The EAF technology evolution and the Consteel® system

P. Argenta, M. Bianchi Ferri

During the past 11 years, steel production by the electric arc furnace route (EAF) has grown on a worldwide basis by 4.1%/year, while the total steel production has grown by 2.7%. The scope of this paper is to illustrate the benefits of steel production through the Electric Arc Furnace route, such as the lower investment costs, higher production flexibility and lower environmental impact, and the latest developments of the EAF based melt shops with the continuous scrap charging and pre-heating completed by hot metal charging.

Key words: steel, hot metal, steel making, environment, energy

CURRENT SITUATION

As stated in the Foreword, during the past 11 years the steel production by the electric arc furnace route has grown on a worldwide basis by 4.1%/year while the total steel production has grown by 2.7%. Nowadays, EAF steel represents 34.2% (330 million tons) of all the steel produced in the world, whilst 11 years ago this figure was 30% (Fig.1).
Between 1992 and 2002, the increase in the proportion of EAF steel has been remarkable in Nafta, Europe and South-East Asia whilst in the former Soviet Union it has slightly declined.
Interesting, inside the worldwide picture, is to focus on China, the most growing country: although in 2002 the production of steel through the EAF route has doubled compared to that of ten years ago, the proportion of EAF based steel has declined due to the fact that BF-BOF technology (Blast Furnace – Blast Oxygen Furnace) has dominated the scene for newly installed capacity.
For the first time since 1992, in 2003 the percentage of EAF steel production is raised, reaching 20%.
The growth of EAF steel production in Western countries as well as in South East Asia, is justified by the following advantages of EAF technology: lower investment cost, higher operational flexibility and reduced environmental impact
This growth has been obtained by updating the installations and technologies; this target has been achieved not only by increasing furnace capacity and power consistent with the available electrical systems and networks, but also by improving their productivity through the optimisation of the chemical process.
Table 1 shows how the main features of the EAF, particularly the furnace capacity and the transformer power, have evolved in highly industrialized countries between 1990 and 1999.
As far as China is concerned, in the year 2000 there were

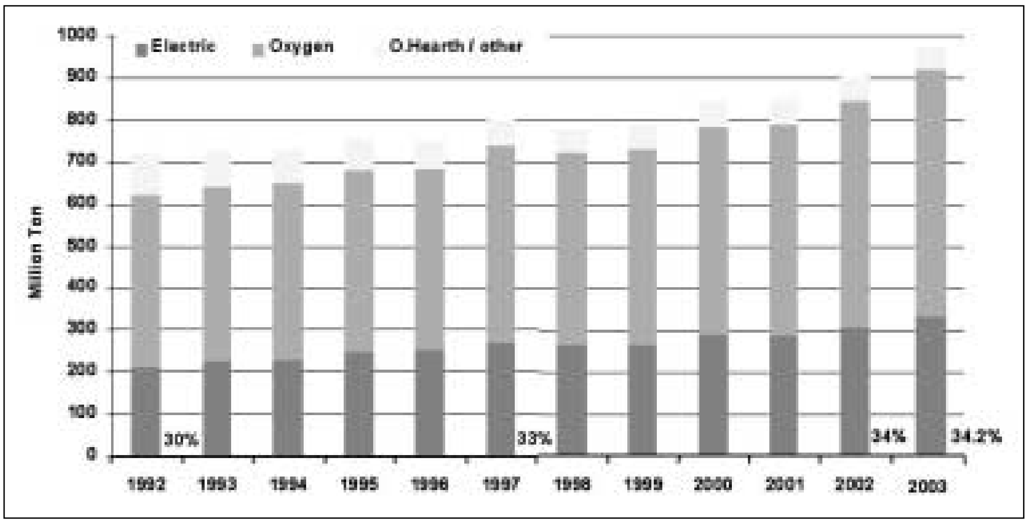

Fig. 1 – World Production of Crude Steel and % of EAF Steel.

Fig. 1 – Produzione mondiale di acciaio grezzo e percentuale di acciaio prodotto con EAF.

Average (Europe + USA + Japan)	1990	1999	% increase
Furnace Capacity (Ton / heat)	86	110	28 %
Transformer Power (MVA)	60	80	33 %
Furnace Productivity (Ton / hour)	61	94	54 %

Table 1 – Evolution of the main features of the EAF in highly industrialized countries between 1990 and 1999.

Tabella 1 – Evoluzione delle principali caratteristiche dell'EAF nei paesi altamente industrializzati tra il 1990 e il 1999.

