Consteel© EAF and conventional EAF: a comparison in maintenance practices

F. Memoli, C. Giavani, A. Grasselli

The present paper highlights the main differences between Consteel® and conventional EAF technologies regarding scheduled and unscheduled maintenance practices. The study has been made on the basis of data collected in plants with high maintenance standards and more than 10 years of operational experience. These data have been analyzed and organized in a comparison table where they have been associated with the relevant maintenance costs. The comparison shows that the Consteel® technology achieves a significant reduction in the overall maintenance costs compared to a conventional EAF.

KEYWORDS:
steel, refractories, melt-shop, refining, steel-making, process control and modelling, energy

INTRODUCTION

The paper starts from some considerations developed in a Graduate thesis on the technological and economical comparison of conventional EAF steelmaking (the so-called top-charge method of loading scrap into and EAF) and the Consteel® EAF steelmaking process. (1).
Until now, the comparison of EAF steelmaking technologies was investigated considering only the melting process. The Consteel® system was compared to the conventional EAF just looking at performances figures, mainly taking in account the technological and energetic differences of the continuous charging and preheating system in comparison to the buckets charge.
The present study proposes to extend the comparison to the entire steelmaking process, considering the logistic features, the disposal cost of the waste products and the overall maintenance of the equipments and then, deducing the relevant cost of the steelmaking process.
The process study is implemented in a Microsoft Excel worksheet which analyses the melting process, performing a mass-energy balance of the heat and deduces the overall cost for both the conventional EAF route and Consteel® EAF route.
The study is carried out considering a top-charge furnace process and than deducing what could happen applying the Consteel® system to the same process conditions. Since different melting processes can be compared only when the same charge mix and the same tapping conditions are considered, a normalization of the mass-energy balance is necessary to perform a correct comparison between the technologies avoiding the effect of the different charge and different energy utilization caused by the different process running. The production target and thereby the charge mix, has a great influence on the melting process. In order to highlight the possible benefits coming from one technology compared to the other, the same operating constraints and the same level of productivity have been assumed.

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APPLICATION OF THE COST MODEL

The cost model, created to quantify the cost difference between the traditional EAF and the Consteel® EAF steelmaking, was developed to analyze the influence of each part of the process.
The model returns the final cost per ton of liquid steel produced, both for the conventional and Consteel® steelmaking processes. Looking at the results, it is possible to distinguish the costs depending on: the melting process, the logistic, the maintenance of the furnace and the equipments and the handling of waste products.
The melting process represents the greatest contribution to the steelmaking cost, see Figure 1. That is one of the reason why, until now, the cost analysis for the EAF steelmaking process took into account just the process parameters and the cost of charge materials, with the assumption that the cost for the logistic and maintenance were basically the same.
Compared with the conventional EAF steelmaking, the Consteel®

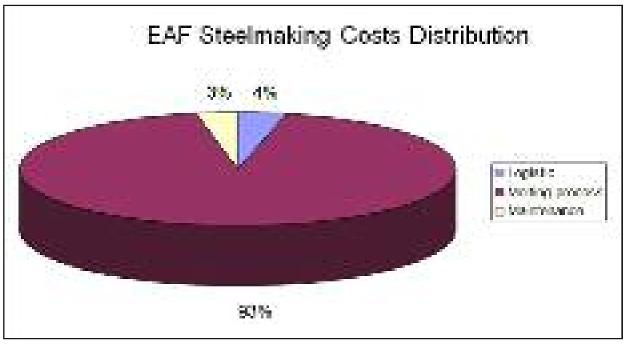


FIG. 1 ***The cost distribution for the EAF steelmaking process, considering also the logistic and maintenance weights. The result refers to the conventional top-charge EAF.***

Distribuzione dei costi nel processo produttivo dell'acciaio tramite forno elettrico ad arco. Sono considerati anche I costi di logistica e manutenzione. Il grafico fa riferimento al forno elettrico convenzionale.

			TC	TS	delta
Process	Electric energy, natural gas, slag forming additives carburizing additives, metallic charge	(€/tls)	281.8	274.4	-7.5
Handling	Costs of cranes, scrap transport, and whole production equipment operation	(€/tls)	11.0	7.3	-3.7
Maintenance	Equipment maintenance, refractory maintenance and consumption, electrode consumption, slag and dust disposal	(€/tls)	9.3	7.1	-2.2
Sum		(€/tls)	302.0	288.8	-13.3

TAB. 1 ***Cost comparison of conventional and Consteel® EAF steelmaking. The result refers to the O.R.I. Martin melt shop.***

Distribuzione dei costi nel processo produttivo dell'acciaio tramite forno elettrico ad arco. Sono considerati anche I costi di logistica e manutenzione. Il grafico fa riferimento al forno elettrico convenzionale.

