

Process and technologies to anneal current and future advanced high strength steel strip

The production of advanced high strength steel (AHSS) grades in a continuous annealing line requires strict cooling control to limit strength variation within the coil to improve homogeneity and formability. Fives has developed a new cooling technology, Wet Flash Cooling®, to reach the required AHSS characteristics.

Author: Eric Magadoux
Fives Stein

Water quench technology has been used on some continuous annealing lines for more than 30 years to produce high strength steel grades. The market trend for such grades is accelerating and various AHSS grades have been developed for which other properties as well as yield strength are also considered to ensure formability. The production of AHSS grades in a continuous annealing line requires strict cooling control to limit strength variation within the coil to improve homogeneity and formability. To reach the required AHSS characteristics, Wet Flash Cooling® has been developed by the international engineering group Fives to offer more flexible control of the strip cooling cycle, including initial and final strip temperatures and modulation of cooling rate.

This technology has been successfully operating in a large capacity industrial continuous annealing line at a major steel plant following its start-up in 2009. This paper describes the new challenges of quenching technologies to respond to evolving AHSS production needs.

AHSS GRADE CHARACTERISTICS

The demand for AHSS is increasing and is used in ever more applications, especially in the automotive industry where numerous steel grades have been developed for this particular requirement [1]. The production of the highest strength grades, which are based on martensite formation, have to comply with cooling speed requirements as per the CCT diagram. If the attainable cooling speed is too low, the steel has to be enriched by a higher content of certain elements, such as silicon or molybdenum to avoid the formation of pearlite and bainite instead of martensite. However, these additions compromise properties, such as weldability and formability.

Consequently, on future process lines a way of decreasing these additional elements is required, which means increasing significantly the cooling rate of the process cycle.

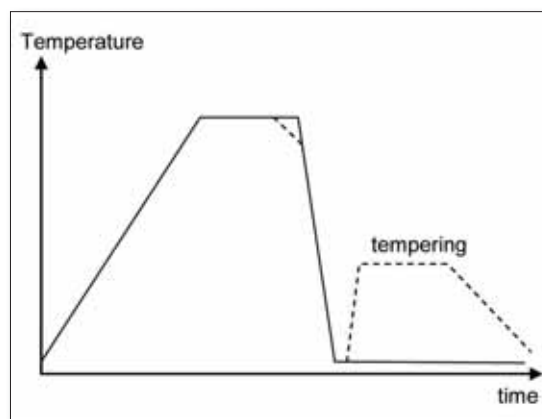


Fig 1 Typical annealing cycle with the WQ process

This higher cooling rate can be achieved by using a higher H₂ content in the gas cooling section. This technology allows a cooling rate up to 200°C/s/mm thickness, which is quite suited for most dual phase (DP) grades. For AHSS of the highest tensile strength, a lean composition with low C is preferred to avoid weld embrittlement and internal fracture, and to improve hole expansion behaviour. This requires cooling rates above 200°C/s/mm.

CURRENT PROCESSES

To obtain ultra-high cooling rates, water quench processes have been developed and applied in industrial annealing lines for more than 30 years. With the aim of improving the mechanical properties, a tempering treatment could also be performed after the water quench (WQ). A typical annealing cycle is shown in *Figure 1*.

It should be noted that this tempering treatment requires a high capacity induction reheating after WQ cooling.

