Charging hot metal to the EAF using Consteel

With 16 furnaces operating worldwide and three more presently on order, the Consteel process has established itself as a reliable method to enhance EAF steel production. Its key benefit is the continuous feeding of scrap preheated by flue gases and post combustion into the furnace. Since 2000, the concept has been extended to include hot metal charging.

AUTHORS: Tang Jiemin, Wuxi Xuefeng, M B Ferri and Paolo Argenta
Iron & Steel Co Ltd and Techint SpA

During the past 11 years, steel production by the EAF route has grown worldwide by 4.1% a year, while total steel production has increased 2.7% per year.

The scope of this paper is to challenge the traditional steelmaking route via the blast furnace – oxygen converter to illustrate the benefits of steel production through a combination of scrap and hot metal charging from the blast furnace using a modified EAF. Lower investment costs, greater production flexibility and lower environmental impact are some of the advantages discussed, as well as the latest developments in EAF melt shops regarding continuous charging of preheated scrap and hot metal charging of iron from the blast furnace.

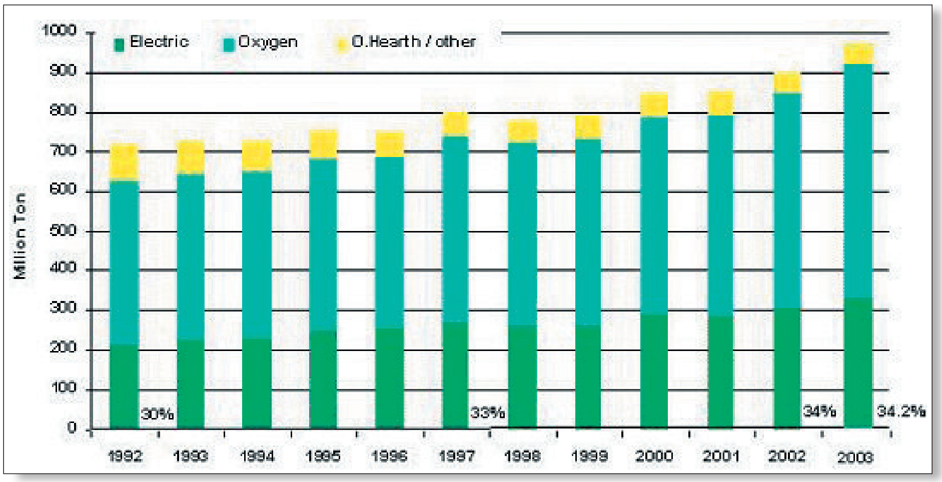


Fig.1 World production of crude steel and EAF %

Today, EAF steel production represents 34.2% (330Mt) of the world's total steel production, while 11 years ago this figure was 30% (see *Figure 1*). This growth has been obtained by updating installations and technologies as well as building new sites. Furnace capacity and power has increased, consistent with the growing availability of stronger electrical networks, but also by improving EAF productivity through optimisation of available chemical energy and sensible heat.

Table 1 shows how furnace capacity, productivity and transformer power, have evolved in highly industrialised countries between 1990 and 1999.

As far as China is concerned, in 2000 there were more than 130 EAFs in operation with an estimated average productivity of 35t/h and an estimated average capacity of 30t/heat. This figure is rapidly growing, since the average capacity of new furnaces installed between 2000 and 2003 is nearly 60t/heat.

From *Table 1* it can be concluded that the productivity of these electric furnaces has grown nearly twice as much as the furnace capacity and transformer power. This has been the result not only of improvements in operating procedures, but also of the massive utilisation of chemical energy both inherent in the melt in the form of carbon and by the use of oxy-fuel burners and lances. Between 1998 and 2003 there were more than 180 installations of new carbon-oxygen lances worldwide. Of these 180 installations, 60% were in Western Europe and North America, while less than 10% were in China.

