Modern Steelmaking Technology

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Introduction.

The requirements on steel products have increased steadily. These requirements include higher strength in order to reduce the weight of a construction, better toughness to allow for its safe application particularly at subzero temperatures, better cold formability and surface quality especially for the automotive industry and better weld ability allowing for more economic high heat input welding processes.

Analytical Requirements.

A term often used is "clean steel", which originally described a steel product with a low level of oxide and sulfide inclusions. The term now also relates to demands to low levels of phosphorus, hydrogen, nitrogen and sometimes even carbon. The table below shows some of the lowest levels, which are actually demanded in certain specifications or internal standards.

By consequent use of available processes, the production of clean steel exhibiting max. 60 ppm as the sum of all the above mentioned elements is possible (1). It is expected that mass production of ultra clean steel in the year 2000 will guarantee max. 30 ppm as the sum of all these elements (2)

Examples of specified low trace elements (1ppm = 0.0001%)

Element	Product	Content
Hydrogen	rail steel	< 1.5 ppm
Carbon	interstitial-free steel	< 25 ppm
Nitrogen	electric sheet	< 20 ppm
Oxygen	wire cord	< 10 ppm
Phosphorus	offshore steel	< 80 ppm
Sulfur	sour gas pipes plus sulfide shape control	< 10 ppm

Besides limitations in these metalloids there are often internal standards, which require low levels of metallic elements, e.g. of those elements, which may have a negative influence on the surface quality of steel. One example is a company, which limits the sum of the elements Cu+Cr+Ni+Sn to max. 0.07% in about 50% of their production (3).

In order to fulfill such stringent requirements, steel- making technology has been subsequently improved by optimizing each production step, i.e. pig iron production, pig iron treatment, scrap selection, oxygen steel making, tapping, ladle treatment, tundish metallurgy and continuous casting. Some of these processing steps will be discussed in the following sections.

Desulfurization and Sulfide Shape Control.

In order to remove sulfur from the liquid metal, it is necessary to use a sulfide-forming agent such as a calcium compound. The sulfide-forming reaction is promoted in a reducing atmosphere, therefore, it is most economical to desulphurize already the pig iron. The most important agent used to be calcium carbide with additives, owing to its favorable costs. But a better desulphurization ratio is achieved by using agents based on magnesium and the joint injection of both elements results in the most economic process as shown in Figure 1 (4). With modern practice the pig iron charged to the converter has typically sulfur content below 0.010%.

