Production of AHSS at Nucor Steel–Arkansas: Innovative Technology for the New Cold Mill Complex

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This paper presents the project of Nucor Steel–Arkansas' new cold mill complex (high-performance push pickling line with in-line skinpass mill, S6-high cold rolling mill, 4-high temper mill and a continuous galvanizing line), which produces the latest generation of advanced high-strength steels (AHSS) for the car body. The project includes the complete equipment delivery with electrics and automation and the start-up of the lines. Combining ANDRITZ's know-how in processing state-of-the-art steel grades (including third-generation AHSS) with the production expertise of Nucor is setting new milestones in the U.S. steel market for automotive applications.

As part of its growth investments, Nucor built a new specialty cold rolling complex, including a galvanizing line, in Blytheville, Ark., USA. One of its main goals is to process the latest advanced high-strength steel (AHSS) used by the automotive industry for lightweight car body design. Besides that, Nucor has expanded its capability to produce motor lamination (ML) and high-strength, low-alloy (HSLA) products. A flexible cold reduction mill will allow Nucor to cold reduce to both lighter gauges and much higher strength levels to meet customers' lightweighting goals. With the galvanizing line, Nucor will be capable of efficiently making the widest variety of grades to support the current and future demand for the coated/third-generation AHSS market. About 500,000 tons of value-added cold-rolled and galvanized product capability is added.

ANDRITZ is supplying the major processing equipment to produce the state-of-the-art steel grades for automotive application consisting of:

1. High-performance push pickling line with in-line skinpass mill.
2. 4-/S6-high combination cold rolling mill and 4-high reduction and temper mill.
3. Continuous galvanizing line for third-generation AHSS.

The push pickling line is designed to process hot coils within a width range from 900 to 1,650 mm, a thickness of 1.5 to 9.5 mm and a maximum coil weight of 32.5 tons. The annual capacity is 800,000 tons.

The cold rolling process is designed for a capacity of 500,000 tons/year. For this production volume, two mills are necessary: first the combination 4-/S6-high reversing reduction mill for a volume of 380,000 tons and second the combination 4-high mill (later extensible with a S6-high insert) for the reversing reduction rolling of the further 120,000 tons and for the temper process of the total 500,000 tons. The goal of this technology is not only to roll this volume in the best quality, but also flexibility with respect to market demand and complete process technology.

The continuous galvanizing line (CGL), with an annual capacity of 455,000 tons, is dedicated mainly to producing advanced high-strength steel. A high amount of the product mix is aimed to treat third-generation, quench and partitioned, high-strength steel.

Third-generation AHSS requires particular heat treatment in order to not only achieve the required mechanical properties, but also to attain acceptable in-use properties for the end user.

Discussion

High-Performance Push Pickling Line With In-Line Skinpass Mill — The push pickling line is equipped with a single entry and a coil preparation station.

The first highlight of the line is the leveler (4-high design), which is designed to handle the whole thickness range of the product mix. The specialty of that leveler is the fact that it is able to correct the strip shape with no strip tension needed and is already fully operational during strip threading. To avoid scratches on the surface, the leveler is equipped with single drives for each roll.

The core equipment of the pickling line is its 6-high turbulence pickling tanks in shallow tank design made of polypropylene instead of the traditional steel – rubber – brick lining concept. A state-of-the-art mathematical model is installed to control and adapt all necessary parameters like pickling temperature, strip speed and acid concentration in the different pickling sections. In this way, best surface quality at highest productivity is ensured while the environmental impact and the operational cost are minimized.

Following the pickling section, a turret-type sidetrimmer takes care of the natural rolling edges of the incoming material and provides perfectly trimmed edges.

After the sidetrimmer, the in-line skinpass mill improves the surface and material characteristic of the strip. The necessary tension for the skinpass mill is provided by a 3-roll bridle in front and two pinch roll sets after the mill.

4-/S6-High Combination Cold Rolling Mill and 4-High Reduction and Temper Mill — To roll different steel grades from low-strength up to high-strength steel, AHSS and ML steel, a flexible technology is needed. The intensive cooperation between Nucor and ANDRITZ enabled a new rolling concept with flexible rolling mill designs for high-quality cold-rolled products for automotive applications which is also designed to be prepared for the future demands of the market.

