Endless Hot Rolled Coil (eHRC) from Arvedi ESP - A New Standard in Rolled Materials

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Endless Strip Production

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Since the development of rolling technology, steel flat products have traditionally been divided into two prominent groups: hot-rolled coils (HRC) and cold-rolled coils (CRC).

After the invention of Arvedi Endless Strip Production (ESP) technology, featuring endless casting and rolling of hot-rolled coils, a new class of rolled coils emerged: the endless hot-rolled coils (eHRC).

eHRC dramatically extends the domain of hot-rolled material into applications traditionally served only by cold-rolled products. This new set of hot-rolled coils offers significant economic savings in transformation costs, dramatically reducing both CAPEX—thanks to the unprecedented layout compactness of ESP plants—as well as OPEX—thanks to the lowest total energy consumption and the highest material yield among all thin slab casting and rolling technologies on the market.

Due to the absence of any immediate fossil fuel consumption and the direct rolling of the cast slabs taking advantage of the original thermal energy of the liquid steel, Arvedi ESP also represents the standard in reducing greenhouse gas emissions in direct and indirect emissions.

The peculiar thermal regime during casting and rolling, without long holding times at high temperatures, makes the Arvedi ESP process much less prone to hot shortness phenomena and, hence, more tolerant concerning the presence of tramp elements in liquid steel. This feature makes Arvedi ESP the perfect match for electric arc furnace-based meltshops using large quantities of scrap. Arvedi ESP pairs with scrap-based production without sacrificing the final product's quality, thus boosting the principles of the circular economy.

With Arvedi ESP, limited space requirements, best-in-class energy utilization, and reduced carbon footprint levels go hand in hand with superior coil quality for profitable and eco-friendly steelmaking.

1. The Beginning of the Journey: "The Thinner the Better"

One of the first goals that historically pushed the development of the "endless" process in the casting and rolling of flat products was the need to produce thinner and thinner gauges as HRC.

As well known, achieving a commercially stable production of gauges below 1.2 mm with a conventional hot-rolling mill, which uses thick slabs, is challenging. The main factors limiting such production are the very high reductions during rolling that affect the stability of the mill and, primarily, the difficulty of threading the very thin strip heads into the finishing mill stands and later transporting them from the exit of the finishing mill to the downcoiler without risking a very high cobble rate.

The introduction of the "thin slab" design concept (in coil-to-coil mode) slightly reduced the problem of mill instabilities due to lower reductions required but did not solve the "flying strip head issue".

In the 1980s / beginning of the 1990s, the semi-endless process was introduced as a tentative solution, feeding the mill with very long thin slabs that corresponded to several coils each and were as long as the tunnel furnace between caster and mill permitted. This configuration allowed the first

coil from the slab to be rolled at a “reasonable” gauge to have the head “safely” reach the downcoiler and then to progressively reduce the thickness on the following coils, while they are rolled in the mill before being divided in separate coils by the final shear, which was now installed just in front of the down coiler.

This process allowed for the first time the production of coils below 1.0 mm on a commercial scale but had the limitation that only a very small amount of thin gauge coils could be produced in a discontinuous campaign. Moreover, the length of tunnel furnaces necessary to produce the very long “mother slabs” made the mill layout extremely long, with very high gas consumption needed to reheat these huge tunnel furnaces on top. These limitations made semi-endless mode not more than an exception in the scenario of hot-strip mills.

The “game changer event” has been the development of the endless process that allowed for the linking of casting and rolling in an uninterrupted sequence for the first time. The “flying head” problem was eliminated because only one strip head had to be threaded at the start of the casting sequence. The production of ultra-thin gauges can then continue, not for just 2 or 3 coils as in semi-endless but for, literally, hundreds of kilometers, uninterrupted.

This paradigm shift was made possible by:

- The evolution of caster design, allowing very high mass flows,
- The direct rolling of the cast strand without reheating to produce the transfer bar,
- The development of reliable induction heating solutions for transfer bar temperature control, and
- the deployment of automation architectures and models that, simultaneously controlling the casting and rolling process, can ensure a flawless production in both steady and transitory conditions.

Figure 1 illustrates a layout with the typical ESP plant configuration.

