NEW CONCEPTS IN STAINLESS STEEL TECHNOLOGY[1]

J. Reichel[2]
L. Rose[3]

Abstract

The prospects for the world economy for the next five years seem to still be characterized by high demand of the last years, obviously with the exception of Europe. New political developments in the Far East, especially in China and India, favour industrial branches which are fundamental for the national economy, also including the steel industry. The consumption of stainless steel has been growing for the past 5 years at 6% p.a. worldwide. In the year 2008 it was supposed to achieve the level of 30.1 million tonnes. Due to the worldwide economic crisis this figure will be not reached. Preliminary figures released by the International Stainless Steel Forum (last update 15.09.2008) indicate a dramatic drop in production. The production of crude stainless steel has decreased in the first half of 2008 by 1.8% compared to the same period of 2007. The general strategy of all major steel producers is reduction or postponing of production and investments. One scenario of further stainless steel production seems to be highly probable: Due to the reduction of production, the scrap availability on the market will temporarily grow but after the economic recovery it will take on a dramatic downward trend. The scrap supply will not be able to keep up with the evolution of steel production. New technologies and new material sources are required when new significant progress in world production has to be achieved. Steel scrap, chromium and nickel as base materials for stainless steel production are suffering strong market restrictions expressed in the form of prices. The same applies to the availability of electrical energy and some process gases. There is a clear trend in the use of hot metal containing chromium and alloys as a replacement for scrap. The electrical energy is able to be substituted by the chemical-free energy of metallurgical reactions. It also has to be stated that ferrochromium and ferronickel charging takes place more and more frequently in liquid form. Based on recent worldwide tendencies, stainless steel production is determined by the application of new iron sources such as hot metal, DRI and of technologies with equipment allowing continuous or semi-continuous metal treatment. BF (blast furnace), SAF (submerged arc furnace) and CONARC SSt are the likely technologies of the next decade. This paper presents an overview of possibilities and new trends in stainless steelmaking technologies.

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2 *Dr.-Ing. Habil., Senior Specialist BOF and Secondary Metallurgy, SMS Demag AG, Düsseldorf, Germany*

3 *Dipl.-Ing. Project Director, SMS Demag AG, Düsseldorf, Germany*

1 MODERN CLASSICAL PROCESS ROUTES

The capability of a steel plant with regard to the economical production of different steel grades as well as their quality is largely determined by the capability of the complete integrated production line. This production line starts with the charged raw materials, fed to the steel plant and then into the caster, and ends at the rolling mills. Only with optimum control of the complete production line can the stringent requirements regarding material composition and temperature control be fulfilled.
The modern production of ferritic and austenitic stainless steel grades works nowadays in two typical configurations: duplex and triplex technology. Figures 1-3 show technology solutions installed by BGYG Shanghai #1 and Extension.
The process routes set up by SMS Demag represent an innovative technology concept on the basis of pretreated hot metal (**D**esiliconization, **D**ephosphorization, **D**esulphurization) and scrap which takes into account the local specific conditions of the steel plant and the high production capacity of the existing blast furnace. Replacing scrap by hot metal as virgin material not only reduces the concentration of tramp elements but also introduces a new source of primary energy. The conventional EAF can be operated economically with up to 50% hot metal.
The availability of hot metal increases possible technological production alternatives. Bypassing the EAF allows direct production using the AOD converter or AOD converter and VOD plant without EAF operation. Duplex, triplex, EAF bypass, AOD bypass, production on scrap basis can only be applied depending on the actual production requirements as well the equipment maintenance schedule.