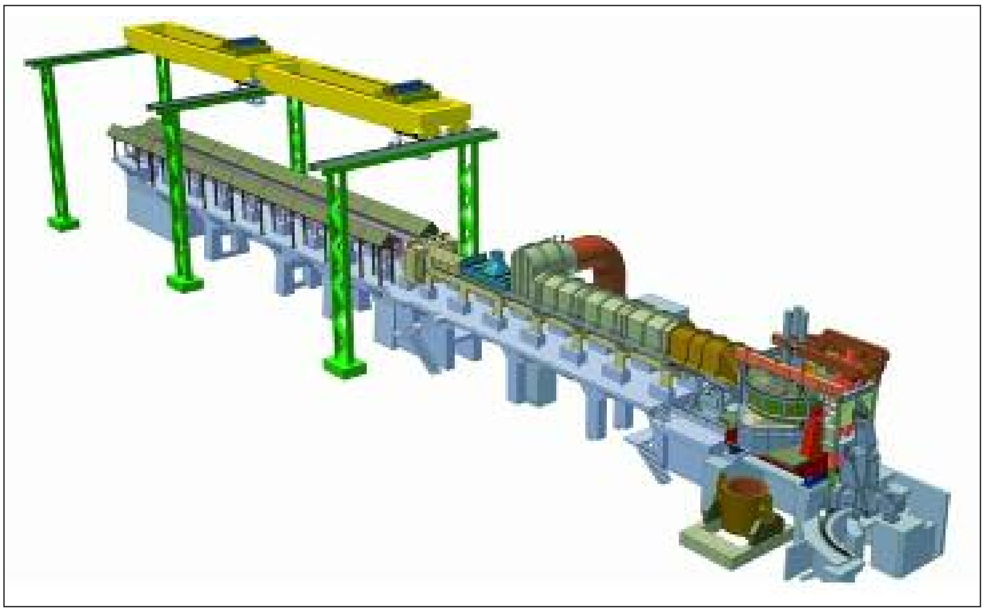


FIG. 2
Consteel® Electric Arc Furnace system. The scrap is set along side the charging section (charged from the ground or directly from rail transportation).

Consteel® Electric Arc Furnace. Il rottame è caricato direttamente sul convogliatore di carica.

technology has a different cost for logistic and maintenance. So, the cost model tries to explain what the differences are and how much is their weight on the total steelmaking cost.
The Table 1 shows the results of the analysis performed with the cost model on the O.R.I. Martin Acciaieria e Ferriera di Brescia case, an 80 t EAF producing roughly seven hundred thousand tons per year of special and quality steels in wire rods and billets. The cost analysis considers the previous steelmaking process with a conventional top-charge EAF solution, compared with the present steelmaking process with the same furnace equipped with the Consteel® system. All the costs refer to the Italian scenario on June 2008.
The cost analysis shows a marked difference between the two processes.
Looking on the cost allocation, is possible to observe that the highest difference can be seen in the melting process cost and in the yield of the Consteel® EAF steelmaking. Letting aside the discussion on the different melting processes, which has been the subject of many studies, this paper will focus on the costs given by logistic and maintenance and will demonstrate that more that 50% of the total saving achievable with the Consteel® system depends on these.

LOGISTICS OF EAF STEELMAKING

The logistics of the melt shop include the operation of handling the materials required for the operation of the electric furnace; the different charging methods have a strong influence. Conventional top-charge and Consteel® system have different logistics needs notwithstanding those are comparable.
The most important operation is the management of the scrap flow, from the scrap-yard to the furnace, supported by the buckets preparation in the conventional EAF steelmaking and by the continuous charging system in the Consteel® technology. The size of the scrap-yard depends on the required scrap-flow rate and on its desired autonomy.
The raw materials handling is usually performed by overhead travelling cranes, in sufficient number to have an adequate margin of safety against failures. The number of cranes depends on the number of buckets that must be prepared in the given time, considering the heat size of the furnace and the scrap density and size of the buckets.
The Consteel® system adopts a different organization of the scarp-yard, usually storing the raw materials along side of the charging conveyor. The size and the number of the charging cranes depend on the maximum scrap feeding rate required by the furnace.
In general, the logistics required for the furnace needs a fairly large number of operators. The required number of operators increases with the number of equipments involved. In this regards, the Consteel® system technology simplifies the steelmaking logistics, minimizing scrap movements and reducing as much as possible the equipment employed for the mo-