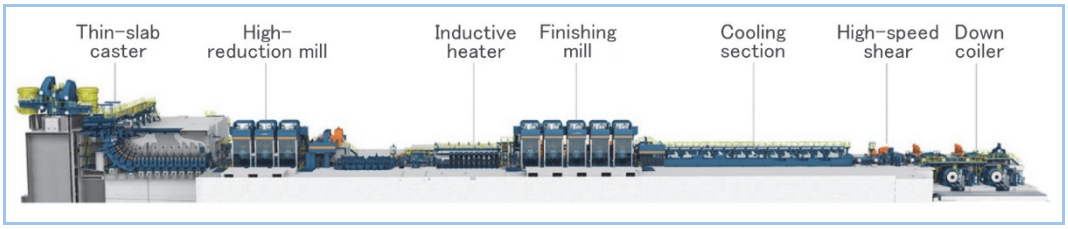

Figure 1 ESP layout

The ESP high-speed thin-slab caster plays a critical role in generating the necessary mass flow and sustaining the endless process. Each component of the caster has been meticulously designed and optimized to ensure stable operations, ultra-high productivity, and superior slab quality, marking it as a key component in the Arvedi ESP process.

The high-reduction mill performs the first rolling step directly after the strand exits the thin-slab caster. It leverages the inverse temperature profile, with a hotter core than the surface temperature, to achieve high reductions, energy savings, and tight tolerances on the transfer bar geometries. No CO_2-emitting furnaces are used in the ESP process.

A powerful and flexible inductive heater provides precise temperature control for the finishing rolling. Transversal and longitudinal flux solutions, along with adjustable clearance between the heating coil and transfer bar, optimize the inductive heating efficiency for varying product thicknesses. Additionally, there is no energy consumption during idle times.

The finishing mill rolls the transfer bar to the final target product dimensions. It is equipped with modern actuators like hydraulic AGC (Automatic Gauge Control), work roll bending/shifting, dynamic work roll cooling, work roll lubrication, and fast hydraulic loopers. The mill produces strips with the narrowest geometrical tolerances, even for hard steel grades at maximum width. The stable endless operation drastically increases work roll lifetime up to double of batch operated processes and contributes with this big lever to heavily reduced OPEX including maintenance costs.

In the cooling section, the endless mode of ESP operation eliminates the challenges of speedups and related cooling obstacles, resulting in uniform temperatures and a consistent strip microstructure.

Just before reaching the down coiler, the strip receives a first straight cut by the high-speed shear. Head and tail crop cuts are history, resulting in the highest overall yield. The down coiler has special features for coiling ultra-thin as well as ultra-thick gauges of the same quality.

2. Endless Strip Production Experience Since 2009

As is well known, the dawn of the new Endless Strip Production era is marked by the startup of the Arvedi ESP plant in Cremona, Italy, in 2009 in partnership with Primetals Technologies. The stable, industrial-scale production of massive quantities of thin and ultra-thin strips below 1.0 mm in thickness became a real fact. The goal for the first ESP plant was to reach a thickness of 0.8 mm, a milestone achieved in 2010. However, this was just the beginning: our Chinese ESP customers already consolidated the production of 0.7 mm and even 0.6 mm minimum gauge, the latter achieved in 2018.

The advantage of this progress is evident: a large portion of products that in the past needed to be first hot rolled and then also cold rolled to reach the desired final thickness can now be produced directly as hot rolled coils. In case cold rolling cannot be completely omitted because the final thickness must be even less, our customers (and/or other re-rollers) can still benefit from the use of thinner input material to decrease both CAPEX and OPEX in their cold complex.

As shown in **Figure 2**, the percentage of the market currently served by CRC that can be targeted by eHRC is significant. The left side shows the typical production ranges of ESP, Cold rolling and Hot rolling. On the right, the pie chart shows the typical world wide distribution of Cold rolling thickness as by average product mix of cold rollers. More than 50% is above 0.8 mm and hence accessible for eHRC and therefore marked orange/blue.

