連携記事

Reaching Maturity in Endless Casting and Rolling Technology with Arvedi ESP

連続鋳造・圧延技術の結実

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Abstract:

Arvedi ESP, developed by Acciaieria Arvedi and designed, manufactured, and sold by Primetals Technologies, has proven its capability to realize production of steel plates with excellent properties at a minimum production cost through continuous casting and rolling in endless mode operation[1-4].

The unique ultra-thin strip production technology applied in the device has made major advancements by setting new hot rolling world records with final strip thickness down to 0.6 mm[5].

It is also the first hot rolling process ever to produce cold rolled substitutes on an industrial scale and a large variety of final products are now produced directly from ESP hot band without implementing a cold rolling process. Energy consumption and related CO_2 emissions are drastically reduced by the compact layout of ESP lines as well as by omitting subsequent cold rolling steps.

This paper describes the structure of the particular ESP line and the results of operation.

要旨

Arvedi ESPは、連続鋳造・圧延をエンドレスモード運転で行うことにより、優れた特性の鋼板の製造を最小の生産コストで実現できることを実証した。Acciaieria Arvedi社が開発し、Primetals Technologiess社が設計、製造及び販売を行っている[1-4]。

独自の超薄物鋼板技術を組み込んだ本設備は、最終板厚0.6mmのホットコイルを製造する世界記録を達成した[5]。

またこの技術により熱間圧延工程で初めて工業的規模で冷間圧延代替品となる広範なホットコイルを製造し、現在では冷間圧延工程を省略し、直接生産できる。冷間圧延工程の省略およびラインのコンパクト化により、大幅な省エネ、ひいてはCO_2排出の削減を実現した。ここでは本設備の構成並びに操業結果について説明する。

1 Introduction

High-strength but lightweight car bodies, ultra-thin structures that possess the highest tensile strength, and lowest-possible production costs – innovative processes are required to meet the demands for automotive and other high-end steel applications. After years of successful operation in Italy, with seven additional lines ordered from China and one plant for USA, today Arvedi ESP is accepted as a proven technology that provides innumerable rolling possibilities to meet the highest downstream requirements. The use of 0.8-mm-thin hot-rolled products as a cold-rolled substitute – either directly or by processing the hot-rolled coils in continuous pickling and galvanizing lines – makes the cold-rolling process unnecessary for many applications. It was developed by Acciaieria Arvedi Steel and is designed, manufactured and implemented by Primetals Technologies. Operational results of the new lines adopting technology as well as possible configurations and processing lines are described.

2 Overall plant configuration

The 180-m-long Arvedi ESP plants are far more compact than conventional casting and rolling mills. A short line length means that lower investments are required for land, civil works, buildings, piping, cabling and construction (Fig.1). Liquid steel for the lines is either supplied from LD (BOF) melt shops or from Electric Arc Furnaces.

The bow-type casters perform continuous strand bending and unbending, and they are equipped with a straight mold for the casting of steel at thicknesses between 90 mm and 110 mm. Online strand-width adjustments are performed using DynaWidth mold-width adjustment technology. This solution allows the target strand width to be accurately met without the need for an edger (Fig.2) .

Three high-reduction mill stands are installed immediately after the final caster segment in order to utilize the remnant heat energy of casting for the initial rolling step. In addition to major energy-cost savings, this enables perfect crown and wedge control to be achieved with work-roll bending, since the hot core of the cast strand is softer and therefore has a higher formability for shape control.

The intermediate strip exiting the high-reduction mill then enters the induction heater, which features a short length of only 10 m. This enables the strip to pass through the furnace in less than 15 seconds, which is decisive for minimum scale formation.

Following reheating and descaling, the intermediate strip then enters the finishing mill equipped with five 4-high finishing stands. Because strip shaping has already taken place in the high-reduction mill, only the first two finishing stands are equipped with Smart Crown rolls that are designed with a bottle-shaped roll contour. This serves as the basis for final rolling of perfectly flat strip by the last three finishing stands, which are outfitted with conventional work-roll contours. Long-stroke shifting of the work rolls under load, which is regulated by a wear-compensation model, maximizes the service life of the rolls before surface grinding is required. What's more, thanks to the endless mode of operation in such plants, strip impact on the rolls – typical for batch-operated plants during strip-head threading – is eliminated. This aspect also contributes to a significant extension of the work-roll lifetime. For example, in a typical production sequence comprising 3,000 tons of liquid steel, a total of 170 km of strip – with a considerable portion of 1-mm gauge – is rolled by the final stand.

