The EU aims for climate neutrality by 2050. Currently, the European steel industry accounts for about 4.7% of total CO2 emissions in Europe. However, zero-carbon steel strip rolling is not a dream of the future. Arvedi ESP is the only technology worldwide enabling zero-carbon rolling of high-quality flat rolled steel already today. Arvedi ESP is known for about 40-65% lower energy consumption to produce hot rolled strip compared to conventional thin slab casting and rolling plants (TSCR). On the way to climate neutrality, it is inevitable for the steel industry to increasingly recycle scrap in the melt shop. The utilization of steel scrap involves gradually rising tramp element contents in the steel (Cu, Sn, etc.). This increases the likelihood of surface defects on the product as a result of Cu-induced hot shortness and similar mechanisms. This paper reveals why ESP is the perfect technology to produce best quality even with high tramp element contents related to increased scrap ratios in contrast to conventional TSCR processes. ESP technology facilitates a high-quality output of the full relevant steel grade spectrum including soft steels, thermo-mechanically rolled HSLA/API steels and AHSS steels.

Keywords

Climate change and the chance to benefit from it

Climate change driven catastrophes are increasing and so are related financial damages. Worldwide politics reacted with 21st Conference of the Parties (COP21) Paris agreement to limit global warming to well below 2, preferably to 1.5 °C, compared to pre-industrial levels. The Paris Agreement is a legally binding international treaty on climate change. As a motivator for everyone to act accordingly, countries introduced Emission Trading Systems (ETS) and carbon taxes. According to the World Bank report 2021, worldwide emission trading rates currently reach up to 137 US$ per ton CO2. The right investment decisions for low CO2 solutions at the current moment can give companies a competitive advantage for the next decades [1, 2, 3].

The potential for further optimization of existing traditional steel making plants is however limited. Most of today’s steelmaking emissions relate to combustion of fossil fuels and reduction of iron ore which are inherent to most production concepts. Switching from a combustion process to one using electrical energy has the advantage of reducing emissions close to zero in case the electrical energy is generated from renewable sources [4, 5]. As an example, Ref. [6] showed that by substituting the traditional BF-BOF-HSM route by an EAF-ESP route for steel strip production, the overall scope 1 (direct) CO2 emissions can be reduced by approximately 95% (scope 1 emissions are process-related emissions mainly due to combustion reaction of carbon carriers). Looking at the casting and hot rolling process alone, substituting the conventional slab casting and HSM route by ESP results in reduction of scope 1 CO2 emissions by even approximately 99%. It is worth noting that the well-established Arvedi ESP technology follows the zero-carbon rolling path already since 2009 exceeding already 80 million tons of green steel.

Arvedi ESP not only provides unmatched advantages regarding CO2 emissions compared to the HSM route, but also compared to conventional TSCR plants. As an example, Fig. 1 gives the specific scope 1 and scope 2 CO2 emissions for a conventional furnace TSCR plant (left) in comparison with ESP (right) for a 2 mm strip in endless mode (scope 2 emissions are associated with the purchase of electricity). Due to the long tunnel furnace in the conventional TSCR plant, the specific CO2 emissions including auxiliaries is about 80% higher than in the case of ESP. This dramatic difference comes from the very long residence time of the material in tunnel furnaces in endless mode. Depending on the tunnel furnace length, this time is typically in the order of 15-30 min. This moreover results in high scale losses there.
Challenges arising through EAF steel making

Steel making via the EAF route reduces CO2 emissions drastically, but at the same time new challenges arise. The global scrap amount will be sufficient to cover the steel demand by 2050. But as the scrap availability increases, inevitably the amount of tramp elements that cannot be removed during the steel making process will rise. The main critical tramp element in this regard is Cu. [7,8]

The longer the time for selective high-temperature oxidation during casting (and soaking), the higher is the enrichment of noble elements like Cu in the subscale regions of the steel. This results in formation of low melting point Cu-rich phases with low liquidus points of around 1090 °C. These phases penetrate and thus embrittle the austenite grain boundaries [9]. This so-called hot shortness can lead to crack formation in hot rolling [7,8] and hence to sliver formation during cold rolling [10]. Already today, typical average Cu contents in scrap are at a level of about 0.3 % [7,8]. Moreover, other austenite grain boundary embrittling residual and trace elements such as Sn, Sb, Pb, P etc. can promote high-temperature crack formation in addition to Cu [11].

Influence of copper in thin slab casting and rolling plants

Fig. 2 shows the two different types of TSCR plants compared in Fig. 1 in more detail. It is apparent that the long tunnel furnace promotes oxidation strongly. Contrary to the narrative that oxidation leads to an improved surface quality (on the cost of yield performance), it is well established in literature that tunnel furnace TSCR plants with EAF route are especially prone to surface defects related to the long heating time before rolling. Due to long time for selective oxidation of iron in the gas-fired tunnel furnace, crack formation due to Cu-induced hot shortness is promoted [9, 12, 13].

