for each header of the Power Cooling device, meaning that most of the time the valves stay at 100% open and target flow for each header is controlled by driving only the pump speed. Consequently, energy consumption of the Power Cooling device will be further reduced, and dynamics of control will be outstanding, making it possible to reduce skid marks even when applied for cooling a transfer bar.

The novel approach is advantageous from a construction point of view as well. Instead of booster pumps with 400 kW power and according converters and piping (installation of pipes e.g. for 17000 m3/h flow required), smaller standard equipment can be used and possibly connected to existing water management system. Then higher dynamics combined with lower energy consumption is possible with even lower costs of installation. This makes Power Cooling a very strong concept for the future.

CONCLUSIONS

Power Cooling technology, developed by Primetals Technologies, is an innovative solution for both new and existing hot-strip mills. It enables the production of high-strength low-alloy steels by achieving the highest possible strip-cooling rates at the run-out table. This is accomplished by applying pressurized coolant to the top and bottom surfaces of the strip, breaking the insulating water vapor layer (Leidenfrost effect) and ensuring enhanced heat transfer and cooling power.

The cooling capabilities of existing hot strip mills are often insufficient to achieve the high cooling rates required for producing new steel grades with higher strength and larger strip thickness. Power Cooling equipment addresses this limitation by using higher operation pressure, which increases the impact pressure and heat flux. This allows for the adjustment of high cooling rates, resulting in a superior microstructure.

"Transfer Bar Cooling" and "Interstand Cooling" enhance throughput in thermomechanical rolling, while "Early Cooling" and "Late Cooling" positions address the austenite-ferrite and austenite-bainite/martensite transformations on the run-out table (ROT) with the smallest possible wet zone length. Additionally, using Power Cooling in the "Late Cooling" section enables stable operation near the Leidenfrost region, which is increasingly important for DP and TRIP steels.

With a comprehensive cooling automation system, it is possible to apply even the highest cooling rates without any loss of temperature performance. Consequently, Power Cooling can be implemented as easily as a standard laminar cooling device, with no further restrictions limiting production.

The benefits of Power Cooling include maximized metallurgical flexibility through a wide adjustment of cooling rates. It helps save operation costs by "alloying with water," reducing the need for alloying elements through higher water-cooling rates. Numerous operating references clearly demonstrate the benefits of Power Cooling, proving its industrial reliability and establishing a new remarkable cooling standard for hot strip mills.

REFERENCES

1. M. Pontremoli et al., *High strength steels for plates, pipes and sections*, Stahl und Eisen 126, Nr.4, 2006.
2. Seilinger et al., *Installation of Power Cooling Unit at ThyssenKrupp Steel*, 2011.
3. G. Kolek et al., *Thicker, wider, high-strength. A hot strip mill continues to develop*, 9th International Rolling Conference 2014, Venice.
4. L. Pichler, A. Seilinger, A. Rimnac, F. Lettner, K. Weinzierl, J. Milbredt and K. White, *Transfer Bar Cooling System Promises Increased Production Capacity at Tata Steel Port Talbot's Hot Strip Mill*, ESTAD Conference proceedings, Düsseldorf, Germany, 2019.
5. H. U. Löffler, K. Weinzierl and R. Döll, *Consideration of Microstructure Evolution in Hot Strip Mill Automation*, In V. B. Ginzburg: Flat-rolled Steel Processes: Advanced Technologies. CRC Press 2009, Chapter 15.
6. K. Weinzierl, A. Reljic, E. Hermann, *Innovation Cooling Model: The Future starts now*, In Aistech Conference and Exposition 2019, Vol. 3, pp1517-1524, Pittsburgh USA, 2019.

