R. GOTTARDI*, S. MIANI**, A. PARTYKA ***

THE HOT METAL MEETS THE ELECTRIC ARC FURNACE STEELMAKING ROUTE

TECHNOLOGIA PROCESU STALOWNICZEGO W PIECU ŁUKOWYM Z WYKORZYSTANIEM CIEKŁEGO WSADU

The operational flexibility and the potentiality of new process tools implemented within the electric arc furnace technology indicates an alterative or an interesting complement to the converters for the steelmaking based on the integrated production cycle.

Recently CONCAST has commissioned a furnace working with a base charge mix composed of scrap and large percentage of hot metal. The furnace configuration, the hot metal charging practice, the installed process tools and the way they are utilised have been analysed. The process aspects and performance results related to various charge mix configurations have been discussed.

Keywords: EAF, raw materials, hot metal, hot metal charging, furnace design, high productivity EAF, alternative energy, oxygen injection, decarburization rates, EAF performance

Eksploatacyjna elastyczność i możliwości nowych narzędzi procesowych wprowadzanych do technologii produkcji stali w piecach łukowych, stwarza alternatywę dla konwertorowych procesów stalowniczych opierających się na zintegrowanym cyklu produkcyjnym. W ostatnim czasie CONCAST oddał do użytku piec łukowy, pracujący na mieszanym wsadzie: złom i duża ilość ciekłego metalu. Przeprowadzono analizę pracy pieca oraz sposób załadunku ciekłego metalu. W pracy poddano analizie wpływ załadunku różnych mieszanek (różne stosunki złom/ciekły metal) na końcowe rezultaty procesu.

1. Introduction

Among the available tools for liquid steel melting, the electric arc furnace demonstrates the highest flexibility with respect to the selection of charge materials and their structure. This particular feature of the EAF allows to select the most convenient charge mix which is less dependent on the level of the market price fluctuations. The feasibility of using steel scrap, DRI (HBI) and hot metal in a wide 0–100% range has been already confirmed by a large number of reference installations.

Initially, the addition of hot metal into EAF charge became popular in the areas where shortage of scrap and/or electric power is observed. Recently, a new trend has appeared on the market showing a growing number of steel plants using both BOF and EAF steelmaking routes. The EAF can be used to utilise the excess production of hot metal from blast furnaces. On the other hand, the use of EAF allows to boost steel production in case the quantity of hot metal is insufficient to run BOF process at full scale. Much lower investment requirements and reduced environmental impact of EAF based production are in a clear advantage being already an alternative to the traditional BOF steelmaking route [1].

The use of hot metal ensures low level of residual elements and allows to produce through EAF the steel grades which traditionally were reserved for integrated steelmakers.

The use of hot metal decreases the demand for electrical energy [2], however an increased carbon content in the charge may result in additional process time required for oxygen injection. Furthermore, due to elevated contents of silicon and phosphorus, lime consumption is typically double than in the case of 100% scrap operation.

Latest developments proved that EAF with hot metal charge can operate with extremely short tap-to-tap times being fully competent with BOF productivity. To reach

* GROUP MANAGING DIRECTOR, CONCAST AG, ZURICH, SWITZERLAND
** SENIOR RESEARCH & DEVELOPMENT ENGINEER, CONCAST TECHNOLOGIES, UDINE, ITALY
*** SENIOR METALLURGIST, CONCAST AG, ZURICH, SWITZERLAND

this goal, the design of the EAF working with hot metal charge needs particular attention. The main issues can be summarised as follows:

TABLE 1

Shell Volume	Allowing to apply single bucket charging
Liquid bath surface	Ensuring high decarburisation rates
Hot metal charging practice	Fully controllable, reliable and safe
Oxygen injection	High specific oxygen flow rates

2. Hot metal charging into the furnace

In order to utilise the advantages of hot metal, its charging is expected to be carried out with closed roof. Logistic and layout limitations problems do not leave too much freedom to select the place where hot metal ladles can be delivered to the melt shop, i.e. on the charging or tapping side of the furnace. The furnace design itself imposes additional limitations. Position of the transformer, off-gas exhaust, etc. seriously limit the available space, where hot metal runner can be inserted into the furnace and the actual runner positioning is compromise among various considerations. The typical solutions are presented below.