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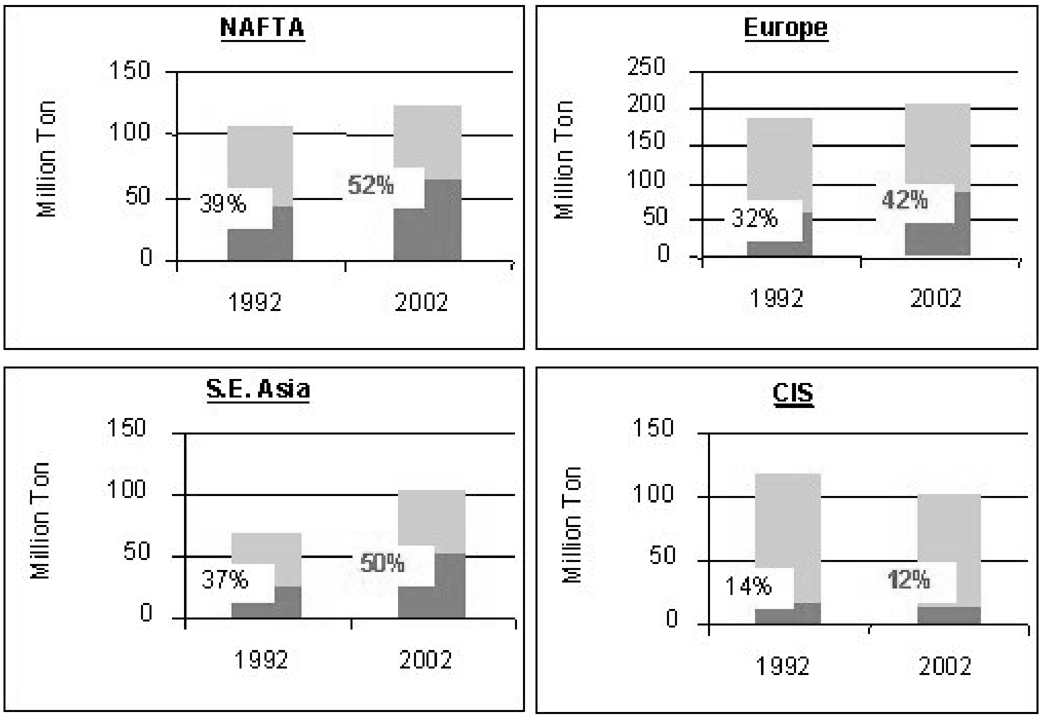


Fig. 2 – Production of Crude Steel and % of EAF Steel in NAFTA, Europe, South East Asia, former Soviet Union (CIS).

Fig. 2 – Produzione mondiale di acciaio grezzo e percentuale di acciaio prodotto con EAF in NAFTA, Europa, Sud Est Asia, Unione sovietica (CIS).