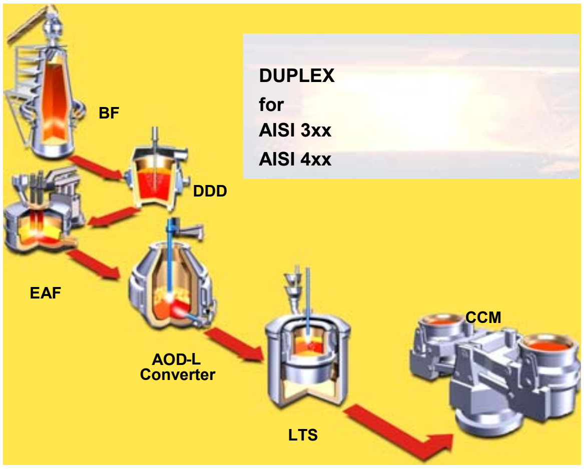


Figure 1

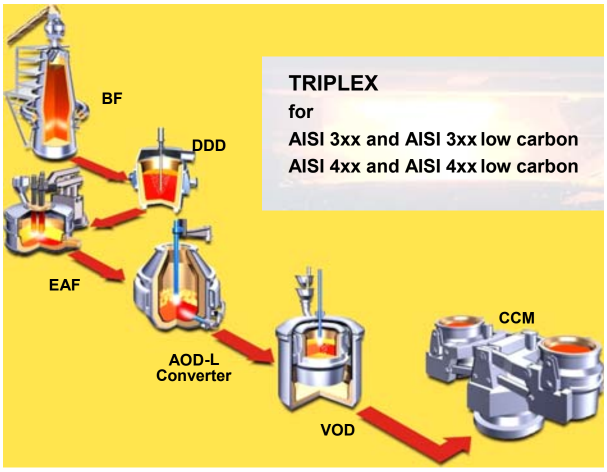


Figure 2

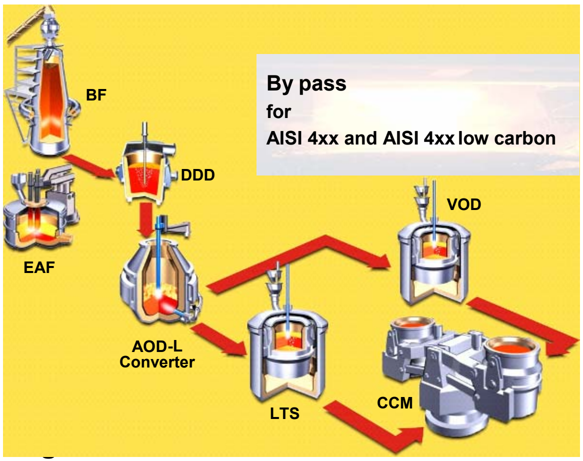


Figure 3

The typical technology used by BGYG is the Duplex process. Low carbon grades are produced by the Triplex process. EAF by- passing works with DDD and AOD In that case pretreated hot metal can be charged directly into the AOD converter.

As a converter charge, the metal constitutes approx. 80-90% of the converter's final weight. The remaining amount comes from alloy additions, mainly solid ferrochrome and ferronickel. The AOD process in the duplex technology allows cost-effective production of steel grades with final standard carbon contents of more than / equal to 0.02%. Steel grades with a lower carbon requirement are produced by the triplex technology as mentioned above. In that case the AOD process is completed at a carbon content in the range 0.25-0.4%, which corresponds to a thermodynamic equilibrium through high Cr content (10-18%), a temperature of approx. 1,700°C and atmospheric pressure. Final refining of the AOD metal takes place in the SS-VOD plant.

Due to the low-priced raw materials (high-carbon alloys), inert gas (nitrogen), refractory life time (shorter treatment times), reduced energy consumption (hot metal application) as well as short treatment times (reduced decarburization), the triplex process is characterized by high efficiency and economy.

Depending on the different commercial or operational situations prevailing in a steel plant, the EAF by-passing ensures production flow. However, the direct use of hot metal in the AOD supplies only part of the necessary energy. A relatively low temperature after the DDD treatment requires a corresponding temperature increase. This is attained by specifically controlling oxidation reactions in the metal bath before charging ferrochromium alloys. Due to the low hot-metal energy input, the process is limited to the production of ferritic or duplex steel grades.

Table 1 shows all possible technological combinations and flexibilities resulting from the installed equipment and its availability.

Table 1. Possible technologies with Shanghai #1 / Extension equipment

Variant	DDD	EAF	AOD-L	VOD	Steel grade AISI	Remark
1	x	x	x		3xx, 4xx 2xx	Duplex , Hot Metal, Scrap
2	x	x	x	x	3xx, 3xxL 4xx, 4xxL 2xx	Triplex, Hot Metal, Scrap
3	x		x		4xx 2xx	EAF-By-pass, Hot Metal
4	x		x	x	4xx, 4xxL 2xx	EAF-By-pass, Hot Metal
5	x	x		x	3xx, 3xxL 4xx, 4xxL 2xx	AOD-By-pass, Hot Metal, Scrap
6		x	x		3xx, 4xx 2xx	Duplex , Scrap
7		x	x	x	3xx, 3xxL 4xx, 4xxL 2xx	Triplex, Scrap
8		x		x	3xx, 3xxL 4xx, 4xxL 2xx	AOD-By-pass, Scrap

2 NEW STAINLESS STEEL PLANT AT JINDAL

In March 2007 SMS Demag set up a new integrated steel plant for Jindal Stainless Ltd at Jajpur, Orissa, in India for the production of 0.8 million t.p.a. of stainless steel slabs (Figure 4).
Two EAFs are to be installed, one for scrap and direct reduced iron (DRI) melting and one for FeCrHC melting. The latter material is supplied upstream from two submerged arc furnaces (SAF). Both EAFs prepare the liquid charge (pre-metal) for refining in a 150t AOD converter. Before continuous casting to slabs, the steel is treated in a downstream ladle furnace (LF) to improve homogeneity regarding temperature and analysis.