The current developments in EAF steelmaking which can extensively use DRI, HBI and hot metal to supplement or replace scrap as raw materials, are leading towards the installation of EAF steel plants in locations previously unforeseen and for producing high quality flat product and special steel grades, more typical of BF-BOF ▷

Average[1] (Europe + USA + Japan)	1990	1999	% change
Furnace capacity (tonne/heat)	86	110	+28
Transformer power (MVA)	60	80	+33
Furnace productivity (tonne/hour)	61	94	+54

[1] *Data collected by IISI from 53 EAFs in Europe, USA and Japan*

Table 1 Growth in size of EAFs in industrialised countries

Productivity	
Ratio of power-on and tap-to-tap time	Between 90% and 95% (power-off only during tapping)
Productivity per MW available	2.5t/h/MW
Plant availability (not including planned maintenance)	More than 98% of the time available
Metallic charge	
Charge dimensions	As per conventional EAF and bigger (up to 2m)
Charge density	No limit and down to an average density as low as $0.4t/m^3$. There is no impact on productivity
Charge yield	1–2% higher compared to a batch charged furnace
Other charges	DRI, HBI, solid and liquid pig iron

Table 2 Benchmark productivity and charge parameters of a Consteel furnace

Consumption	
Electrical energy (kWh/t)	325–350
Oxygen (Nm^3/t)	20–40
Carbon (kg/t)	5–25
Natural gas (including post-combustion) (Nm^3/t)	None used
Electrode consumption (kg/t)	1.0–1.5 for AC EAF 0.9–1.1 for DC EAF
Refractories	Consumption reduced by 40–60% compared to a batch charged furnace
Maintenance	
Manpower for operations/maintenance	Reduction by 66% per shift compared to a batch charged furnace
Plant availability (excluding planned maintenance)	More than 98% of the time available
Maintenance expenses (planned and unplanned)	Less than a batch-charged furnace

Table 3 Benchmark consumption and manpower of a Consteel furnace

steelmaking. These developments will also contribute to the future growth of EAF steelmaking.

CONSTEEL SYSTEM

The Consteel® system (see *Figure 2*) incorporates continuous charging of scrap into the EAF by means of a conveying system that connects the scrap yard with the EAF. No conventional bucket charging takes place. Scrap is loaded onto conveyors by the scrap yard cranes and these conveyors move the scrap in an oscillating motion comprising a slow forward movement and rapid reverse motion which causes the scrap to move together with the conveyor during the forward stroke but to slide on the conveyor surface during the more rapid reverse stroke so

Metallurgical results	
Steel oxidation	Lower compared to batch charging
Nitrogen in the steel	Lower compared to batch charging
Hydrogen in the steel	Lower compared to batch charging
Gas cleaning system	
Primary gases	Flow rate reduced by 20–30% compared to a batch-charged furnace
Secondary gases	Constant flow rate, equal to half of what is required by an equivalent batch-charged furnace during the bucket charge
Dust to be disposed	Reduced by 30–40% compared to a batch-charged furnace
Dust in the working floor	Very low
Fumes from the EAF in the working floor	Very low

Table 4 Benchmark metallurgical results and gas cleaning of a Consteel furnace

Environmental	
Noise	Always below 95dBA 10m away from the slag door. Average during melting below 90dBA
Radioactivity control	High accuracy additional control (in addition to the gate control)
Equivalent tonnes of CO_2 released	Reduced by 10–30% compared to a batch-charged furnace
Dioxins, CO and NO_x emissions	In accordance with German, Japanese and American regulations
Impact on power lines	
Flicker	Reduced by 60–70% compared to a batch-charged furnace
Harmonics	Reduced by 60–70% compared to a batch-charged furnace