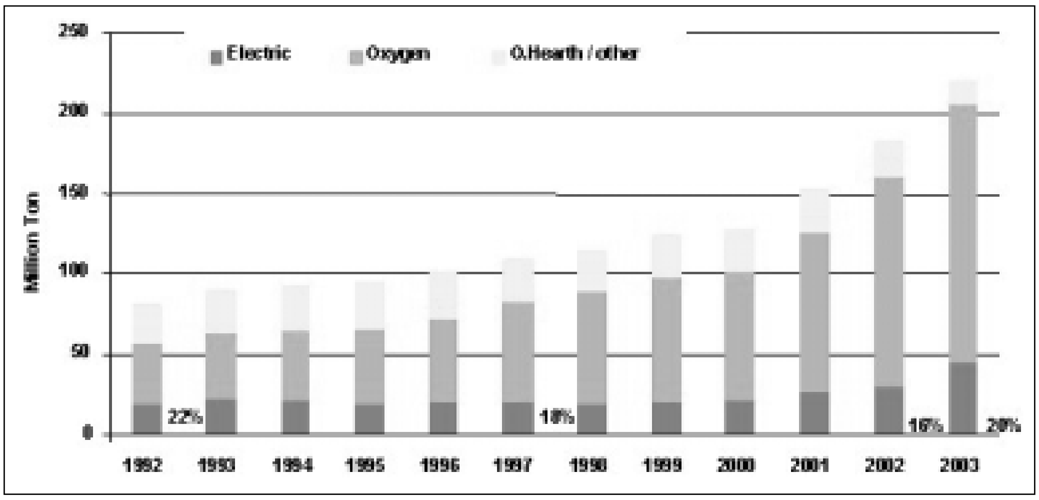


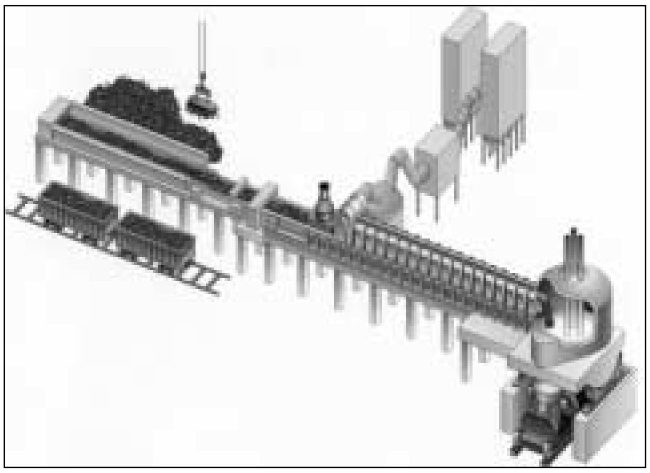
Fig. 3 – Production of Crude Steel and % of EAF Steel in China.

Fig. 3 – Produzione mondiale di acciaio grezzo e percentuale di acciaio prodotto con EAF in Cina.

more than 130 Electric Arc Furnaces in operation with an estimated average productivity of 35 ton/hour and an estimated average capacity of 30 ton/heat. This figure is rapidly growing, since the average capacity of new furnaces installed between the year 2000 and the year 2003 is nearly 60 ton/heat.
From the table above 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 the operating procedures, but also of the massive utilisation of the chemical package.
In fact, between 1998 and 2003 there were more than 180 installations of new carbon-oxygen lances worldwide. Out of these 180 installations, 60% was concentrated in Western Europe and North America whilst less than 10% was concentrated in China.
The latest developments in EAF steelmaking, with extensive use of DRI, HBI and hot metal as raw materials, are leading towards the installation of EAF steel plants in locations and for applications (high quality flat steels, special grades), previously unforeseen and more typical of BF-BOF steelmaking.
These developments will also contribute to the future growth of EAF steelmaking.

Fig. 4 – Consteel® system.

Fig. 4 – Il sistema Consteel®.



THE CONSTEEL® SYSTEM

The Consteel® system (Figure 4) performs the continuous charging of scrap in the EAF by means of a conveying system that connects the scrap yard to the EAF.
With the Consteel® system, scrap is loaded onto conveyors by the scrap yard cranes. Then the conveyors move the

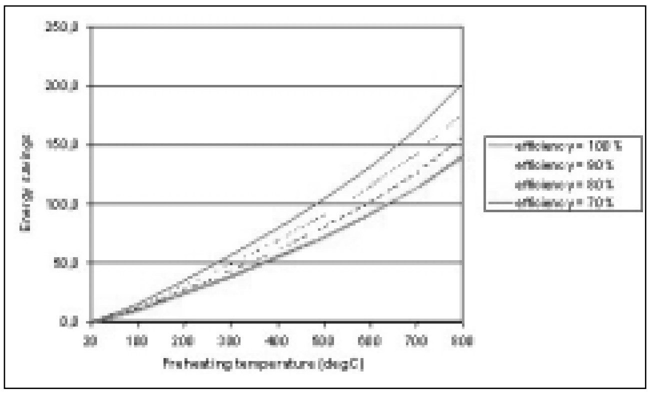


Fig. 5 – Scrap preheating effect.

Fig. 5 – Gli effetti del riscaldamento del preridotto.

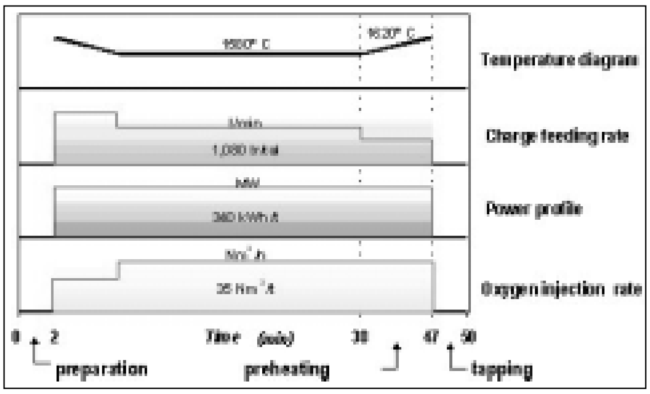


Fig. 6 – Consteel® heat cycle.