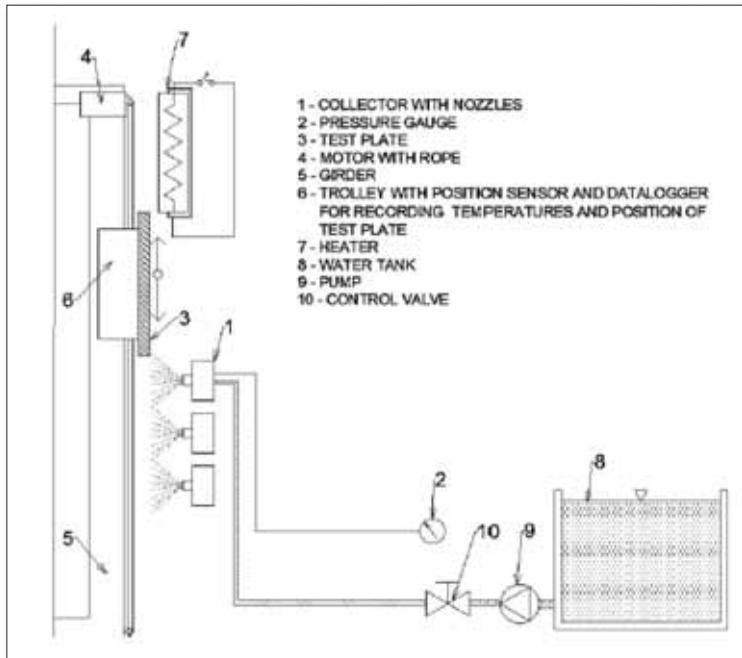


Fig 2 Schematic of the test rig

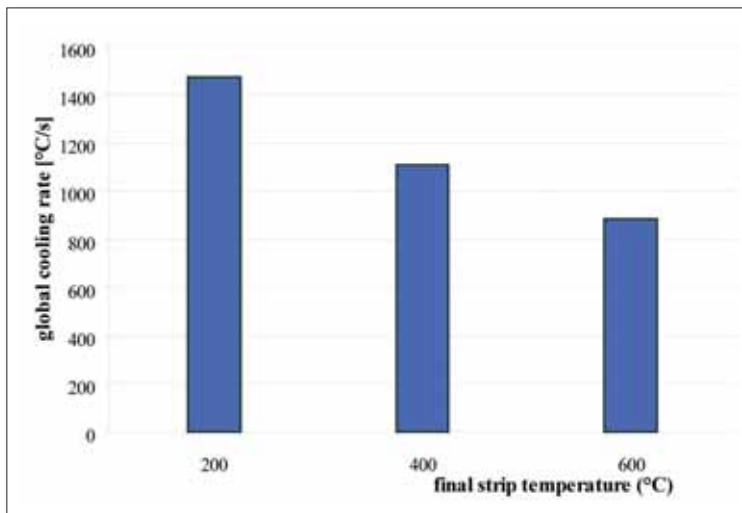


Fig 3 Influence of the final strip temperature on the global cooling rate (initial temperature is 900°C)

However, this WQ process must comply with several requirements:

- A high strip cooling rate, up to 1000°C/s (the cooling rate usually expected by steelmakers is approximately 400°C/s)
- Accurate control of the cooling rate and good strip thermal homogeneity during the whole process. This is required to achieve good width mechanical properties and consequently good strip flatness
- Flexibility in the choice of strip temperature for both the start and the end of the WQ cooling stage
- Our process is based on 'film boiling' conditions, in order to comply with these requirements.

DEVELOPMENT PROGRAM

The current quenching technologies reach adequate performance with regard to the expected cooling rate, even for thick strip (the typical strip thickness for these grades is approximately 1.5mm). However, not all technologies are satisfactory regarding temperature flexibility, especially the ability to stop cooling at any strip temperature coupled with good width temperature homogeneity.

Consequently we performed an extensive development program with this aim, including:

- Numerical calculations
- Test rig to characterise the heat transfer performance of the nozzles, to investigate the uniformity of cooling and flexibility of operation
- Equipment design in order to operate in vertical arrangements and for all steel grades
- Industrial operation.

COOLING RATE

In this study, various geometrical arrangements of the nozzles were tested to optimise the cooling nozzle mesh. The objective was to characterise and improve the heat transfer coefficient according to several parameters. An experimental test rig was developed, including heating and cooling of steel samples (see Figure 2).

The test rig comprises:

- The test plate, equipped with thermocouples
- A vertical trolley supporting the steel plate, able to move upward and downwards
- The plate heating device
- The cooling system.

Before the cooling test, the steel plate is moved upwards to be heated to 900°C. The cooling system is then switched on and the plate is moved downwards at a constant speed of 180m/min. This test is a full scale one and is representative of industrial conditions. These tests led to a spraying geometry, which was then installed in the industrial line. We then continued to refine our design, leading to a second and

more efficient nozzle arrangement. In this second geometry, the nozzle mesh is tighter, and the strip closer to the nozzles (100mm instead of 250mm for the first geometry). The main improvement in the cooling performance of the new geometry is due to the smaller distance between strip and nozzles without interaction between the spraying jets.

Furthermore, it is well-known that the heat exchange coefficient of this type of technology is better when the strip is cold, ie, below the Leidenfrost temperature (typically 400-600°C depending on the configuration). *Figure 3* clearly shows the influence of the final strip temperature on the overall cooling rate (initial temperature is 900°C).