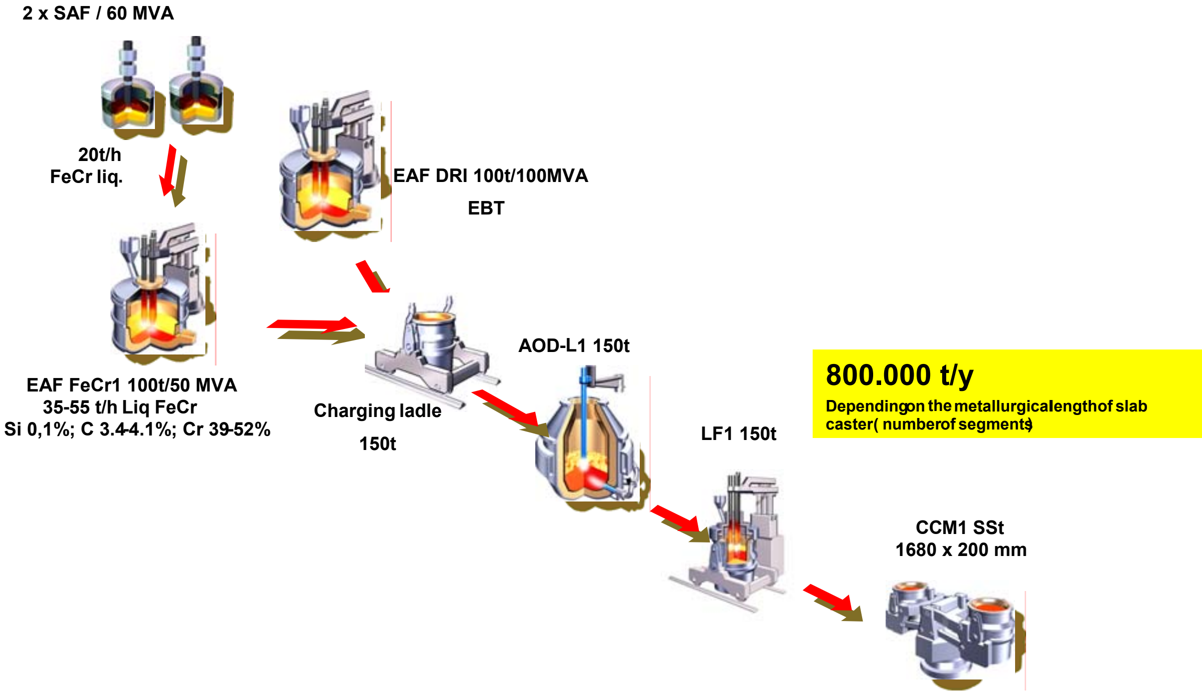
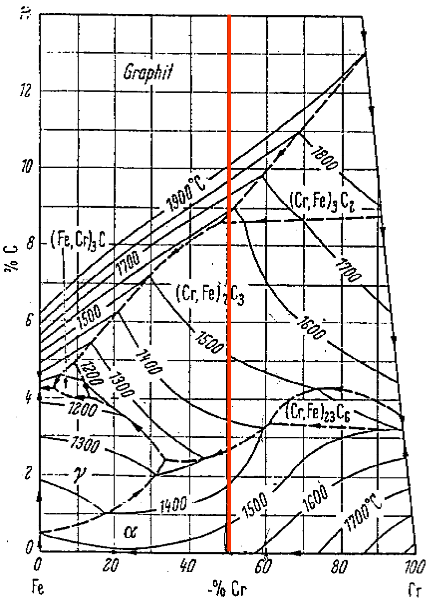


Figure 4. Production line by Jindal Stainless Ltd. Phase #1

The innovative aspect of this technology is found in the pre-metal preparation. Two SAFs (**S**ubmerged **A**rc **F**urnace) work as direct reduction furnaces with a production capacity of 20t FeCrHC per hour. Ferrochromium with approx. 50% Cr, carbon (6-7%C) and silicon (1.5-3%Si) as a SAF final product is characterized by a high liquidus temperature in the range 1550-1600°C (Figures 5 and 6).