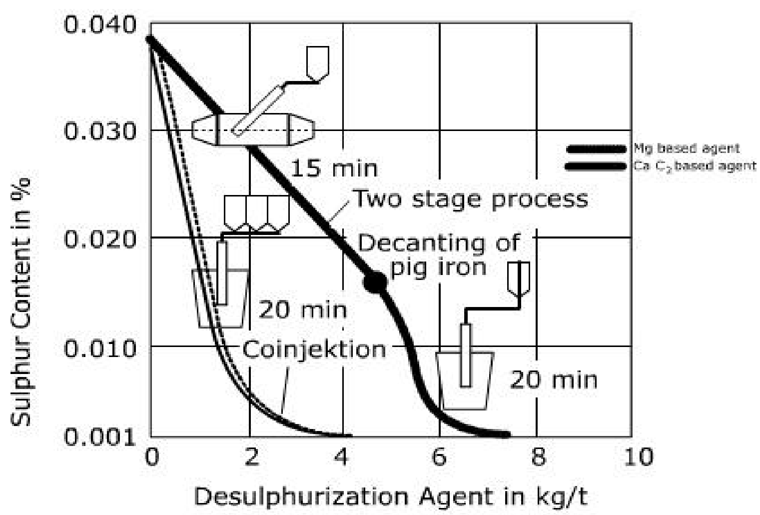


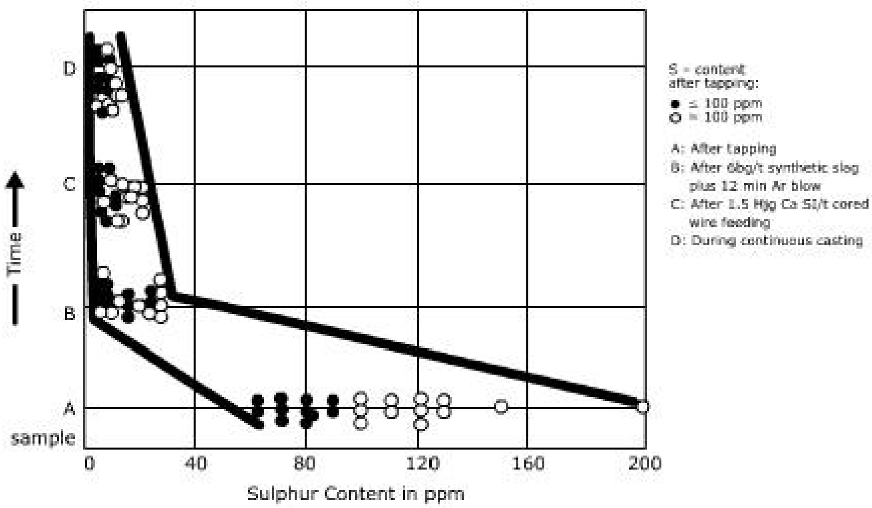
Figure1. Desulphurization of pig iron

Owing to the high oxidation potential any desulfurization during the oxygen steelmaking process is rather low. When starting with very low sulfur content in the pig iron, an increase in sulfur can be observed deriving from the scrap. Typically the sulfur content after tapping is also around 0.010% and a further lowering is made via ladle metallurgy. The following conditions favor desulfurization and these are often prerequisites:

- a low oxidation potential obtained by slag-free tapping, protection of the melt against air by inert gas bubbling and addition of a protective or preferably a reactive slag with a reducing agent, e.g. aluminum

- a ladle with a basic lining;
- high turbulence in the ladle allowing a good dispersion of the desulfurization agent and preparing a high reactive surface;
- a rather high temperature promoting the desulfurization reaction.

The agents typically used for steel desulfurization are either calcium alloys like CaSi or low melting point synthetic slags of the system CaO-Al2 03-CaF2 containing aluminum.



Steel Desulphurization in a 190 t Ladle

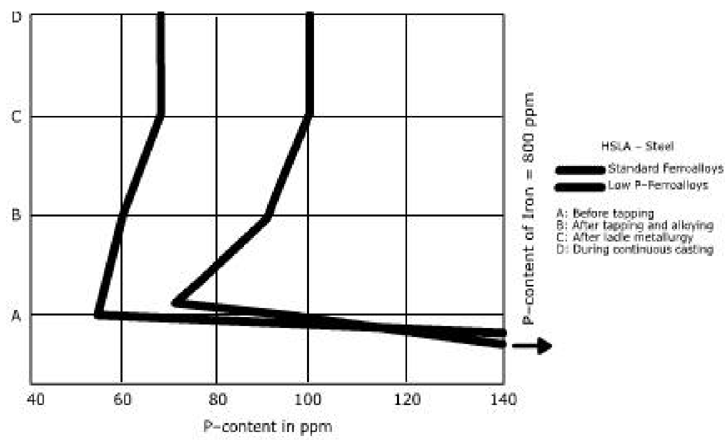
Figure 2

<u>Figure 2</u> (5) describes one processing route to achieve sulfur contents below 10 ppm, necessary for steel to be resistant against hydrogen-induced cracking. These steels also require sulfide shape control, which is made by feeding a cored wire filled with CaSi into the molten metal.

Dephosphorization.

Except for the need of a strong basic oxide, e.g. CaO, the conditions for dephosphorization are quite different than these for desulfurization, since a high oxidation potential and a rather low reaction temperature are favorable conditions. Therefore, both a treatment of the pig iron or the steel ladle metallurgy are not the first choice for cost effective lowering of the phosphorus content. But it should be mentioned that there are other techniques for lowering the phosphorus content, either in the pig iron via a two stage process (6) or using a CaO-FeO containing slag added during low temperature tapping of steel, which then requires follow up operations such as slag removal before deoxidation and reheating of the steel in the ladle (7).