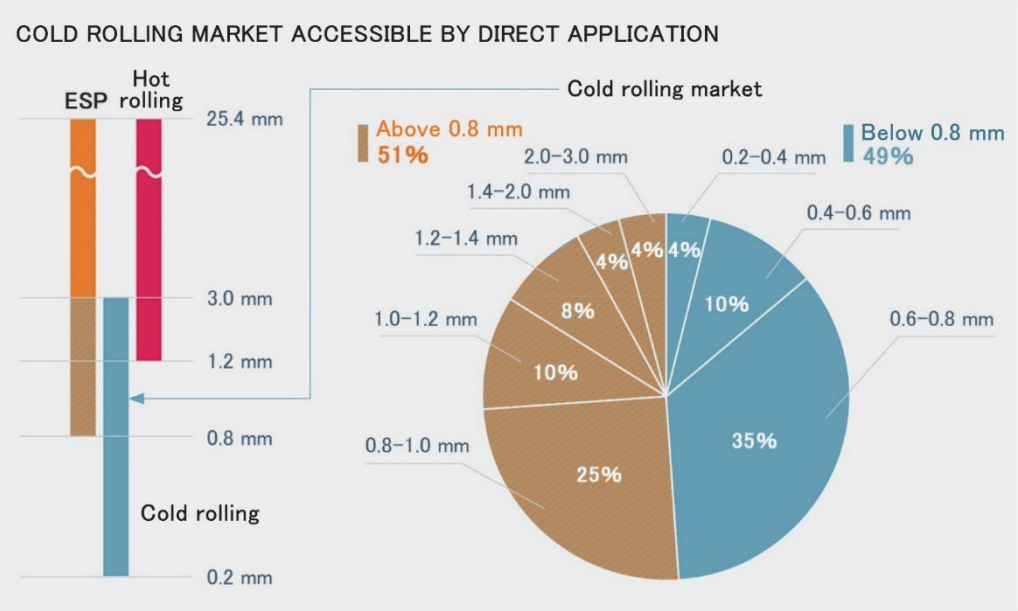

Figure 2 Cold rolled products market divided by thickness share

Furthermore, when cold rolling is completely omitted, the further downstream annealing process (to reduce the internal tensions generated within the material by deformation at low temperatures in CRM) can also be completely avoided (**Figure 3**).

In this case, to fully understand the advantages of "market substitute products," the correct comparison is between an eHRC, sold as pickled and oiled, versus an annealed CRC for a given material and final thickness requested by the end-user. In most cases, according to the experience of Arvedi ESP plants worldwide, even no skin-passing is required; such a process is requested only for the cases where the final use demands smoothing the coil surface roughness provided by pickling.

Such eHRC is, of course, ready either for final use by the end customer or to be further galvanized / color-coated, as the case may be.