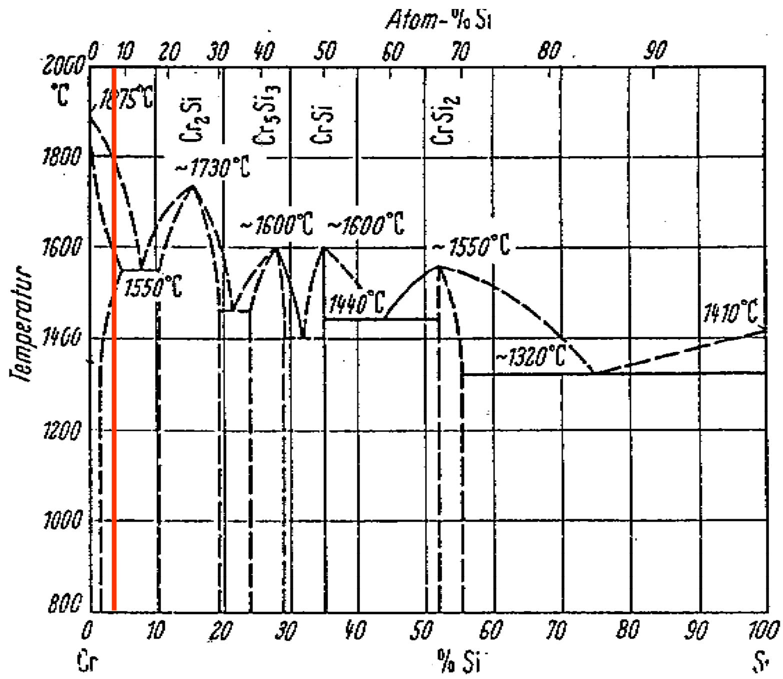


Figure 5. Cr-C equilibrium mixture

Figure 6. Liquidus temperature of Cr-Si

Optimum plant logistics ensure fast transfer of the liquid ferrochromium from SAFs to the EAF FeCr in a temperature range above the liquidus temperature. For the purpose of decreasing the liquidus temperature and avoiding skull formation in the transfer ladle as well as in order to achieve the required chemistry for the AOD converter, a refining step in the EAF FeCr is carried out. The EAF FeCr works with a hot heel, approx. 50% of the total capacity. By oxygen-blowing, carbon is reduced to the level of approx. 3.5% and silicon lower than 0.3% by restrained chromium oxidation. The liquidus temperature of such ferrochromium drops to approx. 1400°C, whereby the tapping temperature is adjusted at approx. 1650°C. For weight build-up and cooling, one bucket with scrap, solid ferrochromium and slag former are charged. Depending on the energy balance, the FeCrHC pellet is charged continuously via the 5th hole of the furnace roof.

Parallel to the ferrochromium refining, a melting of DRI takes place in the EAF DRI. In principle the charge material consists of DRI only. Similar to the EAF FeCr, the process works with approx. 50% of the tapping weight. Both electric furnaces are synchronized with the AOD converter in a cycle between 50 to 60 minutes depending on the produced steel grade. Approx. 50% of each furnace capacity is tapped into one ladle, beginning with the EAF DRI, and transferred to a deslagging station, later charged into the AOD converter.

The process line is distinguished by high flexibility in the AOD pre-metal supplying. All timely production disturbances in FeCrHC supply or in AOD production schedule can be equalized by metal reserve accumulated as a hot heel. Disturbances in the SAF production can be reduced by a corresponding melting of solid FeCrHC. Suitable electrical power of the transformer (50 MVA) and foaming slag practice ensures such situations.

3 EAF FOAMY SLAG PRACTICE IN STAINLESS STEEL

The economics of the electric arc furnace technology is strongly dependent on the efficiency with which electrical energy is introduced into the metal bath. Slag foaming practice for carbon steel grades has been used for a long time but it has not yet been successful for stainless steel grades. The lowering of production cost is achieved by improving thermal efficiency and operating conditions, for example, by stabilizing the arc activity. As a result of such technology, the refractory and electrode consumption as well as noise level is considerably decreased.

All these effects can now be achieved in stainless steel production thanks to a new patented technology of SMS Demag AG / Germany which was developed with the AGH-University of Science and Technology in Cracow /Poland and industrially tested by ArcelorMittal Inox Brazil (formerly Acesita S.A), Jindal Stainless Ltd. / India and BGH Edelstahl Siegen GmbH / Germany.

The new technology differs fundamentally in comparison with all known applied and tested technologies working on the basis of the injection procedure. The specially prepared briquettes are used as reacting agents on the slag and on the metal phase boundary, forming the carbon monoxide and dioxide necessary for the foaming effect. A controlled high foaming level, which completely covers the electric arc, allows for the highest transformer taps resulting in longer electric arcs and a higher heating temperature gradient.

Two factors define the foamy slag formation: the foaming material with the corresponding reacting components, which produce gaseous products, and the slag viscosity, depending on the chemistry and temperature. A liquid slag is a prerequisite for the foam formation.

The principal reaction that creates gas bubbles in the slag is the reduction of iron and chromium oxides. This reaction is shown by the following stoichiometry:

$$(FeO) + C_{particle-or-dissolved} = [Fe] + \{CO\} \quad (1)$$

$$(Cr_2O_3) + 3C_{particle-or-dissolved} = 2[Cr] + 3\{CO\} \quad (2)$$

The first reaction (1) is applied principally in carbon steelmaking because iron oxide is the major component in the slag. When the slag viscosity is suitable for sustaining foam, then simple carbon injection into the slag causes the foaming effect. The other situation applies to stainless steel slag. The major components are CaO, SiO_2 and Cr_2O_3. The SiO_2 is a fluxing component, while the Cr_2O_3 stiffens the slag. Due to the higher chromium affinity to oxygen, the Cr_2O_3 generation is preferred to FeO generation. Therefore it is important to control the chromium oxide content and the slag basicity, responsible for the viscosity, which forces gas bubbles to be temporarily retained in the slag layer.