Combination 4-/S6-High Reversing Mill: The mill is designed to process coils of hot-rolled and pickled low-carbon steel, high-strength steel, and high-grade non-oriented silicon steel with silicon content below 3.0%.

The rolling mill is equipped with a payoff section, mill table entry, mill table exit with bridle roll equipment for tension adjustment, shapemeter control system, the mill stand — which could run in 4-high or S6-high mode — a fully automatic roll changing robot, the necessary media equipment, and the complete electric and automation and control solutions. It also enables a fast reaction to actual plant and/or market situations by a short changing of the rolling modes.

The high-capacity reduction S6-high operating mode is used for high- and medium-strength material grades, but the 4-high operation mode is used for soft and intermediate material grades.

A special feature of the S6-high rolling mill is the side-supported work rolls. The patented Sundwig S6-high side support stabilizes the work rolls of this type of mill stand using mechanical hydraulic lateral support equipment, thus preventing lateral excursion of these rolls. The diameter of the S6-high work rolls only amounts to approximately 30–40% in relation to the 4-high work rolls and double the diameter of those work rolls usually found in a 20-high rolling mill if it comes to comparable strip widths. The small S6-high work rolls combined with the stable and open design

Table 1

Main Technical Data of the Push Pickling Line

Annual capacity	800,000 tons
Strip thickness	1.5–9.5 mm
Strip width	900–1,650 mm
Max pickling speed	200 m/minute
Steel grades	SS, CS, DS, DDS, EDDS, electrical steel, HSLA, AHSS
Yield point	Up to 1,200 MPa
Tensile strength	Up to 1,350 MPa
Max. coil weight	32.5 tons
No. of pickling sections	6
Special feature	In-line leveler in the entry section Pickling tanks made of PP In-line skinpass mill
Leveling force	5,000 kN
Roll force (SPM)	21,500 kN

Table 2

Main Technical Data of the Combination 4-/S6-High Reversing Mill

Annual capacity	380,000 tons
Roll force	21,500 kN, max.
Rolling speed	800 m/minute, max.
Coil weight	29,500 kg, max.

of the lateral support facilitates high pass reduction and the transfer of high rolling torques.

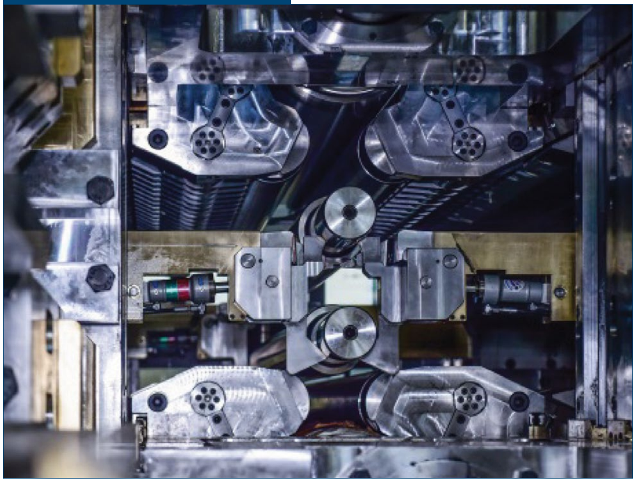
Special features of the S6-high mill, such as the large work roll diameter range, the hydraulically position-controlled adjustment of the screw-down cylinders, the side support cylinders for work roll suspension, the side support cassettes, and the big side support bearing design to take high horizontal side support forces, offer distinct economic advantages.

In comparison to the Z-high design, the adjustment of side support cartridges of the S6-high is completely independent of the intermediate roll and the intermediate roll adjustment.

In consequence, the grinding ranges of work rolls as well as the diameter of side support rolls and bearings are increased by about 20%.

