Improving EAF performance at Dongbu Steel

Following a short investigation, the average specific electrical energy consumption at Dongbu Steel was reduced by around 7%. This was obtained through increased utilisation and optimisation of the Danieli technological functions, such as automatic EAF melting practice, the EAF weighing system to automatically drive Consteel scrap feeding, and dynamic process control for control of slag foaming.

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Dongbu Steel plant, in Asan Bay, South Korea, incorporates two parallel production lines, each comprising a 160t Consteel® AC EAF (see Figure 1), a twin-car LF and a single-strand slab caster, supplied and commissioned by Danieli. In addition, a double tank, double cover VD-OB in line 1 can be used by both lines. The main features of the EAFs are given in Table 1. The furnaces are each equipped with a five load cell weighing system. The weights are used in process control to:

- Evaluate the actual liquid steel and slag present inside the furnace and hence allow the instantaneous calculation and regulation of the specific consumption figures (electric energy, injected oxygen, carbon and gas). In particular, one of its main functions is the regulation of the Consteel scrap feeding rate according to the set Level 2 specific energy profiles.
- Stop automatic scrap charging once the aimed final charged liquid steel is reached.
- Evaluate the hot heel present at the start of each heat.
- Provide automatic regulation of the supersonic oxygen/carbon lance according to the actual liquid steel weight in the furnace.

The power input and electrode movement is managed by the Danieli Automation Electrodes Regulator (HiReg) that optimises arc power, arc length, power factor and electrode current according to the different melting phases throughout the whole heat.

The relationship between Dongbu Steel and Danieli has been characterised by a spirit of cooperation since the plant start-up and, as part of an ongoing policy of continuous process improvements, Danieli was invited in
2011 to target further reductions in conversion costs and improve the quality of the EAF process. A key goal was consistent and repeatable slag foaming. It was agreed to focus the optimisation on EAF 2, after which Dongbu would transfer the knowledge to EAF1.

**PROCESS OPTIMISATION**

It was clear that only by maximising process automation could a precise and accurate process trouble-shooting operation be easily carried out during normal production. It was also clear that more manual intervention would result in more unpredictable and unrepeatable process management and in the end it would badly affect the final overall furnace performance and make resolution of future problems more difficult. The following areas were tackled:

**EAF weighing system** When production resumed after annual scheduled maintenance, the weighing system was recalibrated cold, followed by a hot calibration. The system was then continuously monitored for 10 days (200 heats), together with the electrical and chemical performance of the EAF. A post-calibration analysis was performed, comparing the steel tapped weight given by the EAF weighing system with the tapped weight given by the ladle car weighing system, and was found to be very satisfactory.

**Scrap feeding** The next step was to fully automate the...
Consteel scrap feeding rate. During the first heats, fine-tuning of the feeding rate was carried out in order to get scrap feeding as smooth as possible throughout the melting phase, and with the intention of varying the conveyor speed as little as possible to minimise scrap clogging on the conveyor. Thresholds were set for the minimum and maximum allowed conveyor speed, and the initial ‘delay energy’ was properly set. The delay energy is the energy input quantity after which the Consteel automatic control starts to work dynamically. Prior to this point the conveyor speed is maintained at a constant value to avoid unpredictable Consteel regulation at the beginning of charging due to the fact that specific energy is still not consolidated and reliable at that point in the process. Most of the time, the initial specific energy is very high and automatic regulation would speed up the feeding rate too much, resulting in a consequent buildup of unmelted material at the Consteel door and conveyor clogging.

The last 25t (approx.) of scrap were charged manually at a fixed speed in order to avoid charging pig iron by mistake. Pig iron is charged at the beginning of the process in order to promote initial slag foaming and to provide enough time to decarburise the bath. Due to this final manual charging operation, automatic charging was around 80% of the available charging time.