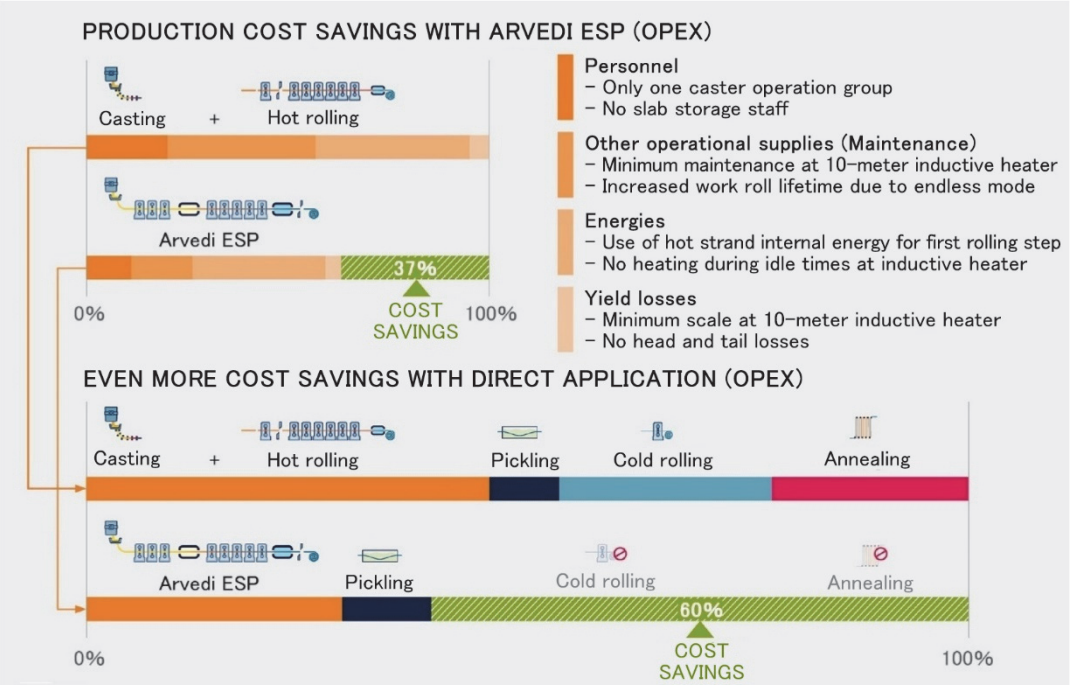

Figure 3 Arvedi ESP OPEX cost savings compared to a conventional process.

The production of thin and ultra-thin gauges is just the first reason for the success of the endless mode. The stable process conditions enable the production within the tightest geometrical tolerances and uniform mechanical properties across an entire coil and throughout a full sequence. This aspect is particularly important when the target is beyond just commodity applications.

ESP producers have fully recognized the advantages of eHRC and are considering it not merely as a different (and better) way to produce coils and save money. Thanks to its unique properties, eHRC is viewed as a distinguished product with its own "personality," to be presented to its customers, even with dedicated brand names to emphasize their added value.

A prime example is the Arvtech™ brand by Acciaieria Arvedi, which offers metallurgical characteristics and geometrical precision that make it an effective alternative to cold-rolled products for many applications. This brand will considerably shorten delivery times compared with the cold rolling cycle (**Table 1**, which is an extract of the Arvtech™ product catalog).

The quality results mentioned in Table 1 are the direct consequence of the endless process.

Having a continuous, stable, and uninterrupted process ensures that the mechanical properties of the coils are absolutely constant along the strip; there is no longer any difference between the head, core, and tail of a coil: the full length of the coils becomes "core." In endless mode, essentially, the complete sequence of, for example, 3,000 tons represents the core.

This uniformity is highly beneficial for coil end-users, reducing the head and tail crops for potential "out of tolerance" issues concerning both geometrical tolerances and mechanical properties. The head and tail ends of each coil are always a straight cut, further increasing the yield of the ESP line.

Figure 4 provides more details on these topics. This includes beside temperature uniformity and mechanical characteristics also geometrical tolerances like thickness, flatness (I-Unit is a dimensionless number that incorporates the height and peak to peak length of a repeating flatness wave across the strip), and profile tolerance (C_{40} means the value along the strip width without 40 mm from both strip edges).

Table 1 Arvtech™ Brand Steel Type Lineup

Type of steel	Arvtech™ designation	Standard designation	Thickness (mm)		Max Width [mm]
			min	max	
Mild steels UNI EN 0111	Arvtech™ DD11	DD11	1.0	3.5	1520
	Arvtech™ DD12	DD12	1.0	3.5	1520
	Arvtech™ DD13	DD13	1.5	3.5	1300
Structural steels UNI EN 10025-2 Delivery condition “as rolled”(+AR)	Arvtech™ S235JR/J0/J2	S235JR/J0/J2	1.0	3.5	1520
	Arvtech™ S275JR/J0/J2	S275JR/J0/J2	1.25	3.5	1520
	Arvtech™ S355JR/J0/J2	S355JR/J0/J2	1.8	3.5	1520
Weather-resistant structural steels UNI EN 10025-5 Delivery condition “as rolled”(+AR)	Arvtech™ S235J2W/J0W	S235J2W/J0W	1.45	3.5	1520
	Arvtech™ S355J2WP/J0WP	S355J2WP/J0WP	2.0	3.5	1520
Micro-alloyed steels UNI EN 10149-2	Arvtech™ S315MC	S315MC	1.25	3.5	1520
	Arvtech™ S355MC	S355MC	1.25	3.5	1520
	Arvtech™ S420MC	S420MC	1.38	3.5	1520
	Arvtech™ S460MC	S460MC	1.5	3.5	1520
	Arvtech™ S500MC	S500MC	1.5	3.5	1520
	Arvtech™ S550MC	S550MC	1.5	3.5	1520
	Arvtech™ S600MC	S600MC	2.0(**)	3.5	1520
	Arvtech™ S650MC	S650MC	2.5	3.5	1300
	Arvtech™ S700MC	S700MC	2.5	3.5	1300
Multi-phase steels UNI EN 10338	Arvtech™ DP600	DP600	1.5	2.5	1520
	Arvtech™ FB590	FB590	1.8	3.5	1520
	Arvtech™ CP800	CP800(**)	2.5	3.5	1520