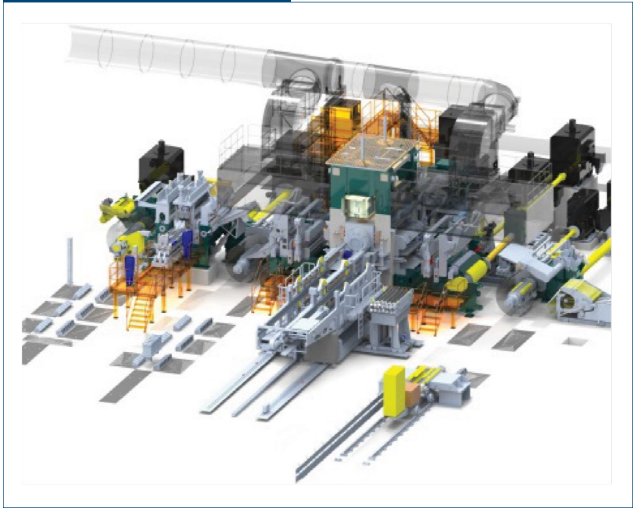
Changing from 4-high to S6-high mode can be done easily and quickly. Thus, high flexibility is given considering the actual market demands.

Figure 1



S6-high technology.

Figure 2



Combination 4-/S6-high reversing cold rolling mill.

Combination 4-High Reversing Reduction Mill and Temper Mill: The mill is designed to process coils of hot-rolled and pickled low-carbon steel, high-strength steel, and high-grade non-oriented silicon steel with silicon content below 3.0% and for the tempering process of annealed cold strip. The mill is prepared for a later installation of a S6-high insert.

The rolling mill is equipped with a payoff section, mill table entry and exit with bridle roll equipment for tension adjustment each, shapemeter control system, the mill stand in 4-high design, a fully automatic roll changing robot, the necessary media equipment, and a complete system of electric and automation and control solutions.

The 4-high is used for reduction rolling of soft and intermediate material grades and for the temper process. In the reduction or temper/skinpass process, not only can the thickness of different hard material grades be reduced but also the strip flatness.

For the reduction process of hard materials and the temper process of soft materials, a double-acting screw-down cylinder requires the highest and lowest roll forces.

In regards to the different grades and strip cross-section, a special tension reel drive concept secures the requested highest and lowest tensions under consideration of the best tension stability over the whole tension range.

The automatic gauge control (AGC) and elongation control secures the highest thickness and elongation tolerances.

Table 3

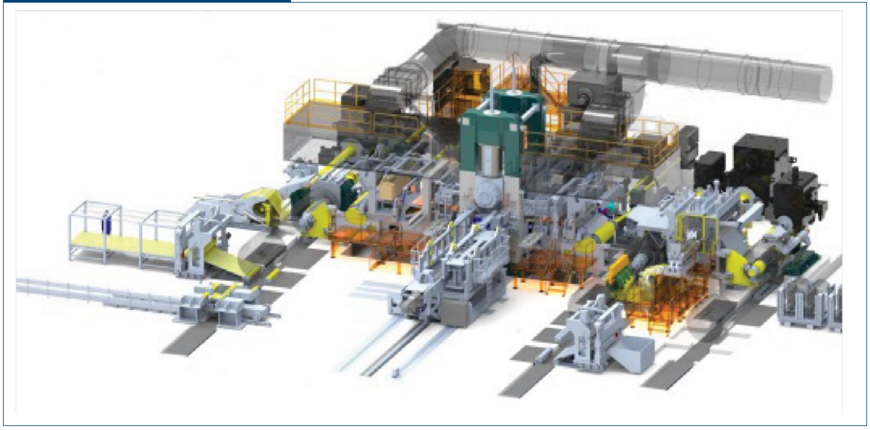
Main Technical Data of the Combination 4-High Reversing and Temper Mill

Annual capacity – reduction mode	120,000 tons
Annual capacity – temper mode	500,000 tons
Roll force, max.	21,500 kN
Rolling speed, max.	800 m/minute
Coil weight, max.	29,500 kg

Advanced Technology for Both Rolling Mills: Besides the reduction of the strip thickness, the enhanced shapemeter system with its specific pre-settings of the rolling mills by the actuators tilting, the S6-high intermediate roll shifting and intermediate roll bending, the 4-high work roll shifting, and work roll bending provide for the customer's desired strip flatness.

The high-impact strip drying system enables a safe rolling process up to the maximum rolling speed.

Figure 3



Combination 4-high reversing cold rolling and temper mill.