vements (the Consteel® process practically eliminates the buckets charge). As result, the number of the operators involved is lower than the conventional EAF route.
It had been assumed that the cranes for the charging of the Consteel® conveyor will have a lifting capacity that is roughly double compared to the cranes used to prepare the buckets for the conventional top-charge EAF process. However, after an accurate analysis of existing melt shops it was determined that there are greater number of lifts for conventional EAF process since bucket preparation is made off-line in respect of the melting process. Furthermore, the Consteel® process practically eliminates the operation of the furnace bay crane for the buckets charge, reducing its weight on the total cost for its work and maintenance.
The cost for the whole scrap handling by crane, in the top-charge EAF case and in the Consteel® EAF case are basically equivalent, but with Consteel® some savings are possible in bucket preparation and transfer operations, as these become practically unnecessary.
In addition to the cost differences expressed by the delta rate, see Figure 3 there are some other important considerations to do: simplify the logistic organization, which means to reduce the risks related to the movements of the scrap and the equipments, minimizing the dust emission generated by the buckets preparation and reducing the environmental impact of the melt shop. Simplify means also to increase the reliability of the system against failures.
Moreover, by the Consteel® conveyor is possible to perform a more accurate control of the metallic charge against the radioactive materials, reducing the occurrence of radioactivity inside the furnace and consequently into the exiting fumes. This feature preserves the environment and reduces the risk of stops for plant restoring.

EAF STEELMAKING: MAINTENANCE PRACTICE

This analysis has divided the maintenance practices in to several areas:
• Maintenance of the scrap-yard equipments;
• Maintenance of the furnace bay equipments;
• Maintenance of the EAF furnace;
• Slag and dust handling and disposal.
Figure 4 shows the costs distribution for maintenance practice and waste handling.

Maintenance of the scrap-yard and furnace bay equipments

The maintenance of the scrap-yard depends mainly on the number of the equipments involved in the material handling. The conventional top-charge EAF route needs more equipments than the corresponding Consteel® EAF:
• buckets;
• bucket-cars;
• tractors;
• weighing station equipments.
The Consteel® system allows reducing the maintenance costs because it has just the overhead travelling cranes for the conveyor charging, which can perform also the weighing operation for each lift. It reduces the occurrence of failures and the consequent employment of extra-equipments to ensure a good margin of safety.

Maintenance of the EAF furnace

The EAF maintenance program is strongly influenced by the melting process in use and the differences in term of costs and organization are important. The thermal and chemical stresses which affect the consumable components of the furnace depend mainly on the parameters of the melting process.

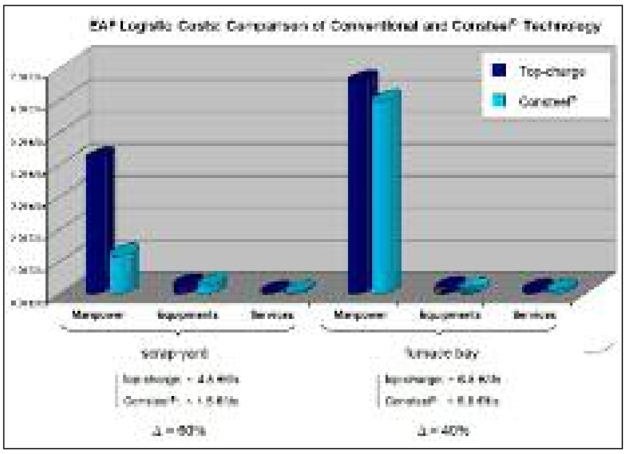


FIG. 3 ***Comparison of EAF steelmaking logistic costs, considering the scrap-yard and the furnace bay differences between the processes.***

Confronto tra I costi dalla logistica del sistema Consteel® e del forno elettrico convenzionale. Sono considerate le operazioni al parco rottame e la logistica fronte-forno.