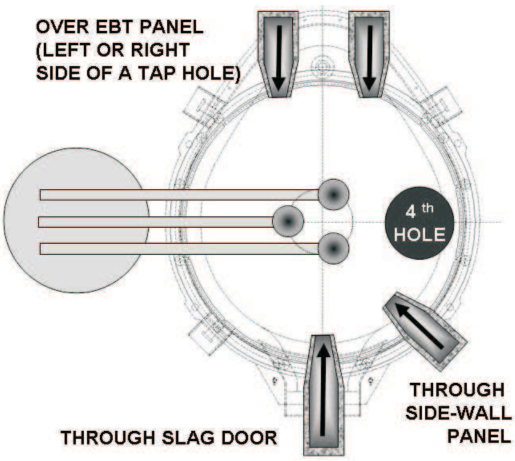

Fig. 1. Schematic ways of hot metal feeding into the furnace

The runner inserted through slag door must be movable (by means of a dedicated hot metal charging car). In other positions, the runner can be either fixed on the furnace shell or on charging car.

The most serious disadvantage of slag door charging is pouring of hot metal against the flow of slag. In some cases this can result in poor phosphorus removal from the bath. Besides, pouring can be started only after the area behind the slag door is free from slag.

Side-wall position of the runner is problematic in case of hot metal overflow. At that place is difficult to collect spilled metal. Furthermore, any overflow creates a risk for all piping installed in the neighbouring area.

The runner located on the EBT balcony seems to be the most advantageous. Thanks to limited scrap presence in that area, charging of hot metal can be started very early. In case of overflow, hot metal can be collected in the tapping pit below the furnace.

Hot metal charging operation requires a great care, since a contact with highly oxidised furnace slag or cold scrap can result in violent reactions. The same usually happens if large carbon concentration gradients can develop in the liquid bath during superheating phase. Lost of a control during hot metal charging ends up with overflow of slag and steel from the furnace, however in extreme cases, damages of electrode arms were also observed during violent eruptions in the furnace. The following solutions for a trouble-free charging of hot metal into the furnace are preferred:

- Hot metal pouring should be carried out with power on to avoid productivity losses;
- Tilting of hot metal ladle should not involve a crane;
- Hot metal ladle tilting control should be precise enough to ensure stable pouring rates;
- Hot metal runner should length should be as short as possible to avoid freezing of hot metal;
- The runner should be preheated between pouring operations.

3. Example EAF designed for hot metal operation

In November 2007, CONCAST commissioned a new furnace at Zhangjiagang Hongchang Wire Rod Co. (ZHW) belonging to Shagang Group in Jiangsu Province, People's Republic of China. This furnace designed for tap-to-tap times not exceeding 35 minutes is a heart of a new production line including LF, VD and 6-strand billet caster with an annual output of 1,100,000 t of SBQ steels for expanding automotive industry in China [3].

The main furnace data are as follows.

TABLE 2

EAF type	AC, full platform
Roof suspension	Jib type
Tapping weight	110 t
Hot heel	15 t
Shell diameter	6.5 m
Shell volume	125 m^3
Flat bath area	27 m^2
Transformer rating	80 MVA + 20%
Electrodes	610 mm
Burners	6×6 MW
Oxygen injection	6×2500 Nm^3/h
Carbon injectionj	3×50 kg/min

Shagang Group runs several melt shops equipped both with BOF and EAF units and has gained a solid experience of using hot metal in the EAF process. The design solutions adopted for that furnace have been intensively tested in practice. This particularly relates to the hot metal charging system.

Hot metal ladle is placed on a tilting stand. The tilter has its own runner with a buffer container improving flow control. During pouring, the tilter is rotated by 90° above the EBT balcony where another short runner attached to the furnace shell.

Fig. 2. Pouring of hot metal through EBT runner

Fig. 3. EAF ready for tapping – exchange of hot metal ladle

Hydraulic tilting of the hot metal ladle is fairly precise. For a reference EAF charge configuration with 35% (40 t) hot metal, the whole pouring operation can be completed within 5 minutes as hot metal can be charged safely with average rates of 7 – 8 t/min. A very efficient dephosphorisation thanks to extended reaction time between hot metal and highly basic slag has proved an additional benefit of hot metal pouring from the EBT side.