Additional gas source of the briquettes is limestone. Thermal dissociation of this material provides CO_2 corresponding to the eq. (3).

$$(CaCO_3) = (CaO) + \{CO_2\} \quad (3)$$

The bubble forming phenomenon is a process that uses the mechanical force from reacting gases to produce a new surface area in the slag. In the presented technology this gas is a product of the reduction of metal oxides by carbon and thermal dissociation of limestone taking place in a briquette or pellet introduced into the metal bath. Buoyancy forces on the bubbles temporarily crack the slag surface, thus saturating the top layer to create the foam. With a sustained gas flow coming from the

reacting briquettes, the population of bubble aggregation as foam continues to grow. As a consequence of this, the height of the foam layer increases. The optimum placing of the briquettes to obtain the maximum foaming efficiency is important for such a mechanism. This optimum placement is the boundary between the slag layer and liquid metal. By controlling the briquette density so that it is between that of slag and metal (3-7 m^3/t), such placement is always attainable. The foam height increases with the increase of the gas flow rate; it is directly proportional to the foaming material rate.
Figure 7 illustrates the principle of the slag foaming.

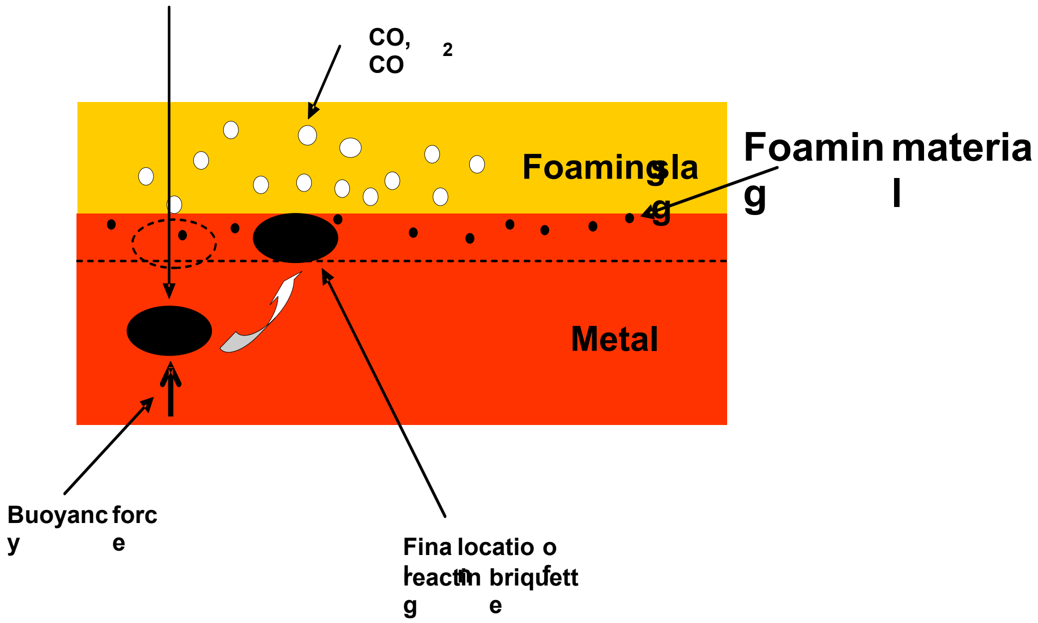


Figure 7. Principle of foamy slag formation in stainless steel

On the basis of the laboratory test, ArcelorMittal Inox Brasil and SMS Demag agreed on a common industrial test with high Cr-oxide foamy slag in an EAF. The test was carried out in the No. 3 EAF in Timoteo, Brazil steel plant and integrated into ongoing production. EAF No. 3 is operated by electrical power divided into nine taps. Tap 28 with an arc length between 15.5 and 21.5 cm enables operation with the maximum power and is generally used in the first melting stage only. Because of intensive energy radiation on the furnace walls during the super heating period, when the metal bath is flat, protected operation is required, e.g. short electric arcs. In operational standards the lowest taps between 20 and 23 are applied with arc lengths of 10 - 16.6 cm. A high foaming slag level above the electrode tips enables operation with higher taps shortening the tap-to-tap time. The real temperature gradient was estimated at approx. 12 - 14 K/min at tap 28, against 3 - 7 K/min at taps 23, 24. Briquettes were fed into the furnace via the fifth hole at controlled speed.
For the purpose of noise measurement during the foaming period in comparison to standard operations, some heats were recorded continuously by a portable sonic measuring device. Figure 8 and Figure 9 illustrates the typical development of the slag height in an AISI 304 heat. The slag heights were measured relative to the electrode diameter. As the curve shows, after approx. two minutes the slag reached the height suitable for covering the electric arc. During the next four minutes this level was maintained, leaving the required range after 4 - 5 minutes. The relationship between electrode consumption and the foamy slag is of undisputed significance.