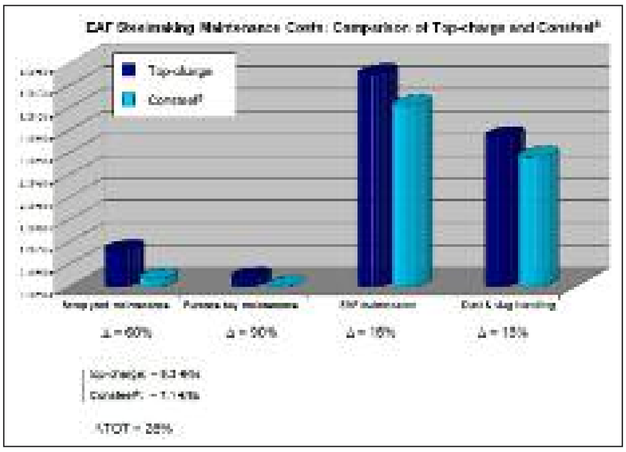


FIG. 4 ***Comparison of EAF steelmaking maintenance costs, considering the top-charge EAF and the Consteel® sysytem.***

Contronto dei costi di manutenzione tra Consteel® EAF e forno elettrico convenzionale.

The electrode consumption and handling is the highest cost in the maintenance program: it depends on the process parameters and on the environment conditions inside the furnace. The electrodes are exposed to high mechanical stresses (vibration, flexure) and thermal cycling. Most of the electrode consumption is through oxidation and tip sublimation. A considerable portion is also lost due to breakages caused by scrap cave-ins during melting or crushing the electrode onto blocks of non-conductive materials present in the charge.
Between the conventional and Consteel® steelmaking there is a slightly differences in electrode consumption, about 15% lower. (2). This is a result of a lower oxidation rate, which is due to the lower post-combustion ratio occurring inside the Consteel® furnace. (3).

$$SIDE\_EROSION = R_{OX} \cdot \frac{A_{OX} \cdot t_{TAP}}{P} \quad [kg/t];$$

$$TIP\_EROSION = R_{SUB} \cdot \frac{I^2 \cdot t_{PO}}{P} \quad [kg/t] \qquad (4.1); (4.2)$$

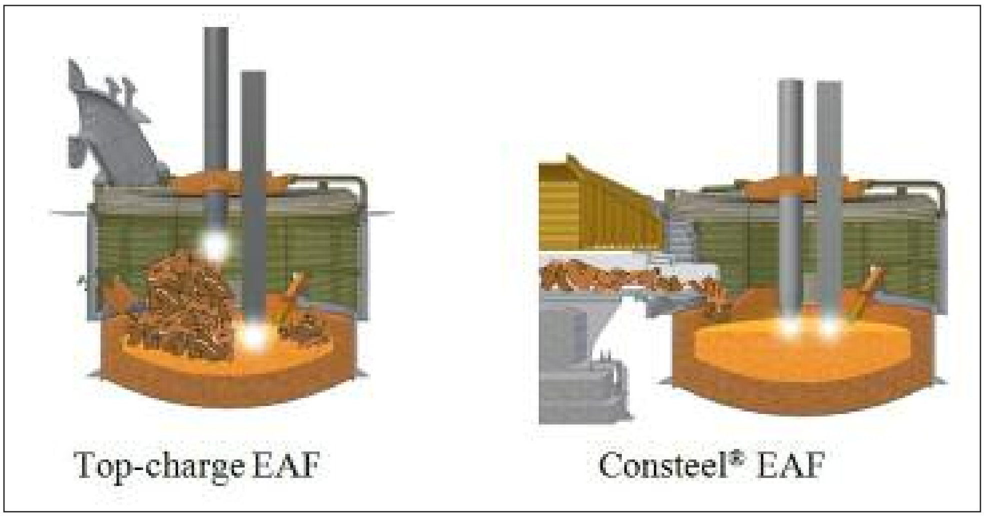


FIG. 5
Comparison of power transfer: melting by direct energy transfer from the electrode to the solid scrap (top-charge EAF) and melting by immersion in a molten pool (Consteel® EAF).
Tipologie di fusione a confronto: trasferimento dell'energia direttamente dagli archi elettrici al rottame solido (forno convenzionale) e fusione per immersione in un bagno di acciaio liquido (Consteel® EAF).

where:
ROX = oxidation rate [kg/m^2 per hour]
AOX = oxidizing electrode surface area [m^2]
tTAP = tap-to-tap time [hour]
P = productivity of the melt shop [t/heat]
RSUB = sublimation rate [kg/kA^2 per hour]
tPO = power-on time [hour]
I = current per phase [kA]

As shown by the Ben Bowman's model (4), the electrode erosion depends also on the productivity of the melt shop. At the same working condition, the Consteel® EAF ensures a higher productivity and the electrode consumption can be considered the same of the conventional top-charge EAF with lower productivity. The cost model considers the same productivity for both the cases: for this reason it is possible to appreciate the difference in electrode consumption.