The fully automatic roll change robot enables the roll change for work rolls, intermediate rolls and side support rolls for substantially shortened rolling mill setup times and, even more importantly, permits contact-free roll change within the shortest time without damaging the rolls.

Also outside the mill stand itself, the total rolling technology will be secured by the experiences of ANDRITZ Sundwig, like the advanced safety concepts, the modern fume exhaust system, the emulsion filtration, the hydraulic equipment, and the electrical and automation system.

Continuous Galvanizing Line for Third-Generation AHSS: The furnace plays a great role in preparing the final material properties as well as the strip surface. This is done by coupling the direct-fired furnace (DFF) with a radiant tube heating (RTH) section. A combination of DFF and final radiant tube heating provides simultaneous cleaning as well as heating to the coating temperature.

In the pre-heating section, the strip is heated in a counterflow heat exchange with the combustion gases from the subsequent direct-fired furnace. In DFF, further cleaning and heating is achieved, while 70–80% of the heating required to reach the annealing temperature is used, thus considerably reducing the radiant tube section. Its special design allows operation in a slightly oxidizing atmosphere for pre-oxidation purposes.

In the next step, the strip is heated to the annealing temperature in the RTH section. Radiant tubes are of a W shape, made of heat-resistant Inconel and are equipped with recuperative burners. This tube design provides a very low thermal inertia and thus reduces the transient time during production changes. The furnace is designed in a way that it can be run in a CGL or CAL (continuous annealing line) mode, where, e.g., a large range of soaking temperatures can be adjusted via a range of ELRADs, combination of jet cooling, additional induction, as well as an overaging section.

The rapid jet cooling technology used in a CAL line is the very heart of the process, which will fix the strip quality and performances.

In CGL and CAL lines, heat cycles based on the "direct quenching practice" are applied. A very rapid cooling is applied in one step without interruption between at least 720°C and the starting point of overaging. For high-strength steel, the direct quenching with such a high cooling rate will save alloy additions while keeping optimum ductility.

Coating Section: The coating pot area is equipped with one liftable pot for GI/GA coating. Provisions have been made for future extension for ZM. An air knife equipped with strip stabilizer and closed-loop control ensures good coatings within narrow limits. After-pot cooling (APC) starts with a low-velocity cooler that begins the cooling process without damage to the coated surface followed by high-velocity coolers that minimize strip oscillation.

Finished Product Quality — Thickness Tolerances, Texturing and Surface Finish: A 4-high skinpass mill is used for the fine adjustment of mechanical properties and texturing in order to improve the strip surface topography. Strip flatness, technological properties and high surface quality are achieved at this stage. In the subsequent leveler, the desired strip elongation and good strip flatness are achieved through

Table 4

Continuous Galvanizing Line Production Data

Annual capacity	455,000 tons
Process speed, max.	150 m/minute
Steel grades	SS, CS, DS, DDS, EDDS, BH, DP/CP, Q&P, HSLA
Strip thickness	0.23–2.7 mm
Strip width	890–1,900 mm
Coil weight, max.	41 tons
Coating	GI, GA, possible extension to ZM
Coating mass	GI/GA 60–335 g/m^2, ZM 90–350 g/m^2
Post-treatment	RoHS compliant trivalent, Hex chrome

a combination of bending and stretch tension.

Enhanced corrosion protection, deep drawing ability and visual appearance of the product are defined in the vertical chemical coater. The coater is designed to apply either Restriction of Hazardous Substances (RoHS)-compliant chrome-free passivation or chromate coatings.