Table 5 Environmental impact and impact on grid

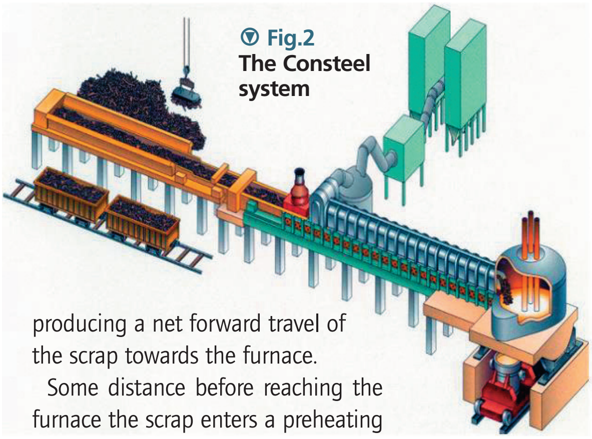


Fig.2 The Consteel system

producing a net forward travel of the scrap towards the furnace.

Some distance before reaching the furnace the scrap enters a preheating section consisting of a tunnel through which the hot gases exiting the EAF flow in a counter direction to the motion of the scrap. In the preheating section carbon monoxide in the exhaust gas is burnt by an automatically controlled injection of air, allowing more energy to be recovered to the scrap.

During the continuous feeding operations the steel bath in the EAF is kept liquid and the scrap entering the furnace is melted by immersion in the bath. The electric arc is thus always working on a liquid bath (flat bath conditions), not on solid scrap. In this situation the arc is stable and it is unaffected by the presence of solid scrap as is the case with batch charging.

Currently Consteel is in operation in 16 melt shops (some in start-up), as follows: Ameristeel (Charlotte, USA), Nucor (Darlington, USA), Kyoei (Nagoya, Japan), CoSteel (Sayreville, USA), NSM (Bowin, Thailand), ORI Martin (Brescia, Italy), Xining (China), Guiyang (China), Ameristeel (Knoxville, USA), Nucor (Hertford, USA), Shaoguan (China), Wuxi (China), Shiheng (China), E'cheng (China), Tonghua (China) and Wheeling Pittsburgh (USA). In addition, three new plants are at the design/ construction phase, namely: Hengly and Jiaxing in China and Sonasid in Morocco.

There are two main characteristics that make the Consteel system different from most other EAF technologies: the combination of preheating and, even more important, continuous charging. Preheating is important to save energy, but the continuous charging has shown to have even greater benefits, namely:

- Low production costs
- High productivity
- Flexibility
- Reduced environmental impact
- Greater safety

CONTINUOUS CHARGING AND PREHEATING

Continuous charging of scrap distributes the charge throughout the whole power-on period. No bucket charges are used and the conveyor feeds the scrap from the yard directly into the EAF. The EAF roof is always closed and so gas suction constantly takes place through the primary circuit, not through canopies in the secondary circuit. In the furnace the scrap melts by immersion and the electric arc is working on a flat bath covered by a foamy slag. The EAF control system automatically adjusts the conveying speed to maintain the steel bath at the target temperature and controls the oxygen and carbon injection to maintain the proper foamy slag.

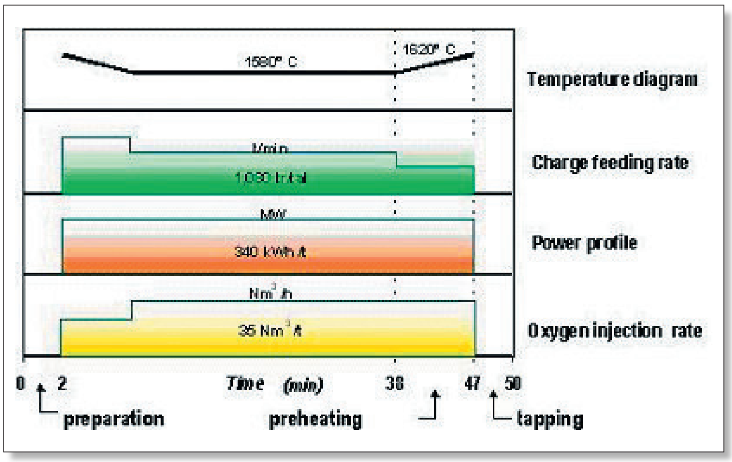


Fig.3 The Consteel heat cycle

Preheating the charge is effective in reducing energy consumption. The energy savings that can be obtained is a function of the preheating temperature and the melting efficiency. Assuming an average preheating temperature of between 400 and 600°C, energy savings ranging from 80 to 120kWh/t of liquid steel tapped are gained. These values are confirmed by the experience of existing Consteel installations.