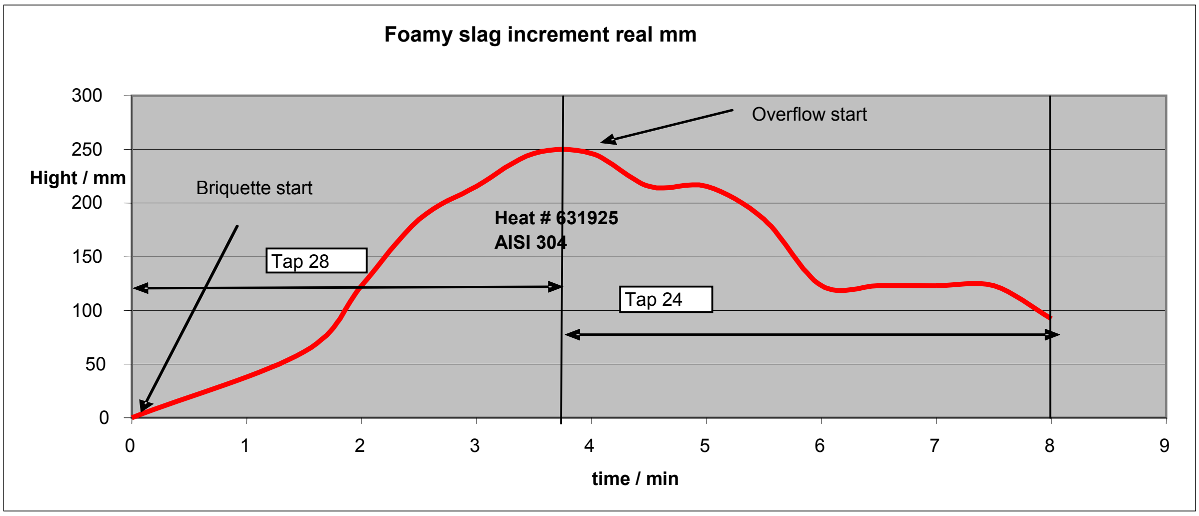


Figure 8 Course of slag height

Figure 10 uses the secondary voltage to illustrate the electric arc behavior in a standard operation and in the presence of foaming slag. Small signal fluctuations with low amplitude level out and lower mechanical and thermal electrical tensions. Consequently, the level of noise generation is also low. Figure 11 shows a comparison of the noise development in the case of a standard heat and of one with foamy slag. It can be seen that in the super heating period, the standard heat is processed with a decisively lower transformer tap 23 and 21, generating a noise level between 100 and 95 dB respectively. The test heats show a clear correlation between foamy slag covering the electric arc and the noise level. The dampening impact of the foam can be clearly seen in the final period where the noise level decreases from approx. 95 dB to 90 dB at transformer tap 24.

The heats were generally tested with a view to the briquette components, their density, control of feeding almost all respects. Regarding the charged materials, chromium, manganese and metal yield, the improvement is approx. 2%. Shortening the super heating period by operation with higher transformer taps has a high potential in increasing a plant's production. However, due to the relatively low number of the test heats (60), a final comparison will be made after more tests. Long-term effects like electrode consumption, refractory life, electrical maintenance of transformer switch contacts and dust emission are also of high significance for the process economy.