Typically the benefits of the combined blowing process are used to achieve a low phosphorus content. it includes an optimization of the nozzle for oxygen blowing onto the bath surface and an inert gas injection through the converter bottom, thus bringing the steel bath and the slag close to the state of equilibrium. Depending on the basicity of the slag and its quantity, low phosphorus contents can be achieved by this way. In order to maintain this low level obtained in the converter, slag free tapping to avoid rephosphorization and the use of alloys with rather low phosphorus content are needed, as shown in figure 3 (3).



Steel Dephosphorization by Combined Blowing

Figure 3

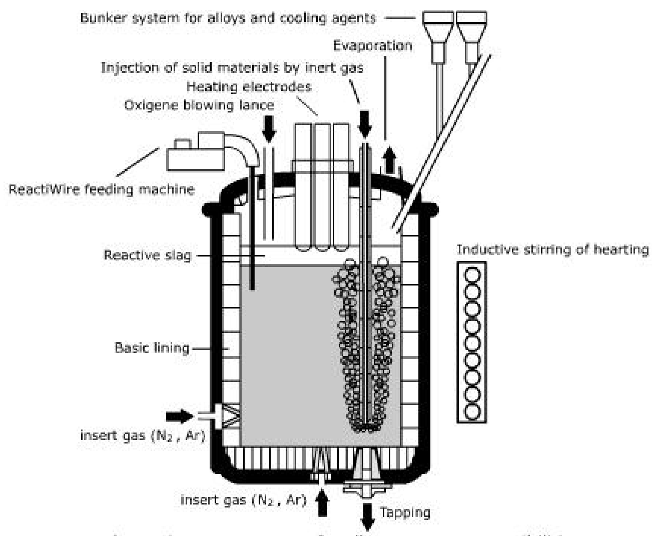
To prevent converter slag being tapped into the steel ladle, two different systems are established, i.e. either a floating stopper of refractory materials (9) or an electromagnetic slag detection system activating a pneumatic stopper (10).

Homogenization.

The described standard technology of slag free tapping, the use of an active slag and inert gas bubbling in the ladle also improve the cleanliness of the steel with regard to oxide inclusions.

Furthermore, this technology also allows a high recovery of the alloying elements when they are added after deoxidation, a homogenization of the melt and the possibility of fine-tuning the chemical composition at a later stage of secondary steelmaking. Therefore, tight chemical composition control from heat to heat is obtained. The same production steps allow for adjustment of the casting temperature. Any lowering of the temperature, if necessary, is carried out by adding well selected scrap until the optimum temperature of just above liquidus is reached.

It might well happen, that the total processing time in the secondary steelmaking could become very long, resulting in a non tolerable temperature loss. Therefore, often the secondary steelmaking facilities also include the possibility for heating the melt. This can be done either by electric energy, typically via three electrodes or by an allotropic process, e.g. by adding aluminum and oxygen to the steel bath.



Schematic Arrangement of Ladle Treatement Possibilities

Figure 4

Figure 4 summarizes the various possibilities of secondary steelmaking by a schematic model reactor for multi-functional steel refining.

Vacuum Treatment.

In a low pressure environment, all chemical reactions resulting in a gaseous product are enhanced. Such a vacuum treatment can for example be combined with the other options of secondary steelmaking in a tank degasser, as indicated already in figure 4. In addition to the above discussed improvements, the low pressure causes a remarkable reduction of hydrogen and also the nitrogen content.