Fig. 6 – Ciclo di colata del Consteel®.

scrap, and the conveying surface oscillates forward slowly and backward faster. This movement allows the scrap to move together with the conveyor during the forward stroke, while the scrap slides over the surface when the conveyor oscillates back. The end result is the movement of the scrap towards the furnace.

Before reaching the furnace the scrap enters the preheating section, in this area the scrap is heated-up by the hot gases exiting the EAF that are moving in the direction opposite to the scrap.

In the preheating section the carbon monoxide in the exhaust gas is oxidized by an automatically controlled injection of air, allowing more energy to be recovered by the system.

During the continuous feeding operations the steel bath in the EAF is kept constantly liquid and the scrap entering the furnace is melted by immersion. The electric arc is working on a liquid bath, not on solid scrap. In this situation the arc is stable and it is not affected by the presence of solids like in the case of batch charges (with or without preheating).

Currently the Consteel® system is in operation in sixteen melt shops (in start-up order): 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 Pitt (USA).

Three new plants are under design/construction phase, namely: Hengly in China, Jiaxing in China and Sonasid in Morocco.

There are two main characteristics that make the Consteel® system different from most of the other technologies available for melting scrap in the EAF: the preheating and the continuous charging.

The preheating is important to save energy, but the continuous charging has shown more benefits for the users in terms of:

- Fast payback
- Low production costs
- High productivity
- Flexibility
- Reduced environmental impact
- Personnel safety.

The Charge Preheating

Preheating the charge is very helpful to reduce the energy consumption of the EAF.

Figure 5 shows the energy savings (in kWh/t) that can be obtained as a function of the preheating temperature and the melting efficiency.

Assuming an average preheating temperature between 400 and 600 degrees Centigrade and an overall melting efficiency between 70 and 80%, we read energy savings between 80 and 120 kWh per ton of liquid steel tapped. These values are confirmed by the experience from existing Consteel® installations.

The Continuous Charging

Charging continuously means to distribute the scrap charge along the whole power-on period. The buckets are not used, and the conveyor feeds the scrap from the yard directly into the EAF. The EAF roof is always closed and the gas suction is constantly performed from the primary circuit, not by the canopies of the secondary circuit. In the furnace the scrap melts by immersion and the electric arc is working on flat bath covered by the foamy slag.

The EAF control system adjusts automatically 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.

Figure 6 shows the typical working diagram for an EAF equipped with the Consteel® system.

These characteristics give the Consteel® substantial advantages in terms of operational savings and environmental impact reductions. The operational characteristics of Consteel® bring to a working environment less noise, less dust and no bucket charge operations. The steel in the furnace is in a better metallurgical equilibrium, thus less likely to generate violent reactions.

Furnace water-cooled sidewalls, roof and lances do not have leakage problems caused by arcing or scrap impacts, minimising the risk of water in the furnace. All of this contributes to create a safer and more comfortable working environment compared to the typical standards of the steel industry.

Consteel® Benchmark Values

The values shown in table 2 can be considered typical for a Consteel® installation with all the improvements that were achieved thanks to a continuous collaboration between Techint and the equipment operators.

The values should be considered referring to a proper operation and maintenance of the equipment.

Consumptions and manpower

The values shown in table 3 refer to the ton of liquid steel tapped and their uncertainty is basically due to the steel grade to be produced and the charge mix (we do not consider any use of DRI, HBI or hot metal).

THE HOT METAL CHARGING

The problems of scrap shortage and insufficient electrical systems can be best overcome through the implementation of mixed BF-EAF installations. In fact, several integrated

Productivity	
Ratio between power-on and tap-to-tap time	Between 90% and 95% (power-off only during tapping)
Productivity per MW available	2,5 t/h/MW
Plant availability (not including planned maintenance)	More than 98% of the time available
Metallic charge	
Charge dimensions	All the EAF ready charge and bigger (up to 2 m)
Charge density	No limits. Down to an average density as low as 0,3-0,4 t/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 – Typical values for a Consteel® installation.

Tabella 2 – Valori tipici di un impianto Consteel®.