Figure 3 illustrates the typical working conditions for an EAF equipped with the Consteel system. These characteristics give Consteel substantial advantages in terms of operational savings and reductions in environmental impact. The operational characteristics of Consteel bring to the working environment lower noise, less dust and the absence of bucket charging with its consequential noise, transport and loss of heat and flue gases when the furnace roof is opened for charging.

Metallurgically, the steel in the furnace is in better equilibrium and less likely to generate violent reactions.

Furnace water-cooled sidewalls, roof and lances do not suffer leakage problems caused by arcing or scrap impacts, thus minimising the risk of water in the furnace.

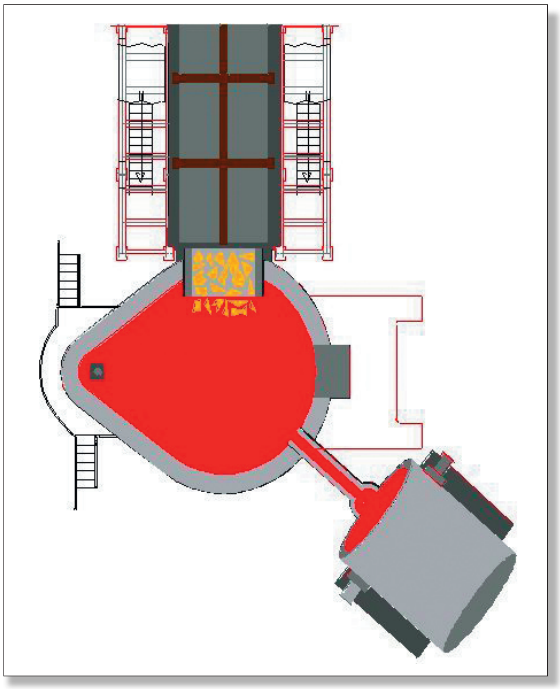
All of this contributes to creating a safer and more comfortable working environment compared to the typical standards of the steel industry.

BENCHMARK VALUES

The parameters in *Tables 2* to *5* can be considered ▹

	With hot metal	With cold pig iron
Charge mix		
Scrap (%)	72	82
Hot metal (%)	28	0
Solid pig iron (%)	0	18
Lime (kg/t)	45	42
Electric power (kWh/t)	260	364
Oxygen (Nm^3/t)	31.7	32.5
Carbon (kg/t)	5.2	6.8
Electrode consumption. (kg/t)	1.42	1.57
Avg. power on time (min)	54	63
Avg. tap to tap (min)	62	71
Heats per day	22	19
Liquid steel per heat (t/h)	100	100
Nitrogen content (ppm)		
Before ladle furnace	45	45
After ladle furnace	60	60
After continuous casting	75	75

Table 6 **Specific consumptions of Shaoguan Consteel furnace**



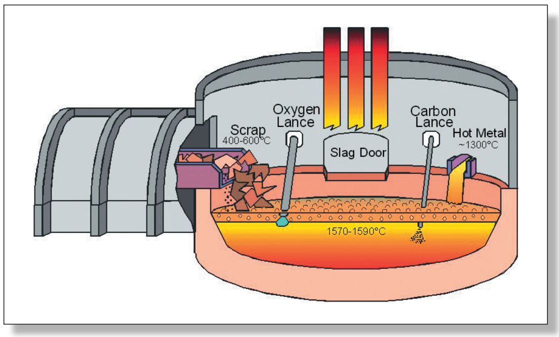
Figs.4a&b **Hot metal charging concept, furnace plan and side view**

typical for a Consteel installation with all the improvements that were achieved thanks to continuous collaboration between Techint and the equipment operators. These values can be achieved provided there is proper operation and maintenance of the equipment.