Thickness range (mm)	Tolerance (mm)(*)
$0.80 < t \leq 1.20$	± 0.04
$1.21 < t \leq 1.60$	± 0.04
$1.61 < t \leq 2.00$	± 0.05
$2.01 < t \leq 2.50$	± 0.06
$2.51 < t \leq 3.50$	± 0.06

(*) The tolerance is not guaranteed from edge to 25 mm for coils with untrimmed edges.
(**) S600MC in thickness 2 mm and the grade CP800 are in development.

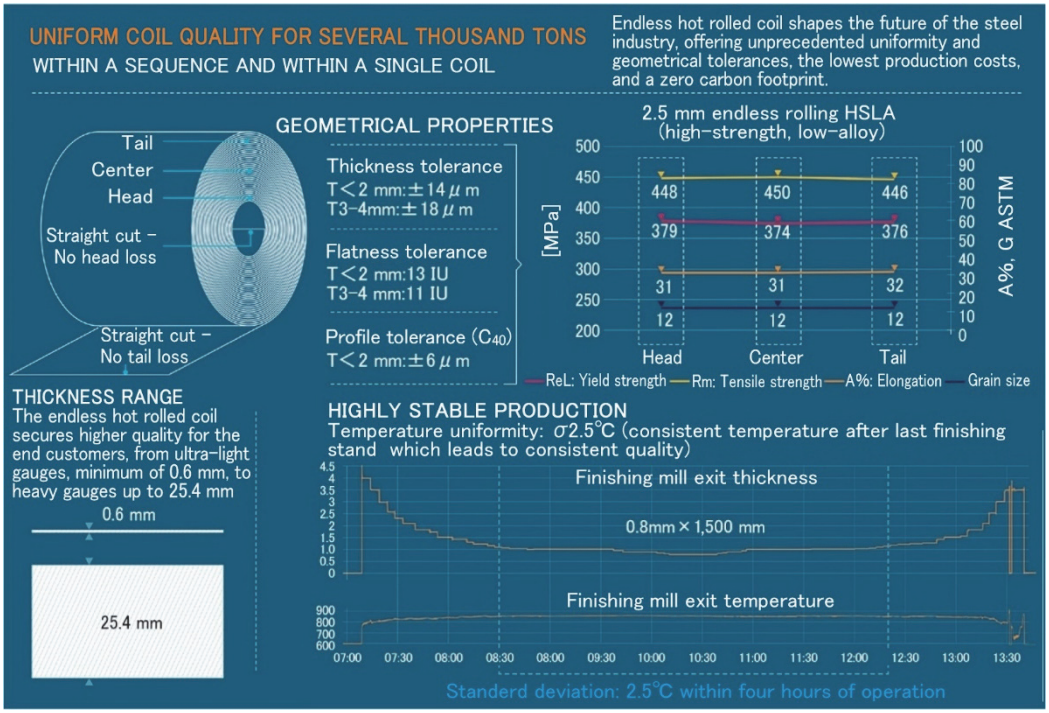

Figure 4 Superior quality features of eHRC

3. The Benefits of the Endless Process Extend Beyond Thin Gauges

The advantages of the endless process in terms of coil quality became so evident that a new market segment emerged as a profitable target: the production in the endless mode of relatively thicker grades with much more advanced added value. Enhancements in ESP equipment now allow targeting products that are qualified not only by their thin gauge but also by their mechanical properties.