The specific electrical energy profile is the final result of continuous tuning of the automatic Consteel operation: the final specific energy values were set using such functions as the continuous monitoring of slag foaming behaviour; the intermittent measurements during the melting phase of the molten bath temperature (aiming an optimal temperature range between 1,550°C and 1,570°C in order to get the proper slag foaming) and, above all, the instantaneous Hireg Plus Arc Coverage /Arc Stability condition output. Table 2 illustrates the electrical parameters and the slag builder addition profiles of the tuned Static – Automatic Melting Profile used during the last few days of the trials. There are 10
phases and one profile is used throughout one heat. ‘Ref’ is the refining phase... scrap charging has finished and the main goal is to raise the temperature up to the tapping temperature.

As can be clearly seen in Figures 2 and 3, the charged weight and, as a consequence the bath-specific energy trend, were smooth. In addition, by using the EAF weighing system output, the hot heel was consistently maintained in the range of 50-80t (around 30-50% of the tapped steel weight), to avoid carryover slag flow into the tapping ladle and to boost initial slag foaming and scrap melting and hence maximum electrical power input and scrap feeding rate.

Utilisation of oxygen injector shrouding burners

One of the major differences of Consteel compared to conventional bucket charging processes, is that, especially in the very beginning of the charging/melting period, the molten metal and slag bath are a long way from the oxygen and carbon injectors on the furnace wall. In order to promote efficient oxygen and carbon injection into the molten bath and obtain good early slag foaming, the use of shrouding gas around the oxygen jets is recommended in the automatic melting profile to exploit its capability of lengthening the supersonic oxygen jet.

However, Dongbu was not using the shrouding burners during oxygen injection, due to frequent clogging, so, following injector head maintenance and setting of the purging air flows, two out of four burners were used during the first half of the oxygen injection period. The injection module layout is shown in Figure 4.

Slag foaming optimisation

The most important task for Danieli was to increase the level of process automation up to the maximum designed level, with the main goal of pursuing consistent and repeatable slag foaming. Having set the proper optimum slag builder addition profiles (as shown in Table 2) dololime and lime were added right from the beginning of the charging phase in order to get a sufficient foamy slag when arcing started, taking into account also the slag builders analysis (CaO, MgO content loss on ignition etc), together with slag

| Main melting phase electrical parameters before/after melting profile optimisation |
|---------------------------------|----------------|----------------|
| Electric arc | Active power | Average power |
| V | kA | MW | MW |
| Static profile before optimisation | 464 | 70.1 | 100 | 95 |
| Static profile after optimisation | 443 | 66.1 | 93 | 93 |
| Dynamic profile with stable arc | 480 | 60.1 | 93 | 93 |
| Variation | + 3% | - 14% | - 7% |

Fig 5 Arc current and noise (THD) trend for a typical heat before/after process optimisation
binary and ternary basicity index targets. Slag foaming was dynamically controlled by the HiReg Plus Chemical Package and incorporates the carbon jets dynamic control system. This package dynamically interacts with the static profile by varying the carbon flow injected into the molten bath according to the real-time harmonic analyser output. When harmonics increase due to deteriorating arc coverage, slag foaminess decreases and so the carbon flows are increased automatically to increase foaming. Thanks to this dynamic regulation the total carbon injection has reduced by 37%.

At the same the HiReg Plus Electrical Package was activated. This additional dynamic process control continuously interacts with the EAF transformer tap changer and electrode regulator during long arc operation and consequently diminishes the electrode current whenever the arc coverage output from the harmonics analyser highlights a sufficiently covered arc (thanks to properly attained slag foaming). This system contributed to production of a more stable arc condition and diminished the noise generated by the furnace during the whole EAF process, even in the most unstable periods.

A summary of the final improvements obtained by activating both the HiReg Plus Electrical and Chemical Packages is shown in Table 3.