The furnace shell volume permits to use single bucket scrap charging practice if the minimum hot metal share is above 30%. Except for at least 15% reduction of the power off time, single bucket charging practice allows also to utilise heat generated through hot metal decarburisation and post-combustion of carbon monoxide for a very efficient preheating of a scrap column inside the shell [4].

The key issue of the furnace is its decarburisation capacity. High carbon content in the charge may require additional time for decarburisation. EAF cannot utilise oxygen injection rates which are typical for BOF practice. Hot metal share exceeding 40% has been considered as a maximum limit above of which the EAF productivity is reduced due to insufficient oxygen injection capacity [5]. The existing oxygen injection limits are usually related to problems with extensive splashing phenomena, backfire, electrode consumption increase and erosion of refractory lining as well as reduced life of roof panels and refractory delta centre piece.

The Shagang EAF has been equipped with CONSO type combined injectors allowing to operate with up to 15,000 Nm^3/h of oxygen flow in supersonic injection mode. The CONSO injectors are proprietary CONCAST design and their effective performance have been demonstrated on more than 40 EAFs. CONSO system is also a base of intensively developed chemical energy package called UHChP (Ultra High Chemical Power) EAF for which the power of installed burners equals to 40% of effectively used electrical power [6]. Before Shagang, high decarburisation capacity of CONSO system was verified on a furnace operating with up to 35% pig iron in the charge.

Totally six CONSO units have been installed o the furnace. Their distribution on the shell perimeter has been decided with the aim to reach perfect thermal equilibration of the furnace volume, elimination of the cold spots and enhancement of the metallurgical reactions by intensive bath stirring and homogenisation.

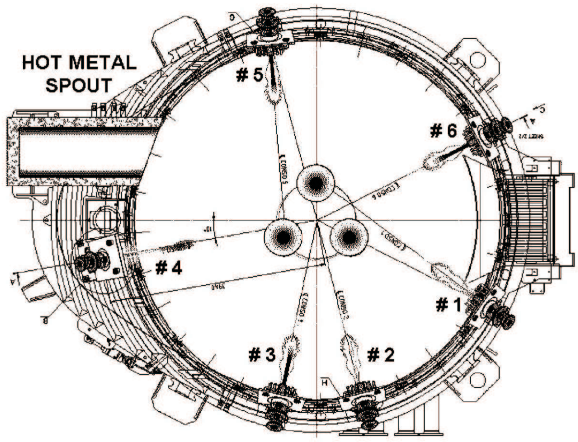

Fig. 4. Layout of CONSO injectors on the EAF shell

Each injector can use up to 600 Nm^3/h of natural gas and 1250 Nm^3/h of oxygen in burner mode. The lance, which is supplied from a separate oxygen line, can operate with 800–1300 Nm^3/h in subsonic injection mode and 1700–2500 Nm^3/h of oxygen in supersonic injection mode.

The injectors No. 3, 5 and 6 are coupled with carbon nozzles allowing to inject carbon precisely into the oxygen jet. Except for slag foaming purpose, early carbon injection is needed for a process safety aspects. Equilibration of FeO content in slag prevents developing of carbon and oxygen gradients inside the liquid bath volume.

After scrap charging, all injectors are switched to low power preheating burner flame with a gradual increase of the power in the cutting mode. The injectors No. 3, 4 and 5 are use more intensively to melt scrap in the hot metal discharge area. These injectors are switched into subsonic oxygen injection as soon as pouring of hot metal takes place. In the same time, the injectors on both sides of the slag door are still kept in full burner mode to melt the remaining scrap.

With about 2/3 of hot metal being already charged, the supersonic oxygen lancing starts – initially using the injectors No. 2, 3, 4 and 5. At that time, the injectors No. 1 and 6 are operated with subsonic oxygen flow delivering oxygen for a post-combustion of large volumes of carbon monoxide generated during hot metal decarburisation.

At melt-down, all injectors are switched to supersonic lance operation. About 3 minutes before tapping, temperature and oxygen activity in bath are measured. Depending on the actual carbon content, the oxygen flow can be then reduced or increased to obtain the target value at tapping.

