Importance of slag quality control for flat steel products based on EAF process

The transition from an integrated to an electric steel process route, results in differences in the steel output for the electric arc furnace, as compared with basic oxygen steelmaking. A key parameter to control is steel cleanliness, alongside controlling the steel residence time in the ladle even where the tap level of sulphur and nitrogen are higher from the EAF. This article discusses the sulphur and nitrogen control needed to produce high quality grades based on proper slag quality control during secondary metallurgy processes.

Author: Bojan Vucinic, *Danieli & C. Officine Meccaniche S.p.A*

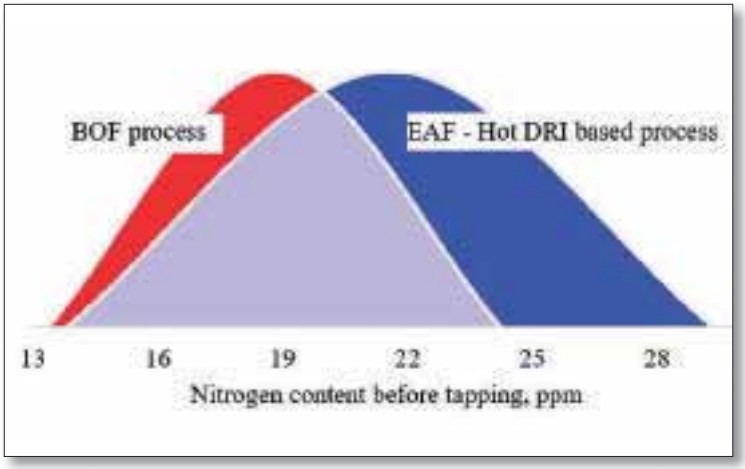

Fig 1 Nitrogen content before tapping from EAF and BOF process (One Sigma data population with errors in the database are included)

EAF APPLICATION FOR LOW CARBON AL KILLED GRADES

The BOF process is limited by the carbon content in the hot metal, hot metal temperature and the ratio between hot metal and scrap. On the other side, the EAF process is suitable to accept different ratios between different raw material and different qualities of raw materials. To fulfil quality demands for low carbon grades in flat steels, it is important is to have a proper steel quality evaluation. This starts with understanding the steel quality demands and evaluating the refining capability of secondary metallurgy units. The final target is to aim for the most optimal charging mix for the EAF process. With carbon based clean material, the nitrogen content before tapping from the EAF is like the nitrogen content before tapping from the BOF (*Figure 1*).

The nitrogen content before tapping is in the range of 20 to 100ppm based on type of EAF design, EAF process control and the quality of the applied raw material. The nitrogen content before tapping can be controlled, provided there is appropriate closed loop process control, such as with the Danieli Q-MELT process, a properly designed shell with optimized inner volume and a target to control the energy balance. It is also essential to have a properly designed chemical package, argon stirring pattern and a small ratio between power off and power on time. Control of the slag foaming index requires control of FeO by injection of carbon, an appropriate content of MgO and slag viscosity.

The typical slag basicity during the EAF process is lower than the slag basicity during the BOF process. From a steel refining point of view, phosphorous has higher priority than sulphur removal. A higher FeO content in the slag followed by higher oxygen potential of steel and slag together with limited slag basicity, is less favourable for sulphur removal. The impact of slag basicity and FeO content of the slag on phosphorous removal is shown in Figure 2. This chart includes data from 784 heats, with an average charge mix <20% pig iron and 80% to 100% scrap.

IMPORTANCE OF SLAG MONITORING

The sulphur content before tapping the EAF is mainly a result of raw material quality. For most low carbon grades in the flat steel

family a low final sulphur content is required. High productivity results mainly from higher casting speeds and there needs to be a limited residence time for steel in the ladle. This results in quick and predictable control of the slag. Slag modification needs to be rapid for sulphur removal. Proper evaluation of the minimum necessary final sulphur content is important to avoid over-reduction of the slag. This has consequences for control of the MgO content in the slag and the steel, as well as the formation of non-deformable alumina inclusions. The application of different types of vacuum degassing units is determined by the differing requirements at the end of ladle furnace process, with the same, or similar overall process duration. A low required level of sulphur content at the end of ladle furnace process necessitates use of the RH degassing process, for two reasons:

1. To maximize nitrogen removal during the RH process.

2. The ladle furnace process is usually is the final process step where sulphur can be removed.

If the product mix will allows for the application of vacuum tank degassing, sulphur removal during the process route can be divided into the two steps:

1. Tapping process followed by sulphur removal during the ladle furnace process.

2. Sulphur removal during the vacuum tank degassing process, enabled by intensive contact between the steel and a customised slag.