Electrical energy	325-350 kWh/t
Oxygen	20-40 Nm^3/t
Carbon	5-25 kg/t
Natural gas (including post-combustion)	Not used
Electrodes	1,0-1,5 kg/t for AC EAF 0,9-1,1 kg/t for DC EAF
Refractories	Consumption reduction by 40-60% compared to a batch charged furnace
Manpower for operations/maintenance	Reduction by 2/3 man/shift compared to a batch charged furnace
Metallurgical results	
Steel oxidation	Lower compared to a batch charged furnace
Nitrogen in the steel	Lower compared to a batch charged furnace
Hydrogen in the steel	Lower compared to a batch charged furnace
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 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
Maintenance	
Plant availability (excluding planned maintenance)	More than 98% of the time available
Maintenance expenses (planned and unplanned)	Less than a batch-charged furnace
Impact on power lines	
Flicker	Reduced by 60-70% compared to the batch-charged furnace
Harmonics	Reduced by 60-70% compared to the batch-charged furnace
Environmental impact	
Noise	Always below 95 dBA 10 m away from the slag door. Average during melting below 90 dBA
Radioactivity control	High accuracy additional control (in addition to the gate control)
Equivalent tons of CO_2 released	Reduced by 10-30% compared to a batch-charged furnace
Dioxins, CO and NOx emissions	In accordance with German and Japanese regulations

Table 3 – Values referring to ton of liquid steel tapped.

Tabella 3 – Valori riferiti a tonnellate di acciaio liquido spillato.

plants around the world are nowadays evaluating the possibility to shut down one (or more) blast furnace(s) 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 energy into the EAF, it reduces energy consumption and increases productivity.
The experience of several years has shown that to charge 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 pig iron in a continuous fashion seems 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).
As of today there are in the world several examples of charging of hot metal in the EAF. However, the latest realizations have been based on the Consteel® feeding and preheating system.
In fact, amongst the sixteen operating Consteel® plants in the world, six are using hot metal charge: Shaoguan, E'-cheng, Shiheng, Tonghua, Wuxi and Wheeling Pitt.

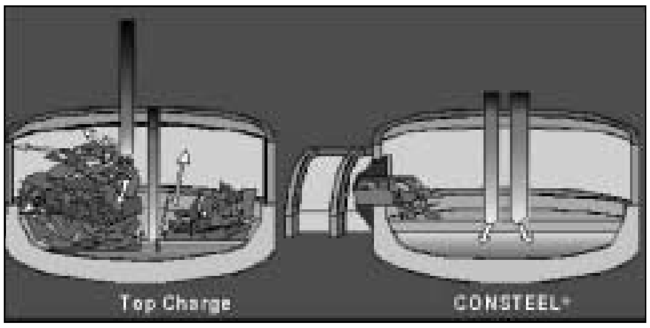


Fig. 7 – Scrap charge on a batch-type top-charged furnace and on Consteel® system.

Fig. 7 – Carica di rottame su un forno tradizionale con caricamento dall'alto e sul sistema Consteel®.

Fig. 8 – Shaoguan furnace.

Fig. 8 – Il forno di Shaoguan.

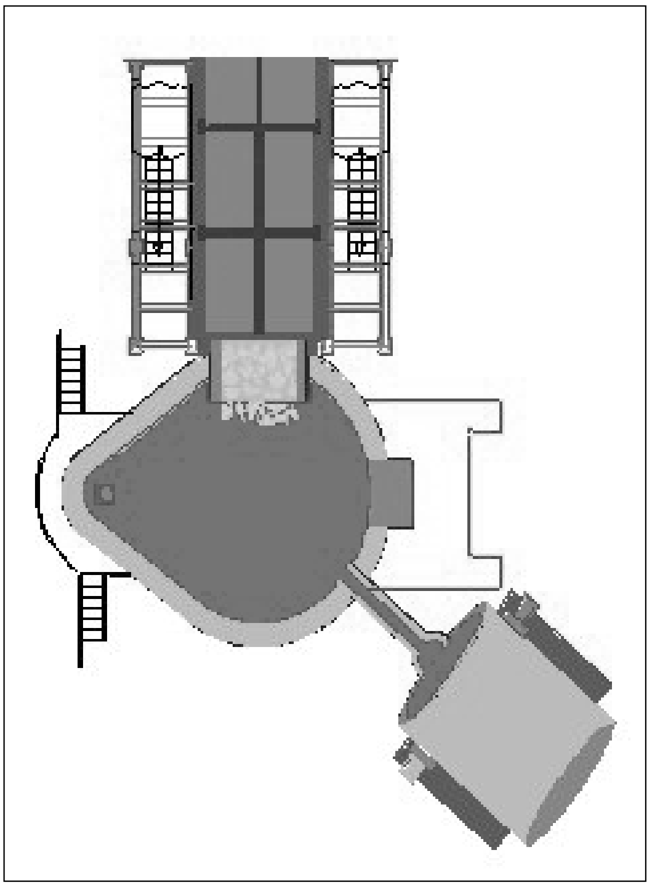


Fig. 9 – Hot metal charging concept – plan view.