The power input program is fully integrated with the operation of the CONSO injectors in the profile executed by the EAF automation. The same applies to the carbon injection system. Usually two carbon injections are in operation, while the third one is kept in stand-by mode.

So far CONSO operation has confirmed all expectations regarding high decarburisation efficiency. The average decarburisation rates of 0.14%C/min are achieved with specific oxygen injection rates close to 300 $Nm^3/h/m^3$ (4 CONSO units operated at 2000 Nm^3/h each). Considering that with 35% of hot metal, the content of carbon in liquid bath is about 2% (1.7%C from hot metal and 0.3%C from scrap), the required continuous lance operation time should be 14 minutes. The average power on time is 25 minutes, leaving 9 minutes for burner operation and oxygen injection at subsonic flow rates. That means that all heats can be completed without extra power off time.

Available results demonstrate that the actual decarburisation rates clearly depend on the carbon content in the liquid bath.

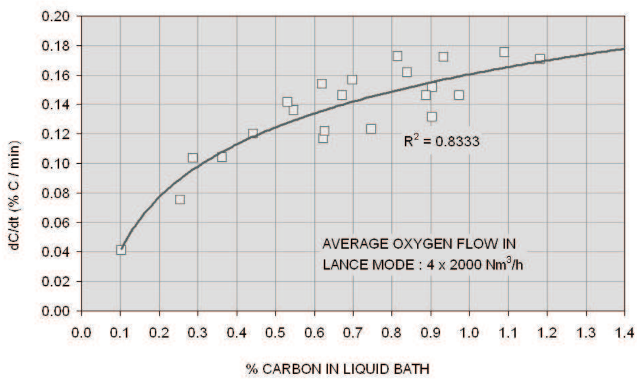

Fig. 5. Decarburisation efficiency with CONSO injectors

4. Operational Results

The EAF entered regular production by end of November 2007. Until the end of January 2008, some 1,300 heats were produced. The results achieved in this early stage of operation are very promising.

The table below shows the results from heats produced with a base charge configuration with about 35% of hot metal.

TABLE 3

	AVERAGE	BEST RESULT
Power ON Time [min]	25	21
Power OFF Time [min]	14	
Tap-to-Tap Time [min]	39	35
Energy Consumption [kWh/t Liquid Steel]	200	160
Tapping Temperature [°C]	1620	
Tapping Carbon Content [%]	0.05	
Natural Gas Consumption [Nm^3/t Liquid Steel]	4	
Total Oxygen Consumption [Nm^3/t Liquid Steel]	43	38
Lime + Dolo Cons. [kg/t Liquid Steel]	45	
Injection Carbon Consumption [kg/t Liquid Steel]	9	
Electrode Consumption [kg/t Liquid Steel]	1	
Yield Charge to Liquid Steel	90.0%	

The average tap-to-tap time of 39 minutes is close to design value of 35 minutes. The excess time is caused by longer power off times (14 minutes versus 10 minutes accepted). Power off times can further be reduced as the Shagang personnel gains more experience.

The actual EAF productivity is 170 t/h. The ratio between productivity and tapping weight (> 1.5) demonstrates that new Shagang EAF is already one of the most efficient furnaces in the world scale.

By end of January 2008, difficult weather conditions and power shortage forced Shagang to operate the furnace in an "unplugged mode" with zero or almost zero power consumption, increasing the share of hot metal in the charge to 70 – 80%.

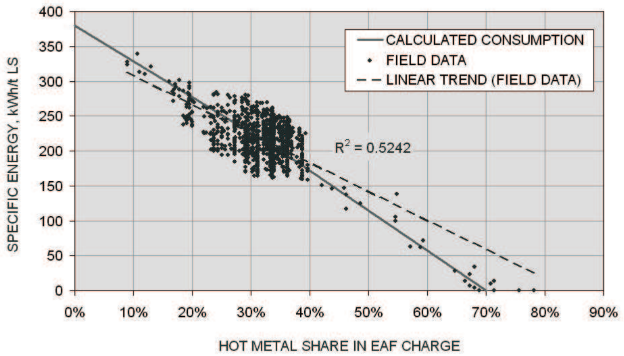

Fig. 6. Specific energy consumption results

The difference between the calculated and real energy consumption for high share of hot metal in the charge can be explained by a fact, that reduced power was used for fine tuning of the tapping temperature.