In the first ESP plants, which were conceived to target the thin and ultra-thin gauges, the maximum coil thickness produced in endless mode was in the range of approximately 4 mm, while thicker gauges were produced in coil-to-coil mode. The most recent developments in ESP technology now enable the production in full endless mode of strip thicknesses up to 1 inch (25.4 mm), even for hard grades (e.g., API pipe grades).

This evolution has been made possible by:

- The increase of the slab thickness, allowing significant reduction rates also for thicker strips.
- The development of optimized roughing mill configurations with 3 or even 4 roughing mill stands.
- The introduction of multi-mode induction heaters, capable of efficiently controlling the heat transfer to both thin and thick transfer bars, making the endless operation energetically convenient also for thicker gauges.
- Patented cooling and power cooling features, tailor-made for each thickness and steel grade.
- The use of advanced rolling strategies to optimize the number of finishing stands involved in rolling.
- The development of powerful shears to cut in endless mode also for thicker strips.

4. The New Markets for eHRC

- Grades for Automotive Industry

  HSLA (High Strength Low Alloy) components, which ensure lightness yet robustness for vehicle structures, have seen impressive development in recent years. With typical thicknesses between 1.0 and 2.0 mm, eHRC with strengths up to 700 MPa is the ideal material for such applications.

  As a point of reference, these automotive applications constituted almost 30% of the market served by the ESP at Acciaieria Arvedi, Italy, out of a total of 42% of HSLA, with thicknesses ranging from 1.0 to over 8.0 mm.

  Examples of automotive applications are illustrated in **Figure 5**.

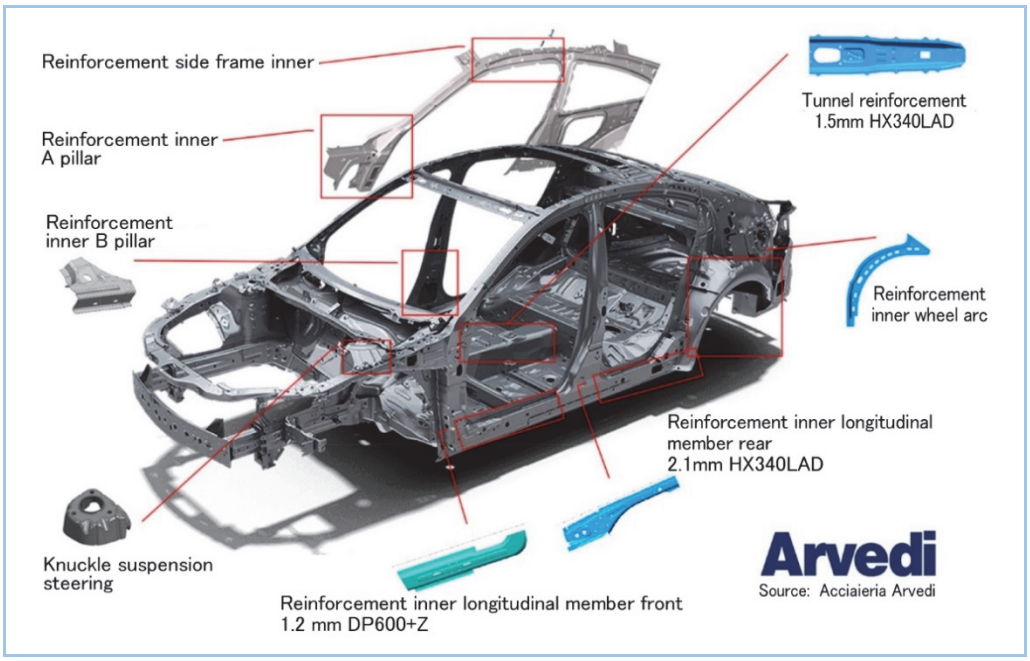

Figure 5 Automotive applications from Acciaieria Arvedi ESP coils

These materials are utilized not only for structural components (such as car bodies) but also for mechanical components (such as distribution shafts) as precision tubes.