Fig. 9 – Caricamento di ghisa liquida – vista in pianta.

During Consteel® operations it is possible to charge the hot metal in a controlled fashion to achieve a control over the carbon level in the bath. The scrap is loaded on to the conveying system and travels toward the furnace. In the last conveyor section, the scrap enters the preheating tunnel, in which gases leaving the furnace flow over the metallic charge. Chemical and sensible heat in the gases is transferred to the charge in a manner similar to that of a counter flow heat exchanger.
An important feature is that there is never any solid scrap present in the furnace. Melting takes place with the electrodes always working on a flat bath. The scrap is not heated by the arc but by the pool of liquid steel in the vessel. Thus the process is quite different from the operation of a batch-type top-charged furnace, as represented in figure 7.
The continuous feeding concept, in which the bath is always in a liquid condition, is ideal to achieve a quick dissolution of the carbon charged with the hot metal. By keeping the carbon level between 0,15 and 0,25%, the foamy slag practice is optimised and the oxygen/carbon reactions in the bath are avoided, thus achieving more energy efficient operations, fewer problems for the equipment and safer operation for the personnel.
Thanks to its characteristics this process is the most suitable to get the economical benefits of the hot metal charge and several plants have been able to take advantage of it. In this regard, the Shaoguan plant in China is a very illustrative example.

THE SHAOGUAN EAF-CONSTEEL® CASE

The plant

In December 2000 the Shaoguan Plant in the Guangdong Province has been commissioned.
This plant, featuring a 90 ton EAF fed via Consteel®, is able to charge liquid pig iron from a 60 ton ladle fed from the torpedo car. A single ladle is used for two consecutive heats.
The Pig Iron is fed from a sidewall runner (refractory lined) during 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 manually until the hot metal starts flowing in the sidewall runner, this operation ensures speed (fast tilting in the first phase) and safety (the operator is forced to follow closely the initial, and most delicate, pouring phase).
Figure 8 shows the tapping area and the hot metal feeding device.
While Fig. 9 shows the layout of basic concept:
- The hot metal is fed via a refractory-lined runner.
- The feeding point is located in the area of the furnace away from the feeding area of the Consteel® where also the water-cooled oxygen lance is located.
- The oxygen lance helps to increase the heat load and the steel bath stirring action in the area where the scrap is falling, thus increasing the melting rate of the incoming solid scrap.

Figure 10 shows a section of the furnace.
This type of design makes possible to process a heat with different charge mixes:
- up to 40% hot metal fed via side-wall runner, solid charge for the remaining percentage (scrap, DRI, HBI or pig iron) fed via Consteel®
- 100% solid charge (scrap, DRI, HBI or pig iron) via Consteel®.

The EAF is also designed to operate by bucket charge.

The achieved performances

Since the starting of December 2000, Shaoguan plants has been working at full capacity, after only six months the tar-

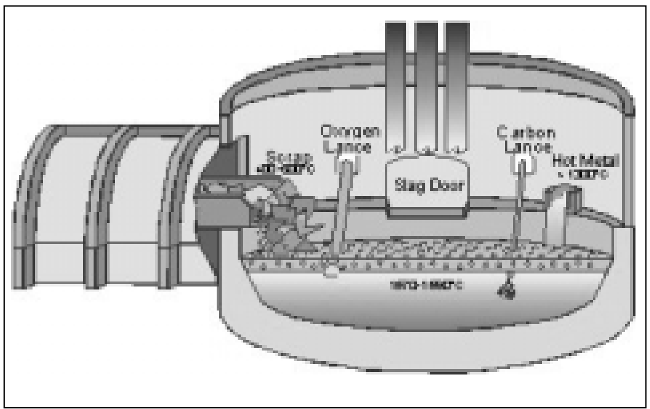


Fig. 10 – Hot metal charging concept – side view.

Fig. 10 – Caricamento di ghisa liquida – vista laterale.

get of performances where already achieved.
The figure 11 shows the results obtained by the Shaoguan plant during the first months of year 2002. In the picture are shown the Chinese and English documents signed by Shaoguan's management.
Noticeable are the 260 kWh/t of electrical energy, obtained with 30% of hot metal charging.
Beside the outstanding results in terms of overall consumptions, it is worth to underline the low nitrogen content in the tapped steel that can allow the production of high quality steels.
Figure 12 refers to an article that was published on the Chinese newspaper "China Metallurgical News" (April 24, 2002) about the successful plant operations.
Among the other plants data, the best results reported on the article are 31 heats/day and 250 kWh/t.
The plant is today running consistently after more than 3 years from the start-up and showing great reliability of the EAF plus Consteel® system, 31 heats per day is a frequently reached days target.
It is worth to underline that more than ninety percent of the heats produced by the Consteel® EAF are utilizing the hot metal charge.