The results are summarised in *Figure 4*, showing the influence of the water pressure on the average cooling rate. Geometry no.1 achieves its optimum performance at approximately 5 bars. Geometry no.2 is more efficient at every pressure. At 12 bar pressure the average cooling rate from 900 to 200°C is approximately 1,500°C/s.

In the industrial design, the nozzles are fed with both water and nitrogen, although the nitrogen is replaced by air in the test rig. The strip cooling rate is controlled by the water pressure as shown in *Figure 4*, the gas flowrate being adjusted accordingly.

This water pressure can be controlled separately in each group of nozzles (or even in each nozzle) and also in the transverse direction, in order to control the cooling rate during the whole cooling time. It is also possible to switch off some groups of nozzles to change the cooling pattern.

COOLING CYCLE FLEXIBILITY

In a conventional water quench process, the final strip temperature is close to water temperature (in any case below M_f), so this requires reheating of the strip prior to tempering. As the Wet Flash Cooling® process allows total control of the cooling slope, ie, initial and final strip temperature and cooling rate, this brings the ability to produce, for example, TRIP and Quenching and Partitioning steel (Q&P) grades [2]. In Q&P grades, a partial transformation from austenite to martensite is required by cooling the steel to a predetermined quench temperature, followed by a partitioning step at a suitable temperature, at which carbon migrates from oversaturated martensite to austenite. An example of an annealing cycle is shown in *Figure 5*.

Thanks to this controllability of the cooling rate, it seems clear this process is well suited to produce the desired structure. Compared with a dry jet cooling technology, in which the cooling rate is notably controlled by the H_2 content in the blowing atmosphere, the Wet Flash Cooling® offers a wider process window (see *Figure 6*).

INDUSTRIAL APPLICATION

This developed concept has been proven over six years of industrial operation on an annealing line in a major steel ▸

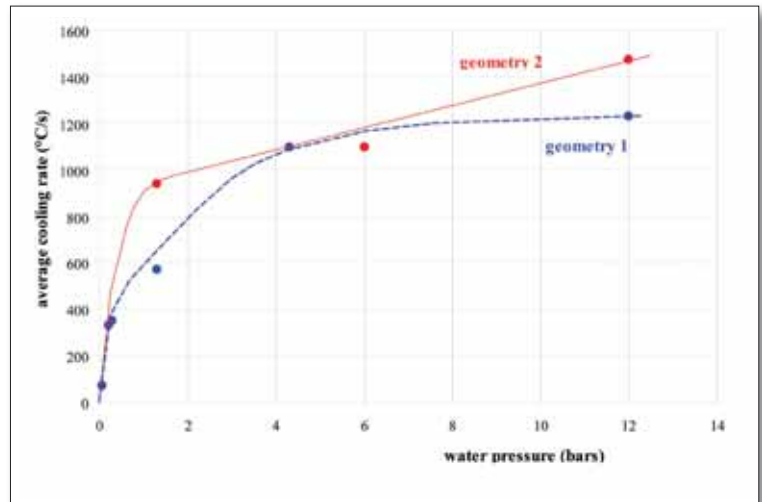


Fig 4 Influence of water pressure on average cooling for the two spraying configurations, from 900 to 200°C