Figure 3 shows a typical sulphur content after tapping, recorded as the first sample at the ladle furnace, together with the sulphur content after the vacuum tank degassing process.

The capacity of slag to absorb sulphur is described by the slag sulphide capacity which is directly linked to the basicity of the slag, the total content of oxides including MgO, the slag viscosity and the temperature during process. A proper argon stirring pattern is needed to promote floatation of non-metallic compounds and intimate contact between the steel and the slag. *Figure 4* shows the impact of slag basicity on slag sulphide capacity. It can be clearly seen that sulphide capacity is higher towards the end of the secondary metallurgy process.

Another way to control slag quality for strong sulphur removal is to control the slag saturation

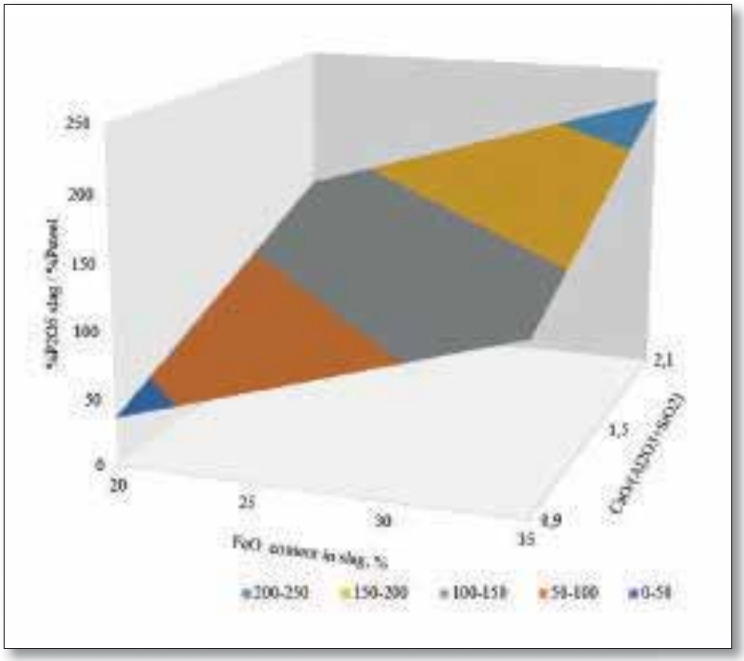

Fig 2 **Phosphorous distribution ratio during the EAF process**

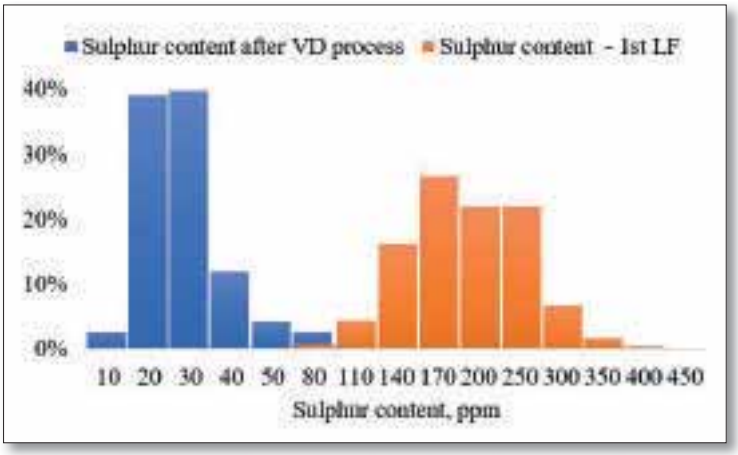

Fig 3 **Sulphur content**

index (*Figure 5*). This requires is control of the CaO level in the slag. A slag saturation index less than one means that alumina still has strong impact on slag behaviour. Where the slag saturation index is higher than one the slag is oversaturated. This is clear confirmation of the need to have closed and dynamic process loop control.

Instead of using slag sulphide capacity, another way to describe the capability of slag to remove sulphur from steel is the Mannesmann index. The Mannesmann index is the ratio of CaO vs Al_2O_3 vs SiO_2 in the slag and can be considered as shortcut for quick slag quality →