As can be seen, when using the HiReg Plus Electrical and Chemical Packages, the electrode currents during the main melting phase have significantly reduced. This is of great benefit for electrode life as tip consumption depends on the squared power of the current passing through them. It must be highlighted that as the current diminished, the relative voltage proportionally increased (as expected) and at the same time the active power input into the furnace...
diminished by 7MW. This did not affect the power-on time – which actually slightly diminished from 39.2 to 38.0 min – indicating better energy transfer resulting from the better foaming slag. This effect, together with lower noise produced is shown in Figure 5, THD (total harmonic distortion) or noise index.

**Level 2-HMI enhancement** Once the process was optimised, a user friendly Level 2-HMI interface window was introduced with the aim of speeding up the creation of the optimal automatic melting profile and to immediately adapt it to any instantaneous problem arising during the process without partially or totally switching the process to manual mode. Thanks to this new interface window, the operators can dynamically directly modify the Level 2 melting profile parameters, an improvement that was particularly appreciated by the EAF operators and boosted their collaboration with the optimisation team, allowing the final settlement of the new optimal profile in only a few days. A view of the control room and screens is shown in Figure 6.

**RESULTS**
Dongbu EAF had already reached a satisfactory level of performance before the starting of these optimisation activities: the comparison between the average process consumption figures attained in the period before the joint work between Dongbu Steel and Danieli (collaboration that took place between 17 August and 4 September) and the improved results achieved during the trials are shown in Table 3.

The achieved results were very satisfactory. As can be seen, the adoption of the automatic tools and their tuned regulations reduced electrical specific energy consumption by 6.6%, total oxygen consumption by 2% and total carbon consumption by 37%. Moreover, power on time decreased from 39.2min to 38.0min (3% reduction), although the average active power diminished by 2% – as explained by the more efficient melting and refining phases, thanks to a better and lengthy slag foaming.

**FURTHER OPTIMISATION**
Between 25 January and 2 February 2012, a further optimisation trial took place through more efficient and automatic usage of the oxygen-carbon supersonic lance. One purpose was to maintain the lance as close as possible to the molten bath throughout the whole melting period, its positioning over the bath being automatically regulated by an encoder and either weighing system output or by the actual energy spent. In this way the efficiency of oxygen and carbon injection through the lance, especially at the beginning of the melting phase, was increased, resulting in even better and faster slag foaming.
Another improvement was to achieve 100% automatic charging (during August-September this only averaged 80%, as described earlier). A solution, which was tested on three heats, was to use a TV camera to spot if some of the pig iron was inadvertently charged at the end of a heat instead of the beginning of the next. If so, more scrap must be charged on the following heat in order to build again the initial scrap-buffer.

Thanks to this expedient, the automatic charging proceeded until the very end of Consteel charging, without increasing the risk of charging the pig iron in the last part of the heat. Figure 7 shows the difference between a heat charged by the old consolidated sequences and the new one. It is clear that in the second one, power input was completed in around two minutes after the charging phase ended (meaning a refining phase of just two minutes) while in the first one the refining phase lasted for around eight minutes.

In this way the auto control of the Consteel and a more stable arc condition was maintained for 100% of the charging time. Improving the arc coverage throughout a heat will, in the long term, result in reduced refractory consumption.

As a final result, notwithstanding the diminished pig iron content in the charge mix (drop from an average of 35% to 20-25%), the smaller amount of injected oxygen (from 39 to 32Nm³/tls) and the worse quality (smaller density) of the majority of the scrap, the EAF performance was immediately improved as shown in Figure 8.

The achievement of this satisfactory and prompt result was possible thanks to the fact that Dongbu personnel were already skilled in using the Danieli tools.

CONCLUDING REMARKS
Pursuing and attaining a consistent improvement in the quality and utilisation of process static/dynamic automatic control almost immediately resulted in process stabilisation and repeatability, allowing improvement in the overall EAF performance figures.

The next optimisation step planned by Dongbu will be the creation of customised Static/Dynamic Automatic melting profiles based on charge mix composition (pig iron and HBI percentage and quality), scrap density (different scrap density will need different Consteel speed control parameters) and furnace thermal state (hot and cold furnace will need different specific energy profiles).

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