Rolling is followed by laminar cooling after which tension-free cutting is carried out by a high-speed shear. The endlessly produced strip with coiled weights of up to 32 tons is distinguished by highly uniform geometrical

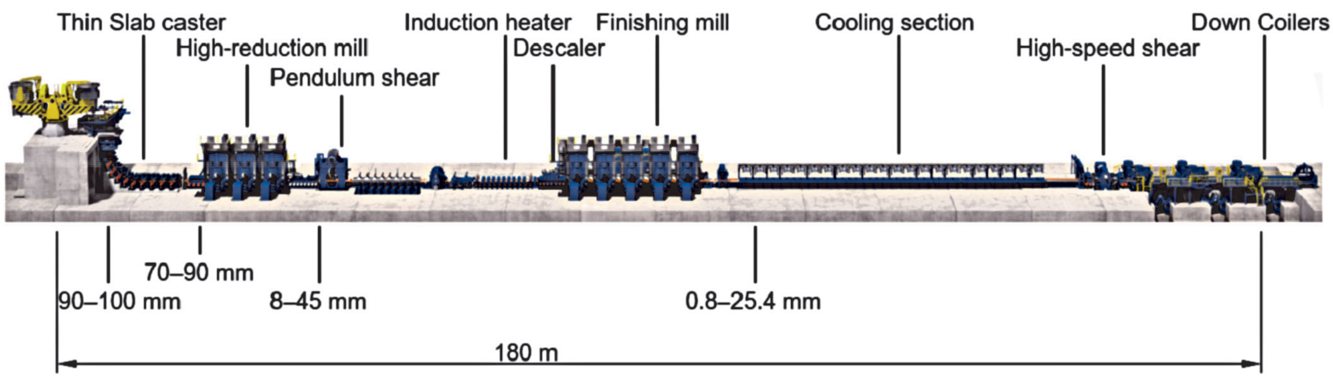

Fig.1 Layout and main components of Arvedi ESP plant.

Fig.2 Funnel mold with special shaped Submerged Entry Nozzle, ESP caster directly coupled to high-reduction mill, Induction furnace, Finishing mill, Laminar cooling, high-speed shear and down coilers.

and mechanical properties throughout its entire length. The fully integrated automation system enhanced with an advanced tracking model ensures exact cutting procedures and coil scheduling in accordance with production orders. The video https://www.youtube.com/watch?v=Y3fDodIPANo[5] gives an overview over the whole plant and its features. The entire process, including all plant technology and automation systems, are protected by Arvedi and Primetals Technologies patents.

3 Profile Control, Metallurgical Properties, Surface Quality

To maintain rolling stability for more than 170 km rolled length, it is important – especially for high amounts of ultra-thin strips - to keep the strip profile（strip thickness over strip width）in a controllable range and in a “good” shape（which is of course directly related to strip flatness）.

In order to achieve a proper strip profile additional points, compared to conventional hot rolling, need to be considered.

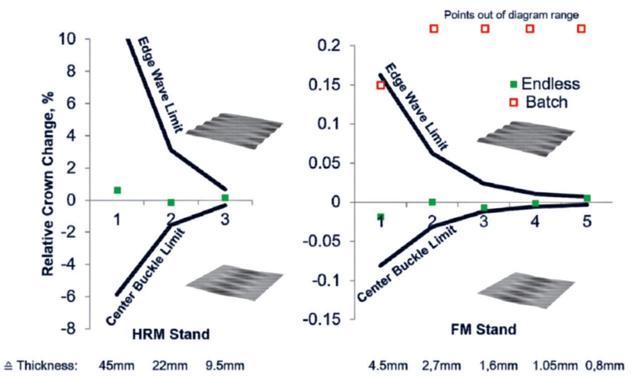

Fig.3　Profile control cone between edge and center buckle limit to target a flat strip for a ≤0.8 mm thick product.

One point is the small profile control window necessary for rolling ultra-thin strips. Thin strips are very sensitive to flatness defects, which means the relative allowable strip profile change（relative profile error）gets very small especially towards the last finishing mill stands. The allowable crown change for a 0.8 mm strip to stay within the limits for flat strip is given in Fig.3. For this, conditions in the finishing mill need to be very stable（no roll force and speed fluctuation, no temperature drift etc.）. Simulations and operational experience imply that only endless operations, preferably with applied work roll lubrication, can provide respective conditions for appropriate profile control.

Another point is that it has been seen, that with conventional work roll and back-up roll shapes（roll stack）only very small amounts of thin products can be rolled. For industrial scale ultra-thin strip production the work roll and back-up roll shapes need to be adapted in such a way to enable compensation of work roll wear on one hand and stable profile control on the other hand.

Even though work roll and back-up roll shapes are strongly adapted to allow a special wear shifting strategy, it has been proven that these roll shapes compared to the conventional hot strip mill philosophy are resulting in an advantageous flat profile, Fig.4. Adaption of roll shapes is not reduced to a parameter variation of conventional shapes but is a completely new approach - especially in the last finishing mill stands. Furthermore, the exploitation of the interplay between work roll and back-up roll shape in combination with wear compensation and constant work roll lubrication is required to achieve a good profile and hence stable rolling.