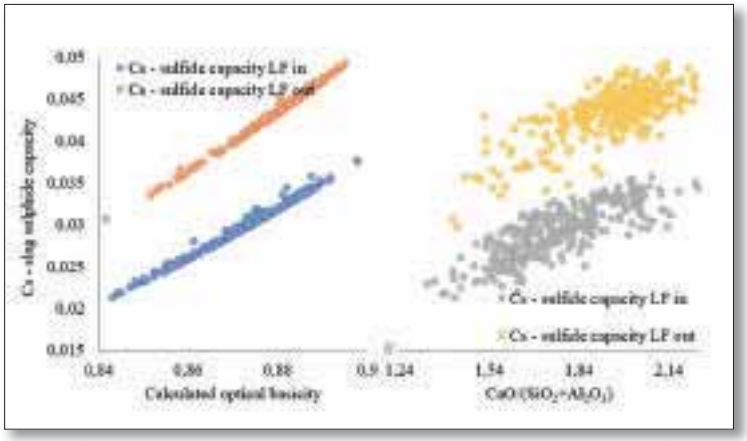

Fig 4 **Slag sulphide capacity during entire ladle furnace process**

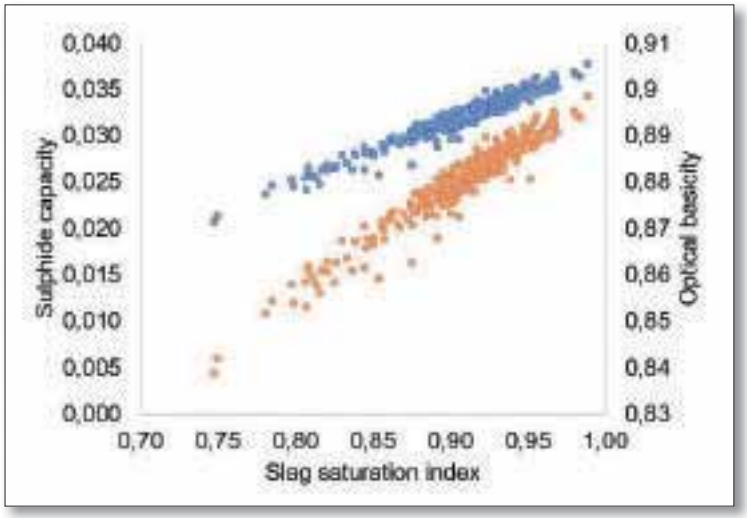

Fig 5 **Impact of slag saturation index on sulphide capacity and the relation with optical basicity at the end of LF process**

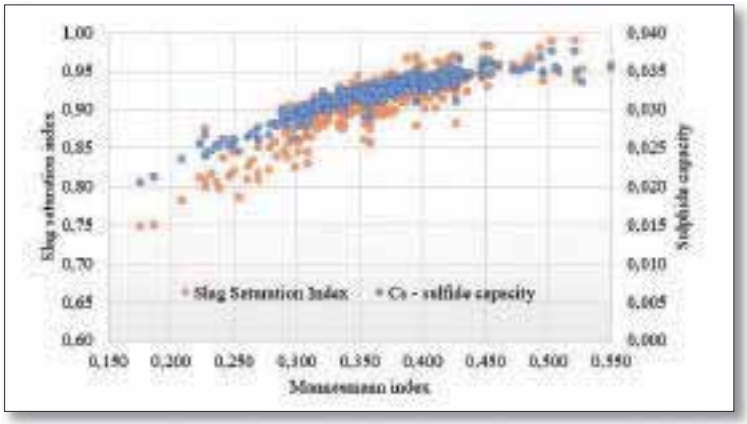

Fig 6 **Mannesmann index vs. slag saturation index and slag sulphide capacity**

evaluation, based on the known slag chemistry composition and dynamic process loop control. The relation between the Mannesmann index, the slag saturation index and slag sulphide capacity are shown in *Figure 6*.

CONCLUSIONS

The EAF based melt shop is a proper and green solution for production of low carbon Al killed grades, for the flat steels family group. A high sulphur content as compared with the BOF based melt shop, may arise as a result of the raw materials used during the EAF process. This calls for a different metallurgical approach. The limited processing time for steel in secondary metallurgy, combined with a higher inlet sulphur content requires a smart and quick approach to slag modification.

Closed loop process control, supported by proper metallurgical models and tailor-made equipment design, can allow for all of the conditions needed to meet the required slag quality, within a limited process time. Achieving this requires: a material handling system with continuous addition of slag modifiers, proper electrical working points, tailor made ladle design with a dedicated argon stirring pattern and a properly designed mechanical vacuum pump system. Together this will enable the right metallurgical results to be achieved for the production of high quality, low carbon grades of steel for a variety of applications, including: automotive, home appliances and pipe grades for sour service application.

These conclusions have been validated by the results achieved by Danieli from various projects, combining design, application and a high level of process know-how. MS

Bojan Vucinic is Technical Sales Manager at Danieli & C. Officine Meccaniche S.p.A, based in Italy.

CONTACT: p.messina@danieli.it