Increase of a hot metal share to 70% dramatically increases the oxygen consumption. Nevertheless, high decarburisation rates still allow to complete the injection of required oxygen volume within 25 minutes without negative impact on the furnace productivity.

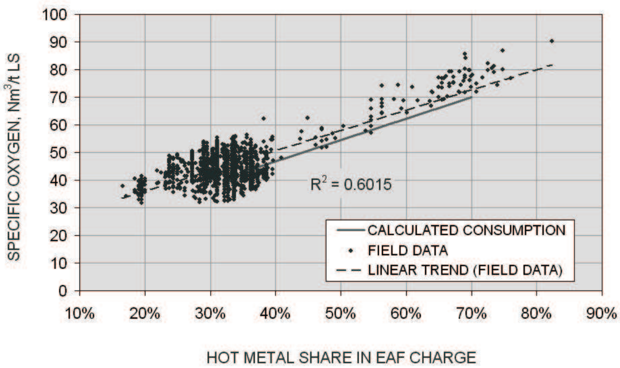

Fig. 7. Specific oxygen consumption results

Observed deviations in the actual energy and oxygen consumptions are caused by inconsistent quality of the hot metal being delivered to the melt shop. The hot metal is produced in four blast furnaces. Depending on the process is control, the hot metal parameters may vary in a relative wide range. The graph below shows the silicon content variations.

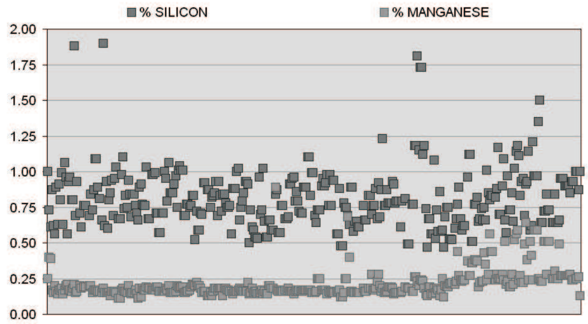

Fig. 8. Variations of silicon and manganese contents in hot metal

Similar variation can be considered for carbon content and the hot metal temperature. The situation could be improved by an installation of a hot metal mixer close to the melt shop.

5. Conclusions

The operational results of the new Shagang furnace clearly indicate that EAF can be an interesting alternative or supplement to the BOF steelmaking shops. Short melting cycle and extremely high productivity can be guaranteed even with high hot metal share in the charge.

Reliable furnace design, appropriate method for hot metal charging and efficient oxygen injection technology are the base of success.

Liquid steel production with of metal allows to produce a wide range of steels with low levels of residual elements. In common with effective secondary refining and casting technologies, the new mini mill has confirmed all Shagang expectations concerning high productivity with outstanding quality of end products.

REFERENCES

[1] L. Iperti, Do Russian Steel Producers Really Have a Competitive Advantage?, La Metallurgia Italiana, **10**, p. 58 (2005).

[2] S. Köhle, Recent Improvements in Modelling Energy Consumption of Electric Arc Furnace, Proceedings, 7th European Electric Steelmaking Conference, Venice (2002), p. 1.305.

[3] J. Liu, G. Bünemann, P. Rivetti, A. Partyka, Single Bucket EAF with Hot Metal Charge, Proceedings, 3rd International Steel Conference on New Developments in Metallurgical Process Technologies, METEC 2007, Düsseldorf, p. 402.

[4] S. Laurenti, R. Gottardi, S. Miani, A. Partyka, High Performance Single-Bucket Charging EAF Practice, Ironmaking & Steelmaking **32**, 3, 195 (2005).
[5] X. Xiaohong, R. Xiaojiang, Z. Guowei, D. Xing, M. Grant, C. Tao, High Efficiency Production Practice of a 100 t DC EBT EAF at Xing Cheng Steel Works, Proceedings, p. 413, AISTech (2006).
[6] R. Gottardi, S. Miani, H. Novak, A. Partyka, Ultra High Chemical Power EAF, Proceedings, Cleveland, p. 246, AISTech 2006.

Received: 2 April 2008.