While geometry and uniformity of metallurgical

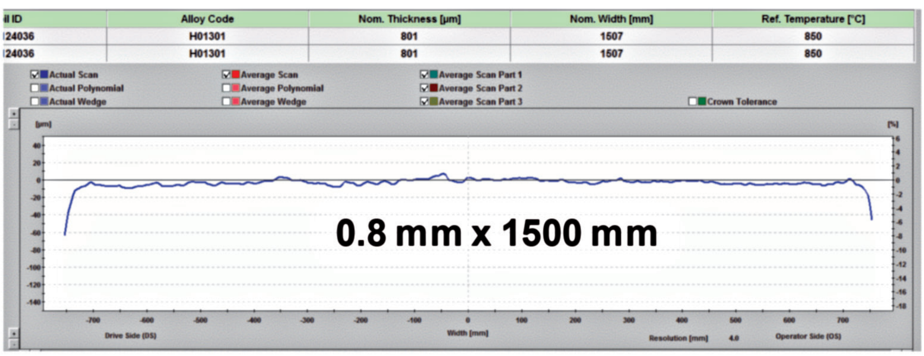

Fig.4　Measured strip profile (with X-ray gauge) at exit of finishing mill of a strip with thickness 0.8 mm and width of 1500 mm.

properties were out of question right from the beginning of ESP demonstrations a further quality point turned into focus – the surface quality. To find the definitive answer, Arvedi ESP material from Cremona had been examined. Several coils went through the automotive production route for pickling, tandem cold rolling mill and finally coating Z100 on the galvanizing line. The excellent geometrical constancy from head to tail paired with extremely low crown and wedge allowed the strip to run in the cold rolling mill smoothly without any fine tuning of the mill. During cold rolling the flatness was observed carefully starting with 7 I-Units of input material after stand 1 featuring a final flatness of 1 I-Unit after cold rolling stand 5. The strip was then further checked with the automatic surface inspection system confirming excellent results.

The test report was summarized as follows

- Hot strip geometry very good
- Thickness tolerances very good
- Width very good with only minor deviations
- Very good formability on cold Mill, strip was running perfectly
- Perfect flatness after cold rolling and galvanizing
- Practically free from surface defects

4 World's first 0.6 mm Hot Strip

Since the introduction of the Arvedi ESP process in 2009, the process and plant design has been constantly improved to follow new customer and market demands. This development peaked in the world's thinnest hot rolled strip ever produced. On October 2nd, 2018 an ultra-thin hot strip with a thickness of just 0.6 mm was rolled at an ESP plant featuring the process belonging to the Chinese steel producer Rizhao Steel Group Co., Ltd (Rizhao). (Fig.5) .

The said ESP line entered service in April 2018, just six months before setting this new record. In Fig.6 an overview of the rolling sequence including 8 coils below a thickness of 0.8 mm can be seen. The minimum thickness was reached by successively reducing the thickness in endless operation from approx. 3.5 mm down to 0.6 mm. The thickness steps for decreasing and increasing the thickness below 0.8 mm were chosen to be 0.05 mm.

5 ESP Material for Direct Application

The product mix of Arvedi ESP plants comprises low- and ultra-low- carbon steels, medium-carbon steels as well as high-strength low-alloyed (HSLA) and dual-phase steel grades. Thanks to the constant process parameters of endless operation, particularly with respect to the strip-temperature profile, production of advanced steel grades is accomplished with a far higher degree of accuracy compared to conventional casting-rolling processes. More details on metallurgical advantages of real endless strip operation can be studied in https://www.youtube.com/watch?v=3ePM7VEwpGs[7].

The required properties for rolled steel strip products are strongly related to their respective field of final application intended. Therefore, there is a vast amount of components in customer specifications for each steel grade, going far beyond its strength class reflecting market requirements for value-added products. The

Fig.5 Arvedi ESP mill produced ultra-thin hot strip with a thickness of 0.6 millimeter.