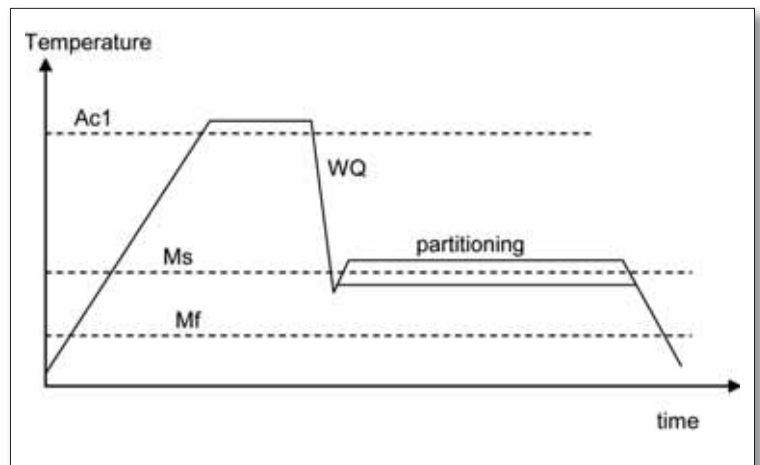


Fig 5 Example of Q&P cycle

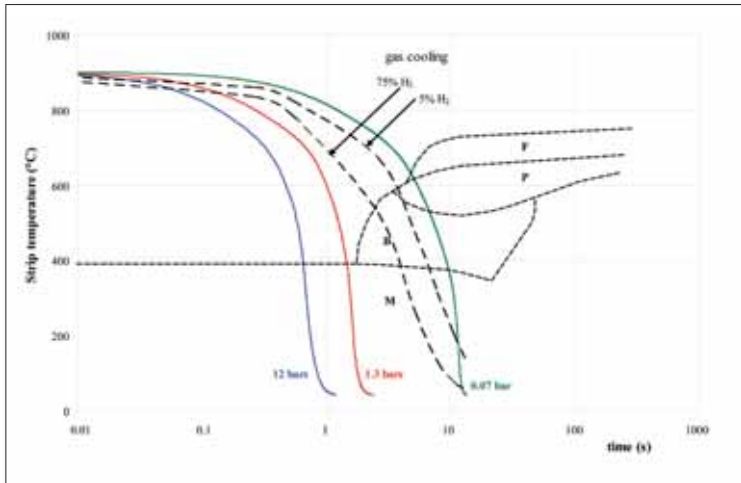


Fig 6 Comparison of various cooling rates on a typical CCT diagram (C 0.2%, Mn 1.2%, Si 0.2%), and comparison with conventional gas jet cooling technology

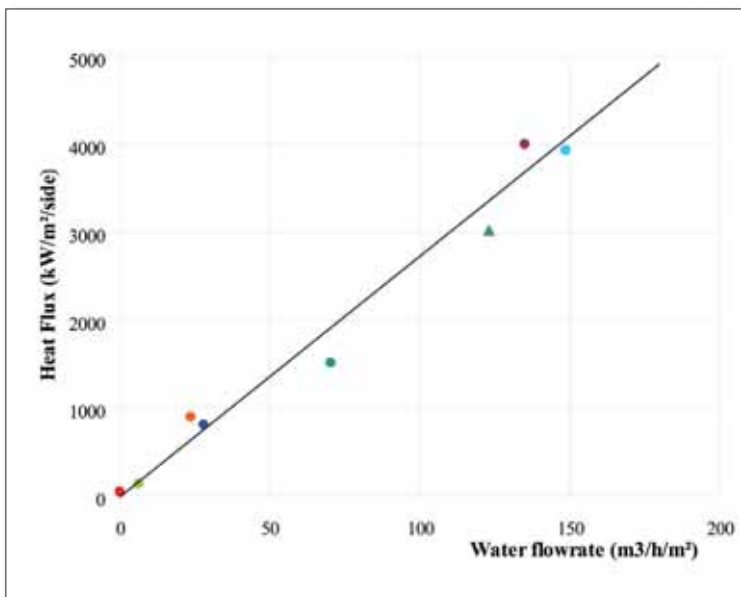


Fig 8 Heat flux and water flowrate per strip size at 400°C strip temperature

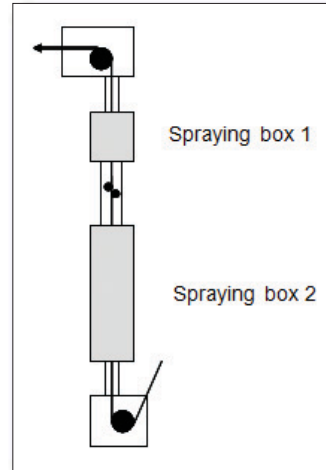


Fig 7 Example schematic of the Wet Flash Cooling® process

plant. A schematic of the cooling pass is shown in Figure 7. The pass line configuration can be vertical upwards or vertical downwards. The water flowrate used to feed the spraying nozzles is quite low (see Figure 8), especially when compared with other technologies [3]. Industrial operation confirmed a good width thermal homogeneity of the strip.

CONCLUSIONS

The Wet Flash Cooling® process is an efficient tool to produce all steel qualities on an annealing line, from commercial quality to martensitic grades. The nozzle design and the mesh geometry allow total flexibility of the cooling pattern. The ability to stop the cooling at any strip temperature is of prime interest to produce specific grades such as Q&P. **MS**

Eric Magadoux is Research & Development Engineer, Fives Stein (France) Maisons-Alfort, France.

CONTACT: eric.magadoux@fivesgroup.com

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