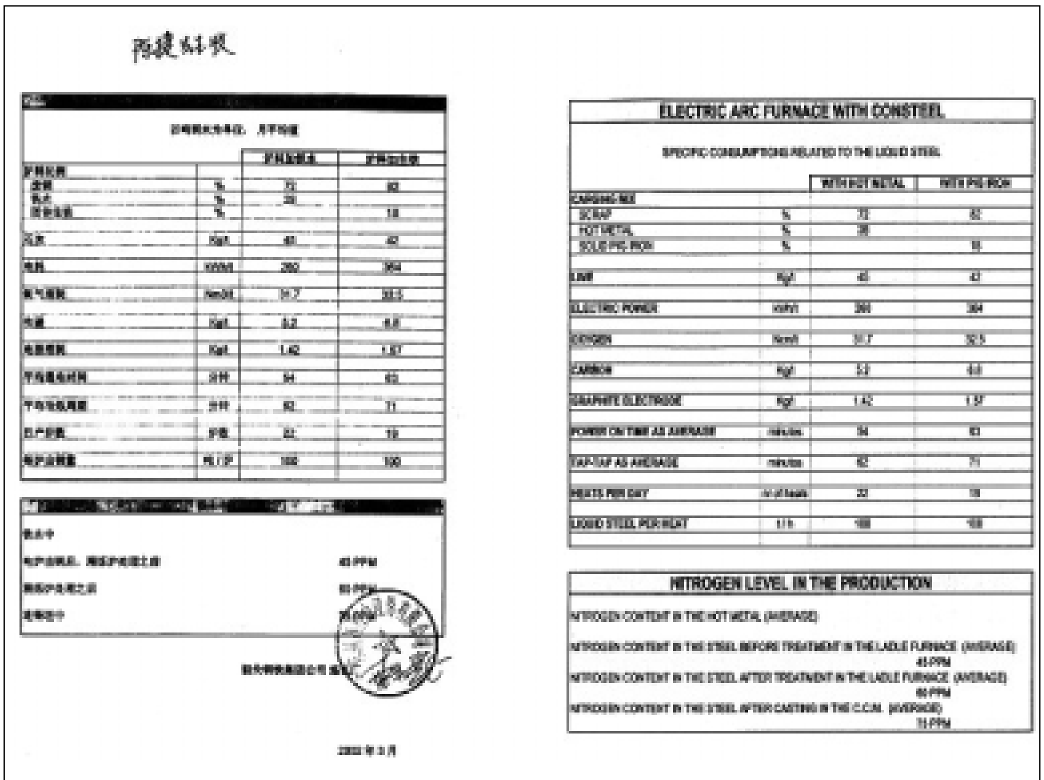

康斯迪电炉在韶钢

Fig. 12 – Article published on "China Metallurgical News" (April 24, 2002).

Fig. 12 – Articolo pubblicato sul "China Metallurgical News" (24 Aprile 2002).

THE WHEELING PITTSBURGH CONSTEEL®-EAF

Another very illustrative example is the Wheeling Pittsburgh project, in the USA, where once again the trend towards the utilisation of EAF technology with hot charge is confirmed. In effect, Wheeling Pittsburgh will feature the biggest Consteel®-EAFs ever built (225 ton of tapping size) coupled with the charge of hot metal, as developed and tested by Techint together with its Chinese customers.


ELECTRIC ARC FURNACE WITH CONSTEEL

SPECIFIC CONSUMPTIONS RELATED TO THE LIQUID STEEL

		WITH HOT METAL	WITH PIG IRON
CHARGING MIX			
SCRAP	%	72	82
HOT METAL	%	28	
SOLID PIG IRON	%		18
LIME	Kg/t	40	42
ELECTRIC POWER	kWh/t	260	364
OXYGEN	Nm3/t	31.7	32.5
CARBON	Kg/t	5.2	6.8
GRAPHITE ELECTRODE	Kg/t	1.42	1.87
POWER ON TIME AS AVERAGE	minutes	54	63
TAP-TAP AS AVERAGE	minutes	62	71
HEATS PER DAY	nr of heats	22	19
LIQUID STEEL PER HEAT	t/h	100	100