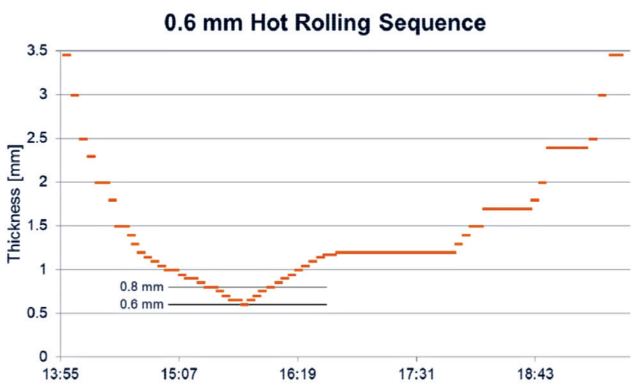

Fig.6 Overview of the 0.6 mm hot rolled coil sequence.

requirements characterizing a specific steel product may be categorized in terms of mechanical properties, e.g., yield and tensile strength as well as elongation, r- and n-value for characterizing drawability and strain hardening as well as internal properties partly reflected and/or required by mechanical properties such as cleanliness, microstructural homogeneity or texture. Besides this, geometrical properties such as thickness, profile, flatness or width as well as surface appearance characterized by tip to tip and average roughness, color, density of imprints or scale defects and suchlike are crucial.

To facilitate comparability among products of different vendors, the above mentioned requirements were cast into international norms and standards such as EN 10111, EN 10025, EN 10163 which characterize requirements for hot rolled general mild steels and structural steels as well as their cold rolled counterparts. Traditionally, the majority of final products was constituted by cold rolled material, especially for the class of mild steel grades. Beside technical limits of respective production equipment, this fact is reflected in the corresponding standards which are much wider for hot rolled than for cold rolled material in nearly every above-mentioned category, making hot rolled products appear as being partly viewed as a kind of semi-finished products. Historically, a rather small number of value-added products could be delivered directly to the market via classical hot rolling facilities without any further downstream processing. However, because of the necessity for tighter tolerances and the limited thickness range for thin gauge accessible via this route, the number of applications and, hence, market share was rather limited. Having a short look on cold rolling production, derived from a comparison of worldwide cold rolling facilities, the thickness distribution can be roughly estimated as shown in Fig.7.

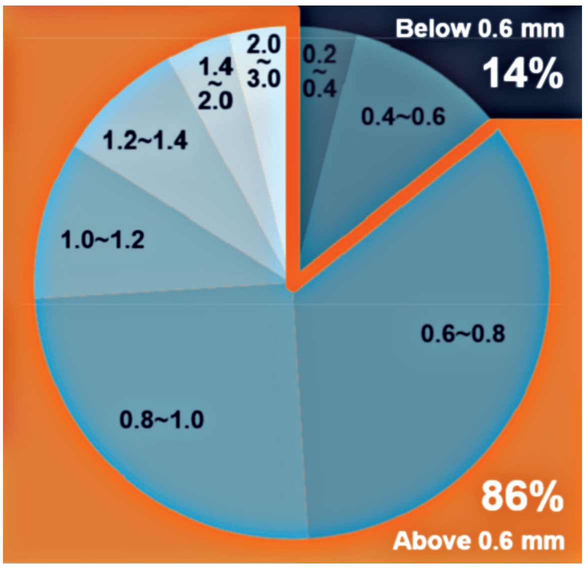

Fig.7 Thickness distribution on cold rolling market.

ESP mills are guaranteed to produce strip thicknesses of 0.8 millimeters, which are used industrially and traded on the market for direct applications. Whereas a strip thickness of 0.8 millimeters covers around 50 percent of cold-rolled thicknesses, a strip thickness of 0.6 millimeters can cover more than 80 percent of cold-rolled thicknesses. Conventional hot strip production has a lower thickness limit of 1.8 millimeters, or 1.2 millimeters for special processes. This widens ESP steel producer's range of products, especially for cold strip substitutes. With our ESP technology, it is not only possible to produce high quality hot rolled coils, but it enables also to partially substitute cold rolled material in just one production step.

6 Energy Consumption and Emissions

The ESP line in Cremona has been audited by TÜV Germany Süd and received a PAS2050 Green certificate identifying extremely low emissions (Fig.8). Compared to conventional plants ESP shows a CO_2 reduction of 39% and minus 88% of NOX emissions. Part of the certificate is also the attestation of 131.6 kWh/t energy consumption

Fig.8 Attestation about energy consumption of the Arvedi ESP process and Certificate PAS 2050:2011 (2012)

for production of 2mm thin and 1,500mm wide low carbon steel. ESP needs no gas for preheating of slabs. When operating the plant for direct application production as cold rolled substitutes energy consumptions and emissions of cold rolling plants are completely omitted.

7 Conclusion

The material coming from an ESP line can be excellently used to be sold directly in a wide range of products of the existing market. The material properties of the hot rolled material are comparable to a normalized grain structure after cold rolling. With such mechanical properties, the majority of the market can be served. If there are further requirements to the formability, as the Lankford value for drawing, the cold rolling step can be optimized as well by having the thin feed stock material of the ESP line.

The ESP product convinces by outstanding geometrical quality, surface quality, as well as the material properties for a wide range of applications, which is normally served by hot and cold rolled products.

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