The values shown in the tables refer to per tonne of liquid steel tapped and their variation is largely due to the steel grade produced and the charge mix (the use of DRI, HBI or hot metal is not included in these values).

Item	Value
EAF nominal capacity (t)	70
EAF transformer (MVA)	45
Electrode diameter (mm)	550
Scrap (%)	70
Pig iron (%)	30
Lime (kg/t)	65
Electricity consumption (kWh/t)	360
Oxygen consumption (Nm^3/t)	32
Electrode consumption (kg/t)	1.2
Tap to tap time (mins)	50
Max daily heats (with solid charge)	31
Tapping capacity (t)	71
EAF refractory life (heats)	550

Table 7 **Performance of Consteel at Wuxi with preheated scrap and solid pig charge**



HOT METAL CHARGING

The problems of scrap shortage and weak electrical supply systems can best be overcome through the implementation of mixed blast furnace/EAF installations. Several integrated plants around the world are evaluating the possibility of shutting down one or more blast furnaces and make up part of the production via the EAF route. Charging hot metal into the EAF can be of benefit to operations. By bringing thermal and chemical (carbon) energy into the EAF, it reduces electrical energy consumption and increases productivity.

The experience over several years has shown that charging hot metal into a traditional top-charged EAF is made difficult by the risk of a strong reaction in the bath. This problem is related to the interaction between oxygen (in the steel and from the lance) and carbon (in the steel, in the hot metal and from the lance). Controlling the carbon content in the bath by feeding the molten pig iron in a continuous fashion appears to be the most efficient way to achieve the maximum benefits in terms of operational safety, chemical control (with effect on tap-to-tap time) and foamy slag practice (with effect on energy consumption).

Presently there are several examples of hot metal charging in the EAF. The most recent of these have been based on the Consteel feeding and preheating system. Of the 16 operating Consteel plants in the world, six are using some hot metal in the charge: Shaoguan, E'cheng, Shiheng, Tonghua, Wuxi and Wheeling Pittsburgh. During Consteel operations it is possible to charge the hot metal in a controlled fashion to achieve control over the carbon content of the bath.

Continuous feeding of the scrap so that the hearth always contains liquid is ideal to achieve a rapid distribution of the carbon charged with the hot metal. By keeping the carbon level between 0.15 and 0.25%, foamy slag practice is optimised and the violent oxygen/carbon reactions in the bath are avoided, thus achieving more energy-efficient operations, fewer problems for the equipment and safer operating conditions for personnel. Thanks to these characteristics this process is the most suitable to get the economic benefits of hot metal charging and several plants have been able to take advantage of this attribute.

HOT METAL CHARGING DESIGN

The typical plant, featuring an EAF fed via Consteel, is able to charge liquid pig iron from a ladle fed from the torpedo car. A single ladle is used for two consecutive heats. The pig iron is fed to the furnace via a refractory lined sidewall runner for almost the whole heat; the feeding speed is automatically controlled to ensure reliable and safe operations. Only the initial ladle tilting is performed by the EAF operator until the hot metal starts flowing into the sidewall runner. This operation ensures speed with fast tilting in the first stage and safety as the operator is forced to closely follow the initial, and most delicate, pouring phase.

Figure 4 illustrates the layout and basic concept of charging hot metal:

- The hot metal is fed via a refractory-lined runner.
- The feeding point into the furnace is located well away from the feeding point of the scrap.
- The oxygen lance is located in the area of scrap entry to increase the temperature here and also to provide bath stirring where the scrap is falling, thus increasing the melting rate of the incoming solid scrap.