Heat Treatment of Third-Generation AHSS

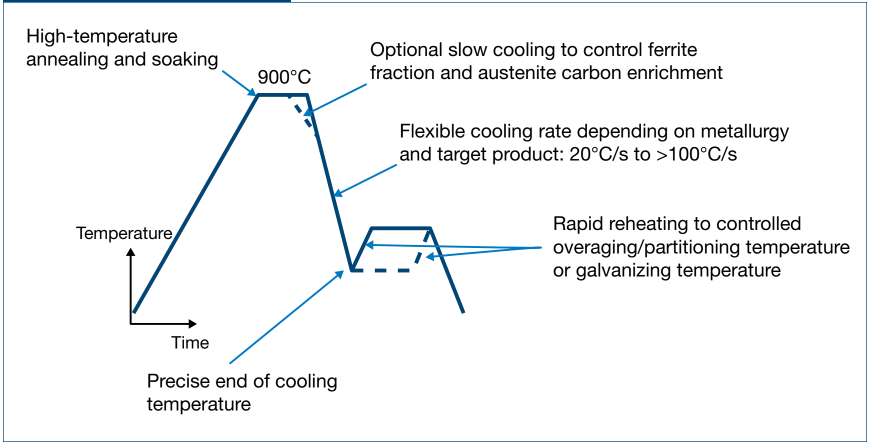
— These particular heat treatments include in general:[1–3]

- High-temperature annealing, typically close to 900°C.
- Followed by slow cooling and rapid cooling, or rapid cooling only, depending on the metallurgical concept.
- Cooling down to "low" temperature, between characteristic bainitic starting temperature (Bs), martensite starting temperature (Ms) and martensite finish temperature (Mf) depending on the product, be it carbide-free bainite steel, or quenched and tempered.

A schematic representation of galvanized third-generation AHSS thermal cycles is shown in Fig 4.

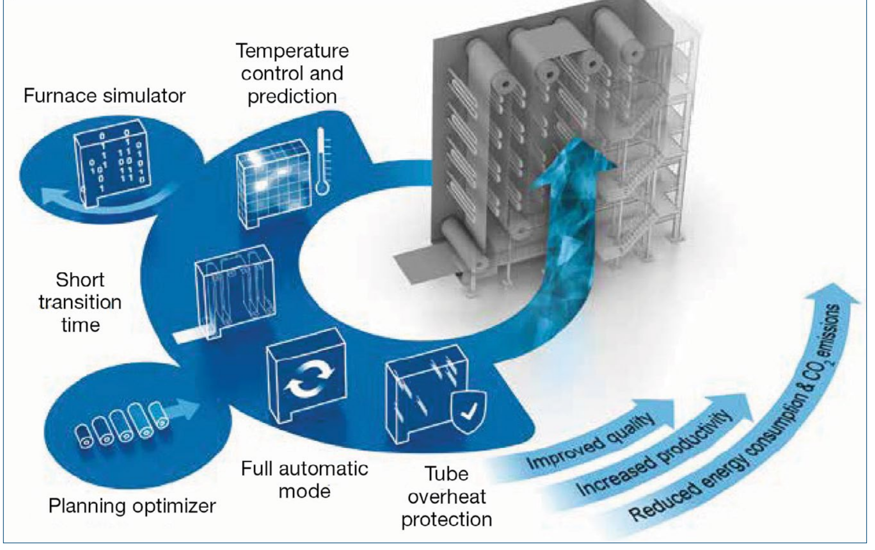
The different sections need to be able to reach "higher" performances as compared to more conventional production lines. For instance:

Figure 4



Thermal cycles for third-generation advanced high-strength steel present special features requiring particular equipment.

Figure 5



Advanced furnace control (AFC).

- The heating and soaking zones need to be able to withstand high-temperature atmospheres.
- The cooling section must reach high cooling rates, such as 100 K/s.mm or even higher. This cooling rate has to be sustained down to a temperature below the bainitic nose (in the case of quenched and partitioned steels, for example) in order to reach the desired microstructure.
- Process accuracy, namely temperature control, is crucial to reach homogeneous properties in these materials.

In addition to the realization of the mechanical properties, in the case of coated products, coatability is obviously of prime importance.

Third-generation AHSS products often contain higher levels of easily oxidable alloying elements such as manganese (Mn), silicon (Si) or chromium (Cr) as compared with the last generation AHSS. During heating of the hot-dip galvanizing process, due to their relatively high content, the alloying elements can form oxides at the surface of the steel substrate, under the usual process conditions of a carbon steel galvanizing line. The formed Mn, Si or Cr oxides are stable under these conditions and cannot be reduced further in the process. On the oxides, liquid zinc will not be able to wet the surface, leading to coating defects known as "bare spots" on the final products, where actually no zinc is on the surface. The corrosion resistance property of the product is therefore severely reduced.