NITROGEN LEVEL IN THE PRODUCTION

NITROGEN CONTENT IN THE HOT METAL (AVERAGE)
NITROGEN CONTENT IN THE STEEL BEFORE TREATMENT IN THE LADLE FURNACE (AVERAGE) 45 PPM
NITROGEN CONTENT IN THE STEEL AFTER TREATMENT IN THE LADLE FURNACE (AVERAGE) 60 PPM
NITROGEN CONTENT IN THE STEEL AFTER CASTING IN THE C.C.M. (AVERAGE) 70 PPM

Fig. 11 – Average of Shaoguan performances as stated by from Shaoguan plant.

Fig. 11 – Media delle performances di Shaoguan dichiarate ufficialmente da Shaoguan.

Wheeling Pittsburgh executives have decided to shut down their blast furnace n.1, which had been due to undergo major relining/revamping work, and to switch into an EAF-based shop. Wheeling Pittsburgh operations will benefit from the higher energy efficiency and the flexibility added by the new melting unit. In fact, its president and CEO, James Bradley, declared in an interview to Steel News that the newly-added flexibility will enable the company to run efficiently in both good and lean times for the steel industry.
The main operating data of the new Wheeling Pittsburgh meltshop are: i) EAF tapping size of 225 ton, ii) Transformer of 140 MVA, iii) Productivity from 225 ton/h (100% scrap) to 295 ton/h and iv) Raw materials: hot metal, scrap, pig iron, DRI and HBI.
The start-up of the plant, which is the highest ranking productivity EAF with its 300 ton/hour productivity design, was started up on November 28th 2004.

CONCLUSIONS

During the last decade the EAF steel production route has shown a higher growth compared to the blast furnace route.
The EAF worldwide production is increasing its share and is moving toward high value-added products, these products require a better control over the tramp elements that cannot be achieved without a virgin source of iron. DRI, HBI, pig iron and hot metal are such sources. Among these the hot metal, when available, is the one that can allow a substantial reduction of the production cost and an increase of the plant productivity.
In the current scenario, the characteristics of the Consteel® process make possible the utilization of hot metal in the EAF without the typical problems related to this type of practice. Under normal conditions, up to fifty percent of hot metal can be charged in the EAF.

A B S T R A C T

L'EVOLUZIONTE TECNOLOGICA DEL FORNO AD ARCO E IL SISTEMA CONSTEEL®

PAROLE CHIAVE:
acciaio, ghisa, siderurgia, ecologia, energia

Negli ultimi dieci anni la produzione di acciaio tramite EAF è aumentata del 3,7% rispetto al 2,3% della produzione globale di acciaio. Attualmente l'acciaio proveniente dagli impianti EAF ha una quota del 34% (305 milioni di tonnellate) della produzione totale paragonata al 30% di 10 anni fa.
La crescita nella produzione di acciaio con EAF è spiegata dai vantaggi di questa tecnologia: meno costi di investimento, alta flessibilità di produzione e basso impatto ambientale.
Questo evento ha causato un cambiamento delle condizioni del mercato del rottame.
I produttori stanno cercando una più alta flessibilità nelle materie prime che possono essere caricate nell'EAF in alternativa al rottame come ad esempio: ghisa (solida e liquida), DRI e HBI.
Il Consteel® ha aiutato lo sviluppo delle acciaierie basate sull'EAF che utilizzano il metallo liquido nel mix di carica.
Attualmente cinque sui 16 impianti nel mondo operanti con sistema Consteel® stanno utilizzando il metallo liquido (Shaoguan, E'cheng, Shi Heng, Tonghua e Wuxi, tutte situate in Cina) e altri due impianti entreranno in produzione entro la fine del 2004 (Hengli in Cina e Wheeling Pittsburgh in USA).
La carica di ghisa liquida con Conteel® riduce i consumi di energia e di materie prime e incrementa la produttività.
L'impatto ambientale è ridotto al minimo con la tecnologia Consteel®.
Il più grande EAF esistente (225 tonnellate spillate), Wheeling Pittsburgh in USA, utilizzerà la tecnologia Consteel® unita alla carica di metallo liquido (sviluppato da Techint sugli impianti cinesi).
Queste caratteristiche garantiranno una capacità di produzione superiore ai 2 milioni di tonnellate da un singolo EAF dove sarà possibile caricare ghisa (solida e liquida), DRI e HBI.