- API pipe grades
  The 2-step rolling configuration of ESP enables perfect control over the temperature profile, aiming to achieve the desired final fine-grain structure via thermomechanical rolling and "pancaking". This production route significantly reduces the required alloying element content (Niobium) to control the precipitation process necessary for refining the grain structure. With the latest developments, the production of API X70 grades in endless mode up to 25.4 mm is now possible.
- AHSS (Advanced High Strength Steels)
  Thanks to exceptional temperature profile control during endless operation, AHSS grades like DP (Dual Phase) or TRIP (TRansformation Induced Plasticity) can be produced with the required multiphase structure, directly out of the ESP line. Such grades can be produced up to 12.7 mm in endless mode.
- Weather-resistant steels
  A prime example of direct application is the production of massive quantities of CORTEN grades by the five ESP lines at Rizhao, PR China. The resulting eHRC, which can be directly used for the manufacturing of containers, typically has a thickness of 1.4 mm.

5. Green Experience, at the Heart

What we have described here is a constant journey of progressive refinement of both equipment technology to materialize innovative processes and operational know-how developed in close collaboration with our partners over more than 15 years and after the production of more than 100 million tons of coils on ESP lines in endless mode.

From its inception, the ESP concept significantly evolved, now serving markets well beyond the original commodity market, with the aim of progressively becoming a standard tool for producing all flat steel products.

We cannot conclude this article without acknowledging the growing environmental awareness over the past decade regarding the necessity to transform the steel industry into an environmentally sustainable sector.

Our customers, particularly the ones serving the most demanding automotive markets, face increasing requirements from their end customers to deliver not just high-quality steel but green steel.

In terms of carbon footprint, the ESP eHRC represents a quantum leap compared to any other available casting and rolling technology for flat products.

Given that ESP uses no fuel at all (no tunnel furnace) and is based on the full exploitation of the thermal energy already present in the cast strand, the overall energy consumption and related greenhouse gas emissions are reduced to an absolute minimum compared to any other process, both conventional and thin-slab based.

This efficiency is proven by an unbeatable value of less than 1.0 kg of CO_2 emitted per ton of eHRC (Scope 1 emissions according to the greenhouse gas protocol) measured from caster to the down coiler, and a total electrical energy consumption in the range of 120 kWh/t for 2.0 mm x 1,500 mm low carbon steel in endless mode (Scope 2 emissions according to the greenhouse gas protocol).

The absence of long tunnel furnaces makes Arvedi ESP plants advantageously within the circular economy. Following this trend, more plants are being designed to operate with an EAF (electric arc furnace) based meltshop, where higher charges of metal scrap can be utilized. However, the maximum amount of scrap is limited by the tolerable amount of residual and trace elements such as Cu, as well as Sn, Sb, Pb, P, etc., since these elements are detrimental to product quality.

In particular, copper is responsible for the formation of high-temperature cracks on the surface of the cast slab and on the final coils (hot shortness phenomena). The occurrence of such defects happens precisely in the temperature range experienced by the slab inside the tunnel furnace. While in a tunnel furnace-based plant, the slab is exposed to these conditions for 10 to 20

minutes (corresponding to the travel time between the exit of the caster to the entry of the first rolling stand), in Arvedi ESP plants, this exposure time is basically reduced to just 1 minute. This capability allows Arvedi ESP to tolerate a Cu content approximately double that tolerated by conventional plants without compromising coil quality.

6. Outlook

Today Arvedi ESP is the most developed thin-slab casting and rolling technology in the world. Since 2009 the design of Arvedi ESP and the benefits of endless production have become state of the art and improvement of the technology continues. For steel strip production Arvedi ESP will be a key technology for the transition to green steel and a higher utilization degree of scrap. More than 100 million tons of green steel have been produced since 2009 on the already operating eight ESP lines.

Accepting scrap based liquid steel from EAF is essential to achieve the transition to green steel. This includes the capability to cope with higher copper content which can be achieved much easier with shortest oxidation times as given by the ultra-compact design of ESP lines.

Further important aspects for accepting thin slab casting and rolling lines are economical and operational performance. 2.5 million tons per year on a single strand have already been demonstrated in 2017 and reaching the new mass flow record of 7.1 t/min in 2020 enables an annual capacity exceeding 3 Mtpy.