Besides the low pressure, the amount of stirring gas in the treatment vessel also favors the degassing process. Figure 5 (11) shows that a low hydrogen level below 6 ppm is obtained almost independently of the hydrogen level before the

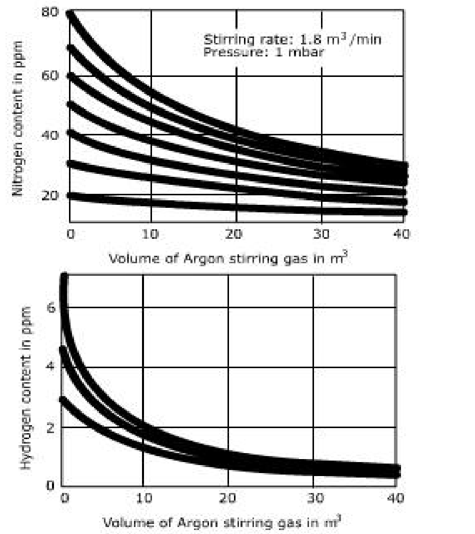


Figure 5

vacuum treatment. But this is different for nitrogen where, besides the initial nitrogen content, elements with high activity to nitrogen such as titanium or aluminum influence the final result.

In mass steel production very large converters of several hundred tons of crude steel per melt are common. For such big tonnages, continuous vacuum treatment of steel melt portions is more economic. One of the most popular processes in this context is the RH process, which has been modified in recent years towards a multifunctional device. Besides the successful lowering of hydrogen and nitrogen the process has gained in importance due to its potential for lowering the carbon content.

Starting material for the production of such ultra low carbon steels are heats produced via the combined blowing process, exhibiting around 0.03% C and according to the equilibrium an oxygen content of about By lowering the pressure a good decarburization via the CO reaction is obtained and it is reported that by using the full capacity of the vacuum pump a carbon level of 12 ppm is obtained in a RH device after 12 minutes (12). The related oxygen content is around 200 ppm, which becomes fixed by aluminum and is low enough to guarantee good cleanliness. In order to maintain the low carbon content, major carbon pick up during the further processing, e.g. deriving from the casting powder, has to be avoided by proper selection of the consumables.

This is not the only way to achieve low carbon contents. A number of companies rely on oxygen blowing into the RH degassing vessel which reduces the reaction time and allows the effective treatment of steel with initially higher carbon levels, thus reducing the heat losses during the vacuum treatment (13).

Continuous Casting.

In order to avoid nozzle clogging by solid alumina particles, which are the most important deoxidation product. Low sulfur steels are often treated with calcium, which promotes the formation of $CaO-Al_2O_3$ inclusions being liquid at the steel casting temperature. Furthermore, in the processing steps following secondary steelmaking, major care is taken to further reduce the oxide inclusions. Therefore, the stirring process in the ladle is continuous during transport to the caster and during the casting process.

There are also several possible sources for contamination of the steel during the casting process, such as reaction with the refractory material or the reoxidation of the steel by the atmosphere. Standard technologies include the application of submerged nozzles between the ladle and the tundish and between the tundish and the mould, the prevention of the ladle slag entering the tundish, the usage of an adequate casting powder and tundish preheating (14). There is also a tendency to improve the tundish metallurgy further with the objective of more complete removal of inclusions. Dams, filters or porous plugs are helpful tools in this regard (15).

The submerged entry nozzle to the mould is constructed to allow an upflow of inclusions followed by their absorption in the mould powder. Major care has to be taken in the mould, not to contaminate the steel by exogenous inclusions originated by inadequate casting conditions.

Actually it is not only the cleanliness of the steel, which is of importance. Some conditions during the continuous casting process, like oscillation and lubrication are optimized for good surface quality and other variables, like little superheat, low bulging and a 'soft' reduction in the final stage of solidification reduce the tendency of steel to form macro-segregations.

Conclusion.

Modern steel making technology is characterized by applying a sequence of metallurgical reactions in separate vessels in order to allow for an optimization of each reaction. By this philosophy it is possible to produce high quality steel products suitable to meet the demands of end users with regard to properties and the homogeneity of the products. The use of these modern technologies also results in a very high yield with regard to end products and consequently an improvement in the overall steel making economy. It has transpired that modern steel making technology is one of the fundamentals, which allows steel to maintain its position as the most important metal.

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Niobium Information No 11/96.