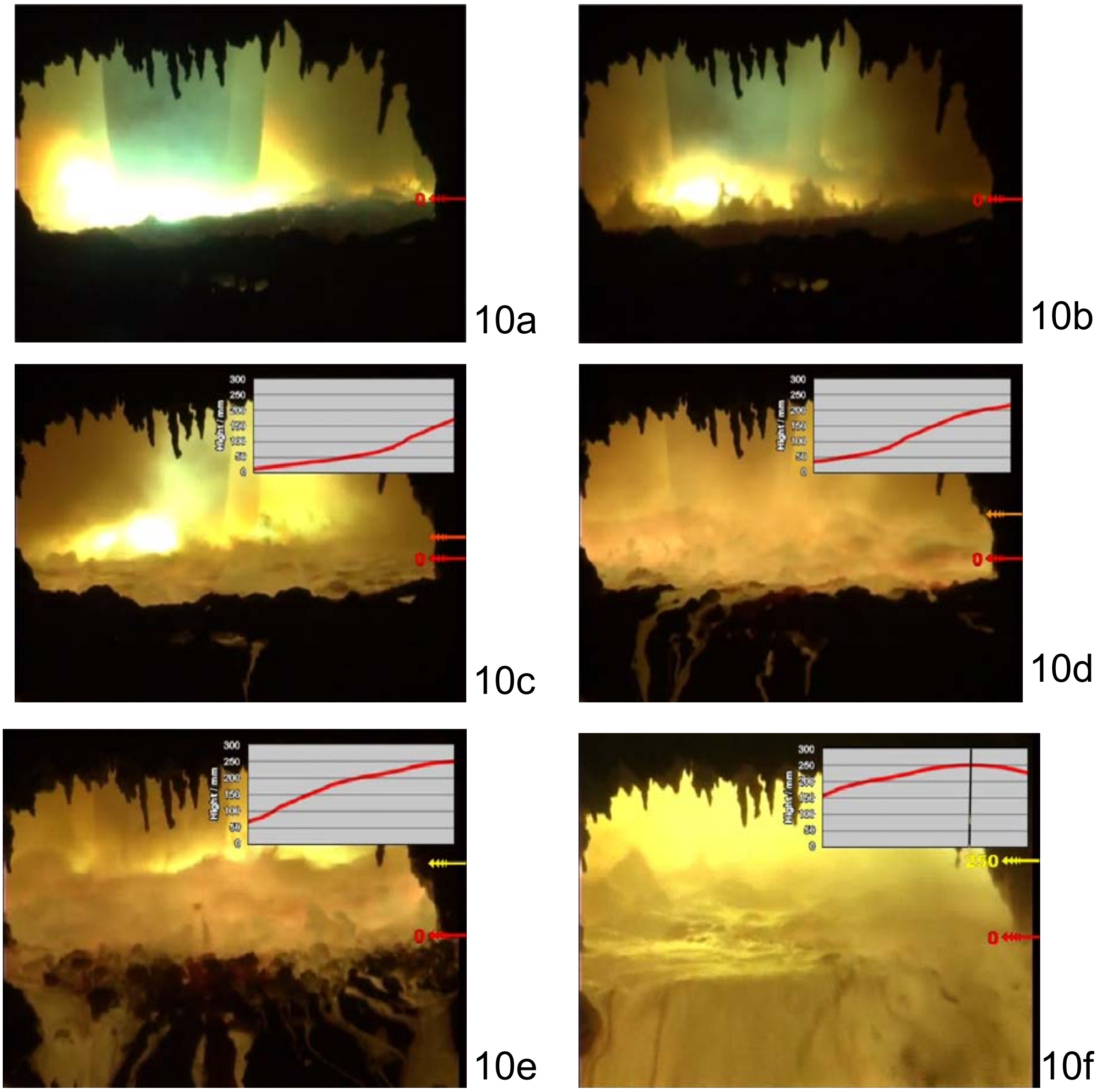


Figure 9. Sequence of slag foaming in an austenitic heat

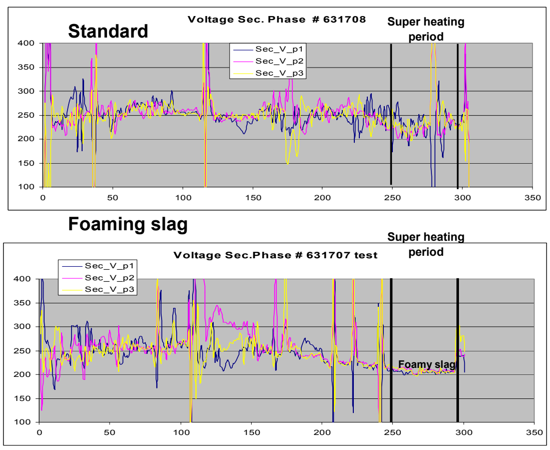


Figure 11 Dynamics of electric arc in standard and foamy slag operation

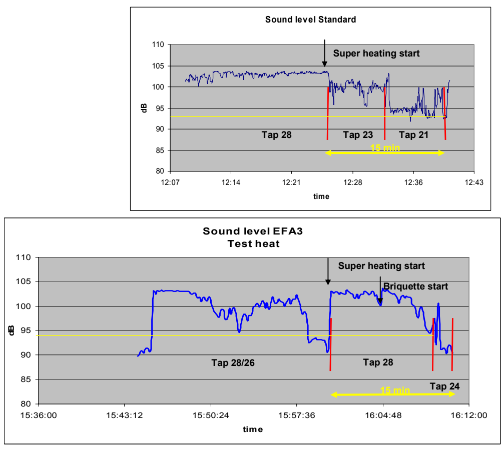


Figure 12. Sound development during super heating

4 CONARC© SSt PROCESS. FUTURISTIC TECHNOLOGY FOR STAINLESS STEEL

The successful results of the **CONARC© CSt** process for carbon steel initiated the idea to introduce this innovative process also for stainless steel production. As shown in Figure 12 the process sequence is completely the reverse of that for carbon steel production. As in conventional stainless steel technology the process starts with melting down the scrap and ferroalloys or, in case of scrap shortage, with hot metal from the blast furnace. The hot metal from the blast furnace has to undergo in such a case special treatments in DDD to serve the requirements of stainless steel. The second phase, refining of the steel, takes place with the oxygen blowing in combination with inert gas blowing. The complete process is executed in one vessel only, which has outstanding economical advantages for the overall production. The **CONARC© SSt** was developed primarily as a process located in the Triplex route in combination with a double vessel SS VOD plant (Figure 13a).

