Innovative direct quenching at Nucor Steel, Tuscaloosa

The successful installation of the world's first DQ system in a Plate/Steckel mill fulfilled the target of reducing the alloy content for selected steel grades. A rapid return of investment is expected.

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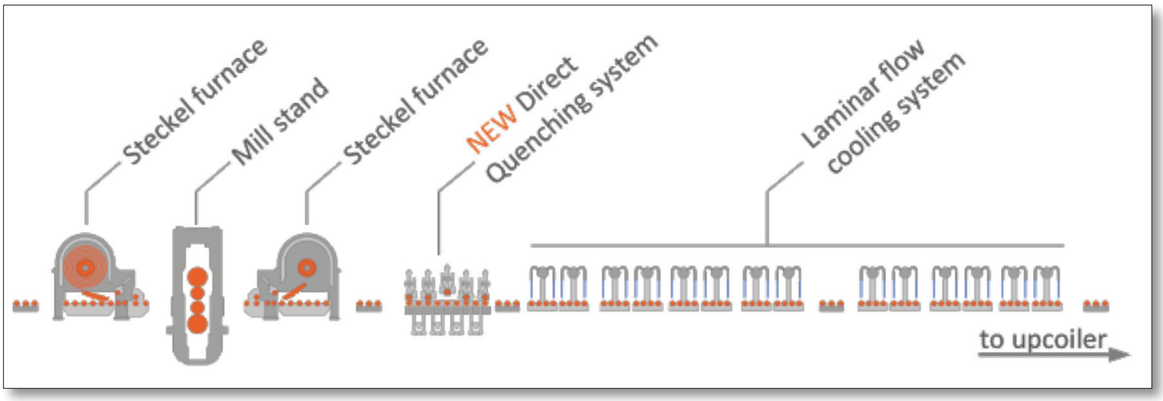

Fig 1 **Schematic layout of the Plate/Steckel mill**

Nucor Steel's Plate/Steckel mill in Tuscaloosa, Alabama, USA, produces coils in the thickness range 4.76 to 25.4mm (3/16" to 1"), and heavy plates up to 63.5mm (2.5"). The maximum product width is 2,438mm (96"). A schematic layout of the mill is shown in *Figure 1*.

Nucor and Danieli identified that an increase in the mill's cooling capability would provide the potential for an effective upgrade of the mill, aiming to reduce operating costs and extend the product mix. To reach these targets, Danieli was assigned to install a Direct Quenching (DQ) system between the Steckel mill and the pre-existing laminar-flow cooling section, the world's first. The laminar cooling section consists of seven low-pressure, laminar flow-banks, each comprising six top and six bottom tube headers positioned between the old leveller (now removed) and the upcoiler, and distributed over a length of approximately 54.5m.

By assembling much of the equipment off-line, the erection phase was limited to a few shutdowns. Hot testing and commissioning were carried out during normal plant operations, minimally interfering with the production schedule. Full industrial production commenced after the final acceptance certificate was released in March 2017.

THE DANIELI DQ SYSTEM

The eight metre-long DQ system (*see Figures 2 and 3*) works with pressurised water provided by three booster pumps. It consists of four zones, each one equipped with two top-cooling headers and two bottom-cooling headers. Eight proportional valves, individually controlled by the Level 2 cooling model, regulate the water flow continuously in the range between 30 and 100% of the maximum flow, which is 560m/h from the top and 850m/h from the bottom of each zone. The top/bottom flow ratio can be set individually for different products. The maximum operating water flow of the whole DQ system is 5,640m/h at a pressure of five bar. In the case of narrow strips, only the central portion of the headers (1,660mm wide) is activated, reducing the water consumption accordingly. The headers are equipped with flat fan Lechler nozzles configured to optimise the water distribution on the strip.

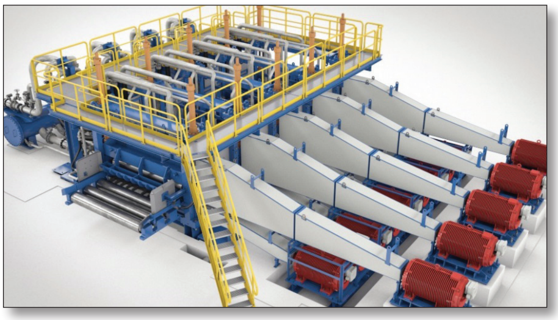

Fig 2 **3D engineering schematic of DQ unit**

Five pinch rolls pairs separate the four DQ zones. Their function is as follows:

- To avoid water leakage outside the DQ and in particular towards the Steckel mill
- To provide a water-free surface to every cooling zone, so maximising their cooling efficiency
- To guarantee material tension during the cooling process
- To counteract the possibility of wave formation due to thermal shock
- To support strip threading

Each top pinch roll is connected to a frame structure that also supports one or two top headers and which is controlled in its vertical movement by hydraulic cylinders that also provide the closing force. The bottom pinch rolls are fixed and integrated by additional rollers along the run-out table. Each pinch roll is driven by a 50kW motor, and each intermediate roll by a 20kW motor. An internal water cooling system reduces the thermal stress of the rolls. When not in operation, the DQ's top pinch rolls and headers can be lifted to a stand-by position of up to 950mm from the pass line, reducing the heat exposure due to passing steel.

Steel guides that do not interfere with the water jets are installed between the rolls in order to minimise the cobble risk and to protect the nozzle from any impact with the strip.

A dedicated pyrometer is installed at the DQ exit, and steel temperature data, together with the coiling temperatures, are used as part of the Level 2 automation system, with feed-forward control to compensate for speed and finishing temperature variations. Feedback data to compensate coiling temperature variations and adaptation to optimise the definition of the thermophysical properties describing the heat transfer in the Level 2 model, are also included within the control algorithms.

The DQ system is fully integrated into the pre-existing cooling section and can work as a stand-alone cooling device or in combination with the laminar flow cooling system, enabling high flexibility in the definition of the cooling strategies. Danieli Automation provided both the Level 1 and Level 2 automation systems and integrated the pre-existing laminar flow cooling section into the new Level 2 automation.

APPLICATION AND RESULTS

The first application of the DQ system was in the production of high strength low alloy steel grades in the thickness range 4.76 to 19.2mm (3/16 to 3/4") coils.

For a given water flow, the cooling rate naturally decreases as strip thickness increases.

In the last rolling pass, the strip exit speed is decreased with increasing thickness, enabling thicker material to spend a longer time in the DQ system. Therefore, for all thicknesses it is possible to obtain significant undercooling at DQ exit, promoting a very fine microstructure that enhances strength and toughness.

Fig 3 DQ system installed at Tuscaloosa

Indeed, significant strength increases were obtained by applying the DQ system's high cooling rates to the above-mentioned steel grades, so that a progressive reduction of alloy content was possible.

The reduction of the alloying elements provided two significant benefits: an immediate economic advantage in terms of alloying costs reduction, and a decreased material resistance to deformation during hot rolling. This second achievement made it possible to extend the dimensional range of high strength products to thinner gauges and/or greater widths that were not rolled before due to torque limitations of the mill.

Additionally, the enhanced cooling capability opens the prospect of developing transformation hardening steel grades for which high cooling rates leading to low cooling stop temperatures are required to avoid the diffusion-driven transformation to a microstructure of polygonal ferrite and pearlite.

The application of the DQ is not limited to the coiled strip but also includes heavy plate products.

CONCLUSION

The successful installation of the DQ system fulfilled the target of reducing the alloy content for selected steel grades. Additionally, the enhanced cooling capability makes possible the development of new, high-value products. A rapid return of investment is therefore expected. MS

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