This type of design makes it possible to process a heat with different charge mixes, but typically with 40% hot metal, although one trial at Wuxi at 80% and without electrical energy was done as a demonstration of what technically could be achieved. It was not an economic advantage.

PERFORMANCES

The performance of some plants operating Consteel with hot metal charging are described below.

Shaoguan In December 2000, the first Consteel plant operating with hot metal charging was commissioned in Shaoguan in the Guandong Province of China.

Since starting Shaoguan has been working at full capacity and after only six months the performance targets were achieved. *Table 6* shows the results obtained during the first months of 2002. Noticeable are the 260kWh/t of electrical energy, obtained with 28% of hot metal charging and the low nitrogen content in the tapped steel which enables the production of high-quality steels.

Today the plant is running consistently after more than three years from start-up and is demonstrating great reliability. As many as 31 heats per day are frequently reached with a power consumption of 250kWh/t. More than 90% of the heats produced use a hot metal charge.

Wuxi The Consteel EAF started up in September 2001 reaching 500kt of good billet produced after the first year of operation. Despite an electric power and scrap shortage influencing running in, productivity in the past three years was above the design production capacity: 546kt of good billet were produced in 2002, 546kt in 2003 and 538kt in 2004.

Since the second half of 2002 the requirements of special steel grades, around 90% of quality steel and pipe billet, as well as the bottleneck in the ladle furnace and caster were downstream factors that limited plant productivity.

Electricity consumption is affected by the scrap yield which averages 89–89.5% due to the poor quality of the scrap available on the local market. Moreover the need to use poor quality scrap has also influenced the overall performance figures.

Table 7 shows the current performances of the Wuxi furnace charged with a mixture of preheated scrap and preheated solid pig iron.

High flexibility and dramatically reduced electric energy consumption was recorded when hot metal was charged continuously with scrap. The specific electric consumption varies between 260 and 280kWh/t, with 20–25% of hot metal charged. This quantity of hot metal was charged into the EAF until a converter was started up. Successful tests of charging up to 80% of hot metal have been run with the aim of proving that melting without using any electrical energy is possible. Currently the Consteel is able to reach 33 heats per day (2,450 tonnes of billet) or 13 heats per shift (8 hours). The Consteel EAF has demonstrated the great improvement in reducing consumption of power and electrodes. ▷

Wheeling Pittsburgh The Wheeling Pittsburgh furnace is the largest Consteel EAF at 225t tapping size, coupled with a charge of hot metal, and is sited on an integrated steelworks.

Wheeling Pittsburgh executives decided to shut down their blast furnace No.1, which had been due to undergo major relining/revamping work, and to add an EAF-based meltshop. Operations will benefit from the higher energy efficiency and the flexibility added by the new melting unit.

The main operating data of the new Wheeling Pittsburgh meltshop are:

- Transformer rating of 140MVA
- Productivity from 225ton/h (100% scrap) to 295ton/h (with 40% hot metal charge)
- Charge materials: hot metal, scrap, pig iron, DRI and HBI.

The successful start up of the furnace took place in November 2004 and the furnace is performing its run-up performance curve steadily. The results achieved so far are in line with best expectations.

CONCLUSIONS

As EAF production is increasing in share and moving toward high value-added products, better control over tramp elements is necessary which requires a proportion of the charge to be virgin iron as DRI, HBI, pig iron or liquid iron. Of these scrap alternatives, hot metal is the only one that can provides a substantial reduction in production cost and an increase in plant productivity. In the current scenario, the characteristics of the Consteel process make possible the charging of hot metal into the EAF without the typical problems normally related to this practice. Under normal conditions, up to 50% of hot metal can be charged into the EAF. **MS**

Tang Jiemin and Wuxi Xuefeng are with Iron & Steel Co Ltd, Wuxi, China. M B Ferri and Paolo Argenta are with Techint SpA, Melt Shops BU, Milano, Italy.

CONTACT: meltshops.sales@techint.it

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