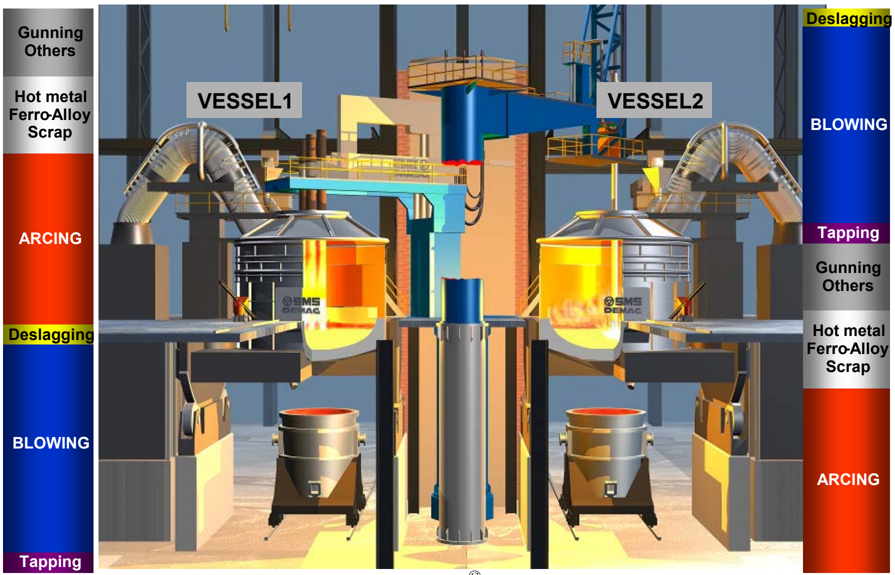


Figure 12. CONARC© SSt process

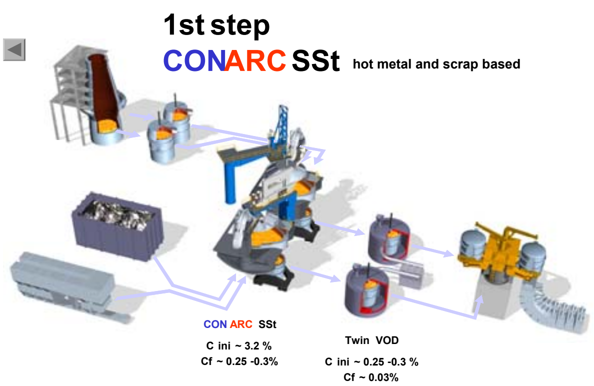


Figure 13a. CONARC SSt in Triplex route

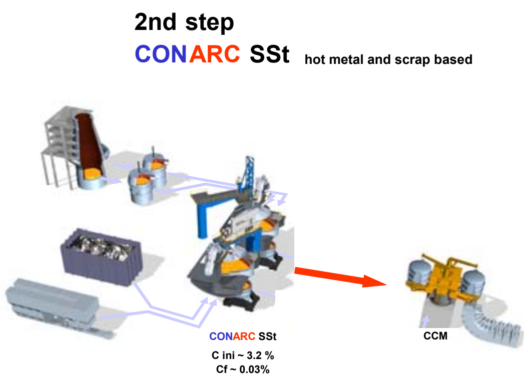


Figure 13b. CONARC SSt in future

The industrial test (1st step) was successfully carried out by TKN in Terni / Italy. In combination with oxygen top blowing and arcing, the **MeltRed** technique with its slag reduction during the melting period was tested as well. By using this technology combined with a VOD plant, all steel grades including low carbon content, i.e. lower than 200 ppm, can be produced. The continuation of the development presented in Figure 13b has the goal of attaining three new significant properties:

- dephosphorization of hot metal in the presence of high chromium content (6-16%) during the arcing period
- steel refining corresponding to the final carbon content of the produced steel grade
- treatment time in sequence less than 110 min in one vessel (for two vessels tap-to-tap time less than 55 min)

Initial calculations indicated production cost savings up to 18 US$ per ton and reduced specific plant investment by about 20 % in comparison with the conventional AOD duplex route.

5 CONCLUSIONS

Steel consumption of a country is closely related to its economic growth and standard living. To supply steel products stably while ensuring harmony with the global environment new technologies are required. They should improve efficiency of processes especially in scope of energy and material optimization. Continuous steel making is still dream in our new twenty-first century. **CONARC** SSt process, with direct Cr-hot metal charging, complete refining, and all new technology components as dephosphorization at chromium presence, foamy slag and MetRed is the first step in this direction.