Also, the flat bath operation maintains a good stability of the electric arcs and practically eliminates the occurrence of the electrode breakages caused by the scrap cave-ins during the melting phase, further reducing the waste of time (the furnace power-off) for replacement.

The Consteel® system also has a lower impact on the wear of the refractory lining, because its operating conditions are smoother than the conventional EAF steelmaking and produce less quantity of iron oxide in the slag. The EAF's refractories are subject to a variety of wear mechanisms: the most important is the chemical reaction of metallic oxides in the slag (iron oxide (FeO), silica (SiO_2) and alumina (Al_2O_3)) with the refractory. These corrosion reactions can be reduced by minimizing FeO content (and the other reacting compounds) and controlling the oxygen level into the slag. (2)

In the Consteel®, provided that slag is foaming correctly, the electric arcs can be completely covered and buried under a protective layer which can preserves the furnace refractory from arcs radiation for almost the entire power-on period. The consumption of the refractory lining is less than compared to the top-charge EAF, where the electric arcs are unprotected for a good portion of the power-on time.

The same condition can be reached only during the refining phase, where the scrap is completely melted. During the "bore-in" phase, the electrodes of the conventional EAF work into a solid lump of raw materials and the energy is directly transferred from the arcs to the scrap. The instance of electric discharge on the panels can occur with a high probability. This is why the maintenance of the shell panels in the conventional EAF has a strong influence on the operating cost. (5).

The Consteel® system practically eliminates the electric discharge on the furnace roof and shell, because it works in flat bath conditions for the entire process. A study on the melt shop of ORI Martin, Brescia, Italy, has demonstrated that the panel's maintenance drastically decreases since the application of the Consteel® system: before, with the top-charge EAF, they change roughly 1÷2 panels per week; since the last ten years after the conversion to the Consteel® system, they broke three. Two of these panels were damaged by the interactions with the charging bucket. It means a great saving in cost and down time.

The first part of the primary off-gas ductwork of the conventional EAF is considered in the maintenance costs, for a correct comparison with the Consteel® EAF case.

Maintenance of the Consteel® conveyor

The Consteel® EAF system, which achieves the continuous scrap feeding into the furnace, is a simple slip-and-stick conveyor where the metallic charge can be preheated by the fumes exiting the furnace.

The conveyor maintenance is simple and only requires periodic inspection of the mechanical structures (inclusive the electrical motors and the hydraulic equipment) and the planned maintenance of the most critical parts. The refractory lining of the preheating section, which follows the water-cooled hood of the connecting-car, has no particular stresses and it can be re-bricked normally every one year of service with SiO_2 – Al_2O_3 bricks. (7).

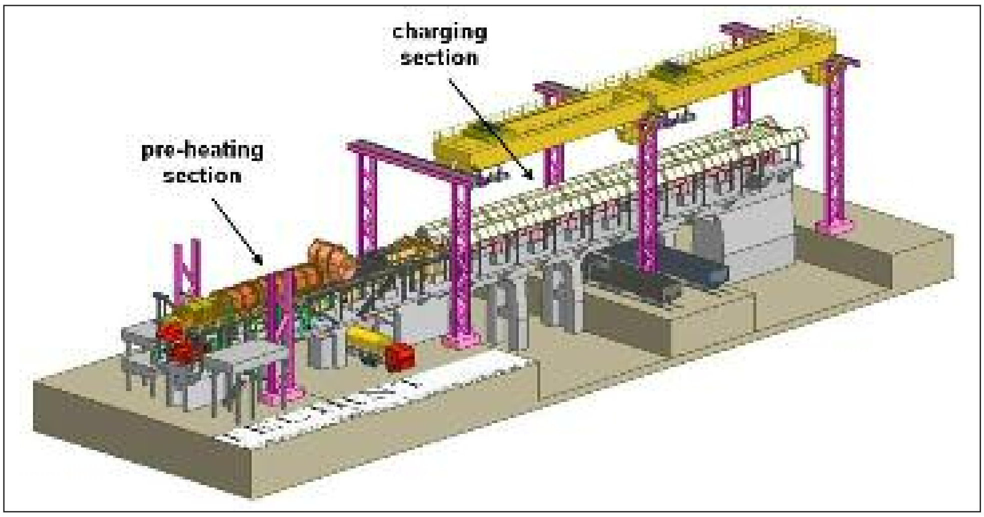
The connecting-car tip is the most stressed component of the conveying system because it receives at the same time the thermal stress of the melting bath and the mechanical load produced by the conveying of the scrap. Because of this it has been seen that the replacement of the connecting-car tip should be part of a planned maintenance program and the experience suggests an average life-time of six months for this component under proper Consteel® operation with consistent slag foaming throughout the entire power-on time.