Typical tunnel furnace temperatures in TSCR plants (1040 – 1150 °C) are exactly in the range where the Cu enrichment and the subsequent penetration and embrittlement of the austenite grain boundaries are strongly favoured. This grain boundary embrittlement by hot shortness can cause severe surface cracking during the following roughing. Note that grain boundary cracking following the tunnel furnace is additionally promoted by the coarse solidification microstructure [11]. To reduce the likelihood of hot shortness and related quality issues on tunnel furnace TSCR plants, a maximum Cu content of only about 0.15 % is recommended [12]. The harmful effect of Cu can be minimized by Ni. However, this can increase the adherence of the scale layer to the steel substrate, thus making clean descaling more difficult [13].
Producer experience shows that the admissible Cu content is substantially higher for ESP lines thanks to the direct coupling of caster and mill compared to conventional tunnel furnace TSCR plants. This observation was the motivation to investigate the steel oxidation behaviour and the influence of Cu in tunnel furnace TSCR plants in comparison with ESP in more detail.

Novel Simultaneous Thermal Analysis (STA) equipment of the University of Leoben (Chair of Ferrous Metallurgy) allows to perform defined high-temperature profiles while subjecting the steel samples to customized realistic oxidation atmosphere conditions. With this novel equipment, the high-temperature oxidation behaviour of a low carbon steel was investigated (0.055 % C, 0.23 % Mn, 0.025 % Si, 0.32 % Cu, 0.055 % Ni, 0.033 % Sn). Two temperature profiles were applied: In the first scenario representing the conventional TSCR route, the oxidation process was simulated from mold exit to tunnel furnace exit. In the second one, simulation was done from mold exit to rougher entry (ESP route). Note that the caster temperature profiles were identical for both scenarios.

Fig. 3 compares the different oxidation behaviour resulting from the two temperature profiles applied. Fig. 3 a) and c) show the scale layer after the ESP temperature profile. Fig. 3 b) and d) present the conditions of the steel surface at tunnel furnace exit. It is apparent that the scale layer after the long oxidation period in the tunnel furnace is nearly 3 times thicker than the one after the ESP temperature profile. The steel surface is very uneven after the tunnel furnace, and as expected from literature, there are considerably more Cu-rich (white) phases present at the interphase compared to the ESP sample. Moreover, penetration of former austenite grain boundaries with Cu-rich phases is practically absent with the ESP sample in contrast to the tunnel furnace TSCR sample where pronounced hot shortness is found. In addition, considerable sulfide and oxide formation is found along the interphase and within the steel substrate close to the interphase with the tunnel furnace sample. These pronounced inhomogeneities at and below the interphase will not be removed during descaling before roughing, and this will also affect the surface quality of the final strip produced on a tunnel furnace TSCR plant.

The results of these novel high-temperature oxidation experiments clearly contribute to understanding the experience that ESP plants can tolerate much higher residual Cu contents before surface quality issues arise than tunnel furnace TSCR plants. This is another profound advantage of ESP since much cheaper scrap can be used. The significantly higher Cu-tolerance illustrates that ESP is the most universal TSCR technology when it comes to cope with different liquid steel qualities related to different steel making routes. In any case, the competitive advantage of ESP regarding EAF steel making will increase gradually as the average scrap quality will decrease inevitably over time. This quality advantage is one cornerstone making sure that ESP is able to cover the full steel grade spectrum starting from surface-critical deep-drawing grades up to advanced and ultra-high strength steels also in future. Moreover, further advantages by the direct coupling of caster and mill in Arvedi ESP are e.g.: an extremely compact layout, only about 5 min from casting to down-coiler, dramatically lower energy consumption and related CO2 emissions, less scale losses, less maintenance efforts, no primary descaler necessary, lower roughing loads, well-proven automation (in-house) and a well-proven emergency concept.
Another highlight of ESP is the possibility to produce the full thickness range from ultra-thin strips up to thick API grades in full endless mode on the same ESP line as presented in Ref. [14]. It is worth noting that batch rolling is also possible on ESP lines by cutting with the pendulum shear right after the roughers.

Owing to the extremely robust endless process in combination with highly flexible inductive heating, ESP is fully versatile regarding using (and switching between) different metallurgical rolling concepts in the finishing mill, namely austenitic rolling (e.g., thermo-mechanical rolling), two-phase rolling and ferritic rolling. This enables producers to apply novel production routes which are not possible using conventional batch rolling.
Summary

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 80 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. New ESP plants reached nominal capacity after 5 months for new ESP users and only 5 weeks with experienced ESP users. Minimum thicknesses of 0.8 mm were reached 6 weeks after start-up. 2.5 million tons per year on a single strand have already been demonstrated in 2017 and reaching the new mass flow world record of 7.1 t/min in 2020 enables an annual capacity exceeding 3 Mtpy.

References


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