Several methods exist to control this surface oxidation,[4–6] mainly using either external oxidation of iron, further reduced in the furnace section, or internal oxidation of the alloying elements by controlling the atmosphere composition in the different furnace sections.

In the case of Nucor Steel–Arkansas, to produce third-generation AHSS, the choice of an ANDRITZ Selas DFF technology at the beginning of the furnace section allows for the suitable temperature for iron surface pre-oxidation to be reached rapidly. This pre-oxidation can be realized in the DFF section thanks to a precise control of the atmosphere composition.

The formed iron oxide layer will then be easily reduced in the radiant tubes' heating and soaking sections, under a 95% N_2 + 5% H_2 atmosphere, allowing a good coating quality at the exit of the line.

The necessary high temperatures in the RTH and RTS sections can be achieved thanks to conventional heating technologies but require a particular design of the chambers in order to sustain the very hot atmospheres.

As exposed earlier, high cooling rates must be reached in the cooling section. The ANDRITZ Selas Differential Rapid Jet Cooling (DRJC) technology can reach cooling rates above 100 K/s.mm down to the desired temperature, with a conventional 95% N_2 + 5% H_2 atmosphere, making it easy to handle for daily operations, with a strip width homogeneity better than 5°C (9°F).

Digitalization and Smart Automation — To fulfill high demands with respect to the plant start-up, commissioning, optimization and sustainable production of high-quality steel sheet, a comprehensive portfolio of intelligent digital solutions have been implemented.

Digital twins, i.e., digitalized drawings of mechanical equipment of the entire line, offer visualization of the lines before construction. Operator trainings are performed on the virtual model of the line before commissioning. Verification and optimization of the line and process control system, such as software testing, debugging and sequence optimization, are performed. Full integration tests as well as ghost and simulation modes during normal and adverse operating conditions (e.g., strip break event) are done prior to shipment to Nucor in ANDRITZ production premises in Austria.

Further, a comprehensive solution for controlling annealing furnaces, an advanced furnace control (AFC) model,[7] will be installed on this line. AFC enables better control of the heating and cooling process while providing an accurate prediction of temperatures at the same time. In this line, the technology was further extended to cover the whole furnace, including the DFF section as well as the DRJC section. Increased throughput, minimization of energy consumption and minimization of CO_2 emissions are realized with this comprehensive control concept.

Conclusions

Serving the automotive industry continuously with newly developed steel grades is a challenge that requires the best production know-how together with the most innovative technology for processing equipment.

- The 4-/S6-high combination mills roll materials with different hardnesses, from soft steel to AHSS. Changing from 4-high to S6-high mode can be realized very quickly, thus enabling high flexibility considering the actual market demands.
- The CGL annealing furnace is designed to reach the required heat cycles for state-of-the-art third-generation AHSS and future developments based on the metallurgical concept.
- Implementing digital solutions together with process technology further improves the quality of the project in terms of optimizing the software development but also the output of high-quality production (e.g., automatic gauge control, advanced furnace control).

This project is setting new milestones in the U.S. for efficient production of AHSS for the automotive industry.

References

1. J.G. Speer et al., *Austenite Formation and Decomposition,* ISS/TMS, 2003.
2. J.G. Speer et al., "The "Quenching and Partitioning" Process: Background and Recent Progress," *Materials Research,* Vol. 8, No. 4, 2005, pp. 417–423.
3. Caballero et al., "Design of Cold Rolled and Continuous Annealed Carbide-Free Bainitic Steels for Automotive Application."
4. Staudte et al., "Galvanizability of High-Mn Grade Versus Mixed Mn-Al and Mn-Si Grades," *Galvatech,* 2011.
5. Kuhn et al., "Evolution and Measurement of Iron Oxide Growth During HDG Annealing Conditions and the Impact on Galvanizing Behavior of AHSS," *Galvatech,* 2015.
6. Ranganathan et al., "Continuous Hot-Dip Galvanizing of a Third-Generation (3G) Advanced Steel," *Galvatech,* 2015.
7. Martin Fein et al., "Model-Based Control and Optimization of Continuous Strip Annealing Furnaces," *Heat Processing,* 2016. ✦

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