To allow the oscillation, the conveyor is suspended with the rods. The suspension-rods are continuously stressed by the oscillations of the conveyor and the load of the metallic charge: this is the reason why can be occurs a failure during the process running. The suspension-rod can be replaced in short time, usually during the furnace down turn. The failure analysis shows an average value of one hundred suspension-rods breakages in a year for a "well charged" conveyor. The most recent suspension-rods design is showing a marked reduction of maintenance requirements (statistical analysis is under way).

Slag and dust handling and disposal

The Consteel® EAF process achieves a lower slag and dust pro-

FIG. 6
Consteel® conveyor with overhead travelling cranes. The figure represents the charging section and the preheating section. (6).
Convogliatore del sistema di carica continua Consteel®. La figura mostra la sezione di carica del rottame e il tunnel di preriscaldo. (6).



duction in comparison to the corresponding conventional EAF. Due to the lower oxidation of the metallic charge, the Consteel® guarantees a further reduction of slag production, about 10% of the total amount.
The dust production of the Consteel® EAF is strongly dependent on the main characteristics of the system: the continuous charging and the preheating of the metallic charge. The elimination of the buckets charge reduce the dust formation in the canopy hood and the pre-heating section of the conveyor works like a settling chamber, where the dust can deposits on the scrap promoting a sort of dust recycling into the furnace: the overall dust emission results about 5÷9 kg/tls less than the conventional top-charge EAF.
In addition to the cost savings achieved by the reduction of disposal operations, the actions are simplified.

CONCLUSIONS

The cost analysis proves that the Consteel® system has some benefits beyond those coming from the different melting process: it permits to save more than 40% of the costs for logistics, maintenance and waste products handling. In addition to the proven savings achieved by the different melting process, the total cost for the Consteel® steelmaking is roughly 6% lower than the traditional EAF route. This cost saving permits to return the investment for the Consteel® system installation in a very short time. The cost model developed during this study can be useful to analyze a general EAF process. The economical advantage achieved by the continuous charging could be variable, depending on the process parameters and on the production target of the melt shop been considered. In this study, where a fixed productivity has assumed for the technologies, the higher productivity, lower tends to be the cost difference between conventional and Consteel® processes (because the equipments and manpower costs will be distributed on a higher liquid steel quantity). In the next version of the cost model tool the productivity advantage of the Consteel system over the conventional EAF will be analysed (reduction of power-off time).
Besides the economical advantages, there are also technological advantages which lead to maximize the efficiency of the process improving the yield of the metallic charge and reducing the energy demands. The Consteel® system reduces also the overall risks and represent the simplest and most efficiently solution to achieve an “environmentally friendly preheating” of the metallic charge, with the advantages of avoiding the uncontrolled emission of pollutants that is typical of the conventional charge by bucket.
In case of revamping, the installation of the Consteel® system with the same EAF permits to maintain the electrical network with the same transformer and the lower impact on the fumes plant without any peaks allow to readapt the existent one, reducing the investment for the technology change.

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Abstract

Consteel© EAF e forno elettrico convenzionale: a comparison in maintenance practices

Parole chiave: acciaio, refrattari, acciaieria, affinazione, siderurgia, controllo processi simulazione numerica, energia

Il presente articolo vuole evidenziare le differenze legate alla manutenzione, programmata e straordinaria, tra il forno elettrico convenzionale (con carica a ceste) e il sistema a carica continua Consteel®. L’analisi fatta si basa su dati operativi e di costo raccolti in impianti con un alto standard manutentivo e con più di dieci anni di esperienza produttiva. Questi dati sono stati ordinati in un modello matematico Excel, dove a ogni singola voce è stato associato un costo di manutenzione corrispondente. Il confronto proposto dimostra che il sistema Consteel® consente una considerevole riduzione dei costi complessivi di manutenzione rispetto al forno elettrico tradizionale.